Australia's National
Science Agency

Hydrogen Electrolyser Manufacturing

A strategic guide for seizing Australia's clean-tech manufacturing opportunity

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This report was authored by James Trevorrow, Nicolás González Castro, Rohini Poonyth, Sean Lim, Katherine Wynn, and Vivek Srinivasan.

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CSIRO acknowledges the Traditional Owners of the lands that we live and work on across Australia and pays its respect to Elders past and present.

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Glossary

Abbreviation	Definition	Unit	
AEM	Anion exchange membrane	GW	Gigawatt
BoP	Balance of plant	Mtpa	Million tonnes per annum
FID	Final investment decision	MW	Megawatt
HEM	Hydrogen electrolyser manufacturing	tpa	Tonnes per annum
LNG	Liquefied natural gas	3N	99.9% purity
NHS	Australian Government’s National Hydrogen Strategy 2024	5N	99.999% purity
NZE	Net Zero Emissions scenario	6N	99.9999% purity
OEM	Original equipment manufacturer		
PEM	Proton exchange membrane		
PFAS	Per- and polyfluoroalkyl substances		
SOE	Solid oxide		
TRL	Technology readiness level		

Executive summary

This report investigates Australia's opportunity for hydrogen electrolyser manufacturing (HEM). It seeks to align with Australia's National Hydrogen Strategy and Federal, State, and Territory manufacturing initiatives by stimulating the domestic HEM ecosystem. HEM presents a unique manufacturing opportunity for the nation, combining a:

- **Nascent, rapidly emerging global electrolyser market**, which creates a window of opportunity for Australia to develop its own advanced manufacturing and material supply chains
- **Strong starting position,** with an emerging cohort of Australian electrolyser manufacturers translating innovations from the country's research sector
- **Significant domestic pipeline of projects seeking to produce renewable hydrogen,** with specific electrolyser procurement and maintenance needs, creating a local market and providing the benefits of a geographically aligned supply chain

By 2050, Australia's HEM industry could generate **AUD 1.7 billion** in revenue and close to **4000** jobs. Installation services for electrolysers could add another **AUD 1.2 billion** in revenue and **1000** jobs. Additionally, the manufacturing capabilities developed for HEM could translate to other manufacturing areas, and the raw material entry points could support onshore processing.

HEM activities are already occurring in Australia at different scales. However, scaling up is a challenge. It will require:

- Aggregated demands across adjacent emerging manufacturing opportunities to advance local production of **intermediate materials**
- Building upon the existing manufacturing capabilities being used in other advanced products to support local **component manufacturing**
- Cost-effective **cell fabrication** and **stack assembly**, with support for system testing and validation at scales relevant to commercial deployment
- Leveraging the comparatively lower barriers of **system assembly** as an entry point for overseas manufacturers interested in Australian facilities
- Identifying, preparing and promoting **manufacturing locations** which optimise local strengths such as renewable electricity prices and firming, while offsetting inflexible costs such as labour rates and logistics
- An exploration of **international manufacturing partnerships** that considers high value process and supply chains through to domestic hydrogen production in a way that optimises Australia's long-term sovereign manufacturing capabilities and needs

Further investigations are suggested whilst the 'window of opportunity' is still available. This includes analysis to aggregate manufacturing demands across adjacent clean-tech manufacturing opportunities; provide stakeholder visibility of ecosystem actors and their capabilities; assess cost-effective manufacturing locations; and inform international partnership discussions.

1 Introduction

1.1 Why hydrogen electrolysers?

A clean alternative, key to the energy transition

The goal of achieving net zero emissions by 2050 is driving a global transition from fossil fuels into renewable sources. While direct electrification will be key, sectors like long distance and heavy freight, chemicals manufacturing (particularly ammonia), and industrial processing (heat for metals production) will be harder to electrify.

Hydrogen is an attractive energy carrier and feedstock for these sectors because of its **high energy density by weight**, potential for **clean combustion** and **versatile presence** in many economically relevant chemical compounds.[1]

While hydrogen is abundant as an element, it is most frequently found as part of other chemical compounds and requires energy and processing for its separation. There are multiple production pathways available to achieve this, including thermochemical, biological, photochemical, geochemical and electrolysis processes.[2,3]

The overall hydrogen supply chain thus comprises three key stages: **1) production, 2) storage and distribution**, and **3) application**.[4] Refer to Figure 1 below.

Electrolysers are the specialised electrochemical equipment that uses electricity to break down water into hydrogen and oxygen, in the presence of a catalyst and sometimes assisted by a secondary energy source (e.g., light or heat). Electrolysis conventionally uses demineralised water as the main input and can rely on electricity from renewable sources to drive the process. This enables a decoupling from direct fossil fuel use and a reduction in the overall emissions stemming from current hydrogen production.

With potential for significant decreases in cost and high maturity for commercial scale deployment, hydrogen produced via electrolysis (renewable hydrogen) has a clear role to play in achieving global net zero emissions targets.

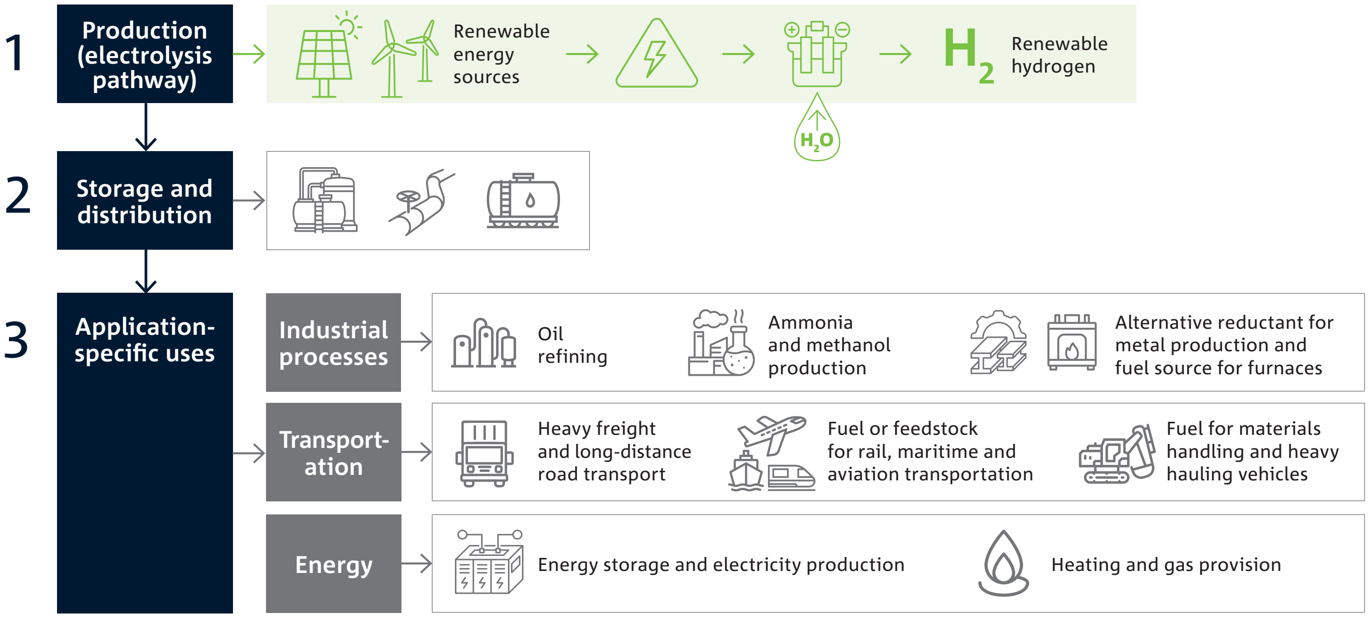

Figure 1. Overarching hydrogen supply chain (with production via electrolysis as an example).

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[1] CSIRO Hydrogen (n.d.). HyResource. <https://research.csiro.au/hyresource/about/hydrogen/> (accessed 29 July 2024); Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018) National Hydrogen Roadmap. CSIRO, Australia.

[2] Hydrogen and Fuel Cell Technologies Office (n.d.) Hydrogen Production Processes. U.S. Department of Energy. <https://www.energy.gov/eere/fuelcells/hydrogen-production-processes> (accessed 29 July 2024); Megía PJ, Vizcaíno AJ, Calles JA, Carrero A (2021) Hydrogen Production Technologies: From Fossil Fuels toward Renewable Sources. A Mini Review. Energy & Fuels 35, 16403; Osselin F, Soulaine C, Fauguerolles C, Gaucher EC, Scaillet B, Pichavant M (2022) Orange hydrogen is the new green. Nature Geoscience 15, 765.

[3] A more detailed description of each pathway, and the individual technologies involved, can be found in a separate CSIRO report – *Hydrogen Research, Development and Demonstration: Priorities and Opportunities for Australia* (Srinivasan V, Temminghoff M, Charnock S, Hartley P (2019). Hydrogen Research, Development and Demonstration: Priorities and Opportunities for Australia. CSIRO, Canberra)

[4] Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018) National Hydrogen Roadmap. CSIRO, Australia; Bossel U, Eliasson B (n.d.) Energy and the Hydrogen Economy. Alternative Fuels Data Center. <https://afdc.energy.gov/files/pdfs/hyd_economy_bossel_eliasson.pdf> (accessed 29 July 2024); US Hydrogen and Fuel Cell Technologies Office (n.d.) Hydrogen Storage. <https://www.energy.gov/eere/fuelcells/hydrogen-storage> (accessed 29 July 2024).

Future production requirements

Approximately 95 million tonnes (Mt) of hydrogen were produced globally in 2022, with 84.3% from fossil fuel-dependent pathways, 15.6% as a by-product of oil refining and only 0.1% from electrolysis.[5] Similar production levels from 2021 (94 Mt) were linked with over 900 Mt of direct CO_2 emissions.[6]

In the International Energy Agency's Net Zero Scenario by 2050 (NZE), overall production needs to change by 2030 to 58.4% of hydrogen coming from fossil fuels, 32.8% from electrolysis, 8.6% as a by-product and 0.1% from bioenergy (Figure 2).[7]

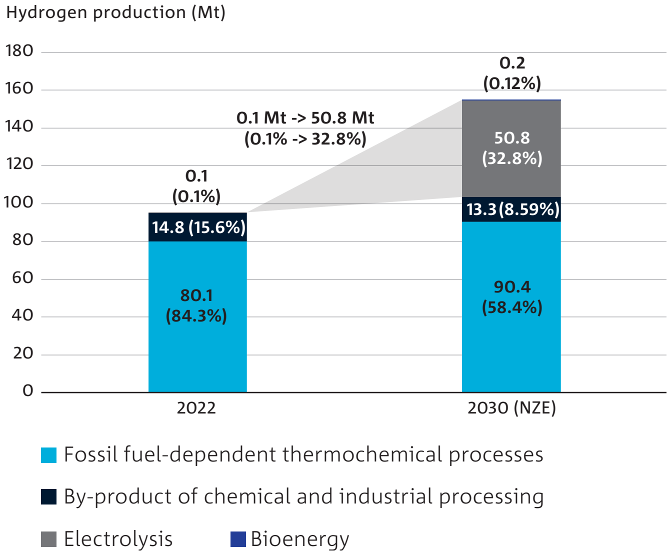

Figure 2. Hydrogen production in 2022 and 2030 (Under the IEA's Net Zero Scenario), by pathway.

Source: IEA (2023) Global hydrogen production by technology in the Net Zero Scenario, 2019–2030. <https://www.iea.org/data-and-statistics/charts/global-hydrogen-production-by-technology-in-the-net-zero-scenario-2019-2030-3>.

Cost considerations

While hydrogen production via electrolysis is currently more expensive than production through fossil fuel-dependent pathways, there is potential for cost reductions over time. Technoeconomic analysis from BloombergNEF estimated that the production cost for renewable hydrogen could go below the level for existing hydrogen plants in 5 countries by 2030 (Brazil, China, India, Spain and Sweden), and for new fossil fuel-dependent plants in 8 countries (out of 28 markets modelled). In their view, economies of scale and supportive policies would play a significant role in enabling such decreases in cost.[8] Similarly, analysis conducted for Australia's National Hydrogen Strategy (2024) shows the cost of renewable hydrogen from two different electrolyser types decreasing up to 2050 (alkaline and proton exchange membrane electrolysers), with potential to match or dip below the level for steam methane reforming (a fossil fuel-dependent pathway).[9]

The cost of electrolyser systems, a significant driver of the levelised cost of hydrogen (LCOH), has margin for improvement and clear strategies to accomplish it. There has been a 90% reduction in the capital cost of proton exchange electrolyser systems from 2000 to 2020 (in terms of USD per kW).[10] The International Renewable Energy Agency (IRENA) has reported that an up to 80% reduction could be possible through performance improvements (across energy efficiency, durability and design), increased system sizes, optimised supporting equipment, manufacturing at scale, and optimised practices (from design to deployment).[11]

The four types of electrolyser systems considered in this report are commercially available and two of them (alkaline electrolysers and proton exchange membrane electrolysers) are already deployed for hydrogen production at large scale. The systems also build upon a longstanding history of development throughout the 20th century.[12]

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[5] Bains P, Bennett S, Collina L, Connelly E, Delmastro C, Evangelopoulou S, Fajardy M, Gouy A, Kotani M, Le Marois J-B, Levi P, Martinez Gordon R, McDonagh S, Pavan F, Pizarro A, Sloots N, Winkler C (2023) Global Hydrogen Review 2023. 64–68. International Energy Agency, Paris. <https://iea.blob.core.windows.net/assets/cb9d5903-0df2-4c6c-afa1-4012f9ed45d2/GlobalHydrogenReview2023.pdf> (accessed 8 July 2024).

[6] IEA (2023) Towards hydrogen definitions based on their emissions intensity. International Energy Agency, Paris. 14–15. <https://iea.blob.core.windows.net/assets/acc7a642-e42b-4972-8893-2f03bf0bfa03/Towardshydrogendefinitionsbasedontheiremissionsintensity.pdf>.

[7] IEA (2022) Global hydrogen production by technology in the Net Zero Scenario, 2019–2030. International Energy Agency, Paris. <https://www.iea.org/data-and-statistics/charts/global-hydrogen-production-by-technology-in-the-net-zero-scenario-2019-2030> (accessed 29 July 2024).

[8] Schelling K (2023) Green Hydrogen to Undercut Gray Sibling by End of Decade. BloombergNEF. <https://about.bnef.com/blog/green-hydrogen-to-undercut-gray-sibling-by-end-of-decade/> (accessed 20 September 2024).

[9] DCCEEW (2024) National Hydrogen Strategy 2024. Department of Climate Change, Energy, the Environment and Water, Canberra. 45. <https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf> (accessed 20 September 2024).

[10] Randolph K, Vickers J, Peterson D, Hubert M, Miller E (2022) Historical Cost Reduction of PEM Electrolyzers. <https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/2 2002-historical-cost-reduction-pem-electrolyzers.pdf?Status=Master> (accessed 20 September 2024).

[11] IRENA (2022) Electrolyser costs. Hydrogen. <https://www.irena.org/Energy-Transition/Technology/Hydrogen/Electrolyser-costs> (accessed 20 September 2024).

[12] Smolinka T, Bergmann H, Garche J, Kusnezoff M (2022) The history of water electrolysis from its beginnings to the present. In Electrochemical Power Sources: Fundamentals, Systems, and Applications. (Eds. T Smolinka, J Garche) 83–164. Elsevier.

1.2 Why electrolyser manufacturing?

Hydrogen electrolyser manufacturing (HEM) is a significant opportunity because of the rapid scale-up in **installed capacity needed** to meet net zero scenarios and the **potential for innovative designs and manufacturing processes to generate cost-competitive advantages**. These factors create a **window of opportunity** for new entrants to influence a market that is still nascent at scale.

Rapid scale up requirements

Electrolysers have a long history of industrial use for other chemical products. However, the scale of deployment needed for hydrogen production requires a significant increase over the current installed capacity to meet net zero targets.

The cumulative installed electrolysis capacity for hydrogen production envisioned in the NZE (in terms of electric input) is 590 gigawatts (GW) in 2030 and 3300 GW in 2050, up from nearly 0.7 GW in 2022 (Figure 3).[13]

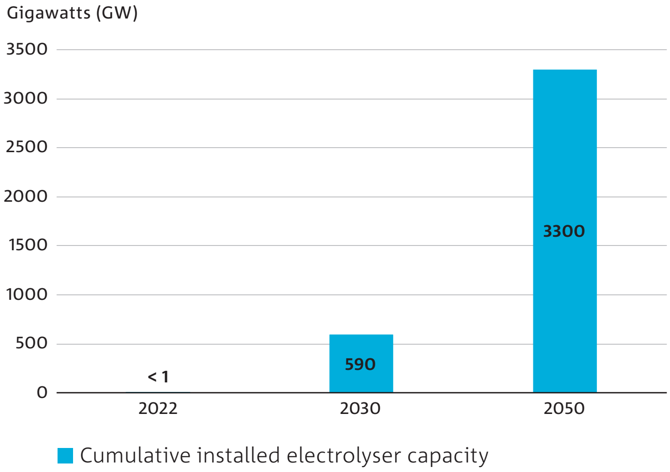

Figure 3. Cumulative installed electrolyser capacity globally in 2030 and 2050, under the IEA Net Zero Emissions Scenario.

Source: IEA (2023) Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. International Energy Agency, Paris. 101. <https://iea.blob.core.windows.net/assets/9a698da4-4002-4e53-8ef3-631d8971bf84/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf>.

Window of opportunity

The current electrolyser manufacturing landscape is emerging in terms of scale and activity is more geographically dispersed compared to other renewable energy technologies, providing space for new market entrants and changes in capacity distribution as the industry grows. For context, the ten largest electrolyser manufacturing facilities by nominal capacity have entered operations only in the past 5 years.[14]

Electrolyser manufacturing starts from a comparatively small nominal global capacity of 23 GW (as of 2023) and a low utilisation rate, with an estimated 2.5 GW output in 2023. China accounted for 60% of this capacity, Europe for 20%, and the United States (US) for 16%.[15] While 170 GW of overall manufacturing is expected by 2030 based on announced projects, only 13% has reached final investment decision (FID) or is under construction.[16] The lower rate of commitment to new facilities could enable improved manufacturing processes to play a disruptive role.

A significant increase in installed electrolyser capacity over a comparatively short period of time also means that a sustainable expansion of global manufacturing capacity will be required. Currently, supply chain constraints and the high volume of orders for some manufacturers are translating into long lead times for projects,[17] highlighting both the demand for expanded capacity and the interest in manufacturers that can provide reliable, de-risked products.

Finally, the growing scale of electrolysis projects for hydrogen production and the need to compete with low-cost hydrogen from fossil fuel-dependent pathways make the market more susceptible to disruption. Electrolyser systems optimised for increased performance and lower capital costs will be needed and represent a pathway for emerging manufacturers to enter the market.

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[13] Source: IEA (2023) Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. International Energy Agency, Paris. 101. <https://iea.blob.core.windows.net/assets/9a698da4-4002-4e53-8ef3-631d8971bf84/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf>.

[14] Wood Mackenzie Hydrogen Lens (August 2024). Search conducted for hydrogen electrolyser vendors with operational status as of August 2024.

[15] IEA (2024) Advancing Clean Energy Manufacturing. 43–45. International Energy Agency, Paris. <https://iea.blob.core.windows.net/assets/7e7f4b17-1bb2-48e4-8a92-fb9355b1d1bd/CleanTechnologyManufacturingRoadmap.pdf>.

[16] IEA (2024) Advancing Clean Energy Manufacturing. 43–45. International Energy Agency, Paris. <https://iea.blob.core.windows.net/assets/7e7f4b17-1bb2-48e4-8a92-fb9355b1d1bd/CleanTechnologyManufacturingRoadmap.pdf>.

[17] Hydrogen and Fuel Cell Technologies Office (2023) Water Electrolyzer Installations: Summary Report – September 2023. 14. U.S. Department of Energy. <https://www.energy.gov/sites/default/files/2024-03/water-electrolyzer-installations-summary-report.pdf> (accessed 26 August 2024); Ernst & Young LLP (2023) Shortage of electrolyzers for green hydrogen – February 2023. <https://www.ey.com/content/dam/ey-unified-site/ey-com/en-in/insights/energy-resources/documents/ey-shortage-of-electrolyzers-for-green-hydrogen-v2.pdf> (accessed 26 August 2024).

1.3 Why Australia?

The rapid increase in scale, demand from electrolysis projects around the world, and the space for new entrants create a clear window of opportunity for countries like Australia to develop their electrolyser supply chains.

Australia also has natural attributes that position it well for renewable hydrogen production at scale – from extensive areas where a combination of wind and solar sources could power electrolysis projects, to large geological formations that could be adapted for hydrogen storage.[18] Moreover, the country has established strategies and support initiatives at the national and state and territory levels to translate these attributes into an economic opportunity.

Ambitious national strategies and support mechanisms – Hydrogen and manufacturing

The Australian government has set a vision of a low-emissions, innovative, safe, and internationally cost-competitive hydrogen industry by 2050, which produces economic benefits for Australian communities and allows it to be a significant global supplier and investment destination. This vision is supported by an overarching strategy, funding mechanisms, and clear target metrics.[19]

Some of the relevant targets in the National Hydrogen Strategy 2024 (an update on the original strategy published in 2019) include:

- Producing 15–30 million tonnes of renewable hydrogen by 2050.
- Meeting annual hydrogen production milestones that increase every 5 years in the path to 2050, starting with 0.5–1.5 million tonnes in 2030.
- Exporting 0.2–1.2 million tonnes of renewable hydrogen (directly or its equivalent in embodied products) annually by 2030.[20]

State and Territory governments have set their own goals for hydrogen production using renewable energy sources, with different focus areas.

Production of hydrogen from renewable energy, and the electrolysers that enable it, are also priority areas for federal programs like the National Reconstruction Fund (NRF) and the Future Made in Australia package (FMIA). The NRF includes at least $3 billion for renewable and low emissions technology manufacturing, while the FMIA considers two separate priority streams: one for green metals, low carbon liquid fuels and renewable hydrogen production, and another for critical minerals processing and clean technology manufacturing (specifically solar photovoltaic panels and batteries). The FMIA package further includes a $1.7 billion innovation fund administered by the Australian Renewable Energy Agency (ARENA), to support the translation and commercialisation of Australian innovations in the priority streams.[21]

There are also relevant State programs, like NSW's Net Zero Manufacturing Initiative, which has up to $150 million in funding for manufacturing components used in renewable energy technologies, including electrolysers.[22] Combined, these mechanisms could directly and indirectly support an electrolyser manufacturing ecosystem in Australia.

For more details on national, state and territory strategies and funding mechanisms, please see Appendix 5.3.

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[18] https://www.ga.gov.au/aecr2024/hydrogen

[19] DCCEEW (2024) National Hydrogen Strategy 2024. Department of Climate Change, Energy, the Environment and Water, Canberra. 41–46. <https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf> (accessed 13 September 2024); Commonwealth of Australia (2019) Australia's National Hydrogen Strategy. 67–71. <https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf>; DCCEEW (2024) Australian Energy Update 2024 (August 2024). Australian Government Department of Climate Change, Energy, the Environment and Water, Canberra. <https://www.energy.gov.au/sites/default/files/2024-08/australian_energy_update_2024.pdf> (accessed 6 September 2024).

[20] DCCEEW (2024) National Hydrogen Strategy 2024. Department of Climate Change, Energy, the Environment and Water, Canberra. 91–92. <https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf> (accessed 13 September 2024).

[21] Australian Government (2024) Future Made in Australia National Interest Framework: Supporting paper. 15. Australian Treasury, Canberra. <https://treasury.gov.au/sites/default/files/2024-05/p2024-526942-fmia-nif.pdf>; Australian Government (2024) Budget 2024–2025. <https://budget.gov.au/content/03-future-made.htm> (accessed 12 August 2024); Bathgate B (2024) New industrial policy: a Future Made in Australia. <https://www.aph.gov.au/About_Parliament/Parliamentary_departments/Parliamentary_Library/Budget/reviews/2024-25/NewIndustryPolicy> (accessed 12 August 2024); ARENA (2024) ARENA Corporate Plan 2024-25 to 2027-28. Australian Renewable Energy Agency. 8. <https://arena.gov.au/assets/2024/08/ARENA-Corporate-Plan-2024-FIN.pdf> (accessed 30 September 2024).

[22] Government (2024) Net Zero Manufacturing Initiative. Programs, grants and schemes. <https://www.energy.nsw.gov.au/business-and-industry/programs-grants-and-schemes/net-zero-manufacturing> (accessed 13 September 2024).

Strong domestic demand and pipeline

Australia has a strong pipeline of projects seeking to produce renewable hydrogen, each with specific electrolyser procurement and maintenance needs (see Case study 1). This provides a rare opportunity to establish a strong onshore electrolyser manufacturing ecosystem.

As noted in the section below, economic analysis developed for this report indicates Australia could produce 14 million tonnes of hydrogen in 2050, enabled by approximately 138 GW of installed electrolyser capacity. Achieving this long-term target could see 3 GW of installed capacity by 2030.

The country's renewable hydrogen production prospects are further reflected in its project pipeline, which is one of the largest in the world and could represent a demand source for electrolysers manufactured locally.

- The country could account for 20% of global electrolyser capacity in 2030, when considering all projects announced as of 2023.[23]
- Australia is second after India in terms of prospective net production (Mtpa) when considering projects at all stages, from announced to operational (Figure 4).[24]
- Eighty-seven hydrogen-related projects involving electrolysis were listed in HyResource,[25] as of August 2024. These are distributed across all States and Territories, with Queensland and Western Australia having the majority (twenty-three and twenty-one respectively).[26]

Most domestic projects, and the prospective capacity that they entail, have only been announced or remain at the development stage. This emergent nature of the renewable hydrogen pipeline is not exclusive to Australia, with 96% of global projects announced for 2030 at the feasibility stage or lower.[27]

A steady progression of projects to FID in the near term will be critical to enable and sustain a domestic electrolyser manufacturing opportunity. However, this early state of the renewable hydrogen pipeline also represents an upside, with a dual opportunity for Australian electrolyser manufacturers with clear technical innovations. With the bulk of potential demand still to come, timely development and scale-up could position innovators to both:

- **Drive down the costs of domestic hydrogen production,** and
- **Export to early-stage international projects** (which make up most of future electrolyser capacity globally).

CASE STUDY 1: Large scale electrolyser capacity for ammonia and hydrogen production in South Australia

Amp, a global developer of renewable energy assets, announced in May 2024 a commercial agreement to develop the Cape Hardy Advanced Fuels Project in South Australia. The project, which is currently at the pre-Front End Engineering Design (pre-FEED) stage, envisions an initial 1 GW electrolyser capacity (as part of a potential 10 GW overall scale over two stages) to produce ammonia, hydrogen, methanol and sustainable aviation fuels.[28]

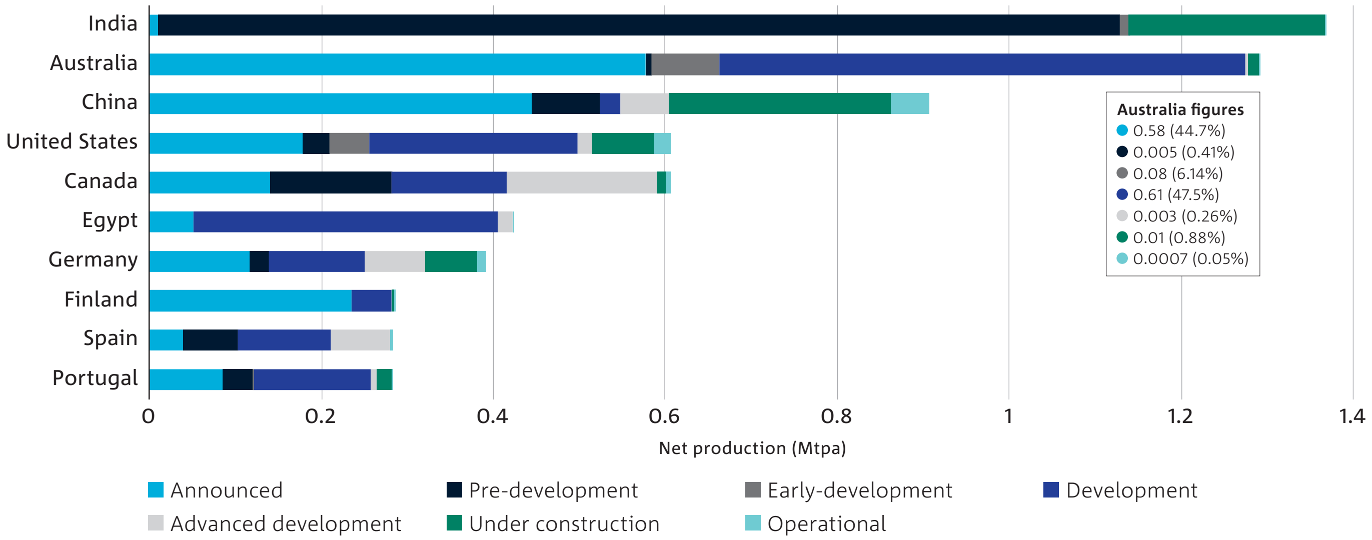

Figure 4. Renewable hydrogen pipeline across the 10 largest countries by prospective net production.

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[23] IEA (2023) Global hydrogen Review 2023. 68–71. International Energy Agency, Paris. <https://iea.blob.core.windows.net/assets/cb9d5903-0df2-4c6c-afa1-4012f9ed45d2/GlobalHydrogenReview2023.pdf>.

[24] Wood Mackenzie Hydrogen Lens (August 2024). Search conducted for hydrogen projects featuring alkaline, pressurised alkaline, PEM, solid oxide and AEM electrolysers.

[25] HyResource is a national-scale collaborative platform established by CSIRO, the Future Fuels CRC and the Australian Hydrogen Council to share knowledge on hydrogen projects in Australia.

[26] CSIRO (2024) HyResource (29 August 2024 update). <https://research.csiro.au/hyresource/projects/projects-spreadsheet/>.

[27] IEA (2023) Global hydrogen Review 2023. 70–71. International Energy Agency, Paris. <https://iea.blob.core.windows.net/assets/cb9d5903-0df2-4c6c-afa1-4012f9ed45d2/GlobalHydrogenReview2023.pdf>.

[28] CSIRO (2024) Cape Hardy Advanced Fuels Project. HyResource. <https://research.csiro.au/hyresource/cape-hardy-advanced-fuels-project/> (accessed 13 September 2024).

Novel economic opportunity

Growth in the number of projects that use electrolysis to produce hydrogen at scale could represent a new economic opportunity for Australia over the coming decades, if a competitive manufacturing ecosystem is developed.

By 2050, Australia's HEM industry could generate **AUD 1.7 billion in revenue** and another **AUD 1.2 billion in revenue** for installation services in the Central scenario. **Nearly 4000 jobs** could be created, with approximately three-quarters in manufacturing and another one-quarter in installations. This is also characterised by an annual electrolyser capacity demand of **14 GW**.

Key model parameters supporting this market estimate are summarised in Table 1. These parameters were collected from multiple sources and tested with research and industry experts. It considered three scenarios aligned to the hydrogen demand estimates in the 2024 National Hydrogen Strategy.[29] For a detailed description of the methodology, refer to Appendix 5.2.

Table 1. Market opportunity for Australian-manufactured electrolysers in 2050, by scenario

	Low	Central	High
Alignment to NHS 2024	Low scenario	Central scenario	High scenario
Additional assumptions	Little or no external support	Strong support for local procurement	Strong support for local procurement and export, and commercialisation of unique, IP-protected electrolyser products.
Hydrogen Production via electrolysis (Mtpa) Projected hydrogen production via electrolysis in Australia	4	14	31
Domestic unit revenue (AUD/kw) Revenue potential in Australia for every unit of electrolyser capacity	329	329	229
Domestic Market Capture (%) Potential market capture for local electrolyser manufacturing	36%	55%	85%
Export demand (Domestic-to-export ratio) Potential export opportunity	0.33	0.33	0.47
Market opportunity for HEM in Australia (million AUD)	**144**	**1,726**	**3,907**
Market opportunity for installation services in Australia (million AUD)	**138**	**1,177**	**1,690**
Number of jobs	**368**	**3,974**	**8,047**

The market size for each scenario is shown in Figure 5, with revenue split across stack manufacturing, balance of plant manufacturing, and installation services.

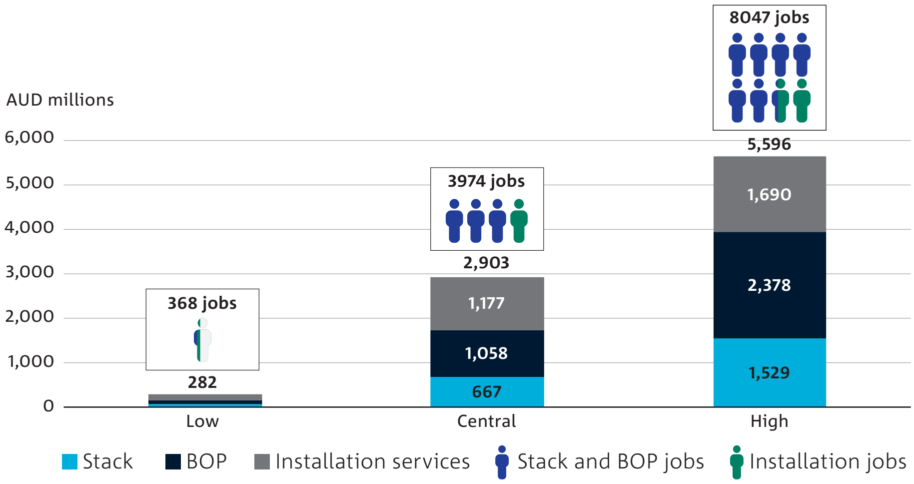

Figure 5. Market size for Australian-manufactured electrolysers and associated jobs in 2050, by scenario.

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[29] DCCEEW (2024) National Hydrogen Strategy 2024. Department of Climate Change, Energy, the Environment and Water, Canberra. 41. <https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf> (accessed 13 September 2024).

An advanced manufacturing and minerals base to launch from

Advanced manufacturing

Australia has an existing advanced manufacturing base that currently supplies products and components across the automotive, aerospace, defence, and medical technology sectors. Local companies across them regularly use materials, processes, and skills for production at scale that are relevant to electrolyser manufacturing (see Case study 2).

This includes core processes and skills in coating, pressing, sealing and assembly, and expertise in the design, operation, and automation of assembly lines. Bolstered through domestic electrolyser manufacturing, these capabilities could contribute to other renewable energy technologies and advanced manufacturing opportunities that the country may pursue.

CASE STUDY 2: Building advanced manufacturing capability out of existing players and innovative manufacturing processes

- Samvardhana Motherson Reflectec (SMR), a specialised component manufacturer and supplier to the automotive industry with manufacturing operations in Australia, partnered with the University of South Australia to develop a new mirror. This was accomplished through the development of a novel coating and the use of thin-film technology on an injection-moulded plastic substrate, resulting in a lightweight, shatterproof part.
- The mirror went into production in 2012 and generated $170 million in global sales over 5 years, with the coating technology itself enabling SMR to develop products for other markets. After the disappearance of the Australian automotive sector, diversification along with transition funding from the South Australian and Federal governments helped the company move its Australian operation into other advanced manufacturing opportunities across defence, aerospace and biomedical applications.[30]

Minerals

Australia also has significant mining operations for some of the raw materials used across different electrolyser types (see Table 2) and industrial production of steel and ceramic materials.

Many of these materials are relevant to other renewable energy technologies that could have specific manufacturing steps in Australia. Electrolyser manufacturing could generate further aggregated demand and offtake pathways, facilitating the development of onshore mid-stream processing capabilities to add further value to Australia's mineral resources.

Table 2. Raw materials relevant to different electrolyser types for which Australia has high reserves and production.

Raw material	World ranking for resources	World ranking for production	Electrolyser relevance
Aluminium (bauxite)	3 (12%)	1 (27%)	SOE
Cobalt	2 (19%)	4 (3%)	SOE
Gold	1 (22%)	3 (10%)	Alkaline, PEM
Iron	1 (31%)	1 (35%)	Alkaline, PEM, SOE, AEM
Manganese	4 (16%)	3 (10%)	SOE
Nickel	1 (23%)	5 (5%)	Alkaline, AEM
Titanium (rutile)	1 (65%)	1 (27%)	PEM
Cerium, gadolinium, samarium and yttrium (as part of mixed rare earth oxides)	6 (4%)	3 (5%)	SOE
Zirconium (zircon)	1 (74%)	2 (25%)	SOE

Source: World rankings for resources and production are adapted from Geoscience Australia (2023) Australia's Identified Mineral Resources 2023 – Commodity Summaries (March 2024 update). <https://www.ga.gov.au/aimr2023/commodity-summaries#mineral-sands-section>.

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[30] University of South Australia (n.d.) Shatterproof mirrors for safer, lower-emission cars. Enterprise Hub – Case studies. <https://www.unisa.edu.au/connect/enterprise-hub/case-studies/shatterproof-mirrors-for-safer-lower-emission-cars/> (accessed 8 September 2024); Australian Research Council (2019) Building future manufacturing capability for an automotive industry in Australia. Impact. <https://dataportal.arc.gov.au/EI/Web/Impact/ImpactStudy/634> (accessed 8 September 2024)

Proven R&D and innovation capability

The current window of opportunity for emerging manufacturers depends on successfully developing, scaling up and commercialising systems that surpass existing offerings. In turn, this requires a strong R&D ecosystem and an active commercial base.

Australian research is globally significant in areas that are key to electrolyser development, such as electrochemistry and materials science. The country ranks in the top twenty for both areas in terms of publication output and is in the top three among those twenty countries for citation impact metrics.[31]

Australia's research and innovation activity in electrolysis is also evident in the significant number of active projects from research institutions and industry taking place across most States and Territories. As an indicator, 58 active research projects related to electrolysis were listed in the HyResearch platform as of September 2024.[32] There is also an emerging set of testing and validation facilities to support the scale-up of novel Australian electrolysers.

Furthermore, innovations originating in the country's research sector are translating into commercial products developed by an emerging cohort of companies, including Fortescue, Hysata, Hadean Energy, Endua, and Cavendish Renewable Technology.

These Australian companies are at various stages of development, but all are advancing towards the commercialisation of different electrolyser types (Table 3).

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[31] Based on a bibliometric analysis by location performed with Clarivate's InCites platform, using the InCites dataset and covering all available years (1980 – July 31, 2024). 'Electrochemistry', and a combination of 'Materials Science, Composites', 'Materials Science, Coatings & Films', 'Materials Science, Ceramics', 'Materials Science, Characterization & Testing', and 'Materials Science, Multidisciplinary' were used as research areas in the Web of Science schema.

[32] A complement to HyResource, HyResearch is a knowledge sharing platform on research, development and demonstration (RD&D) projects related to hydrogen, developed by CSIRO and the Australian Hydrogen Research Network. Results filtered for "electrolysis" and active status. CSIRO (2024) HyResearch: Australian Hydrogen R&D Portal. Projects. <https://research.csiro.au/hyresearch/projects/> (accessed 11 September 2024).

Table 3. Australian hydrogen electrolyser manufacturers

Company	Electrolyser type	Development stage	Description
Fortescue	PEM	Commercial (2,000 MW scale)[33]	Fortescue is currently the only large scale, commercial phase hydrogen electrolyser manufacturer in Australia. The company opened its 2 GW Gladstone Electrolyser Facility (QLD) in 2024, leveraging an automated production line to assemble cell stacks used in their PEM electrolyser systems. The company also envisions additional research and investment in other electrolyser technologies to support its commercial growth.[34]
Hysata	Alkaline	Commercial demonstration (5 MW scale)[35]	Hysata has developed a capillary-fed alkaline electrolyser that could increase energy efficiency at the system level.[36] The company is building a 100 MW production line at its Port Kembla manufacturing facility (NSW), which will produce a complete 5MW electrolyser system for commercial demonstration at Stanwell Corporation's Future Energy and Innovation Training Hub (FEITH) in Queensland.[37]
Hadean Energy	SOE	Commercial demonstration (5 kW scale)[38]	Hadean Energy is advancing the commercialisation of tubular solid oxide electrolyser technology, which leverages heat from industrial operations for hydrogen production. Co-founded by CSIRO and RFC Ambrian, the company has announced small scale pilots: with BlueScope (Australia) at its Port Kembla Steelworks facility, and EDF (France) at one of its power plants in the United Kingdom (UK).[39]
Endua	PEM	Commercial demonstration (20 kW scale)[40]	Endua has developed a modular renewable hydrogen production and storage unit for energy storage in off-grid settings. The power bank, which features PEM electrolyser technology from CSIRO, a fuel cell, and storage modules, is being produced and tested in Brisbane. The company also commercialises the electrolyser as a standalone solution.[41]
Cavendish Renewable Technology	AEM	Commercial (single systems up to 5 MW)[42]	Cavendish Renewable Technology (CRT) is advancing the commercialisation of an AEM electrolyser system. The company relies on proprietary materials, designs and fabrication processes, with development and manufacturing occurring across its facilities in Victoria.[43] In 2022, CRT signed a technology licensing agreement with Adani New Industries, a prospective manufacturer considering a gigawatt-scale manufacturing plant in India.[44]

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33 Fortescue (2024) Fortescue Hydrogen Systems. <https://fortescue.com/what-we-do/fortescue-hydrogen-systems> (accessed 6 August 2024).

34 Fortescue (2024) Fortescue Hydrogen Systems. <https://fortescue.com/what-we-do/fortescue-hydrogen-systems> (accessed 6 August 2024); Fortescue (2024) Fortescue officially opens Gladstone Electrolyser Facility. News and Media. <https://fortescue.com/news-and-media/news/2024/04/08/fortescue-officially-opens-gladstone-electrolyser-facility> (accessed 7 August 2024).

35 ARENA (2023) Hysata Capillary-fed Electrolyser Commercial-Scale Demonstration Project. Australian Renewable Energy Agency. <https://research.csiro.au/hyresearch/hysata-capillary-fed-electrolyser-commercial-scale-demonstration-project/> (accessed 6 August 2024).

36 Hodges A, Hoang AL, Tsekouras G, Wagner K, Lee C-Y, Swiegers GF, Wallace GG (2022) A high-performance capillary-fed electrolysis cell promises more cost-competitive renewable hydrogen. Nature Communications 13, 1304.

37 Webster A (2023) Hysata to build next-generation hydrogen electrolyser. ARENAWIRE. <https://arena.gov.au/blog/hysata-to-build-next-generation-hydrogen-electrolyser/>; HyResearch (2024) Hysata Capillary-fed Electrolyser Commercial-Scale Demonstration Project. <https://research.csiro.au/hyresearch/hysata-capillary-fed-electrolyser-commercial-scale-demonstration-project/> (accessed 7 August 2024); Hysata (2023) Hysata and Stanwell Commercial Demonstration Project. <https://hysata.com/news/hysata-and-stanwell-commercial-demonstration-project/> (accessed 7 August 2024); Hysata (2023) Hysata opens new electrolyser manufacturing facility in Port Kembla with $23 million vote of confidence from Australian and Queensland Governments. <https://hysata.com/news/hysata-opens-new-electrolyser-manufacturing-facility-in-port-kembla-with-23m-vote-of-confidence-from-australian-and-queensland-governments/> (accessed 7 August 2024).

38 Carroll D (2024) Australian startup teams with French utility to test electrolyser technology. PV Magazine Australia. <https://www.pv-magazine-australia.com/2024/05/15/australian-startup-teams-with-french-utility-to-test-electrolsyer-technology/> (accessed 6 August 2024).

39 Hadean Energy (2023) About. <https://hadeanenergy.com.au/about/> (accessed 7 August 2024); CSIRO (2023) New CSIRO company pursues hydrogen game changer for heavy industry. News release. <https://www.csiro.au/en/news/All/News/2023/August/Hadean> (accessed 7 August 2024); HyResource (2024) Tubular Sollid Oxide Electrolysis. <https://research.csiro.au/hyresearch/tubular-solid-oxide-electrolysis/> (accessed 7 August 2024).

40 Endua, Consultation.

41 Endua (n.d.) Power bank. Products. <https://www.endua.com/power-bank> (accessed 7 August 2024); Endua (n.d.) Electrolyser. Products. <https://www.endua.com/electrolyser> (accessed 7 August 2024); HyResearch (2023) Green Hydrogen Energy Production and Storage for Distributed Energy Systems. <https://research.csiro.au/hyresearch/green-hydrogen-energy-production-and-storage-for-distributed-energy-systems/> (accessed 7 August 2024); AuManufacturing (2023) Endua unveils prototype power bank system. <https://www.aumanufacturing.com.au/endua-unveils-prototype-power-bank-system> (accessed 7 August 2024).

42 Cavendish Renewable Technology, Consultation.

43 Cavendish Renewable Technology (2022) Our Research and Technology. <https://cavendishrenewable.com.au/research-and-technology/> (accessed 7 August 2024); Cavendish Renewable Technology (2022) Facilities and Partners. <https://cavendishrenewable.com.au/facility-and-partners/> (accessed 7 August 2024).

44 Gupta U (2022) Australia's Cavendish Renewable signs hydrogen electrolyzer agreement with Adani arm. pv magazine India, December 9. <https://www.pv-magazine-india.com/2022/12/09/australias-cavendish-renewable-signs-hydrogen-electrolyzer-agreement-with-adani-arm/> (accessed 07 September 2024).

Local conditions and standards

The Australian context involves unique environmental conditions and regulatory standards that could be best served by local manufacturers.

For example, renewable hydrogen projects in Australia will have to withstand high temperatures and severe weather events (e.g., cyclones). These impact the operational reliability and durability of electrolysers, which are directly relevant to project economics. Such conditions may not be as prominent in the countries where electrolysers have traditionally been made and will require technical modifications by the manufacturer.

Similarly, interpretation of Australian standards varies across States and Territories, and these are different from those of large jurisdictions like the United States (US) and European Union (EU). This creates an alignment risk with the manufacturer and can make deployment lengthier and costlier on account of rectifications or modifications that need to be made onshore to internationally supplied equipment.[45]

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[45] Wheatley G, Thompson N, Purkess C (2023) Electrolyser Manufacturing Business Case. ITM Power Pty and Linde Engineering Pty. 20. <https://www.wa.gov.au/system/files/2023-09/public-knowledge-sharing-report-electrolyser-business-case-statement.pdf> (accessed 27 August 2024); BOC Limited (2022) Renewable Hydrogen Production and Refuelling Project (ARENA Project 2018(ARP178): Lessons Learnt Report. <https://arena.gov.au/assets/2022/02/boc-renewable-hydrogen-production-and-refuelling-lessons-learnt.pdf> (accessed 27 August 2024).

2 Electrolysers – technical context

This section provides the **technical foundation** to support the understanding of the pathways identified in Section 3. It includes an analysis of **electrolyser configurations, types**, **materials used, manufacturing processes and areas of innovation**.

This report covers the four main electrolyser types that are currently commercially relevant: **Alkaline, Proton Exchange Membrane (PEM), Solid Oxide (SOE),** and **Anion Exchange Membrane (AEM)**. Inclusion of these electrolyser types is based on the current use and production at scale of alkaline and PEM; the relative technological readiness and efficiency improvements in specific applications of SOE; and the potential for adequate performance with less expensive materials of AEM.

Each electrolyser type also carries a range of possible modifications intended to improve overall performance or enable operation under more challenging, but economically beneficial conditions. These include, but are not limited to, capillary-fed electrolysers and novel materials for electrolysis using seawater.[46] Specific modifications are mentioned where relevant throughout this report but are not assessed systematically.

2.1 General configuration

All hydrogen electrolyser types leverage a common principle and a similar arrangement: water splitting into hydrogen and oxygen, driven by an electric current passing between two electrodes (an anode and a cathode) that are separated by an electrolyte or diaphragm. See Figure 6.

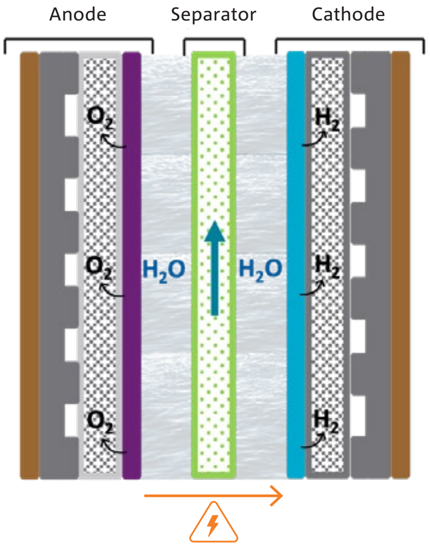

Figure 6. Basic structure of an electrolyser cell.

This arrangement of electrodes surrounding a separator is the basis of an electrolysis cell, the basic operating unit for hydrogen electrolysers. Multiple connected cells form a cell stack, which is in turn supported by peripheral equipment (balance of plant, BoP) that handles input and output flows (e.g., water, hydrogen, electricity), temperature control and gas compression.[47] See Figure 7 below.

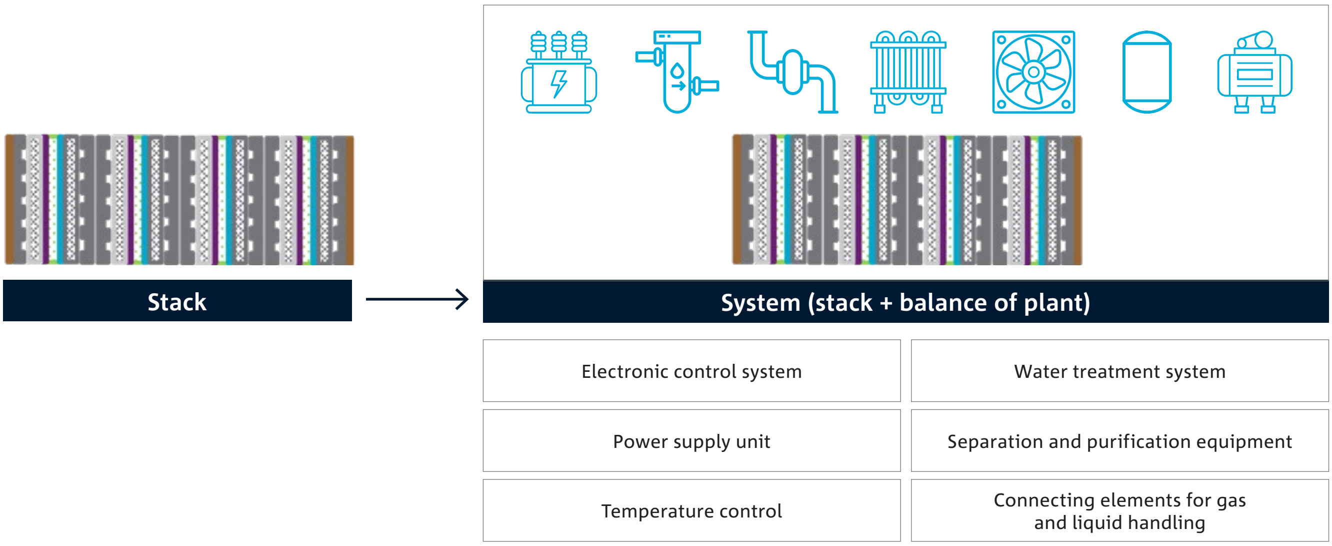

Figure 7. Basic overview of an electrolyser system.

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[46] Hodges A, Hoang AL, Tsekouras G, Wagner K, Lee C-Y, Swiegers GF, Wallace GG (2022) A high-performance capillary-fed electrolysis cell promises more cost-competitive renewable hydrogen. Nature Communications 13, 1304; Guo J, Zheng Y, Hu Z, Zheng C, Mao J, Du K, Jaroniec M, Qiao S-Z, Ling T (2023) Direct seawater electrolysis by adjusting the local reaction environment of a catalyst. Nature Energy.

[47] IRENA (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal. 31–32. International Renewable Energy Agency, Abu Dhabi. <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf>

2.2 Componentry

Electrodes: catalysts and support layers

Each electrode comprises a catalyst layer, a porous transport or support layer that facilitates gas and liquid flow, and an outermost layer that provides further support, flow and electric connectivity (either a bipolar plate or interconnector layer).

The catalyst layers enable the overall electrolysis process via metallic compounds that support oxygen production at the anode and hydrogen at the cathode. Accordingly, the composition of the porous and outermost layers varies to accommodate the physicochemical conditions generated at each electrode.

Electrolyte

Electrolytes selectively transport ions produced at one electrode to the other, completing the electrochemical circuit and coupling the production of hydrogen and oxygen. Electrolytes can also help prevent mixing of the two gas products to varying degrees, depending on characteristics like thickness and composition.

The electrolyte itself varies according to electrolyser type. Alkaline electrolysers use an insulating membrane (diaphragm) that contains a concentrated liquid electrolyte to transport hydroxide ions (OH^-). PEM and AEM use solid polymer membranes as electrolyte, transporting protons (H^+) or hydroxide ions respectively. Similarly, SO electrolysers use a solid ceramic material as the electrolyte to transport O^{2-}.

Balance of plant

The balance of plant varies depending on the electrolyser type and specific product, but broadly includes an electronic control system, a power supply unit, temperature control equipment, a water treatment circuit, separation and purification equipment, and connecting elements for liquid and gas management. The power supply unit comprises a transformer and a rectifier; temperature control encompasses a heat exchanger and cooling unit; the water treatment circuit includes filters and reverse osmosis or desalination equipment; separation and purification involve liquid-gas separators, de-oxygenation units and dryers; and liquid-gas management requires pumps, gas compressors, pipes and storage vessels.

Specific electrolyser types also have additional requirements, such as circuits to process the concentrated electrolyte in alkaline systems, specialised water treatment filters in PEM systems, or heating and evaporator elements in solid oxide electrolysers.[48]

Electrolyser types differ in terms of electrolyte, catalyst and electrode materials, cell design, and BoP equipment. These differences are the result of leveraging distinct electrolysis mechanisms, which in turn influence operating conditions. Refer to Figure 8 and Figure 9 on the following page for the generic structures across the major electrolyser types considered in this report.

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[48] IRENA (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5^0C Climate Goal. 34–39. International Renewable Energy Agency, Abu Dhabi. <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf>

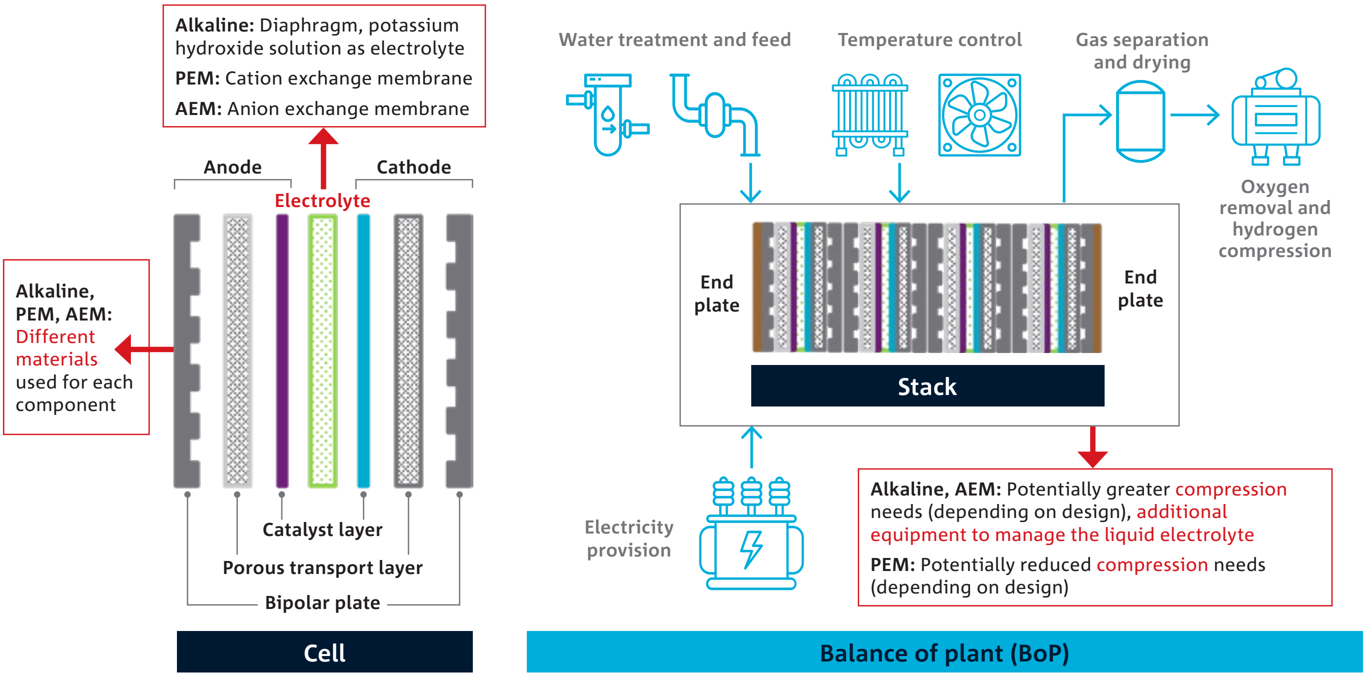

Figure 8. Generic structure and components for alkaline, proton exchange membrane (PEM) and anion exchange membrane (AEM) electrolysers with a zero-gap cell design.[49]

Note: AEM electrolysers use a less concentrated solution as liquid electrolyte and can operate at higher pressures compared to conventional alkaline electrolysers, resulting in comparatively lower electrolyte handling and compression requirements.

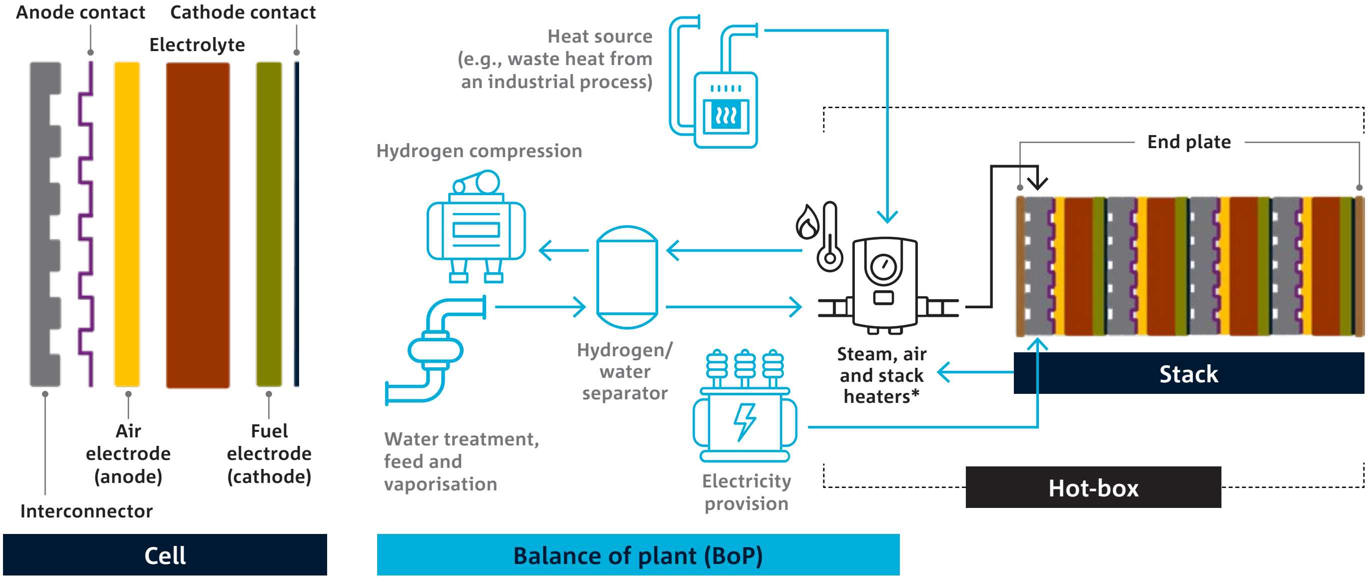

Figure 9. Generic structure and components for a solid oxide electrolyser (SOE) with a planar cell design.[50]

Note: Conventionally, the thicker support layer is the electrolyte (as depicted), but other substrates are possible (e.g., the cathode).

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[49] **Cell and stack based on:** Badgett et al. (2022) WATER ELECTROLYZERS AND FUEL CELLS SUPPLY CHAIN DEEP DIVE ASSESSMENT. U.S. Department of Energy. <https://www.energy.gov/sites/default/files/2022-02/Fuel%20Cells%20%26%20Electrolyzers%20Supply%20Chain%20Report%20-%20Final.pdf>; Lagadec MF, Grimaud A (2020) Water electrolysers with closed and open electrochemical systems. Nature Materials 19, 1140; Lim A, Kim H, Henkensmeier D, Jong Yoo S, Young Kim J, Young Lee S, Sung Y-E, Jang JH, Park HS (2019) A study on electrode fabrication and operation variables affecting the performance of anion exchange membrane water electrolysis. Journal of Industrial and Engineering Chemistry 76, 410; López-Fernández E, Sacedón CG, Gil-Rostra J, Yubero F, González-Elipe AR, de Lucas-Consuegra A (2021) Recent Advances in Alkaline Exchange Membrane Water Electrolysis and Electrode Manufacturing. Molecules 26, 6326; Ove Arup & Partners Limited (2022) Assessment of electrolysers: Final report. Edinburgh. <https://www.gov.scot/publications/assessment-electrolysers-report/pages/3/> (accessed 1 August 2024); Tüysüz H (2024) Alkaline Water Electrolysis for Green Hydrogen Production. Accounts of Chemical Research 57, 558–567. **Balance of plant based on:** IRENA (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal. 36–37. International Renewable Energy Agency, Abu Dhabi. <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf>.

[50] **Cell and stack based on:** Flis G, Wakim G (2023) Solid Oxide Electrolysis: A Technology Status Assessment. 9–10. Clean Air Task Force, Boston, United States. <https://cdn.catf.us/wp-content/uploads/2023/11/15092028/solid-oxide-electrolysis-report.pdf>. **Balance of plant based on:** IRENA (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal. 36–37. International Renewable Energy Agency, Abu Dhabi. <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf>; Flis G, Wakim G (2023) Solid Oxide Electrolysis: A Technology Status Assessment. 11. Clean Air Task Force, Boston, United States. <https://cdn.catf.us/wp-content/uploads/2023/11/15092028/solid-oxide-electrolysis-report.pdf>.

2.3 Differentiating factors between electrolyser types

The differences in materials and cell design across electrolyser types affect the components and fabrication techniques used during manufacturing, as well as the final configuration of the system.

These differences also determine technical parameters like temperature and pressure conditions, energy efficiencies, stack durability, ramping dynamics, and hydrogen purity, which are directly relevant to the economics of electrolysis at large scale. Table 4 summarises the economic implications of key operational parameters that vary between electrolyser types.

Table 4. Economic implications of key operational parameters varying across electrolyser types

Operational parameters	Economic implications
Energy efficiency	Energy efficiency at the stack and system level affects a project's operational expenditure and, ultimately, its financial viability. This is due to the large influence of electricity prices on the overall cost to produce one kilogram (kg) of hydrogen.
Stack durability	Stack durability can impact both operational and capital expenditure. A reduced stack lifetime can result in more frequent replacements of a high value component, requiring additional capital investment. Progressive degradation can also reduce stack efficiency, leading to greater electricity consumption to maintain the same hydrogen output, which increases operating expenditures and overall production costs.
Operating pressure	The pressure at which an electrolyser operates determines the extent of additional compression required. This influences the balance of plant equipment to be used and overall system footprint, both of which have capital expenditure implications. Adequate compression itself is also important for the economically viable transport and distribution of hydrogen.
Operating temperature	Operating temperature can increase energy efficiency at the stack level but potentially reduce the durability of sensitive components (such as electrolytes), with the expenditure and production implications outlined above.
Ramping dynamics	Ramping dynamics determine an operation's capacity to respond strategically to variations in the electricity supply, either in terms of price or availability. This can influence operational expenditure, as projects may ramp down hydrogen production during periods with higher cost and ramp up at other times. Additionally, off-grid operations may contend with the intermittency of renewable energy sources. This is particularly relevant in countries like Australia, that seek to leverage renewable energy sources extensively for large electrolyser projects.
Hydrogen purity	The purity of the hydrogen produced also has capital and operational expense implications. Lower purity hydrogen may not be usable in sensitive applications (such as silicon devices or fuel cell-powered vehicles) and may require further processing, which translates into additional balance of plant equipment.

Distinct features enable each electrolyser type to play a role in contexts most suited to their use. Table 5 provides an overview of each electrolyser type, their maturity at scale, the materials and designs used, key features, possible contexts of use and areas of interest for innovation.

Table 5. Overview of key differentiators across electrolyser types

Maturity (TRL at scale) [a]	Share of installed capacity (2022) [b]	Materials and design [c]	Distinctive features [c]	Potential contexts of use	Areas of recent innovation [d]
Alkaline					
9	**60%**	Potassium hydroxide solution as liquid electrolyte, nickel-based catalysts, nickel and stainless steel in porous transport layers and bipolar plates, and a zirconium oxide-polysulfone membrane in either a conventional or zero-gap design (in which the electrodes and diaphragm are immediately adjacent, without spacing).	**Less expensive materials** used in key components, helping reduce cost at the stack level. **Compatible with renewable energy sources** due to sufficiently fast ramp up and down rates. However, the power range over which fast ramping dynamics take place could be limited by the crossover of hydrogen into the anode side at lower current densities. Crossover results in high proportions of hydrogen in oxygen, which attracts safety considerations. **Larger system footprint and expenditure in balance of plant equipment, which can translate into increased capital costs**. Alkaline electrolysers reach a lower maximum pressure and hydrogen purity than PEM (up to 5N), potentially requiring additional components for compression and purification. The use of a concentrated potassium hydroxide solution also requires additional processing.	Alkaline electrolysers may be used in **large scale projects with lower purity requirements** to manage capital investment. This can include industrial applications like heat provision for alumina refineries or calcination in mineral processing.	**Improving energy efficiency and balance of plant requirements:** Recent designs aim to produce pressurised hydrogen and reduce electric resistance, minimising the energy lost as heat and increasing overall efficiency. Pressurisation and reduced heat production also minimise the need for balance of plant components involved in compression and cooling, enabling cost reductions.

Maturity (TRL at scale) [a]	Share of installed capacity (2022) [b]	Materials and design [c]	Distinctive features [c]	Potential contexts of use	Areas of recent innovation [d]
Proton exchange membrane (PEM)					
9	**30%**	Iridium and platinum-based catalysts (for anode and cathode respectively), gold or platinum-coated titanium for the porous transport and outermost layers, and a fluoropolymer-based proton exchange membrane for H^+ transport from anode to cathode, in a zero-gap design.	**Reduced need for additional purification and compression that can reduce capital and operational costs**, due to production of highly pure hydrogen (up to 6N) at high pressure. **Highly compatible with renewable energy sources**, due to the fastest ramp dynamics among electrolyser types in this report. Like alkaline electrolysers, ramping is limited by hydrogen crossover, but the power range over which it can occur is wider for PEM. **Cost challenges** from the expensive materials used in catalysts, porous transport layers, and bipolar plates to withstand highly acidic conditions. **Attracts environmental and economic considerations for end-of-life (EOL) disposal and recycling.** This is due to the fluoropolymer-based membrane (which constitutes a per- and polyfluoroalkyl substance, PFAS) and the potential for recovering the highly expensive metals present in catalysts, porous transport layers and bipolar plates.	PEM electrolysers may be used in **applications requiring pressurised production at high purity**, or where reduced footprint with high production volumes can reduce capital expenditure. This may be desirable for aviation fuel production or heavy haulage vehicle recharging stations, where the space available is limited. PEM electrolysers may also be deployed as **part of systems requiring fast, flexible ramping**, like independent renewable energy grids or peaking power plants for energy conversion.	**Developing alternative materials for greater efficiency and lower cost:** Enhanced membranes (based on alternative polymers, reduced thickness, increased conductivity, and lower hydrogen crossover) could avoid the use of current fluoropolymers, improve overall energy efficiency and increase hydrogen purity. Meanwhile, alternative catalyst materials could replace or reduce the use of expensive elements in current PEM models. Improving techniques used to form catalyst layers to minimise losses and optimising membrane handling to prevent defects are also areas of interest.

Maturity (TRL at scale) [a]	Share of installed capacity (2022) [b]	Materials and design [c]	Distinctive features [c]	Potential contexts of use	Areas of recent innovation [d]
Solid oxide					
8	**<1%**	Slightly different cell design comprising mostly ceramic materials: a solid electrolyte made of yttrium-stabilised zirconia (YSZ); an anode (or air electrode) containing lanthanum and strontium-based compounds that also feature transition metals like manganese, iron and cobalt; a cathode (or fuel electrode) composed of nickel oxide and YSZ; metal and metal oxide current collectors (for anode and cathode); an outermost interconnector layer comprising ferritic stainless steel and ceramic material, or metal (for anode and cathode respectively); and glass-ceramic sealants (e.g., barium aluminosilicates). An intermediate layer of gadolinium-doped ceria (GDC) or yttrium-doped ceria (YDC) may also be present between the electrolyte and the anode (or air electrode) to help with thermal expansion.	**Increased hydrogen production efficiency by using heat**, with potential for reduced operational expenditure. **Less expensive ceramic materials**, which can reduce stack costs. **Reduced durability** of the ceramic materials due to damage caused by large thermal differences in frequent start-shut off cycles. **Limited compatibility with renewable energy sources** due to slow ramping dynamics. **Potential for additional operational and capital costs from additional processing for sensitive applications.** This is because hydrogen purity (up to 3N) and output pressure are lower than those obtained with PEM systems.	Solid oxide electrolysers are likely to be deployed in **industrial or energy production operations that have excess or waste heat available**, to leverage the increase in energy efficiency associated with higher temperatures. For example, while not traditional hydrogen producers, nuclear power plants could be a group of interest given the availability of high-grade heat and electricity that can be supplied. This would apply to countries in which the plants are already available and operate cost-effectively. Solid oxide electrolysers are also capable of co-electrolysis – the simultaneous use of hydrogen and carbon dioxide to produce hydrocarbon compounds. This opens a potential role in producing value-added compounds from captured CO_2, such as sustainable aviation fuels (SAF), methanol for maritime engines, or methane for natural gas replacement.	**Increasing durability and coupling with other processes for product versatility:** Increasing the durability of ceramic materials when exposed to significant temperature changes, advancing cell geometries with mechanical advantages (e.g., advanced tubular designs), minimising stack degradation and reducing the cost of components like the interconnector can extend stack lifetime and reduce its cost. Besides durability, the development and implementation of alternative ceramic materials that conduct protons (H^+ as opposed to O^{2-}) can provide benefits across higher conductivity, lower operating temperatures, and higher purity of produced hydrogen. Other major areas of interest include the use of SO electrolysers in reversible mode (i.e., as fuel cells), co-electrolysis to process CO_2 into carbon-containing feedstock (e.g., methanol, SAF), and coupling with downstream processes for energy-efficient ammonia production.

Maturity (TRL at scale) [a]	Share of installed capacity (2022) [b]	Materials and design [c]	Distinctive features [c]	Potential contexts of use	Areas of recent innovation [d]
Anion exchange membrane (AEM)					
6	**No data**	Uses a zero-gap design with a anion exchange membrane that transports OH^- from cathode to anode. Alkaline conditions allow nickel and cobalt-based catalysts, along with nickel, stainless steel, and carbon-based materials for the porous transport and outermost layers (depending on the electrode side).	**Less expensive materials and fast ramping dynamics**, which makes it compatible with intermittent energy sources. **Lower conductivity, durability and stability** of current anion-exchange membranes than PEM counterparts. However, the polymers used are not classified as PFAS, avoiding the regulatory considerations these attract. **Potential for additional operational and capital costs** from the use of a potassium hydroxide or potassium carbonate solution to increase overall performance (at significantly lower concentrations than those of alkaline electrolysers). The use of such solutions involves additional processing requirements and can reduce membrane durability.	AEM electrolysers may be used in **projects targeting higher operating pressures than those of alkaline electrolysers and lower capital costs than PEM systems**.	**Improving performance and durability:** Areas of interest include increasing membrane stability, reducing resistance, minimising the need for alkaline conditions (e.g., through alternatives to potassium hydroxide), and exploring alternative catalysts.

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[a] The 4 electrolyser types are already commercially available but have different maturity levels at scale. Based on IEA (2023) Electrolysers – Innovation. Low-Emission Fuels. International Energy Agency. <https://www.iea.org/energy-system/low-emission-fuels/electrolysers> (accessed 1 August 2024).

[b] The percentages are presented as reported by the International Energy Agency. Shares do not add to 100%, likely due to absence of definitive information on the specific electrolyser type used in a portion of the projects assessed. IEA (2023) Global hydrogen Review 2023. 68–70. International Energy Agency, Paris. <https://iea.blob.core.windows.net/assets/cb9d5903-0df2-4c6c-afa1-4012f9ed45d2/GlobalHydrogenReview2023.pdf>.

[c] **General:** IRENA (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5°C Climate Goal. 32, 65–66. International Renewable Energy Agency, Abu Dhabi; Martinez Lopez VA, Ziar H, Haverkort JW, Zeman M, Isabella O (2023) Dynamic operation of water electrolyzers: A review for applications in photovoltaic systems integration. Renewable and Sustainable Energy Reviews 182, 113; and Ove Arup & Partners Limited (2022) Assessment of electrolysers: Final report. Edinburgh; **Alkaline:** de Groot MT, Kraakman J, Garcia Barros RL (2022) Optimal operating parameters for advanced alkaline water electrolysis. International Journal of Hydrogen Energy 47, 34773; Moreno-González M, Mardle P, Zhu S, Gholamkhass B, Jones S, Chen N, Britton B, Holdcroft S (2023) One year operation of an anion exchange membrane water electrolyzer utilizing Aemion+® membrane: Minimal degradation, low H2 crossover and high efficiency. Journal of Power Sources Advances 19, 100109; Trinke P, Haug P, Brauns J, Bensmann B, Hanke-Rauschenbach R, Turek T (2018) Hydrogen Crossover in PEM and Alkaline Water Electrolysis: Mechanisms, Direct Comparison and Mitigation Strategies. Journal of The Electrochemical Society 165, F502; Tüysüz H (2024) Alkaline Water Electrolysis for Green Hydrogen Production. Accounts of Chemical Research 57, 558–567; **PEM and AEM:** Badgett et al. (2022) WATER ELECTROLYZERS AND FUEL CELLS SUPPLY CHAIN DEEP DIVE ASSESSMENT. U.S. Department of Energy. <https://www.energy.gov/sites/default/files/2022-02/Fuel%20Cells%20%26%20Electrolyzers%20Supply%20Chain%20Report%20-%20Final.pdf>; Lagadec MF, Grimaud A (2020) Water electrolysers with closed and open electrochemical systems. Nature Materials 19, 1140; Lim A, Kim H, Henkensmeier D, Jong Yoo S, Young Kim J, Young Lee S, Sung Y-E, Jang JH, Park HS (2019) A study on electrode fabrication and operation variables affecting the performance of anion exchange membrane water electrolysis. Journal of Industrial and Engineering Chemistry 76, 410; López-Fernández E, Sacedón CG, Gil-Rostra J, Yubero F, González-Elipe AR, de Lucas-Consuegra A (2021) Recent Advances in Alkaline Exchange Membrane Water Electrolysis and Electrode Manufacturing. Molecules 26, 6326. **SOE:** Badgett A, Brauch J, Buchheit K, Hackett G, Li Y, Melaina M, Ruth M, Sandor D, Summers M, Upasani S (2022) WATER ELECTROLYZERS AND FUEL CELLS SUPPLY CHAIN DEEP DIVE ASSESSMENT. U.S. Department of Energy. <https://www.energy.gov/sites/default/files/2022-02/Fuel%20Cells%20%26%20Electrolyzers%20Supply%20Chain%20Report%20-%20Final.pdf>; Gaikwad PS, Mondal K, Shin YK, van Duin ACT, Pawar G (2023) Enhancing the Faradaic efficiency of solid oxide electrolysis cells: progress and perspective. npj Computational Materials 9, 149; He S, Zou Y, Chen K, Jiang SP (2023) A critical review of key materials and issues in solid oxide cells. Interdisciplinary Materials 2, 11; Nechache A, Hody S (2021) Alternative and innovative solid oxide electrolysis cell materials: A short review. Renewable and Sustainable Energy Reviews 149, 111322.

[d] Consultations with industry and research stakeholders conducted by CSIRO Futures; Harrison SB (2024) Electrolyser innovations PEM, alkaline, SOEC, and AEM. Hydrogen Tech World Conference, Essen. 26th June 2024. <https://hydrogentechworld.com/wp-content/uploads/sites/22/2024/07/1.7.-Stephen-B-Harrison-sbh4-consulting.pdf>; Kim D, Lee TK, Han S, Jung Y, Lee DG, Choi M, Lee W (2023) Advances and challenges in developing protonic ceramic cells. Materials Today Energy 36, 101365.

2.4 Manufacturing process

End-to-end manufacturing of hydrogen electrolysers can be broken down into five stages:

1. **Raw material processing,** producing intermediate materials (out of scope for this report).
2. **Component manufacturing,** combining materials into individual cell components like membranes and bipolar plates.
3. **Cell fabrication,** bringing individual components together into the core of the cell architecture, the membrane electrode assembly (MEA); with the process varying slightly for SO electrolysers due to differences in material and overall configuration.
4. **Cell stack assembly,** combining individual MEAs with the bipolar plates to form single cells, aligning the cells (in a semi- or fully automated way), and compressing into stacks; with additional steps for SO electrolysers**.**
5. **System assembly,** connecting stacks to the balance of plant equipment, completing the overall system.

Specific techniques can vary depending on the electrolyser type (notably for solid oxide electrolysers), specific model, scale of production, and manufacturer. Figure 10 and Figure 11 provide an overview of the electrolyser value chain and the general manufacturing processes used.

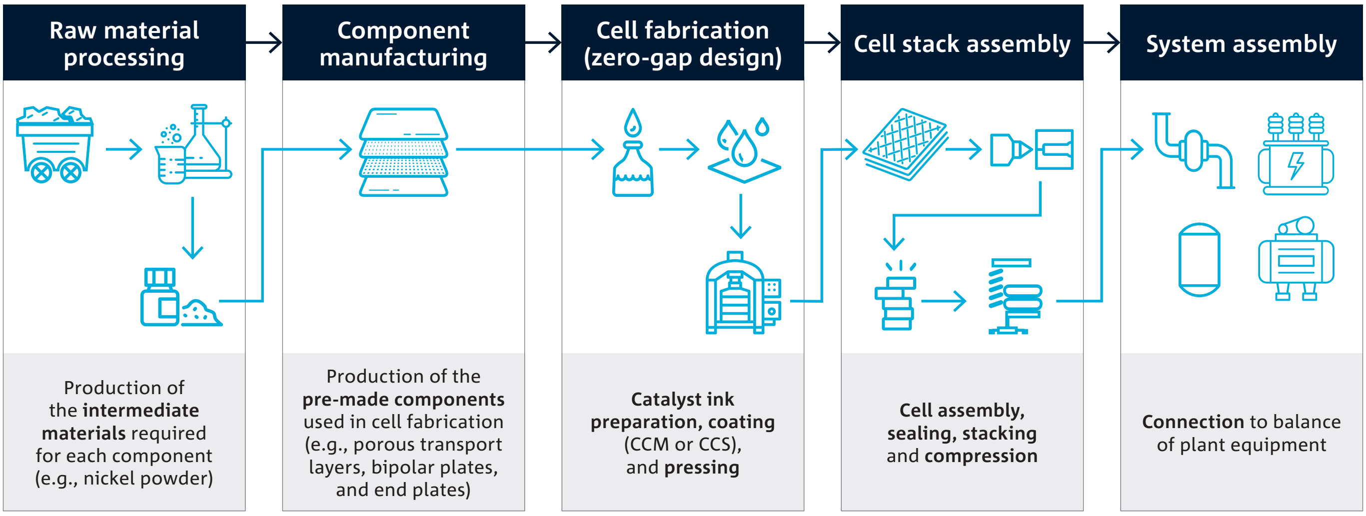

Figure 10. General manufacturing processes for alkaline, PEM and AEM electrolysers with a zero-gap cell design

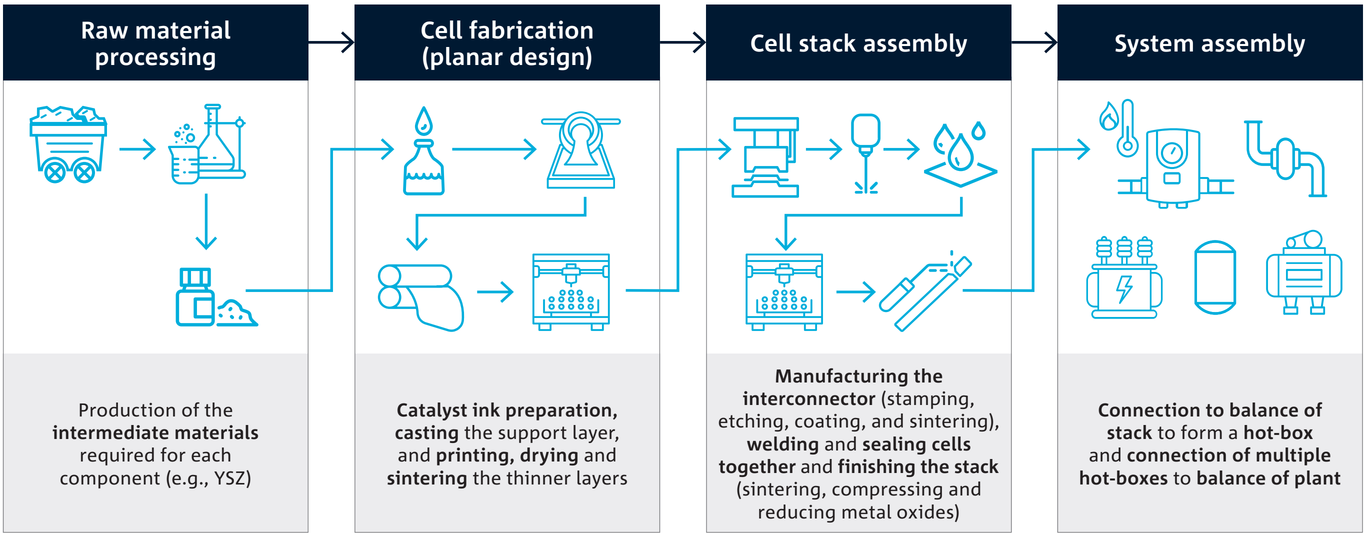

Figure 11. General manufacturing processes for SO electrolysers with a planar cell design [a]

[a] In SO electrolysers, intermediate materials can be used directly to fabricate the cell, so this stage is not depicted. However, it is worth noting that the end plates for the stack would still require a component manufacturing stage.

1. Raw materials processing

Raw material processing, out of scope for this report, includes all activities to produce the intermediate materials used in component manufacturing, such as perfluorosulfonic acid, iridium oxide, or nickel metal powder.

2. Component manufacturing

Component manufacturing covers the methods needed to combine the intermediate materials into key cell components: separator (membrane or diaphragm), porous transport layers, outermost layer (bipolar plates, interconnector plates and endplates), frames, and seals.

3. Cell fabrication

Cell fabrication focusses on forming catalyst layers, bringing together the membrane with the porous transport layers, and sealing them to form a single membrane electrode assembly (MEA). For SO electrolysers cell fabrication works similarly, although the process focusses on sequentially producing electrolyte and electrode layers.

Formation of the anode and cathode catalyst layers is crucial to this stage:

- **PEM, AEM and Alkaline: zero-gap designs**

  PEM, AEM and Alkaline electrolysers with a zero-gap design use either a catalyst-coated membrane (CCM) or catalyst-coated substrate (CCS) approach. Both involve preparing a catalyst ink by thoroughly mixing the catalyst material alongside a solvent and a suitable binder, at specific proportions. Then, coating either the membrane (CCM) or the porous transport layer (CCS) with the ink through a process compatible with commercial scale production, followed by hot or cold pressing.[51]

  Direct membrane deposition is an emerging alternative in which the porous transport layer is first coated with the catalyst and afterwards with a thin layer of the material that forms the membrane.[52]

- **Solid Oxide electrolysers**

  SO electrolysers employ a slightly different fabrication process, but can leverage similar equipment to produce layers and coatings at high volume (e.g., roll-to-roll tape casting and screen printing). The process involves preparing catalyst and electrolyte inks and laying an initial, thicker support layer through a casting method followed by sintering at high temperature. Conventionally, this support layer is the electrolyte or the cathode, although the anode or other substrates may be chosen instead.[53] Thinner layers are then printed onto the support layer, dried and sintered to form: the electrolyte or cathode (depending on which was used as the support layer), an intermediate or barrier layer (if required), and the anode. Laser cutting can be used at different stages of the process to separate individual cells.[54]

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[51] Lin X, Seow JZY, Xu ZJ (2023) A brief introduction of electrode fabrication for proton exchange membrane water electrolyzers. Journal of Physics: Energy 5, 034003; Mayyas A, Ruth M, Pivovar B, Bender G, Wipke K (2018) Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers. National Renewable Energy Laboratory, Golden, CO. <https://www.nrel.gov/docs/fy19osti/72740.pdf>; Raja Sulaiman RR, Wong WY, Loh KS (2022) Recent developments on transition metal–based electrocatalysts for application in anion exchange membrane water electrolysis. International Journal of Energy Research 46, 2241; Ruth M, Mayyas A, Mann M (2017) Manufacturing Competitiveness Analysis for PEM and Alkaline Water Electrolysis Systems. National Renewable Energy Laboratory, Fuel Cell Seminar and Energy Expo. <https://www.nrel.gov/docs/fy19osti/70380.pdf> (accessed 4 August 2024).

[52] Lin X, Seow JZY, Xu ZJ (2023) A brief introduction of electrode fabrication for proton exchange membrane water electrolyzers. Journal of Physics: Energy 5, 034003; Xu Q, Zhang L, Zhang J, Wang J, Hu Y, Jiang H, Li C (2022) Anion Exchange Membrane Water Electrolyzer: Electrode Design, Lab-Scaled Testing System and Performance Evaluation. EnergyChem 4, 100087.

[53] Different support substrates attract performance and operational implications. The use of an inert external substrate or the interconnect is also possible. Kuterbekov KA, Nikonov A V., Bekmyrza KZh, Pavzderin NB, Kabyshev AM, Kubenova MM, Kabdrakhimova GD, Aidarbekov N (2022) Classification of Solid Oxide Fuel Cells. Nanomaterials 12, 1059.

[54] The side in which the layers are printed will vary depending on whether the electrolyte or the cathode are selected as the support layer. In a cathode-supported cell the electrolyte would be printed, followed by the intermediate layer and then the anode. In an electrolyte-supported cell the cathode would be printed on one side, with the intermediate layer and the anode printed on the other side.

Anghilante R, Colomar D, Brisse A, Marrony M (2018) Bottom-up cost evaluation of SOEC systems in the range of 10–100 MW. International Journal of Hydrogen Energy 43, 20309; James BD, Prosser JH, Das S (2022) HTE Stack Manufacturing Cost Analysis. Strategic Analysis. <https://www.energy.gov/sites/default/files/2022-03/HTE%20Workshop-Strategic%20Analysis.pdf> (accessed 10 October 2024); Nechache A, Hody S (2021) Alternative and innovative solid oxide electrolysis cell materials: A short review. Renewable and Sustainable Energy Reviews 149, 111322; Ureña V, Ruiz K, Ciaurriz P, Judez X, Aguado M, Garbayo I (2023) Solid Oxide Electrolysis Cells Fabrication: From Single Cells to Batch Production. ECS Transactions 111, 295.

4. Cell stack assembly

In alkaline, PEM and AEM, the MEA and the bipolar plates are assembled to form single cells (with sealing material printed or injection moulded to serve as gaskets). Multiple cells are aligned, connected, and compressed into stacks, with metal end plates added to each side.[55]

At this stage, SO electrolysers manufacture the outermost interconnection layer, which requires its own process of stamping, etching and cutting the metal connector, followed by coating with a perovskite material (on the anode side) or adding a thin metal contact (on the cathode side). The interconnector is brought together with the electrodes and the cells are aligned, welded, sealed together and sintered to form the stack. The stack itself is then subjected to conditioning, which involves compression and hydrogen reduction to ensure any nickel oxide present in the catalyst is reduced to its metallic form. As with other electrolyser types, end plates are also added to each side of the stack.[56]

After assembly, cell stacks for all electrolyser types undergo quality control and testing to ensure stack integrity and adequate operation.

5. System assembly

The full electrolyser system is assembled by connecting the stacks to the balance of plant equipment, a process sometimes referred to as packaging. For SO electrolysers there is an extra step of connecting balance of stack components to form a hot-box, a unit comprising the stack, insulation material and potentially heat management components (e.g., a heat exchanger). Multiple hot-boxes are then connected to balance of plant equipment, completing the system.[57]

An overview of more specific materials and processes used across the four electrolyser types is available in Appendix 5.6.

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[55] Mayyas A, Ruth M, Pivovar B, Bender G, Wipke K (2018) Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers. National Renewable Energy Laboratory, Golden, CO. <https://www.nrel.gov/docs/fy19osti/72740.pdf>

[56] Anghilante R, Colomar D, Brisse A, Marrony M (2018) Bottom-up cost evaluation of SOEC systems in the range of 10–100 MW. International Journal of Hydrogen Energy 43, 20309; James BD, Prosser JH, Das S (2022) HTE Stack Manufacturing Cost Analysis. Strategic Analysis. <https://www.energy.gov/sites/default/files/2022-03/HTE%20Workshop-Strategic%20Analysis.pdf> (accessed 10 October 2024); Rachau M (2023) Production of Solid Oxide Fuel Cell and Electrolyzer Stacks using HORIBA FuelCon's Sintering Equipment. Feature Article – HORIBA. <https://static.horiba.com/fileadmin/Horiba/Company/About_HORIBA/Readout/R57E/R57E_18_Feature_Article_Mathias_RACHAU.pdf> (accessed 11 October 2024).

[57] van 't Noordende H, van Berkel F, Stodolny M (2023) Next Level Solid Oxide Electrolysis. Institute for Sustainable Process Technology, Netherlands. <https://ispt.eu/media/20230508-FINAL-SOE-public-report-ISPT.pdf>

3 The pathways to HEM

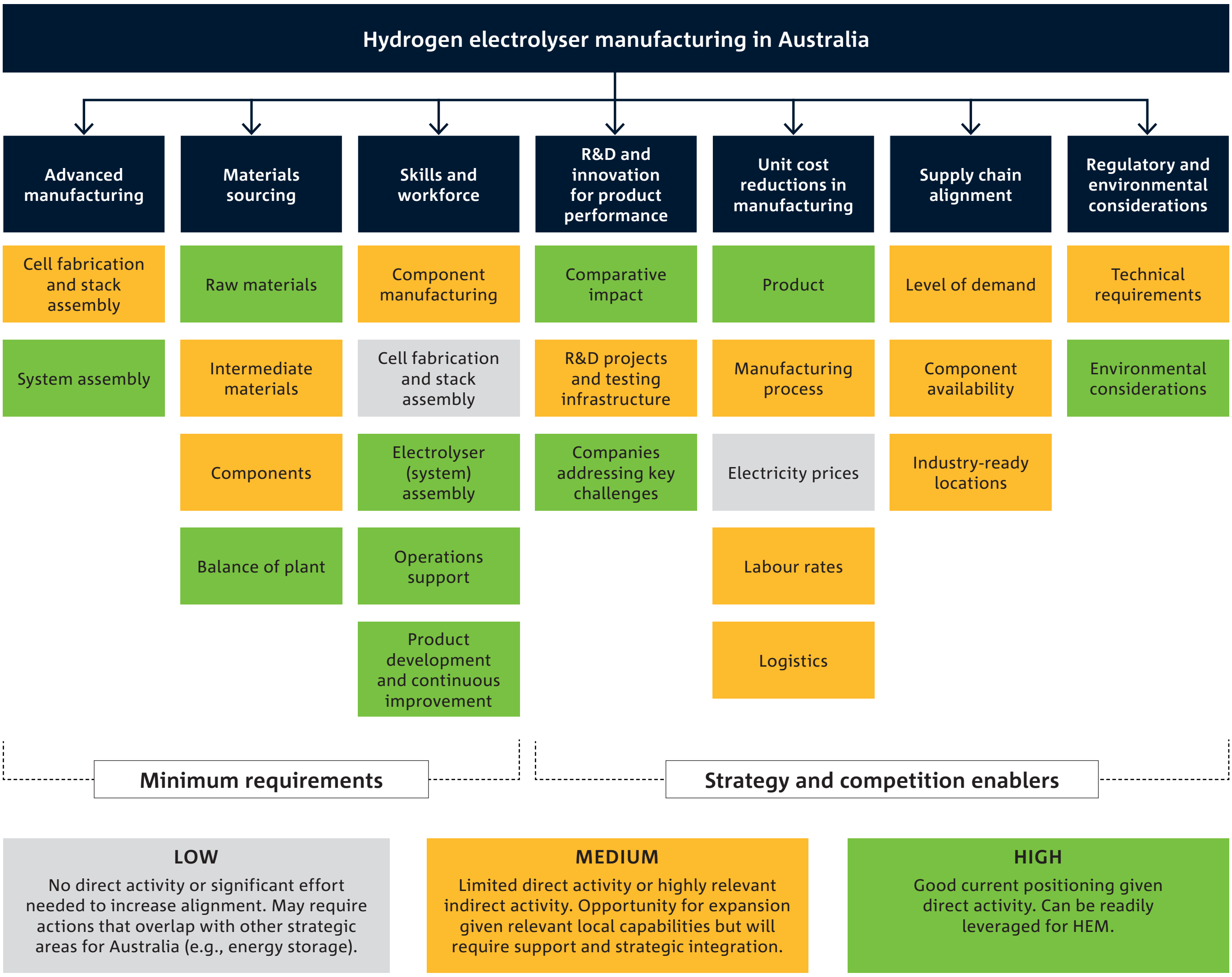
This chapter assesses HEM in Australia across seven key areas: **Advanced manufacturing**, **materials sourcing**, **skills and workforce**, **R&D and innovation, unit cost reductions, supply chain alignment, and regulatory and environmental considerations**.

Each of these seven key areas is broken down into sub-areas, which consider:

- Electrolyser manufacturing requirements
- Australia's current alignment with these requirements, and
- Scale-up considerations for Australia to bridge the gaps between what is required and the current state.

This basis can help identify tangible pathways towards an Australian role across the hydrogen electrolyser value chain. Figure 12 below presents an overview of the seven areas, with further context provided in each individual section.

The assessment was formulated through a combination of desktop review and consultations with researchers, national and international electrolyser manufacturers, and other hydrogen industry stakeholders. Case studies are provided where relevant, but these are not exhaustive of the direct and indirect capabilities in the Australian manufacturing ecosystem that could be leveraged for HEM.



Hydrogen electrolyser manufacturing in Australia

Advanced manufacturing	Materials sourcing	Skills and workforce	R&D and innovation for product performance	Unit cost reductions in manufacturing	Supply chain alignment	Regulatory and environmental considerations
🟨 Cell fabrication and stack assembly	🟩 Raw materials	🟨 Component manufacturing	🟩 Comparative impact	🟩 Product	🟨 Level of demand	🟨 Technical requirements
🟩 System assembly	🟨 Intermediate materials	⬜ Cell fabrication and stack assembly	🟨 R&D projects and testing infrastructure	🟨 Manufacturing process	🟨 Component availability	🟩 Environmental considerations
	🟨 Components	🟩 Electrolyser (system) assembly	🟩 Companies addressing key challenges	⬜ Electricity prices	🟨 Industry-ready locations	
	🟩 Balance of plant	🟩 Operations support		🟨 Labour rates		
		🟩 Product development and continuous improvement		🟨 Logistics		

⬜ **LOW**
No direct activity or significant effort needed to increase alignment. May require actions that overlap with other strategic areas for Australia (e.g., energy storage).

🟨 **MEDIUM**
Limited direct activity or highly relevant indirect activity. Opportunity for expansion given relevant local capabilities but will require support and strategic integration.

🟩 **HIGH**
Good current positioning given direct activity. Can be readily leveraged for HEM.

Figure 12. Australia's current alignment with HEM requirements across seven key areas.

Note: The minimum requirements for hydrogen electrolyser manufacturing are presented on the left, starting with advanced manufacturing as the core activity. Areas that directly influence the opportunity as strategy and competition enablers are presented on the right, starting with R&D and innovation as a key differentiator.

3.1 Advanced manufacturing

What it is: In the context of this report, advanced manufacturing is defined as the use of knowledge- and technology-intensive synthesis, modification, or fabrication processes for novel or conventional products; or the production of a specialised, knowledge-intensive end-product through novel or conventional means.[58] Electrolysers fit under both interpretations of the definition, given the use of advanced fabrication processes and technology for production at scale, and the technical complexity of the product itself.

Why it is important: Domestic advanced manufacturing is key to reduce reliance on imports, capture the economic benefits from high-value and IP-intensive segments of a value chain, and build sovereign capabilities that may be transferrable across multiple manufacturing opportunities.

Moreover, alongside materials and design, reliability in manufacturing at scale is key to a cell stack's efficiency, long-term durability and stability under harsh operational conditions (from highly acidic or alkaline environments to elevated temperatures and pressures).

Key areas: Electrolyser manufacturing can be divided into two types of facilities. Those focussed on **cell fabrication and stack assembly** and those performing **system assembly**.

Each facility has different manufacturing processes, relevant technical skills, and operational requirements. A description of the electrolyser manufacturing process can be found in Section 2.4.

What is involved?	Australia's alignment with requirements
Cell fabrication and stack assembly involve processes across casting (drop, tape or slip), printing (screen or inkjet), spraying, deposition (electrodeposition, chemical or physical vapour deposition), decal transfer, etching, pressing (hot or cold), sealing, and sintering (in the case of SO electrolysers). These processes require high quality and consistency and are currently performed slowly, particularly by emerging electrolyser manufacturers. Catalyst ink preparation and coating processes in particular involve significant know-how and optimisation to ensure adequate catalyst quantity and uniform dispersion. Both cell fabrication and stack assembly are highly amenable to automation and achieving higher throughput will involve parallel equipment or manufacturing innovations to directly increase speed.	**MEDIUM** Cell fabrication and stack assembly are being performed at smaller scale by emerging Australian manufacturers. This activity will require integration with national and international component manufacturers and scaling up to remain in Australia. Since the manufacturing processes required have not traditionally been done at scale in Australia, the capabilities must be brought in from overseas markets or transferred across from other local industries. Crucially, the processes used in this area are relevant to the manufacturing of other renewable energy technologies (e.g., lithium-ion batteries) and remain an area of continuous development for everyone, not just Australian companies.
System assembly involves connecting cell stacks to the balance of plant, from the electronic components needed to control the overall operation, to auxiliary systems for gas and liquid handling. It is a more manual process by virtue of the welding and fitting required and the confined spaces to reach. However, there is scope for digital- and automation-driven approaches to streamline tasks while ensuring high precision, to the benefit of cost and scalability.	**HIGH** The country already has the basis needed for electrolyser assembly, which is reliant on mechanical, electrical and gas handling expertise.

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[58] This definition builds upon similar concepts from the Australian Bureau of Statistics, the Australian Government Department of Industry, Science and Resources, and the United States' National Strategy for Advanced Manufacturing. ABS (2015) Summary of IT Use and Innovation in Selected Growth Sectors, Australia, 2013-14. <https://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/8166.0.80.001Main%20Features22013-14?opendocument&tabname=Summary&prodno=8166.0.80.001&issue=2013-14&num=&view=> (accessed 25 September 2024); DISR (n.d.) Advanced manufacturing and materials technologies. Department of Industry, Science and Resources. <https://www.industry.gov.au/publications/list-critical-technologies-national-interest/advanced-manufacturing-and-materials-technologies> (accessed 25 September 2024); Subcommittee on Advanced Manufacturing (2022) National Strategy for Advanced Manufacturing. National Science and Technology Council. 2. <https://www.whitehouse.gov/wp-content/uploads/2022/10/National-Strategy-for-Advanced-Manufacturing-10072022.pdf> (accessed 25 September 2024).

Implications for Australia

Scaling up will be an important challenge for both segments of the HEM value chain, with three complementary pathways for Australian participants:

Importing overseas manufacturing equipment	Integrating relevant local activity from other manufacturing areas	Considering manufacturing partnerships with international partners
The manufacturing equipment required for cell fabrication and stack assembly at scale (e.g., tape casting, coat printing and roll-to-roll) is conventionally obtained from overseas at a premium, potentially affecting the cost of locally made electrolysers. This can create a comparative disadvantage for Australia with countries that have a large scale domestic industry producing the required manufacturing equipment (e.g., China).	Cell fabrication and stack assembly are already done locally at smaller scales in Australia. For instance, Cavendish Renewable Technology currently performs membrane manufacturing, substrate coating with catalysts and stack assembly onshore.[59] Similarly, Fortescue, Endua, Hysata and Hadean all have the required capabilities for their respective designs and electrolyser types. Prospective Australian manufacturers do not have to target every portion of the value chain immediately or perform manufacturing at scale in isolation. It is possible to scale up and build a domestic HEM ecosystem progressively by integrating existing activities from other manufacturing areas and strategically using locally developed IP. Some of the key manufacturing processes relevant to HEM are presented below, as a reference to map and integrate local capabilities.	Emerging electrolyser manufacturers may leverage a triple pronged approach where they focus on product development and improvement, produce systems themselves for smaller scale applications, and enter joint ventures where overseas partners can manufacture the equipment at large scale and closer to hydrogen producers. This pathway to a scaled up operation would rely on recent patents for electrolyser and manufacturing innovations and strong protection practices to retain control over locally developed IP.

Commonalities – manufacturing processes used across different electrolyser types

A location may not have a longstanding history with electrolysers specifically, but some of the techniques required may already be in use at scale by local manufacturers for other purposes. Awareness of shared processes can help connect relevant stakeholders, guide the transfer of capabilities, inform the establishment of clean technology manufacturing precincts that aggregate processes in a single location, or highlight future opportunities across different electrolyser types.

Table 6 shows areas of overlap for each production stage, and Appendix 5.6 provides a complete overview of the materials, components and manufacturing processes required for each electrolyser type.

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[59] Harrison S (2023) Interview: Ensuring AEM will be a significant slice of the electrolyser pie. Gasworld, November 24. <https://www.gasworld.com/feature/interview-ensuring-aem-will-be-a-significant-slice-of-the-electrolyser-pie/2129984.article/> (accessed 8 September 2024).

Table 6. Overlaps in manufacturing processes used for each electrolyser type, across production stages.

	Component manufacturing						Cell fabrication (zero-gap design)			Cell stack assembly			Electrolyser assembly
	Membrane or diaphragm	**Porous transport layer (anode side)**	**Porous transport layer (cathode side)**	**Bipolar plate (anode side)**	**Bipolar plate (cathode side)**	**Frames and sealing**	**Catalyst ink preparation**	**Membrane or substrate coating**	**Pressing layers**	**Cell assembly**	**Stacking**	**Quality control**	**System assembly**
Alkaline [a]	Solution or extrusion casting	Powder metallurgy, deposition, de-alloying	Same processes as anode side, smelting and casting, or carbon cloth production	Stamping, physical vapour deposition, or spraying methods	Stamping, physical vapour deposition, or spraying methods	Injection or insertion moulding	Mixing and dispersion methods (e.g., ball, attrition or roll milling, ultrasonication)	Spraying, printing (screen or inkjet), deposition, hydrothermal, roll-to-roll, or decal transfer methods	Hot or cold pressing	Assembly of MEA with bipolar plates, screen printing or injection moulding gaskets, and curing	Aligning, compressing and connecting	Conditioning and testing	Connecting cell stack with balance of plant equipment
Proton exchange membrane (PEM) [b]		Powder metallurgy and coating process	Powder metallurgy or carbon cloth production			Injection moulding							
Anion exchange membrane (AEM) [c]			Smelting and casting or carbon cloth production		Smelting and casting or moulding/ machining								

[a] James B, Huya-Kouadio J, Acevedo Y, McNamara K (2021) Liquid Alkaline Electrolysis Techno-Economic Review. Strategic Analysis. <https://www.energy.gov/sites/default/files/2022-02/7-TEA-Liquid%20Alkaline%20Workshop.pdf> (accessed 4th August 2024); Razmjooei F, Liu T, Azevedo DA, Hadjixenophontos E, Reissner R, Schiller G, Ansar SA, Friedrich KA (2020) Improving plasma sprayed Raney-type nickel–molybdenum electrodes towards high-performance hydrogen evolution in alkaline medium. Scientific Reports 10, 10948; Ruth M, Mayyas A, Mann M (2017) Manufacturing Competitiveness Analysis for PEM and Alkaline Water Electrolysis Systems. National Renewable Energy Laboratory, Fuel Cell Seminar and Energy Expo. <https://www.nrel.gov/docs/fy19osti/70380.pdf> (accessed 4 August 2024).

[b] Lagadec MF, Grimaud A (2020) Water electrolysers with closed and open electrochemical systems. Nature Materials 19, 1140; Lin X, Seow JZY, Xu ZJ (2023) A brief introduction of electrode fabrication for proton exchange membrane water electrolyzers. Journal of Physics: Energy 5, 034003; Mayyas A, Ruth M, Pivovar B, Bender G, Wipke K (2018) Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers. National Renewable Energy Laboratory, Golden, CO. <https://www.nrel.gov/docs/fy19osti/72740.pdf>; Yu HN, Lim JW, Kim MK, Lee DG (2012) Plasma treatment of the carbon fiber bipolar plate for PEM fuel cell. Composite Structures 94, 1911.

[c] Lim A, Kim H, Henkensmeier D, Jong Yoo S, Young Kim J, Young Lee S, Sung Y-E, Jang JH, Park HS (2019) A study on electrode fabrication and operation variables affecting the performance of anion exchange membrane water electrolysis. Journal of Industrial and Engineering Chemistry 76, 410; López-Fernández E, Sacedón CG, Gil-Rostra J, Yubero F, González-Elipe AR, de Lucas-Consuegra A (2021) Recent Advances in Alkaline Exchange Membrane Water Electrolysis and Electrode Manufacturing. Molecules 26, 6326; Raja Sulaiman RR, Wong WY, Loh KS (2022) Recent developments on transition metal–based electrocatalysts for application in anion exchange membrane water electrolysis. International Journal of Energy Research 46, 2241; Tricker AW, Lee JK, Shin JR, Danilovic N, Weber AZ, Peng X (2023) Design and operating principles for high-performing anion exchange membrane water electrolyzers. Journal of Power Sources 567, 232967; Xu Q, Zhang L, Zhang J, Wang J, Hu Y, Jiang H, Li C (2022) Anion Exchange Membrane Water Electrolyzer: Electrode Design, Lab-Scaled Testing System and Performance Evaluation. EnergyChem 4, 100087.

	Cell fabrication (planar design)				Cell stack assembly				Electrolyser assembly	
	Electrolyte ink preparation	**Catalyst ink preparation**	**Support layer formation**	**Thinner layer formation**	**Interconnection manufacturing**	**Perovskite layer manufacturing**	**Mounting and assembly**	**Quality control**	**Hot-box assembly**	**System assembly**
Solid oxide (SO) [d]	Mixing and dispersion methods (e.g., ball, attrition or roll milling, ultrasonication) [e]		Tape casting and sintering [f]	Screen printing, co-casting, or tape casting with lamination; drying, and sintering [f]	Stamping and etching	Mixing, coating, sintering	Assembly, welding and sealing	Conditioning and testing [g]	Connecting with balance of stack and heat management components in an insulated unit	Connecting with other hot-boxes and balance of plant equipment

[d] Anghilante R, Colomar D, Brisse A, Marrony M (2018) Bottom-up cost evaluation of SOEC systems in the range of 10–100 MW. International Journal of Hydrogen Energy 43, 20309; Ghezel-Ayagh H (2023) Solid Oxide Electrolysis System Demonstration DE-EE0009290. U.S. Department of Energy Hydrogen Program 2023 Annual Merit Review and Peer Evaluation Meeting. <https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review23/ta039_ghezel-ayagh_2023_o-pdf.pdf> (accessed 4 August 2024); Korkmaz H, Timurkutluk B, Timurkutluk C (2016) Effects of fabrication parameters on the performance of solid oxide electrolyzer cell. International Journal of Hydrogen Energy 41, 9723; Li P, Chen X, Sun Y, Chen T, Zhang B, Li F, Zhou J, Wang S (2023) Fabrication of anode supported solid oxide electrolysis cell with the co-tape casting technique and study on co-electrolysis characteristics. Journal of Power Sources 569, 232912; Nechache A, Hody S (2021) Alternative and innovative solid oxide electrolysis cell materials: A short review. Renewable and Sustainable Energy Reviews 149, 111322; van 't Noordende H, van Berkel F, Stodolny M (2023) Next Level Solid Oxide Electrolysis. Institute for Sustainable Process Technology, Netherlands. <https://ispt.eu/media/20230508-FINAL-SOE-public-report-ISPT.pdf>; Rachau M (2023) Production of Solid Oxide Fuel Cell and Electrolyzer Stacks using HORIBA FuelCon's Sintering Equipment. Feature Article – HORIBA. <https://static.horiba.com/fileadmin/Horiba/Company/About_HORIBA/Readout/R57E/R57E_18_Feature_Article_Mathias_RACHAU.pdf> (accessed 11 October 2024); Ureña V, Ruiz K, Ciaurriz P, Judez X, Aguado M, Garbayo I (2023) Solid Oxide Electrolysis Cells Fabrication: From Single Cells to Batch Production. ECS Transactions 111, 295.

[e] The design and component differences of solid oxide electrolysers prevent a direct alignment to alkaline, PEM and AEM. Manufacturing methods similar to those employed in the other 3 electrolyser types and used for comparable components or production steps are underlined.

[f] Multiple layers may also be sintered simultaneously, given the need to minimise the defects and costs associated with multiple separate sintering steps.

[g] Conditioning includes stack compression and hydrogen reduction.

3.2 Materials sourcing

What it is: Materials sourcing refers to obtaining the core items (materials or equipment) required in each segment of the HEM supply chain.

Why it is important: An accessible domestic or international supply that is stable and consistent reduces vulnerability to supply chain disruptions, increases the level of certainty over input costs and facilitates expansion of local activities and procurement by overseas manufacturers. Having upstream activity in intermediate materials and components, and downstream activity in balance of plant equipment also creates a broader ecosystem capable of supporting other advanced manufacturing opportunities and facilitates maintenance and repair activities onshore.

Key areas: Materials sourcing encompasses raw materials, intermediate chemical compounds, cell components, and equipment used in the balance of plant. Refer to Section 2.3, Table 5 for a detailed description of the materials used in each electrolyser type.

What is involved?	Australia's alignment with requirements
Sourcing raw materials involves mining and pre-processing minerals that contain the metals used in catalysts, porous transport layers, bipolar plates, and end plates (e.g., lateritic nickel ores or rutile).	**HIGH** Providing raw materials such as nickel, iron, gold, titanium, zirconium and rare earths could be an opportunity for Australia given local deposits and current production (see Table 2).
Sourcing intermediate materials involves processing minerals and chemical feedstock to produce high-purity compounds that can be used directly in component manufacturing or during cell fabrication (e.g., iridium oxide or fluoropolymers). Each intermediate material has its own processing pathway, which is out of scope for this report.	**MEDIUM** There are materials for cell fabrication and stack assembly for which Australia may have to lean on suppliers from other countries, due to limited availability. For instance, there is no visible local production at scale of the intermediate compounds mixed to form catalyst inks or of the polymers used to fabricate membranes or diaphragms. This includes the nickel-based precursors used in alkaline and AEM catalysts, the iridium and platinum compounds used in PEM catalysts, and the rare earths-containing ceramic materials involved in SOE. Other materials are available locally but could be more expensive or in limited supply, such as the nickel metal used to produce bipolar plates (for alkaline and AEM electrolysers) and the steel used extensively in all electrolyser types (across both stack and balance of plant).
Sourcing components involves manufacturing each of the individual pieces used in electrolyser cells (e.g., porous transport layers or bipolar plates). An overview of the materials and processes used, which vary by component, is presented in Appendix 5.6.	**MEDIUM** Component manufacturing is currently limited in Australia. However, there are no clear barriers that would prevent greater activity in the country. Particularly for alkaline and AEM electrolysers, which use nickel extensively across a range of components. Moreover, there is relevant component manufacturing activity in other areas, like the aerospace and automotive sectors, in addition to local capabilities across laser cutting, metal stamping and machining.
Sourcing balance of plant equipment involves manufacturing the ancillary components that support an electrolyser stack (e.g., a power supply unit or water treatment plant). Each piece of equipment has its own value chain, which is out of scope for this report.	**HIGH** The local availability of balance of plant varies. Rectifiers for the electrical supply, water treatment equipment, and piping can all be obtained in Australia. Control system electronics, driers, absorbers, valves, and pressure transducers are commonly sourced from overseas. Items like storage vessels are available locally but may be procured from other countries due to lower costs.

Implications for Australia

Electrolyser manufacturing at scale, both domestic and international, represents a potential source of demand for a range of Australian minerals. As is the case with the supply chains of other renewable energy technologies (e.g., batteries, magnets, solar PV panels), increasing the value of those resources will require greater onshore processing into intermediate materials. However, there is limited direct activity in both intermediate materials and component manufacturing in Australia currently, which simultaneously reduces opportunities for local offtake and use of minerals and poses a challenge for scaling up cell fabrication.

Supplying balance of plant equipment to facilities focussed on system assembly could represent an opportunity for Australian companies with local manufacturing operations. Moreover, certain segments, like electricity management components, have cross-cutting importance across different renewable energy technologies. For example, demand from the hydrogen electrolyser value chain for rectifiers could add to the large domestic demand for the inverter units used in solar PV panels. The close technological similarity between the two components could allow domestic manufacturers to further justify investment and build a core capability relevant to multiple market segments.

Below are two possible pathways to establish a broader ecosystem that supports cell fabrication and stack assembly at scale in Australia. An overview of intermediate materials used in various electrolyser types is also provided at the end of this section, to serve as a reference that guides the expansion and integration of local activity.

Connecting other manufacturing areas to advance local production of intermediate materials	Building upon existing capabilities to support component manufacturing
Raw material processing into intermediate compounds is a long-term area of interest to add value to Australian minerals and could benefit the local manufacturing of other renewable energy technologies. A local electrolyser manufacturing ecosystem could contribute towards aggregated demand and offtake pathways that support the level of capital and time investment required. Moreover, there are local companies with relevant chemicals manufacturing expertise that could be leveraged to support the expansion of an Australian intermediate material ecosystem. For example, Boron Molecular focusses on boronic acid and fine chemicals production (including electroactive polymers). There are also pilot scale capabilities for carbon fibre, the basic input to the carbon-based components used in the cathode-side porous transport layer of PEM and AEM electrolysers. This is illustrated by Deakin University's Carbon Nexus, a carbon fibre development and manufacturing facility in Victoria.[60]	There are local metallurgical, plastics production and coating capabilities that could serve as the basis for component manufacturing for electrolysers in Australia (see Case study 3). Components like nickel mesh for the porous transport layer can be obtained from local suppliers of international products but, alongside nickel foam (another potential porous transport layer), could be produced from the local nickel supply, by drawing capabilities from the production of other metallic products. Similarly, the porous transport layer for PEM electrolysers (titanium), the interconnector for solid oxide electrolysers (stainless steel) and general components like gaskets (plastic), and end plates (titanium and stainless steel) could also be produced onshore by leveraging local supplies and extending capabilities. Moreover, there are Australian companies producing surface-treated components for advanced end-products, a capability that could be relevant to produce catalyst-coated porous transport layers or high-cost components like nickel-plated bipolar plates. For example, Precision Catalysts produces 3D printed metallic mixers coated with catalyst layers for use in chemicals manufacturing.[61] Meanwhile, Lovitt Technologies Australia, a Boeing-certified supplier, uses electroless nickel plating at its Electromold facility in Victoria to coat parts used in aerospace applications.[62]

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[60] Deakin University (2024) Carbon Nexus Capabilities. Institute for Frontier Materials. <https://carbonnexus.com.au/capabilities/> (accessed 16 September 2024).

[61] Boron Molecular (n.d.) About us. <https://www.boronmolecular.com/about/> (accessed 16 September 2024); Precision Catalysts (2024) Innovating the worldwide approach to chemical manufacture. <https://precisioncatalysts.com.au/> (accessed 16 September 2024).

[62] Cardé J (2014) Good chemistry: How one small company in Australia became part of the Boeing supply chain underscores the importance of finding opportunities to grow the company's international business—and build relationships. Frontiers, 12(9), 38–40. <http://www.lb.boeing.com/news/frontiers/archive/2014/february/pubData/source/Frontiers_Feb14.pdf> (accessed 9 September 2024); Lovitt Technologies Australia (2024) Electromold. <https://www.lovittech.com.au/electromold/> (accessed 9 September 2024).

CASE STUDY 3: Making a ceramic fuel cell ecosystem in Australia

Ceramic Fuel Cells Ltd (CFCL) began operations in 1992 focussed on the development and commercialisation of solid oxide fuel cells (SOFCs), building upon the ceramic materials expertise accumulated at CSIRO.

The company established purpose-built cell fabrication and testing facilities at Monash University's Churchill campus, which included tape casting, screen printing and testing equipment at the kW range. In 2000 it consolidated its activities, from R&D to production and testing at Noble Park (VIC), followed by a main assembly plant and commercialisation centre in Germany in 2006 to target the European market.

CFCL launched its first certified product in 2010, a micro combined heat and power system (micro-CHP) commercially known as BlueGen that was based on its multilayered anode-supported ceramic cell. By 2012 the Noble Park facility was manufacturing 100,000 cells per year (equivalent to 1 MW per year), along with matching quantities of coated interconnects and sealing. A maximum capacity of 500 stacks per year could be manufactured at the facility to supply BlueGen products deployed internationally. The company also assembled a larger quantity of stacks and balance of plant at its facility in Germany, leveraging robotic assembly and a specialty sintering process.[63]

The company moved most of its manufacturing activities out of Noble Park after 2012, some to its operation in Germany and some via outsourcing to supply partners. The shift in focus to Europe was framed by a corporate restructure to reduce costs and supporting measures deployed in the region. There were significant Federal and regional incentives in Germany aimed at increasing energy production from combined heat and power systems. These incentives reduced the capital costs of alternative energy systems for customers, while a feed-in tariff for supplying power to the grid contributed further to amortisation, a measure that was also adopted in the United Kingdom.[64]

The German subsidiary was acquired in 2014 by SOLIDpower (now SolydEra), which maintained a Melbourne-based operation and continued to develop experienced personnel and collaborations with local component manufacturers.[65] However, CFCL itself went into administration in 2015. Upon liquidation, Chaozhou Three Circles Co (a contract manufacturer and shareholder for CFCL) acquired the company, its IP and Melbourne-based equipment, transferring it to China. A subsequent licensing agreement was struck with SOLIDpower on the production of BlueGen cell stacks.[66]

Despite no longer being in operation, CFCL built an advanced manufacturing ecosystem in Australia supported by a global raw material and component supply chain that encompassed companies in Australia and offshore. For instance, the company collaborated locally to fabricate the coated steel interconnects for its stacks. This included Brenco Surface Engineering (an organisation with surface coating and component engineering expertise), Tetlow Kilns (furnace manufacturers) and a dedicated subsidiary of Columbia Australia, a toolmaking business with injection moulding and metal component expertise, originally established in 1956 to provide dies, moulds and sand cores for automotive companies.

Growth and diversification have been part of the latter's history. Columbia Australia has expanded its local capabilities over time and eventually established an operation in the US (Columbia Tool & Die), which went on to supply aerospace and medical companies.[67]

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[63] CSIRO Futures, consultation; Ward C (2014) Slid Oxide Fuel Cell Technology. CSIROpedia – Achievements. <https://csiropedia.csiro.au/ceramic-fuel-cells/> (accessed 12 September 2024).

[64] Parkinson G (2012) Ceramic Fuel Cells packs its bags and moves to Europe. Renew Economy, October 30. <https://reneweconomy.com.au/ceramic-fuel-cells-packs-its-bags-and-moves-to-europe-47229/> (accessed 11 October 2024); Dow B (2012) Annual General Meeting. Ceramic Fuel Cells presentation, October 29. 9–17. <https://announcements.asx.com.au/asxpdf/20121029/pdf/429rz157v1rgn9.pdf> (accessed 11 October 2024).

[65] SolydEra (2023) What to know about SolydEra. The Company. <https://www.solydera.com/en/the-company/> (accessed 12 September 2024).

[66] CSIRO Futures, consultation; Fuel Cells Bulletin (2015) Ceramic Fuel Cells now in administration, despite tech progress. 2015, 10. <https://www.sciencedirect.com/science/article/abs/pii/S1464285915300596?via%3Dihub> (accessed 11 October 2024); Fuel Cells Bulletin (2016) SOLIDpower links with Chinese partner to expand BlueGEN market, German deal. 2016, 6. <https://www.sciencedirect.com/science/article/pii/S1464285916301444> (accessed 11 October 2024).

[67] Automated Solutions Australia (2018) Client Case Study – Brenco Surface Engineering, Victoria. <https://automatedsolutions.com.au/brenco-surface-engineering/> (accessed 11 October 2024); Businesswire (2019) MOGAS Acquires Brenco Group, Trusted Australian Provider of Surface Coating and Engineering Processes and Aerospace Technologies. <https://www.businesswire.com/news/home/20190731005576/en/MOGAS-Acquires-Brenco-Group-Trusted-Australian-Provider-of-Surface-Coating-and-Engineering-Processes-and-Aerospace-Technologies> (accessed 11 October 2024); COLUMBIA Tool & Die (n.d.) History of Columbia Tool & Die. <https://columbiatoolanddie.com/history/> (accessed 12 September 2024); CSIRO Futures, consultation.

Commonalities – materials used across multiple electrolyser types

While different materials are used in each electrolyser type to account for operating conditions, costs and performance, there are still overlaps. Material commonalities can inform electrolyser manufacturing strategies in new regions, both by guiding the integration of local products and by highlighting areas of interest for a component manufacturing and research ecosystem. Table 7 below summarises the intermediate materials that can be used cross components of multiple electrolyser types.

Table 7. Overlaps in possible intermediate materials across the four electrolyser types.

	Iridium oxide	Carbon-supported platinum	Nickel powder, foam or mesh	Titanium mesh, felt or foam	Stainless steel	Carbon fibre, cloth, paper, or graphite	Polymer resins
Alkaline			Porous transport layer (anode)	Porous transport layer (cathode)	Nickel-coated, bipolar plates (anode and cathode)		Frames and seals
Proton exchange membrane (PEM)	Catalyst layer (anode)	Catalyst layer (cathode)		• Gold or platinum-coated, porous transport layer (anode) • Porous transport layer (cathode) • Platinum-coated, bipolar plate (anode) • Gold coated, bipolar plate (cathode)		• Porous transport layer (cathode) • Bipolar plate (cathode)	Frames and seals
Solid oxide (SO)			• Cathode (as nickel oxide with YSZ) • Interconnector (as coating and cathode contact layer)		Interconnector		
Anion exchange membrane (AEM)	Catalyst layer (anode) [a]	Catalyst layer (cathode) [a]	Porous transport layer (anode)	Porous transport layer (anode) [a]	Bipolar plate (anode)	• Porous transport layer (cathode) • Bipolar plate (cathode)	Frames and seals

Note: Despite commonalities in use and composition, material specifications will vary between electrolyser types, attracting additional processing.

[a] AEM electrolysers can use these materials, but also less expensive alternatives.

3.3 Skills and workforce

What it is: Skills and workforce considers the availability of personnel with the required training and expertise to perform key tasks across each segment of the HEM value chain.

Why it is important: A workforce with the required skills, training and expertise optimises production capacity, serves as an attraction factor for overseas manufacturers, and increases the potential for subsequent innovations at the product or process level. Conversely, skill shortages could increase costs and hinder growth.

Key areas: Producing an electrolyser system involves roles across the entire product cycle – product development and continuous improvement, component manufacturing, cell fabrication and stack assembly, system assembly, and operations support. It is worth noting that knowledge, training and skills on the safety of hydrogen production and handling are relevant to all roles mentioned, particularly given the downstream implications of electrolyser design, manufacturing and servicing.

What is involved?	Australia's alignment with requirements
Component manufacturing involves skills across smelting, casting, powder metallurgy, carbon material production, metal stamping, and deposition techniques, with specific process expertise varying by component.	**MEDIUM** Producing individual components such as membranes, porous transport layers or bipolar plates in Australia will require relevant experience and preparation, but not necessarily an electrolyser-specific background. For example, in addition to producing an adequately shaped and stamped metal sheet, the porous transport layers and bipolar plates used in some electrolyser types require a specialised metal coating. This involves deposition and plating processes that could be transferred from the existing metallurgy industry.
Cell fabrication and stack assembly at industrial scale involve skills and experience across manufacturing process engineering, use of specialised manufacturing equipment, automation (design and implementation), robotics, and data capture and analytics. Operationally, cell fabrication and stack assembly involve two types of roles: personnel for setting up and maintaining the manufacturing equipment (manufacturing engineers) and technicians that use the equipment. For advanced or emerging processes where the equipment itself is novel, a new technician segment not defined by the traditional categories of electrician or mechanical fitter may also be required. Moreover, at smaller scales and lower levels of automation, personnel in the use and maintenance categories may require more preparation or training in advanced manufacturing processes.	**LOW** Australia used to have a pool of experience and skills linked to the automotive sector. When it disappeared, part of this workforce migrated to other countries that had advanced or high-value manufacturing opportunities. It is now challenging to find local expertise on the establishment and operation of the highly efficient, automated assembly lines required for production at large scale. To address this, local manufacturers turn to overseas engineering procurement companies (EPCs). However, this can introduce challenges in terms of costs, delivery timelines and alignment of specifications. Local companies also recruit internationally where needed, in a process that is challenging and costly (in terms of wages that prompt key personnel to relocate).
Electrolyser assembly involves connecting stacks to balance of plant components, which is harder to automate. The final assembly step involves skills across mechanical and electrical fitting, plumbing, welding, industrial gas handling, and design of control systems. The close operational link of balance of plant equipment with hydrogen storage and handling (out of scope for this report), also requires technical expertise on pressurised vessels, applicable standards, certifications and safety considerations.	**HIGH** The areas of expertise required are both readily available in Australia and could be further strengthened via workforce training programs.
Operations support involves roles beyond manufacturing, including supply procurement for components and balance of plant, logistics, and customer support (across technical, engineering and maintenance aspects).	**HIGH** While not unique to the country, this workforce segment is readily available in Australia and is supported by a strong education system. Importantly, distance and time zone proximity to customers in the Asia-Pacific region can be advantageous for Australian companies.
Product development and continuous improvement involves research and optimisation roles across novel materials, cell designs, system configurations and manufacturing processes, generating additional IP and improving product competitiveness.	**HIGH** Australia has a highly skilled R&D workforce with relevant qualifications, training, and experience in key areas like electrochemistry, materials science and engineering (process, chemical, mechanical, electrical and robotic).

Implications for Australia

Making the most of a comparatively small workforce pool with skills and expertise relevant to electrolyser manufacturing is a key challenge, with three possible pathways to support HEM at scale in Australia.

Local collaboration with suppliers to other advanced products for skills and knowledge transfer	Building a cell fabrication and stack assembly workforce progressively	Providing sector and product-specific training to leverage opportunities in areas of high alignment
Adequately supported to derisk their expansion, local companies that already produce components for other advanced products can become suppliers and development partners to Australian electrolyser manufacturers, setting the foundation for a HEM ecosystem. This could expand their capabilities, provide new revenue streams, and facilitate skills transfer into electrolyser manufacturers. This pathway is shared across advanced manufacturing for cell fabrication and stack assembly at scale, and materials sourcing of intermediate materials, highlighting the importance of local collaboration.	The current alignment gap in terms of a cell fabrication and stack assembly workforce could be addressed progressively and strategically. **Attract:** To supplement the workforce present in Australia, a first cohort of personnel with electrolyser and automation experience will likely be hired from overseas, going on to help build local know-how and practical expertise over time. **Build:** Simultaneously, university and technical courses on automation, materials characterisation and advanced manufacturing processes can prepare subsequent domestic cohorts. **Connect:** Structured working environments, clear capability mapping and training support programs within manufacturers can then play a key role in facilitating skills transfer and expansion.	A suitable workforce is already available in Australia for electrolyser assembly, operations support and product development. However, local personnel will still require training to meet product-, company-, and sector-specific requirements (e.g., national standards in electrical equipment or safety in hydrogen production, storage and handling).

3.4 R&D and innovation for product performance

What it is: In the context of this report, R&D and innovation encompasses the domestic capability to generate novel materials, designs, manufacturing processes and complete electrolyser systems, as well as the technical expertise to reliably scale them up.

Why it is important: R&D can improve technical aspects that drive capital and operational expenditure during electrolyser deployment and use. Specific improvements have been operationalised in the US and EU into key performance indicators, targets to enable the low-cost production of hydrogen at scale.[68] Appendix 5.5 provides a summary of three targets relevant to the key areas discussed below, as set by the US Department of Energy, the EU's Clean Hydrogen Joint Undertaking Strategic Research and Innovation Agenda (JU SRIA) and IRENA. It also contains an overview of relevant R&D priorities across electrolyser types.

Disruptive innovations meeting those targets have the potential to enable renewable hydrogen production that is cost-competitive with fossil fuel-driven thermochemical pathways. This can advance renewable hydrogen closer to the 2 USD per kg average production cost of hydrogen from fossil fuels, down from the 4.5–12 USD per kg range in 2023 (depending on location).[69]

Australian innovations are also at the core of establishing and scaling up local electrolyser manufacturers and serve as enablers of partnerships with overseas stakeholders.

Key areas: Global research and innovation in electrolysers focusses on three technical challenges.

- **Increasing energy efficiency**, to maximise production and indirectly moderate the effect of electricity as a major cost driver for renewable hydrogen production
- **Improving stack lifetime**, to better manage the operational costs associated with degradation and replacement, and
- **Minimising overall system costs**, to lower the deployment barrier posed by high upfront capital costs.

Australia has a high comparative impact in fundamental research, multiple R&D projects and emerging testing infrastructure, and companies actively addressing those three challenges.

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[68] DoE Hydrogen and Fuel Cell Technologies Office (n.d.) Water Electrolyzer Targets. U.S. Department of Energy. <https://www.energy.gov/eere/fuelcells/hydrogen-production-related-links#targets> (accessed 1 August 2024); Clean Hydrogen Partnership (2022) Strategic Research and Innovation Agenda 2021–2027. Annex to GB decision no. CleanHydrogen-GB-2022-02. <https://www.clean-hydrogen.europa.eu/system/files/2022-02/Clean%20Hydrogen%20JU%20SRIA%20-%20approved%20by%20GB%20-%20clean%20for%20publication%20%28ID%2013246486%29.pdf> (accessed 26 September 2024); Horizon Europe (2022) HORIZON JU Research and Innovation Actions – Design for advanced and scalable manufacturing of electrolysers. <https://www.horizon-europe.gouv.fr/design-advanced-and-scalable-manufacturing-electrolysers-29633> (accessed 1 August 2024).

[69] Schelling K (2023) Green Hydrogen to Undercut Gray Sibling by End of Decade. BloombergNEF. <https://about.bnef.com/blog/green-hydrogen-to-undercut-gray-sibling-by-end-of-decade/> (accessed 20 September 2024).

What is involved?	Australia’s alignment with requirements
Fundamental research involves the study, characterisation and optimisation of novel materials, cell designs and fabrication processes that are relevant (directly and indirectly) to electrolyser manufacturing.	**HIGH** Australian research in electrochemistry and materials science is globally competitive, particularly considering the country's comparatively smaller population.[70] See Appendix 5.7 for more details on the supporting bibliometrics analysis. As with other research areas, the Australian publication count in electrochemistry and materials science ranks the country in the top 20 globally. The citation impact of Australian publications, as measured by multiple comparative indicators, further ranks the country in the top 3 among those 20 countries. These high rankings remained consistent in an analysis of the four electrolyser types considered in this report. However, impact in terms of citations from patents is lower, with the country ranking 11 in the more specific bibliometrics analysis. The ratio of documents to citations from patents is also low compared to countries with a similar output, indicating a gap in the translation, or acknowledgement, of highly impactful Australian publications in patents.
R&D projects and testing infrastructure involve research and testing activities specific to electrolysers, focussed on improving key parameters, advancing technology readiness levels, or scaling up a locally developed system.	**MEDIUM** Australia has a significant number of relevant R&D projects from research institutions and industry, taking place across most States and Territories. As an indicator, 58 active research projects related to electrolysis were listed in the HyResearch platform as of September 2024.[71] In addition to modelling, materials innovation, and the development of novel designs, some projects are focussed on establishing testing facilities to characterise key operational parameters and validate new technology, materials, or processes at different scales. Access to facilities with sufficient testing capacity is key to scale up products developed locally. Table 8 below provides an overview of these projects.
Companies addressing key R&D challenges means having local, commercial development of products with distinct innovations and clear operational improvements over current generation electrolysers, particularly in terms of energy efficiency, stack durability and overall cost.	**HIGH** Multiple prospective manufacturers perform their development activities in Australia, having been established around IP from the local research ecosystem. Collectively, their activities encompass all electrolyser types, different production scales and development stages. Moreover, some of their innovations specifically address key challenges for a more cost-effective production of renewable hydrogen (Case study 4).

Table 8. Emerging Australian facilities for electrolyser testing at different scales.

Project	Description
“Australia’s fuel cells and electrolysers prototyping and testing facility”	Collaborative infrastructure project between 9 Australian universities announced in 2024. The project aims to establish a multidisciplinary setting for prototyping, validating, and benchmarking fuel cells and electrolysers developed in Australia, to facilitate their translation.[72]
H2xport Pilot Plant	Facility at the Queensland University of Technology that integrates renewable energy generation (at the 50 kW scale) with hydrogen production via PEM and AEM electrolysers, using local water sources (rain and seawater).[73]
Kwinana Energy Transformation Hub (KETH)	Future Energy Exports CRC project with a planned 2 MW PEM electrolyser for hydrogen production and ancillary facilities for testing, certification, and training.[74]
Future Energy and Training Hub (FEITH)	Precinct being developed at Stanwell’s Central Queensland Power Station to enable research, testing, demonstration, and training across multiple renewable energy technologies, including a 5 MW capillary-fed alkaline electrolyser developed by Hysata.[75]

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[70] The bibliometric analysis by location was conducted using Clarivate’s InCites platform. It was based on the InCites dataset, covered all available years (1980 – July 31, 2024), and used ‘Electrochemistry’, and a combination of ‘Materials Science, Composites’, ‘Materials Science, Coatings & Films’, ‘Materials Science, Ceramics’, ‘Materials Science, Characterization & Testing’, and ‘Materials Science, Multidisciplinary’ as research areas in the Web of Science schema.

[71] Results filtered for “electrolysis” and active status. CSIRO (2024) HyResearch: Australian Hydrogen R&D Portal. Projects. <https://research.csiro.au/hyresearch/projects/> (accessed 11 September 2024).

[72] Australian Research Council (2024) LE240100084 — The University of Sydney. Grant. <https://dataportal.arc.gov.au/NCGP/Web/Grant/Grant/LE240100084> (accessed 11 September 2024).

[73] Love J, Boulaire F, Mohammadshahi S, Gorji S, Gane M, Mackinnon I (2023) Design, construction and commissioning of a hybrid renewable hydrogen test facility: QUT's H2xport Pilot Plant (February 10, 2023). Proceedings of the Australian Hydrogen Research Conference 2023 (AHRC 2023) 8-10 February 2023. <https://ssrn.com/abstract=4479114> (accessed 11 September 2024).

[74] Luth Eolas (n.d.) Kwinana Energy Transformation Hub. <https://www.keth.com.au/> (accessed 23 September 2024); HyResearch (2023) Kwinana Energy Transformation Hub. <https://research.csiro.au/hyresearch/kwinana-energy-transformation-hub/> (accessed 23 September 2024).

[75] Stanwell (2024) Future Energy Innovation & Training Hub (FEITH). Projects in development – FEITH. <https://www.stanwell.com/future-energy-innovation-and-training-hub> (accessed 11 September 2024); CSIRO (2023) Hysata Capillary-fed Electrolyser Commercial-Scale Demonstration Project. HyResearch – Projects – Research & Development. <https://research.csiro.au/hyresearch/hysata-capillary-fed-electrolyser-commercial-scale-demonstration-project/> (accessed 11 September 2024).

Implications for Australia

Scaling up is a key challenge for Australian R&D and innovation related to HEM. This is related to two aspects, which also represent possible pathways:

Expanding the coverage and overall capacity of testing infrastructure	Facilitating a centralisation model for Australian manufacturers
Prospective Australian testing facilities separately cover the tens of kW and single-digit MW scale, but there is no dedicated capability for the middle range of hundreds of kW. Adequate coverage across different ranges and sufficient capacity across facilities is necessary for Australian electrolysers to scale up and to enable a faster innovation cycle. The absence of accessible facilities in the higher ranges (hundreds of kWs and above) and of sufficient testing capacity means Australian manufacturers bear the cost of construction and equipment acquisition, often in partnership with large prospective users. Moreover, it can hamper or delay the uptake of Australian electrolysers by large hydrogen producers, who seek solutions already tested at scales close to those expected in their projects.	As the technology readiness of locally developed electrolysers progresses and approaches commercialisation, Australian manufacturers will have to commit to a strategy for scaling up production in Australia or overseas. Electrolyser manufacturers often rely on a model where the core technical steps of component manufacturing, cell fabrication and stack assembly are performed in a centralised location or a reduced set of locations. Partially this stems from the advantages of maintaining close control over high value elements, more advanced processes, skills and IP, potentially in proximity to where R&D is performed. Additionally, achieving manufacturing excellence at one facility requires time, resources and alignment, so it may not be immediately desirable or advantageous to replicate the process at scale elsewhere. Support for Australian locations where cell fabrication and stack assembly can be performed and scaled-up cost-effectively is therefore important to enable a centralisation model that maintains the core technical steps of electrolyser manufacturing in the country.

CASE STUDY 4: Three Australian innovations with potential to improve energy efficiency, stack durability and system cost

Hysata's electrolyser design eliminates two of the main sources of electrical resistance in traditional alkaline electrolysers: the distance between electrodes and the generation of bubbles. The company accomplishes this via a zero-gap design with a capillary separator that delivers the liquid electrolyte.[76]

Reduced resistance can result in higher energy efficiency, to the potential benefit of operating costs, while the alkaline nature of the electrolyser enables less expensive materials, which can reduce stack costs.

Hadean's electrolyser uses a tubular design instead of the planar structure found in conventional solid oxide electrolysers.[77] This structure may cope better with the expansion-contraction experienced over large temperature changes, which is associated with lower durability.

The use of less expensive materials and the higher efficiency of solid oxide electrolysis in the presence of heat can result in benefits to stack and operational costs.

CRT's AEM electrolyser targets a simpler manufacturing process, fast ramping dynamics, and increased durability. The company builds towards these improvements through a combination of novel coating technologies, intrinsic AEM characteristics, and lower operating temperatures.[78]

The reduced balance of plant components and less expensive materials compared to PEM electrolysers can reduce system costs, while the fast responsiveness and durability may assist with operating costs.

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[76] Webster A (2023) Hysata to build next-generation hydrogen electrolyser. ARENAWIRE – Hydrogen energy. <https://arena.gov.au/blog/hysata-to-build-next-generation-hydrogen-electrolyser/> (accessed 11 September 2024).

[77] CSIRO (2024) Tubular Solid Oxide Electrolysis. HyResearch – Resources – Australian research and innovation case studies. <https://research.csiro.au/hyresearch/resources/case-studies/tubular-solid-oxide-electrolysis/> (accessed 11 September 2024).

[78] Harrison S (2023) Interview: Ensuring AEM will be a significant slice of the electrolyser pie. Gasworld, November 24. <https://sbh4.de/assets/ensuring-aem-will-be-a-significant-slice-of-the-electrolyser-pie%2C-gasworld-nov-2023.pdf> (accessed 11 September 2024).

3.5 Unit cost reductions in manufacturing

What it is: Reductions in the production cost of electrolysers per unit, via improvements to the materials, designs and manufacturing processes used.

Why it is important: Cost reductions can influence the price of Australian electrolysers, which is an important decision factor for renewable hydrogen producers alongside system quality and reliability of support from a manufacturer.

Key areas: The major cost drivers for electrolyser manufacturing can be grouped into three categories – the product, the manufacturing process, and location-specific factors. Electrolyser manufacturers actively look to optimise these categories through continuous R&D, process upgrades and careful selection of a manufacturing location.

What is involved?	Australia's alignment with requirements
Cost reductions associated with the electrolyser itself involve the materials used, durability of the stack, energy efficiency at the stack and system levels, and the design and equipment requirements of the balance of plant. The economic implications of these factors are described in section 2.3.	**HIGH** Electrolyser systems from Australian manufacturers actively seek to improve characteristics like energy efficiency, durability, and materials cost, and are supported by specific innovations in those areas that could translate into lower cost at the manufacturing and operational levels.
Cost reductions associated with the manufacturing process involve improvements to the techniques used, the level of automation and the scale of production.	**MEDIUM** Some Australian electrolyser manufacturers are implementing automation solutions or developing simpler production processes, which can help reduce costs at the manufacturing level. However, the early state of HEM in Australia means process scalability and sustainability over time remain to be tested.
Cost reductions associated with location-specific factors involve electricity prices, labour rates, logistics, standards and regulations, and project approval pathways.	**LOW (Electricity prices)** With significant potential for electricity production from renewable sources, more efforts will be needed ensure cost-competitive prices and minimal intermittency of supply. **MEDIUM (Labour rates)** Australian labour rates are higher than other manufacturing countries in the Asia-Pacific region, but there is potential to diminish the impact via product and manufacturing improvements. Separately, productivity indicators place Australia close to the middle among the 38 OECD countries, above the average for the group. **MEDIUM (Logistics)** A significant pipeline of renewable hydrogen projects can make domestic electrolyser manufacturing beneficial from a logistics perspective, but adequate identification, communication and integration with component and balance of plant manufacturers will be needed to maximise cost reductions.

Implications for Australia

Cost reductions are critical to increase the competitiveness of Australia’s HEM ecosystem, its attractiveness to electrolyser manufacturers considering facilities in Asia-Pacific, and the likelihood of a lower levelised cost of hydrogen for projects using locally developed electrolysers. Each major cost driver category has a possible pathway to support progress locally.

While cost reductions related to product and process are specific to electrolysers, those linked to location-specific factors may require broader actions that influence other advanced manufacturing opportunities.

Demonstrating Australian systems at scale and communicating their cost reductions	Supporting manufacturing innovations and demonstrations of cost-competitiveness in the Australian context	Identifying, improving and promoting cost-competitive locations
Electrolyser systems developed by emerging Australian manufacturers already focus on cell design and material improvements that could result in cost reductions (see Case study 4). Local companies are also engaged in demonstration projects to test their systems at scale in relevant environments, with collaboration from industry partners (refer to section 1.3, Table 3 for an overview of these projects). Besides technical testing, demonstrations could inform techno-economic assessments of novel Australian systems, to determine and communicate their associated cost reductions.	Local innovations on how electrolysers are built at scale will be particularly important to ensure Australian manufacturers are competitive. Like the electrolysers themselves, novel manufacturing processes could also benefit from dedicated research, development, demonstration and assessment in the Australian context. Collaborations with local and international manufacturers of other advanced products, particularly renewable energy technologies, could further support these activities and increase their cost-effectiveness (see section 3.1 – Implications for Australia).	Labour cost, electricity prices, and availability of local supply chains are significant cost drivers, but their importance and interaction vary depending on the jurisdiction. Identifying, improving and promoting the Australian locations that can best leverage local strengths while offsetting unavoidable costs could support greater Australian competitiveness in HEM. **Electricity prices** The price of electricity is a significant cost driver for manufacturing in general, with electrolyser manufacturing in particular demanding a significant amount of electricity during component manufacturing and testing steps. Properly leveraging Australia's potential for renewable energy generation will be key both to enable cost reductions and for scaling up. This is due to its direct effect on electricity prices and the possibility to attract other renewable energy technology manufacturers onshore. However, the intermittency of renewable energy sources will require adequate firming capacity of the local grid via energy storage solutions, to help offset the cost and volatility of the electricity supply, particularly during peak periods. **Labour rates** Australian labour rates are higher than most manufacturing countries in Asia, but comparable to those found in central and northern Europe, Canada, and the US.[79] Similarly, Australian productivity is above OECD average and comparable to the UK, Canada, and countries in southern Europe.[80] Reliable product offerings with clear technical advantages, adequate automation, and sufficient production scale can help minimise the impact of labour rates in the overall cost of manufacturing and contribute to increased productivity in Australia. **Logistics** If Australia decides to pursue an opportunity in the system assembly part of the value chain, supply chain logistics will be important for cost reductions. A well-integrated manufacturing ecosystem will be necessary to avoid importing a large portion of the balance of plant equipment. Significant reliance on importing for components could also reduce Australian competitiveness in previous steps of the value chain, like cell fabrication and stack assembly. Shipping and transportation logistics grow in importance as project sizes increase, given the aggregated weight of the equipment to be transported. This, in addition to shorter delivery times, helps explain why local manufacturing becomes attractive when a certain demand can be reached.

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[79] Based on hourly labour costs in USD reported by the International Labour Organization (ILO). Only 56 countries are shown, and data varies by country depending on the latest year available. For Australia, this corresponds to 2011. ILO (2024) Statistics on labour costs (11 January 2024 update). ILOSTAT. <https://ilostat.ilo.org/topics/labour-costs/> (accessed 10 September 2024).

[80] Based on labour productivity in 2022 measured by gross domestic product (GDP) per hour worked and gross national income (GNI) per hour worked, considering current prices and purchasing power parities. OECD (2024) OECD Compendium of Productivity Indicators 2024. OECD Publishing, Paris. 28–32. <https://doi.org/10.1787/b96cd88a-en> (accessed 14 October 2024).

3.6 Regulatory and environmental considerations

What it is: Requirements from the local regulatory landscape to 1) guarantee a safe deployment and reliable operation of electrolysers in Australian contexts and 2) mitigate potential environmental risks associated with HEM.

Why it is important: Differences in standards, unique environmental conditions and frameworks to manage materials of concern can affect how electrolyser manufacturing is performed or alter the product itself, which is relevant to both Australian and overseas manufacturers.

Key areas: This area includes the technical requirements for electrolyser deployment in Australian jurisdictions and the mechanisms governing the use of materials of concern.

What is involved?	Australia's alignment with requirements
Technical requirements involve specifications that an electrolyser system must meet to be used in each Australian State or Territory: from weatherproofing to withstand severe climate conditions to modifications across electric systems and hydrogen storage vessels for compliance with local standards.	**MEDIUM** Australia faces unique environmental and electrical grid conditions, which directly impact the technical requirements for electrolysers that will be deployed locally. For instance, fluctuations in use linked to the cost of renewables in the Australian energy grid will require high energy efficiencies and responsive balance of plant equipment. In terms of compliance standards, differences with large electrolyser markets (e.g., US and EU) and between Australian States and Territories can result in products from overseas manufacturers requiring a degree of local customisation. This can lengthen delivery timelines, increase overall project costs and raise the likelihood of specification misalignments between customer needs and manufacturer actions.[81]
Environmental considerations involve the regulations and monitoring systems in place to oversee materials of concern and minimise risks associated with them, including their potential environmental release.	**HIGH** Environmental considerations vary according to the electrolyser type and the materials used in its fabrication. For instance, the fluoropolymers used to produce proton exchange membranes are per- and polyfluoroalkyl substances (PFAS), which are subject to environmental regulations in multiple jurisdictions, including Australia.[82] As a result, pathways for the safe disposal and recycling of membranes at end-of-life (EOL) will be particularly relevant. Identifying and implementing replacement compounds is an area of R&D interest for PEM electrolyser manufacturers, particularly as potential broad PFAS bans (like one recently proposed in the EU) could cover the fluoropolymer membranes used, affecting manufacturing operations.[83] Similarly, the fabrication of AEM and alkaline systems involves nickel electroplating, which attracts its own Australian regulations, safety measures, and compliance costs to prevent the release of nickel compounds into the environment.[84]

Implications for Australia

Electrolysers to be deployed in Australia require adaptations to meet local standards and operate reliably under unique climate and environmental conditions. Customisation at scale has economic implications for manufacturers, with two possible pathways to both minimise associated costs and turn what is currently a challenge into a driver for Australian facilities.

Leveraging unique product requirements alongside the domestic project pipeline to incentivise local manufacturing facilities	Aligning interpretation of relevant standards across States and Territories to minimise costs associated with misalignment
Electrolysers from established manufacturers are often designed and built for the environment of other countries, without accounting for electric grid differences or the temperature, humidity and cyclone protection needed for reliable operation in Australian climates. This can translate into additional time and money spent on local modifications once equipment arrives onshore. While unique conditions pose a challenge to address, they are also a reality that benefits from local knowledge and expertise. Alongside the large domestic pipeline, this could be leveraged to incentivise the establishment of manufacturing facilities in Australia, along with a domestic operation, maintenance, and repairs sector.	Some differences in standards compared to other countries is expected based on fundamental differences. However, harmonisation and communication of interpretations at a national level can minimise the barrier that different standards can pose to hydrogen production projects, international companies looking to supply the Australian market, and domestic electrolyser manufacturers. Importantly, while customisation may be manageable at lower production volumes, its impact grows at scale. Smaller manufacturers and recent market entrants may be particularly affected, given the cost and time implications of delayed delivery times.

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[81] Wheatley G, Thompson N, Purkess C (2023) Electrolyser Manufacturing Business Case. ITM Power Pty and Linde Engineering Pty. 20. <https://www.wa.gov.au/system/files/2023-09/public-knowledge-sharing-report-electrolyser-business-case-statement.pdf> (accessed 27 August 2024); BOC Limited (2022) Renewable Hydrogen Production and Refuelling Project (ARENA Project 2018(ARP178): Lessons Learnt Report. <https://arena.gov.au/assets/2022/02/boc-renewable-hydrogen-production-and-refuelling-lessons-learnt.pdf> (accessed 27 August 2024).

[82] Australian Industrial Chemicals Introduction Scheme (n.d.) Per- and Polyfluoroalkyl Substances (PFAS). Australian Government Department of Health and Aged Care. <https://www.industrialchemicals.gov.au/consumers-and-community/and-polyfluoroalkyl-substances-pfas> (accessed 10 September 2024).

[83] ECHA (2024) Next steps for PFAS restriction proposal. European Chemicals Agency. <https://echa.europa.eu/-/next-steps-for-pfas-restriction-proposal> (accessed 26 September 2024).

[84] National Industrial Chemicals Notification and Assessment Scheme (2020) Water soluble nickel(2+) salts: Environment tier II assessment. Australian Government Department of Health. 13–14, 22–23. <https://www.industrialchemicals.gov.au/sites/default/files/Water%20soluble%20nickel%282%2B%29%20salts_%20Environment%20tier%20II%20assessment.pdf> (accessed 10 September 2024).

3.7 Supply chain alignment

What it is: Alignment of a location to the upstream and downstream factors that guide the placement and specific activities of a new electrolyser manufacturing facility.

Why it is important: Identifying and improving locations with a high alignment facilitates the attraction of overseas manufacturers and the scale up of local companies in a cost-competitive environment.

Key areas: Supply chain alignment encompasses three areas. Demand in the prospective region to justify a large upfront investment in a new facility; local supply of key components; and conditions that enable a cost-effective operation, from suitable industrial land to workforce and logistics.

What is involved?	Australia's alignment with requirements
The level of demand refers to the electrolyser capacity that a region collectively requires on an annual basis, stemming from projects that have reached final investment decision and have clear deployment timelines.	**MEDIUM** Australia has a significant pipeline of renewable hydrogen projects that could demand electrolysers in the future, but most are still in development and have not reached FID.
Component availability refers to a region's capacity to supply the items (components and equipment) needed to manufacture an electrolyser, from individual cells to balance of plant. For instance, a plant focussed on cell fabrication and stack assembly will benefit from nearby providers or reliable supply chains for membrane materials, porous transport layers, and bipolar plates. Meanwhile, a plant performing system assembly will require local companies capable of producing or delivering power supply units, connection components, and liquid-gas handling equipment.	**MEDIUM** There is an Australian manufacturing base in other industry areas with relevant skills, experience and products. However, their expansion into a local HEM supply chain will require strong communication, integration, and support mechanisms.
Industry-ready locations refer to the presence of factors conducive to a cost-competitive manufacturing operation, from a suitably qualified workforce and logistics infrastructure to utility connections with adequate capacity.	**MEDIUM** Australian locations with a suitable workforce for each stage of the HEM value chain, availability of industrial land, potential for low renewable electricity prices with reliable supply, and efficient logistics will have to be optimised for industry-readiness and actively promoted to attract electrolyser manufacturers.

Implications for Australia

Consulted stakeholders have noted that what worked in countries like Spain and China to attract electrolyser manufacturers is a combination of multi-year anchored offtake agreements (3 to 4 years in duration, for a large total capacity of 2 GW), local partners to supply components, support from local governments, a physical location close to relevant industries, and sufficient renewable energy to stimulate demand for electrolysers (see Case study 5). Australia has a foundation to build a similar case to attract local manufacturing facilities, supported by three pathways.

Supporting a steady progress of the local project pipeline into final investment decisions	Identifying, communicating and integrating local component manufacturers	Identifying, improving and promoting industry-ready locations
There needs to be a sufficiently large aggregated demand to sustain electrolyser manufacturing at scale, which consulted stakeholders have estimated to be 500 MW per year or more for a single manufacturer. As a result, steady progress towards final investment decisions will be needed to aggregate yearly demand to a level that can sustain a domestic HEM ecosystem. This may overlap with broader strategic efforts to unlock demand by supporting hydrogen uptake and advancing additional uses.	Even with a manufacturing facility in place in Australia, operation at scale may not make sense if all components have to be imported. The electrolyser manufacturing business case developed by ITM Power (UK) and Linde Engineering for the WA government highlighted the potential and value of having local suppliers that can provide key components more cost-effectively than imported alternatives.[85] Clear support mechanisms for prospective local suppliers may therefore be needed to de-risk their expansion, such that they can support the establishment of a facility by an overseas electrolyser manufacturer. A strong and accessible ancillary manufacturing ecosystem will also be necessary for domestic companies to scale up over time. This is because production itself can be highly modularised and replicated to increase capacity, but suppliers are outside of a manufacturer's direct control and will also need to increase their outputs to meet demand. Moreover, strong communication, clear visibility over supplier activities, and forecasting will all be important to ensure a continuous and sustainable operation.	Ideally, manufacturing facilities should be in places sitting at the intersection of a qualified construction, maintenance and operations workforce, proximity to manufacturing ecosystems and hydrogen hubs, low renewable electricity prices compared to other countries, and easy accessibility to facilitate transport of materials and products. Clearly identifying these locations in Australia, ensuring their industry-readiness, and promoting them will be necessary, both to attract established international manufacturers and to support emerging Australian companies that may scale up in the country.

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[85] Wheatley G, Thompson N, Purkess C (2023) Electrolyser Manufacturing Business Case. ITM Power Pty and Linde Engineering Pty. 28–29. <https://www.wa.gov.au/system/files/2023-09/public-knowledge-sharing-report-electrolyser-business-case-statement.pdf> (accessed 27 August 2024)

CASE STUDY 5: Leveraging an aligned location and government support to incentivise new electrolyser manufacturing facilities

Cummins (United States), one of the largest electrolyser manufacturers in the world by nominal capacity, announced in 2021 that it had selected Castilla-La Mancha (Spain) as the location for a new PEM electrolyser assembly and testing facility. The plant, which started operating in 2024, has a 500 MW per year capacity (scalable to 1 GW per year) and took 14 months to build, with a reported investment of EUR 75 million.[86]

The original announcement followed a partnership between Cummins and Iberdrola (an international energy company headquartered in Spain) for renewable hydrogen projects in the Iberian peninsula.[87] The selection is also framed by a context of alignment across suitable location, aggregated demand, and government support.

For instance, approximately 50% of electricity generation in Spain comes from renewable sources and the country could reportedly reach 5 GW of installed electrolyser capacity in 2030, with its government's strategy setting an even higher target of 12 GW.[88] Spain also has a diverse manufacturing sector with significant automotive, metal products, chemicals and machinery segments,[89] and its national government has established a EUR 750 million incentive program to support local manufacturing of renewable energy technologies, including electrolysers.[90]

Importantly, financial support as a mechanism to scale-up, retain and attract electrolyser manufacturers is not exclusive to Spain. It has been recently deployed across other European countries and the US via loan agreements, tax credits, and grants. These support measures are aimed at enabling research initiatives on design and manufacturing aspects (e.g., catalysts used, coating processes, optimised balance of plant), testing and demonstration projects at larger scales, and the establishment or improvement of manufacturing facilities. Table 9 provides a sample of relevant incentives provided to electrolyser manufacturers in Europe and the US.

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[86] Cummins (2021) Cummins selects Spain for its gigawatt electrolyzer plant & partners with Iberdrola to lead the green hydrogen value chain. Cummins Newsroom – Our Innovation, Technology and Services. <https://www.cummins.com/news/releases/2021/05/24/cummins-selects-spain-its-gigawatt-electrolyzer-plant-partners-iberdrola> (accessed 26 September 2024); Blanco Orozco J (2024) Ya se fabrican en Guadalajara electrolizadores para producir Hidrógeno Verde. SER Guadalajara, 1 July. <https://cadenaser.com/castillalamancha/2024/07/01/ya-se-fabrican-en-guadalajara-electrolizadores-para-producir-hidrogeno-verde-ser-guadalajara/> (accessed 26 September 2024).

[87] Cummins (2021) Cummins selects Spain for its gigawatt electrolyzer plant & partners with Iberdrola to lead the green hydrogen value chain. Cummins Newsroom – Our Innovation, Technology and Services. <https://www.cummins.com/news/releases/2021/05/24/cummins-selects-spain-its-gigawatt-electrolyzer-plant-partners-iberdrola> (accessed 26 September 2024).

[88] Ritchie H, Roser M, Rosado P (2024) Renewable Energy. Our World in Data. <https://ourworldindata.org/renewable-energy> (accessed 26 September 2024); Le MK, Selvaraju K (2024) Spain sets sights on dominating regional hydrogen market, on track to hit 2030 national target. Rystad Energy. <https://www.rystadenergy.com/news/spain-dominating-regional-hydrogen-market> (accessed 26 September 2024); Lombardi P (2024) Spain increases green hydrogen goal. Reuters, 24 September. <https://www.reuters.com/business/energy/spain-increases-green-hydrogen-goal-sets-12-gw-capacity-by-2030-2024-09-23/> (accessed 26 September 2024).

[89] Montoriol Garriga J, Díaz S (2021) An overview of Spain's manufacturing industry. CaixaBank Research – Sectoral analysis – Industry. <https://www.caixabankresearch.com/en/sector-analysis/industry/overview-spains-manufacturing-industry> (accessed 26 September 2024).

[90] Sánchez Molina P (2024) Spain announces €750 million incentive scheme for clean-tech manufacturing. pv magazine, 27 February. <https://www.pv-magazine.com/2024/02/27/spain-announces-e750-million-incentive-scheme-for-clean-tech-manufacturing/> (accessed 26 September 2024).

Table 9. Illustrative sample of support measures for electrolyser manufacturers across Europe and the United States, announced in the last 5 years

Company	HQ location	Electrolyser type	Incentive type	Organisation	Value (millions)
Bloom Energy	United States	SOE	Investment tax credit	US Department of Energy (Office of Manufacturing & Energy Supply Chains – MESC)	USD 75
Electric Hydrogen	United States	PEM	Grants	US Department of Energy (Hydrogen and Fuel Cell Technologies Office – HFTO)	USD 46.3
Electric Hydrogen	United States	PEM	Investment tax credit	US Department of Energy (MESC)	USD 18.3
Elogen	France	PEM	Grants	Government of France	EUR 86
Green Hydrogen Systems	Denmark	Alkaline	Grants	European Climate, Infrastructure and Environment Executive Agency (CINEA)	EUR 9
Hydrogen Pro	Norway	Alkaline	Grants	Export and Investment Fund of Denmark (EIFO)	DKK 35
ITM Power	United Kingdom	PEM	Grants	German Federal Ministry of Education and Research (BMBF)	EUR 1.95
ITM Power	United Kingdom	PEM	Grants	UK Department for Business, Energy and Industrial Strategy (BEIS)	GBP 9.3
John Cockerill	Belgium	Alkaline	Investment tax credit	US Department of Energy (MESC)	USD 34
McPhy	France	Alkaline	Grants	Government of France	EUR 114
Nel	Norway	Alkaline, PEM	Grants	US Department of Energy (MESC)	USD 41
Nel	Norway	Alkaline, PEM	Grants	US Department of Energy (HFTO)	USD 50
Nel	Norway	Alkaline, PEM	Grants	State of Michigan (US)	USD 75
Sunfire	Germany	Alkaline, SOE	Loan agreement	European Investment bank	EUR 100
Sunfire	Germany	Alkaline, SOE	Grants	Previously approved, undrawn grant funding	EUR 200
thyssenkrupp nucera	Germany	Alkaline	Grants	US Department of Energy (HFTO)	USD 50
Topsoe	Denmark	SOE	Grants	EU Innovation Fund	EUR 94
Topsoe	Denmark	SOE	Investment tax credit	US Department of Energy (MESC)	USD 135.9
Topsoe	Denmark	SOE	Loan agreement	European Investment bank	EUR 45
Verdagy	United States	Alkaline	Grants	US Department of Energy (HFTO)	USD 39.6

Source: All sources for Table 9 were accessed on 14 October 2024.

Bloom Energy: Bloom Energy (2024) Bloom Energy to Receive up to $75 million in Federal Tax Credits for Fremont Manufacturing Plant. Press Release. <https://newsroom.bloomenergy.com/news/bloom-energy-to-receive-up-to-75-million-in-federal-tax-credits-for-fremont-manufacturing-plant>;

Electric Hydrogen: Electric Hydrogen (2024) U.S. Department of Energy Awards Electric Hydrogen $46.3M Grant for Electrolyzer Manufacturing under the Bipartisan Infrastructure Law's Clean Electrolysis Program. Press Release. <https://eh2.com/u-s-department-of-energy-awards-electric-hydrogen-46-3m-grant-for-electrolyzer-manufacturing-under-the-bipartisan-infrastructure-laws-clean-electrolysis-program/>; Electric Hydrogen (2024) Electric Hydrogen receives $18.3M transferable DOE tax credit for its gigafactory in Massachusetts, bringing total Department of Energy support to $65M. <https://eh2.com/electric-hydrogen-receives-18-3m-transferable-doe-tax-credit-for-its-gigafactory-in-massachusetts-bringing-total-department-of-energy-support-to-65m/>;

Elogen: Elogen (2022) Press Release: As part of the Hydrogen IPCEI, the Elogen project will benefit from the support of the French State to the amount of 86 million Euros. <https://elogenh2.com/en/2022/09/29/press-release-as-part-of-the-hydrogen-ipcei-the-elogen-project-will-benefit-from-the-support-of-the-french-state-to-the-amount-of-86-million-euros/>;

Green Hydrogen Systems: Green Hydrogen Systems (2021) Green Hydrogen Systems has been granted EUR 9 million to develop a 6MW test module for a 100MW solution worth more than EUR 48 million in contract value subject to later qualification. News Details. <https://investor.greenhydrogen.dk/announcements-and-news/news-details/2021/Green-Hydrogen-Systems-has-been-granted-EUR-9-million-to-develop-a-6MW-test-module-for-a-100MW-solution-worth-more-than-EUR-48-million-in-contract-value-subject-to-later-qualification/default.aspx>;

HydrogenPro: HydrogenPro (2024) HydrogenPro to receive substantial grant from the Danish government. <https://hydrogenpro.com/2024/06/04/grantdanishgovernment/>;

ITM: ITM (2022) Grant Award in Germany for SINEWAVE Project. News. <https://itm-power.com/news/grant-award-in-germany-for-sinewave-project>; ITM (2022) UK Government Award GBP9.3M for Gigatack Testing. News. <https://itm-power.com/news/uk-government-award-9.3m-for-gigastack-testing>;

John Cockerill: John Cockerill (2024) John Cockerill Hydrogen awarded $34 million in tax credit for the Baytown Gigafactory Project. <https://hydrogen.johncockerill.com/en/press-and-news/news/john-cockerill-hydrogen-awarded-34-million-in-tax-credit-for-the-baytown-gigafactory-project/>;

McPhy: McPhy (2022) French government boosts support for the hydrogen industry: EUR 114 million in public funding for the McPhy Gigafactory project. Press releases. <https://mcphy.com/en/press-releases/french-government-boosts-support-for-the-hydrogen-industry-e114-million-in-public-funding-for-the-mcphy-gigafactory-project/?cn-reloaded=1>; bpifrance (2024) The French success story fuelled by European subsidies. <https://www.bpifrance.com/2024/05/16/the-french-success-story-fueled-by-european-subsidies/>;

Nel ASA: Nel ASA (2024) Nel ASA: Additional USD 41 million in tax credits for manufacturing expansion in Michigan. Press release. <https://nelhydrogen.com/press-release/nel-asa-additional-usd-41-million-in-tax-credits-for-manufacturing-expansion-in-michigan/>; Nel ASA (2024) Nel ASA: Received additional USD 75 million in support for Michigan facility. Press release. <https://nelhydrogen.com/press-release/nel-asa-receives-additional-usd-75-million-in-support-for-michigan-facility/>;

Sunfire: Sunfire (2024) Sunfire Secures More Than EUR 500 Million to Accelerate its Growth. News. <https://sunfire.de/en/news/sunfire-secures-more-than-eur-500-million-to-accelerate-its-growth/>; **thyssenkrupp nucera:** thyssenkrupp nucera (2024) thyssenkrupp nucera Selected for $50 Million Grant from the U.S. Department of Energy. <https://thyssenkrupp-nucera.com/2024/03/18/thyssenkrupp-nucera-selected-for-50-million-grant-from-the-u-s-department-of-energy/>;

Topsoe: Frøhlke U (2023) Topsoe Warded EUR 94 Million From the EU's Innovation Fund to Build SOEC Factory. <https://www.topsoe.com/press-releases/topsoe-awarded-eur-94-million-from-the-eus-innovation-fund-to-build-soec-factory>; Martinez G (2024) Topsoe Announced Plans for New State-Of-The-Art US Electrolyzer Factory for Clean Hydrogen. <https://www.topsoe.com/press-releases/topsoe-announces-plans-for-new-state-of-the-art-us-electrolyzer-factory-for-clean-hydrogen>; EIB (2022) Denmark Haldo Topsøe signs WUR45 million funding deal with EIB to drive green energy transition. European Investment Bank. <https://www.eib.org/en/press/all/2022-006-denmark-haldor-topsoe-signs-eur45-million-funding-deal-with-eib-to-drive-green-energy-transition>;

Verdagy: Verdagy (2024) Verdagy Awarded $39.6 Million Grant from the Department of Energy. <https://verdagy.com/verdagy-awarded-39-6-million-grant-from-the-department-of-energy/>.

4 Conclusion

HEM is a unique opportunity for Australia by virtue of the electrolyser market's nascency at large scale, strong starting position with an emerging cohort of Australian electrolyser manufacturers, and domestic renewable hydrogen pipeline. It seeks to align with Australia's hydrogen and manufacturing agendas, presents a significant economic opportunity, and provides a case to develop the domestic manufacturing ecosystem and raw materials processing base, with spillover benefits to other clean energy technology manufacturing opportunities.

This report profiles Australia's emerging electrolyser manufacturing industry, estimates the economic potential that could be created, and explores the pathways Australia can take to capture the opportunity. It serves to stimulate the domestic HEM ecosystem by considering existing actors, providing an overview to potential new entrants on the roles they could play, and informing broader strategic decisions and investments.

The window of opportunity in which Australia is well-positioned to play a significant role is finite. To seize the opportunity while it is still accessible, the following should be considered:

- **Aggregated manufacturing demands:** What is the aggregated demand across renewable energy technologies and how can it inform effective manufacturing initiatives and potentially unlock onshore raw materials processing opportunities?
- **Stakeholder visibility:** Who are all the actors across the electrolyser value chain in Australia, what role do they currently play, what capabilities do they have, and how are they transferrable?
- **Cost effective locations:** What are the Australian locations that can best leverage local strengths such as renewable electricity prices and firming, while offsetting unavoidable costs such as labour rates and logistics? How can hydrogen hubs and manufacturing ecosystems be developed around these locations?
- **Developing sovereign manufacturing capabilities whilst investigating international partnerships:** How can Australia leverage HEM to develop long term sovereign manufacturing capability, whilst potentially improving shorter term cost competitiveness by exercising international partnerships? How do the high value opportunities remain onshore?

This work was developed in consultation with domestic and international stakeholders, including the research community, investment entities, Australia's emerging electrolyser innovators, multi-national manufacturers, facility designers, technology specialists, hydrogen producers and consumers, government agencies and industry bodies. On-going collaboration in Australia and internationally will be key to overcome scale-up challenges and realise the unique opportunities that HEM presents for Australia.

5 Appendices

5.1 Consulted organisations

- Accelera (Cummins)
- ARENA
- Arup
- Australian Hydrogen Council
- BP
- Cavendish Renewable Technology
- Central Queensland University
- Columbia Australia
- CSIRO
- Enapter
- Endua
- Fortescue
- Hadean Energy
- Horizon Fuel Cells
- Hysata
- International Energy Agency
- IP Group
- Manufacturing Catalyst
- Plug Power
- Powering Australia
- Siemens

5.2 Supporting information for economic analysis

5.2.1 Economic factors affecting the potential electrolyser market size

Demand for renewable hydrogen

Renewable hydrogen demand sits at the base of the electrolyser manufacturing opportunity. As industries and governments work toward decarbonisation, renewable hydrogen will play a vital role in reducing greenhouse gas emissions while meeting energy needs. Electrolyser manufacturing, in turn, grows in response to this increasing demand for hydrogen.

Two key factors drive the expansion of renewable hydrogen demand. The first is the ongoing shift away from high-emission hydrogen, traditionally produced from fossil fuels. Key industries, including oil refining, industrial production of ammonia, methanol and steel, and long distance road transportation, are under increasing pressure to reduce their carbon footprints and are shifting toward renewable hydrogen as part of their decarbonisation strategies. Renewable hydrogen can also play a role in smaller scale hydrogen uses across industrial gas and chemical feedstock production, glassmaking and semiconductor manufacturing.

The second factor is the development and uptake of additional applications for renewable hydrogen. This includes:

- Replacement of carbon-based reductants and fuels for industrial processing (e.g., for metal production and in heat supply to furnaces);
- hydrogen or hydrogen-derived fuels to power rail, maritime and aviation transportation;
- powering off-grid vehicles for materials handling and heavy hauling (e.g., mining vehicles);
- energy storage and electricity production; and
- gas blending for heating and domestic provision.[91]

The advancement of other decarbonisation technologies will also influence renewable hydrogen demand. Certain technologies will provide direct alternatives to hydrogen use (e.g., batteries and direct electrification), while others will require hydrogen directly or indirectly (e.g., fuel cells and ammonia-powered ship engines).

Cost competitiveness

Even with high demand for renewable hydrogen, it needs to be cost-competitive with fossil fuel-based production to make electrolyser projects viable at scale.

A major barrier to the adoption of renewable hydrogen is the capital costs of electrolysers. A significant reduction in these costs is crucial for making hydrogen a viable alternative to fossil fuels in various applications. Potential sources of price reductions include scaling up production processes and advancing innovations in electrolyser materials, system efficiency, and overall durability.

However, it is worth noting that price changes have multiple effects. A reduction in electrolyser prices can boost demand, but it also directly reduces the market size in monetary terms. This is because market size is typically calculated as the quantity demanded multiplied by its unit price. As prices drop, even with increased demand, the total market value can shrink due to the lower revenue generated per unit sold. This creates a complex relationship between the cost of electrolysers and market size, as both the quantity of electrolysers sold and the price at which they are sold influence the total market valuation.

Market share of Australian electrolysers

Australia could demand up to ~23 GW of electrolysers annually by 2050, creating a substantial market opportunity. However, the actual market size potential will be directly influenced by the level of market share captured by Australian manufacturers. This will ultimately depend on the competitiveness of local systems across the technical factors discussed in section 2.3 – Differentiating factors between electrolyser types, and the strategic aspects presented in chapter 3 – The pathways to HEM. However, mechanisms observed in other countries, like local content strategies and the continued need for electrolyser customisation, may influence how local demand is met.

Volume of exports

Exports of electrolyser stacks represent another source of revenue for Australian manufacturers, potentially expanding the market opportunity. However, exporting advanced industrial products poses challenges across customer relations, trade barriers, and regulatory compliance, which can limit export volumes.
Export potential also depends on whether Australia successfully commercialises a unique, IP-protected electrolyser product.

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[91] Australian Hydrogen Council (2022) How we get to scale. In Unlocking Australia's hydrogen opportunity. 33–35. <https://h2council.com.au/wp-content/uploads/2022/10/AHC_White_Paper_Ch2_2021-09-30-013033.pdf>; IEA (2023) Global hydrogen Review 2023. 20–43, 65–67. International Energy Agency, Paris. <https://iea.blob.core.windows.net/assets/cb9d5903-0df2-4c6c-afa1-4012f9ed45d2/GlobalHydrogenReview2023.pdf>.

5.2.2 Australia market sizing and job analysis methodology

Introduction

CSIRO conducted an economic analysis to assess the commercial opportunity and potential job creation of HEM in Australia by 2050. This appendix summarises the results, parameters and methodology used to produce the estimates presented in this report.

This study employed a bottom-up market sizing approach to estimate the combined revenue of all market participants involved in electrolyser deployment, including electrolyser stack manufacturing, balance of plant (BoP), and installation services.

This model introduces three scenarios that align with the 2024 National Hydrogen Strategy (NHS) Low, Central, and High projections for hydrogen production in Australia.

In the Low scenario, the market is expected to grow without external support. The Central scenario assumes some support for local procurement, helping Australian manufacturers gain a stronger presence in the domestic market. In the High scenario, support extends to exports, with the additional assumption that Australia commercialises a unique, IP-protected electrolyser product that is in demand internationally, and allows it to become a major player in global markets.

Parameters

The parameters used for this calculation are summarised in Table 10, followed by a detailed discussion of each parameter. These parameters were initially sourced through comprehensive desktop research, leveraging existing data and industry reports. We then validated and refined them through consultations with various industry experts to ensure their robustness.

Table 10. Summary of parameters, 2050

Parameters		Low	Central	High
(A)	**Australian hydrogen production via electrolysis (Mtpa)**	4	14	31
(B)	**Average yearly operating hours (hours)**	5000	5000	4800
(C)	**Hydrogen Generation Efficiency (kwh/kg)**	50	47.5	45
(D)	**Stack replacement time (‘000 hours)**	100–120	100–120	100–120
(E)	**Stack replacement cost (% of capital cost)**	40%	40%	40%
(F)	**Lead time (years)**	0.5	0.5	0.5
(G)	**Domestic market capture (% of domestic electrolyser demand)**	Stack and BoP: 36% Installations: 100%	Stack and BoP: 55% Installations: 100%	Stack and BoP: 85% Installations: 100%
(H)	**Export ratio (domestic-to-export ratio)**	0.33	0.33	0.47
(I)	**Domestic unit revenue (AUD/kw)**	Stack and BoP: 230 Installations: 99	Stack and BoP: 230 Installations: 99	Stack and BoP: 160 Installations: 69
(J)	**Export unit revenue (AUD/kw)**	117	117	82
(K)	**Revenue per employee (AUD)**	Stack: 640,915 BoP: 591,482 Installations: 1,029,360	Stack: 640,915 BoP: 591,482 Installations: 1,029,360	Stack: 640,915 BoP: 591,482 Installations: 1,029,360

A) Australian hydrogen production via electrolysis

The projected hydrogen production in Australia aligns with the three scenarios in the 2024 National Hydrogen Strategy (NHS). The NHS data for hydrogen production via electrolysis was available only at five-year intervals between 2025 and 2050, so linear interpolation was applied to estimate the values in between. Hydrogen production for 2022 to 2025 was estimated by assessing the current and planned projects using the HyResource database (July 2024 update).[92] Production capacities for 2022 and 2023 were discounted by 90% to align with the global average utilisation rate for electrolysers, while projected capacities for 2024 and 2025 were discounted by 70% and 50%, respectively, to account for project uncertainties. This is shown visually in Figure 13.

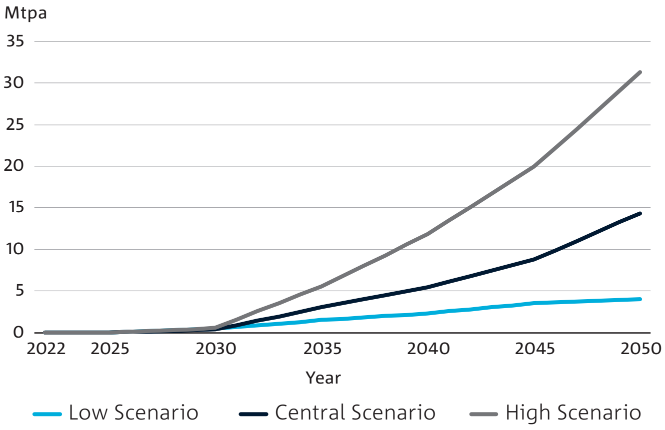

Figure 13. Australian hydrogen production via electrolysis in million tonnes per annum (Mtpa)

B) Average yearly operating hours

This parameter refers to the total duration that an electrolyser system is actively operating and producing hydrogen. The operating hours of electrolysers directly affect the total hydrogen produced and influence the frequency of electrolyser stack replacement, which is based on cumulative operating hours.

Electrolyser's average yearly operating hours were assumed to start at 8000[93] hours and gradually decline at the same rate as GenCost[94], reaching 5000[95] hours by 2050 for the low and central scenario and 4800 hours for the high scenario[96]. Currently, electrolysers operate at a high utilisation rate because capital costs are a larger cost driver than electricity prices for hydrogen production, making electrolysers viable only for certain industries where hydrogen costs are not a major cost factor. As production volumes increase and capital costs decrease, more applications will become viable, and electricity prices will become a more significant factor in hydrogen production costs. Consequently, operators will be more selective about the hours they choose to operate.

C) Hydrogen generation efficiency

Hydrogen generation efficiency, measured in kWh/kg, is the electrical energy needed to produce one kg of hydrogen. Lower values signify greater electrolyser efficiency in energy conversion. A 1 kW electrolyser installed capacity can consume 1 kWh of electrical energy in an hour. As electrolysers age, their efficiency declines. This parameter reflects the weighted average efficiency of all active installed electrolysers.

Projects for hydrogen generation efficiency were aligned to estimates and targets from IRENA[97]. In the Low scenario, average efficiency is expected to be in the lower range of 2020 electrolyser system performance. The High scenario assumes that the 2050 targets are met, while the Central scenario reflects the average of the Low and High scenarios. Hydrogen generation efficiencies for the Low, Central, and High scenarios are 50, 47.5, and 45, respectively. In all three scenarios, it is assumed that efficiency decreases linearly from 57.5[98] in 2022.

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[92] HyResource (2024) Projects spreadsheet (accessed 12 July 2024).

[93] According to IEA, the installed capacity for electrolysers is 687 MW in 2022. IEA's Global Hydrogen Review 2023 states that Hydrogen generated via electricity is 0.1% of the 95 Mt hydrogen produced in 2022. Assuming a current efficiency rate of 57.5, electrolysers operated an average of 7950 hours in 2022.

[94] Refer to parameter I) Price of hydrogen electrolysers.

[95] Analysis by CSIRO considering forecasted hourly electricity prices to determine when it is cost-effective to operate, focusing on times of the day when electricity prices are lower.

[96] Lower operating hours are assumed in the high scenario because reduced capital costs make electricity prices a more significant factor in determining whether to operate the electrolysers.

[97] Table 6. State-of-the-art and future KPIs for all electrolyser technologies. – IRENA Green Hydrogen Cost Reduction (2020)

[98] Average efficiency of PEM and Alkaline electrolysers in 2022. Table 5-7: Electrolyser configuration and performance Aurecon 2022 Costs and Technical Parameter Review

D) Stack replacement time

The efficiency of cell stacks gradually declines over time, requiring more power to operate each year, even when they remain functional. Eventually, it becomes more cost-effective to replace the electrolyser stack rather than continue consuming additional electricity to maintain the same hydrogen output.

According to IRENA[99], the current replacement timeframe typically falls within 50,000 to 80,000 cumulative hours of operation. IRENA's target for the stack lifetime of PEM and ALK electrolysers is between 100,000 to 120,000 hours by 2050. It was assumed that the stack replacement time would gradually increase to IRENA's target timeframe for 2050, following the same rate of change as electrolyser prices[100]. The first cell stack replacement is assumed to occur once cumulative operational hours reach the lower limit of the stack replacement timeframe, with subsequent replacements continuing at regular intervals until all stacks are replaced by the upper limit.

E) Stack replacement cost

When replacing the stack, the cost is a fraction of the initial capital cost outlay because all the other plants and equipment could still be used. It is assumed the stack replacement cost is constant over time at 40%[101] of the overall capital cost.

F) Lead time

Lead time calculates the interval needed for electrolysers to be installed before they commence hydrogen production. The lead time is assumed as the time difference between when the main equipment is needed on-site for an electrolyser project and the COD (commercial operation date), according to Aurecon[102] estimates. Lead time is assumed to be constant over time and rounded up to the nearest integer.

G) Domestic market capture

Domestic market capture refers to the share of the domestic market that Australian electrolyser manufacturers and service providers could capture. There is a strong case for domestically manufactured electrolysers, driven by needs such as local customisation, logistics, commissioning, and after-sales support. In the Low scenario, with little or no external market support for local procurements, the market capture for manufacturers is based on the median market capture (~36%) of comparable industries using data from IBIS World. These industries[103] were identified through expert consultations. In the Central scenario, it is assumed that manufacturers can capture a majority market share (55%[104]), bolstered by additional government support to increase local procurement. In the High scenario, it is assumed that Australia develops a unique, IP-protected electrolyser product that is in demand both globally and domestically, enabling it to dominate (85% market share) the local market. It is assumed that the industry will achieve its market capture ratio by 2040 in a linear progression and will maintain a steady state thereafter.

Revenue from installation services is assumed to be generated domestically, resulting in a 100% market capture for installations in all three scenarios.

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[99] PEM currently has a stack life between 50,000-80,000 hours, while ALK has a stack life of 60,000 hours. Table 6. State-of-the-art and future KPIs for all electrolyser technologies. – IRENA Green Hydrogen Cost Reduction (2020)

[100] CSIRO GenCost 2023–24

[101] According to Yates et al. (2020), Techno-economic Analysis of Hydrogen Electrolysis from Off-Grid Stand-Alone Photovoltaics Incorporating Uncertainty Analysis

[102] Table 5–8: Technical parameters and project timeline of the Aurecon 2022 Costs and Technical Parameter Review

[103] Industries include: Commercial Refrigerator Manufacturing in Australia; Food Processing Machinery Manufacturing in Australia; Power Automation Products and Other Electrical Equipment Manufacturing in Australia; Heating, Cooling and Ventilation Equipment Manufacturing in Australia; Mining and Construction Machinery Manufacturing in Australia; Measurement and Other Scientific Equipment Manufacturing in Australia; Pump and Compressor Manufacturing in Australia; Medical and Surgical Equipment Manufacturing in Australia; Industrial Machinery Manufacturing in Australia; Automotive Electrical Component Manufacturing in Australia; Electric Cable and Wire Manufacturing in Australia

[104] The Inflation Reduction Act in US mandates that energy projects with more than 55% domestic content will qualify for bonus tax credits. Robert RE, Debin Collinsworth AE (2023) Domestic Content Requirements of the Inflation Reduction Act: Basic Requirements, Qualification Analysis, and Lingering Questions. Sheppard Mullin Richter & Hampton LLP. <https://www.lexology.com/library/detail.aspx?g=328f420e-2abb-403c-a787-dea72c9d0b97 (accessed 17 September 2024).

H) Export ratio

The export ratio measures the potential additional export value for every dollar of domestic revenue generated. Australia could reasonably capture the Pacific market and a portion of the Asian market (excluding China) because of its geographic proximity and stronger trade relationships. Without any export support in the Low and Central scenarios, the target export ratio is assumed to reach the median of the comparable industries identified above, or AUD 0.33 for every domestic revenue. In the High scenario, it is assumed that Australia successfully commercialises a unique, IP-protected electrolyser product and there is export support, resulting in the target export ratio reaching the third quartile of the same comparable industries identified above, or AUD 0.45 for every dollar of domestic revenue earned. It is assumed that exports will commence in 2030 and will increase linearly until the target export ratio is reached in 2050.

I) Domestic unit revenue

Domestic unit revenue refers to the comprehensive cost to a hydrogen producer to purchase and implement an electrolyser system in Australia. This includes the electrolyser stack (~21%), the BoP (~49%), and installation services (~30%), based on NREL and Aurecon reports[105]. Domestic unit revenue of electrolysers is assumed to be constant and was calculated using the cost of hydrogen electrolysers from GenCost 2023–2024[106], excluding the portion related to land costs[107]. The Low and Central scenarios correspond to the GenCost Global NZE (Net Zero Emission) post-2050 scenario, while the High scenario corresponds to the Global NZE by 2050 scenario prices. For each scenario, the weighted average electrolyser price was calculated based on the relative production volumes of PEM and Alkaline electrolysers, as outlined in NHS 2024. This analysis only considered the prices and production volumes of PEM and Alkaline electrolysers to align with NHS and GenCost models. This is shown visually in Figure 14.

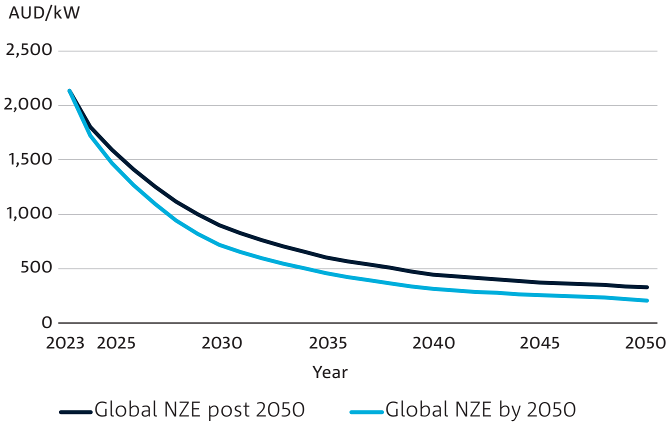

Figure 14. Price of electrolysers (AUD/kw), 2022 to 2050

J) Export unit revenue

Not all revenue from exporting can be captured in Australia. For example, electrical BoP has been identified as a core component of the electrolyser system and is often exported, but other BoP components may be more competitively sourced within the destination country. Similarly, installation typically occurs in the destination country. Although manufacturers may capture some installation revenue by deploying experts to assist with commissioning the electrolyser system and provide other support, this is a relatively small component of installation revenue. This model assumes 100% of stack manufacturing revenue, 30% of BoP revenue[108], and no installation revenue can be captured through exports.

K) Revenue-to-employee ratio

The revenue-to-employee ratio refers to the average revenue generated by each employee. Experts were consulted to identify comparable industries for stack[109], BoP[110] and installation services[111]. The revenue-to-employee ratios for all three scenarios were then benchmarked to the average of these comparable industries up to 2029 using IBIS World. IBIS World did not forecast past 2029, so we took the average compounded annual growth rate (CAGR) of these industries and projected them to 2050. The revenue-to-employee ratio for stack manufacturing is projected to be AUD 640,915 in 2050, BoP manufacturing at AUD 591,482, and installation services at AUD 1,029,360.

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105 Equipment cost is around 70% of total EPC cost – Table 5-9: Technical parameters and project timeline of the Aurecon 2022 Costs and Technical Parameter Review. Stack is 30% and BOP is 70% of the equipment cost at 1GW annual production capacity – Table 10: Manufactured Cost Estimates at Various Production Rates Updated Manufactured Cost Analysis for Proton Exchange Membrane Water Electrolyzers

106 CSIRO GenCost 2023–24 report

107 Land costs account for 7% to 9% of electrolyser CAPEX cost in GenCost 2023-2024.

108 NREL estimates electrical BOP is around 30% of all BoP with a 1 GW annual production capacity Updated Manufactured Cost Analysis for Proton Exchange Membrane Water Electrolyzers.

109 The comparable industries for stack manufacturing were: Automotive Electrical Component Manufacturing in Australia; Measurement and Other Scientific Equipment Manufacturing in Australia; Mining and Construction Machinery Manufacturing in Australia; Industrial Machinery Manufacturing in Australia; and Power Automation Products and Other Electrical Equipment Manufacturing in Australia.

110 The comparable industries for BoP manufacturing were: Automotive Electrical Component Manufacturing in Australia; Heating, Cooling and Ventilation Equipment Manufacturing in Australia; Commercial Refrigerator Manufacturing in Australia; Power Automation Products and Other Electrical Equipment Manufacturing in Australia; Electric Cable and Wire Manufacturing in Australia; and Pump and Compressor Manufacturing in Australia.

111 The comparable industries for installation services were: Wind Farm Construction in Australia; Heavy Industry and Other Non-Building Construction in Australia; and Solar Panel Installation in Australia.

Methodology

The model starts by assuming that the existing installed electrolyser capacity fully meets the hydrogen production from previous years. Therefore, only the additional hydrogen production required each year will need new electrolyser capacity. It then calculates the annual additional electrolyser capacity required to meet hydrogen production targets based on assumptions regarding electrolyser efficiency, annual utilisation hours, lead time, and electrolyser stack replacement schedule[112]. This is then adjusted by the assumed market share that local suppliers could capture and further multiplied by an export-to-domestic ratio to determine export potential. The annual capacity demanded for Australian-manufactured electrolysers is then multiplied by the domestic and export unit revenue respectively. The sum of domestic and export revenue provides the estimated Australian market size for electrolysers. The market size for the stack, BoP, and installation segments of the market were also estimated separately using the split of revenue discussed above. The potential job creation was estimated by dividing the respective market sizes by the revenue per employee of those industries. Table 11 below outlines the calculation steps based on the parameters detailed in the previous section.

Table 11. Calculation steps

Calculations	
(1) Annual additional hydrogen production (kg/year)	$= (A)_t - (A)_{t-1}$
(2) Annual hydrogen production per kW of electrolyser (kg/year)	$= B_t/C_t$
(3) New electrolysers required annually (kW)	$= (1)_t/(2)_t$
(4) Stack replacement (full electrolyser system equivalent) (kW)[113]	$= \sum_{i=0}^{t-1} (5)_i \times \frac{C_t}{C_i} \times E_t \ \ if \sum_{j=i}^{t} B_j \geq D_i$
(5) Annual electrolyser demand (kW)	$= (3)_t + (4)_t$
(6) Annual electrolyser demand given lead time (kW)	$= (5)_{t+F}$
(7) Domestic market capture of Stack and BoP by local suppliers (kW)	$= (6)_t \times G_{Stack\ and\ BOP,t}$
(8) Domestic market capture of installation services by local suppliers (kW)	$= (6)_t \times G_{Installations,t}$
(9) Export demand (kW)	$= (7)_t \times H_t$
(10) Market size for Australian suppliers (AUD)	$= (7)_t \times I_{Stack\ and\ BOP,t} +$ $(8)_t \times I_{Installations,t} + (9)_t \times J_t$
(11) Potential Australian jobs (#)	$= \sum_i \frac{(10)_{i,t}}{K_{i,t}}$ $where\ i = stack, BOP\ and\ installation\ services$

Note: *t=2025, 2026, …., 2050.*

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[112] This study did not consider a full plant replacement (typically occurring after 25 years).

[113] This is a simplified version of the equation. The actual model uses an upper and lower bound for replacement time and assumes that replacements are uniformly distributed between the two points.

Results

Table 12 summarises the estimates of the potential market size and jobs using this methodology.

Table 12. Australia's electrolyser market size and jobs, 2030 and 2050

	Low		Central		High	
	2030	2050	2030	2050	2030	2050
Annual capacity demanded for Australian electrolysers (GW)	0	1	1	10	3	33
Australian Market Size ($ Million)	717	282	1,987	2,903	4,497	5,596
Potential job creation (#)	905	368	2,615	3,974	6,209	8,047

Note

- The discrepancy in summations is due to differences in rounding.
- All figures are reported unadjusted for inflation in current Australian dollars.

In the Low scenario, market size and job creations in 2030 exceed those in 2050 because domestic unit revenue (AUD/kW) declines faster than the increase in demand, as seen in Figure 14 above.

5.2.3 Sensitivity analysis

Sensitivity analysis was conducted on selected parameters to identify key drivers that have the greatest impact on potential HEM market size and job creation for 2050. Australian hydrogen production via electrolysis has the biggest impact on both the market size and potential jobs, followed by the domestic market capture and domestic unit revenue.

Table 13 below presents CSIRO's best estimate of the 80% confidence interval for each parameter derived from expert consultations. Each parameter was then varied individually from the lower bound to the upper bound to determine the resulting impact on market size and jobs.

Table 13 Estimates of the 80% confidence intervals for the parameters

	Parameters	Lower bound	Upper bound
(A)	**Australian hydrogen production via electrolysis (Mtpa)**	4	31
(B)	**Average yearly operating hours (hours)**	6000	4000
(C)	**Hydrogen Generation Efficiency (kwh/kg)**	40	52
(D)	**Stack replacement time ('000 hours)**	140	80
(E)	**Stack replacement cost (% of capital cost)**	30	50
(G)	**Domestic market capture (% of domestic electrolyser demand)**	Stack and BoP: 21% Installations: 100%	Stack and BoP: 85% Installations: 100%
(H)	**Export ratio (domestic-to-export ratio)**	0.11	1.15
(I)	**Domestic unit revenue (AUD/kw)**	Stack and BoP: 70 Installations: 30	Stack and BoP: 315 Installations: 135
(J)	**Export unit revenue (AUD/kw)**	0	190
(K)	**Revenue per employee (AUD)**	Stack: 959,158 BoP: 863,910 Installation: 2,687,330	Stack: 439,297 BoP: 447,741 Installation: 666,265

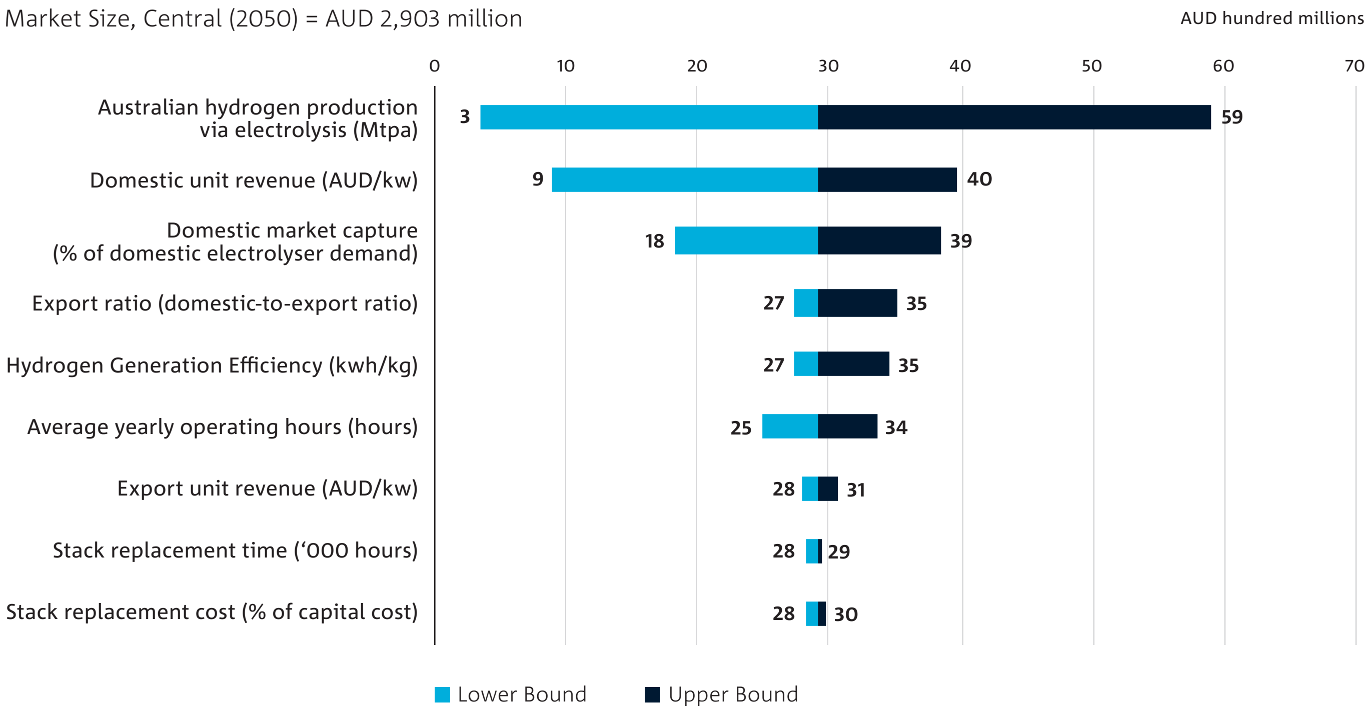

Figure 15. Sensitivity analysis of Australia's HEM market size, Central (2050)

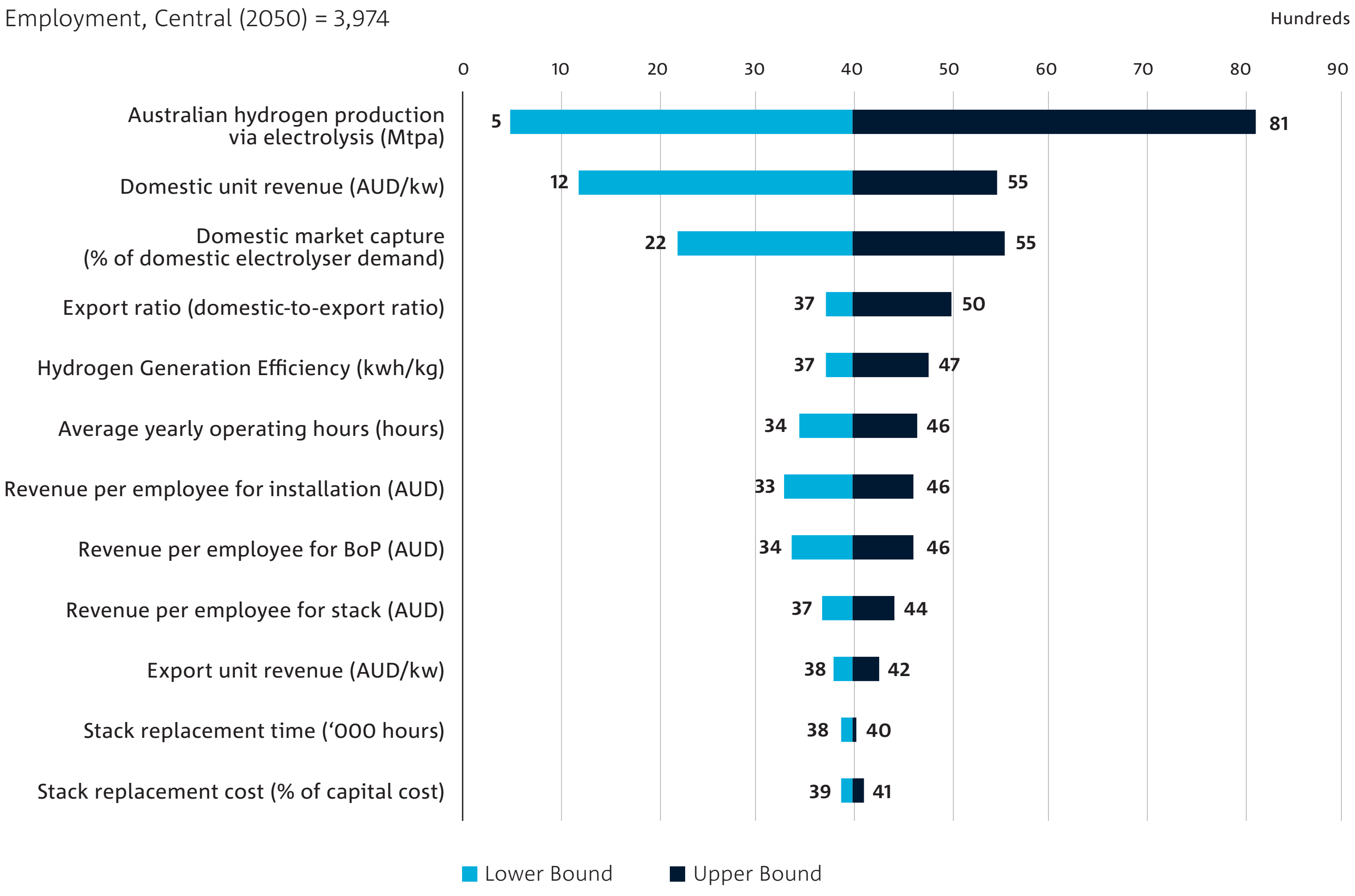

Figure 16. Sensitivity analysis of Australia's HEM employment, Central (2050)

5.3 Government strategies and support mechanisms relevant to HEM in Australia

5.3.1 Government programs

Australian stakeholders, from government to industry and research, are working to make Australia a major global player in hydrogen use and provision by 2050. This vision is outlined across strategies at the National and State and Territory levels.

National Hydrogen Strategy

The 2024 National Hydrogen Strategy (an update on the original strategy published in 2019) set clear targets and several strategic actions relevant to electrolyser manufacturing.[114] These include:

Targets

- Australia will produce at least 15 million tonnes of renewable hydrogen per year, with a stretch potential of 30 million tonnes by 2050.
- Australia's progress towards the 2050 production target will be measured against the following milestones:
  - 2030: 0.5–1.5 million tonnes
  - 2035: 3–5 million tonnes
  - 2040: 5–12 million tonnes
  - 2045: 9–20 million tonnes
- Australia will export a base amount of 0.2 million tonnes, with a stretch potential of 1.2 million tonnes of renewable hydrogen (or equivalent in hydrogen embodied products) per year by 2030.

Actions

- "Action 2: Provide early policy support to enable the scaling up of the hydrogen industry to achieve production costs that are competitive with incumbent fossil fuels and to secure early offtake agreements."
- "Action 10: Support the development of sovereign clean technology and emissions-reduction manufacturing industries."
- "Action 11: Identify opportunities that leverage Australia's research, development and demonstration (RD&D) capabilities to advance hydrogen technology manufacturing in Australia."
- "Action 13: Australia will seek opportunities to increase RD&D investment in the TRL 4–6 range through programs and grants, including through ARENA."
- "Action 14: Identify opportunities to work with partners on RD&D and position Australia at the forefront of international hydrogen-related research collaboration."

States and Territories

State and Territory governments have set their own goals for hydrogen production using renewable energy sources, with differing focus areas. The subset of goals with specific associated actions or metrics is presented below.

Western Australia

The Western Australian Renewable Hydrogen Strategy (2021) specifically highlights as goals for 2030 the provision of a renewable hydrogen blend in the state's gas network, wide uptake of renewable hydrogen for mining haulage vehicles and regional transportation, and a market share of global hydrogen exports comparable to that achieved for liquefied natural gas (LNG).[115]

New South Wales

The New South Wales (NSW) Hydrogen Strategy (2021) has set stretch targets for 2030. Like the WA strategy, it includes goals on providing a hydrogen blend (up to 10% by volume) in gas networks and integrating hydrogen in transportation, in the form of 10,000 hydrogen-powered vehicles, 100 refuelling stations and 20% of the government's heavy vehicle fleet using hydrogen. It also outlines specific targets for production: 700 MW of installed electrolyser capacity, 110,000 tonnes per annum (tpa) production capacity, and a price below $2.8 per kilogram.[116]

A suite of programs and investment initiatives have also been announced by each State and Territory, aligned to their own priorities and strategic approach to a hydrogen industry. An overview of these can be found in the 2024 National Hydrogen Strategy.[117]

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[114] DCCEEW (2024) National Hydrogen Strategy 2024. Department of Climate Change, Energy, the Environment and Water, Canberra. 91–92. <https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf> (accessed 13 September 2024).

[115] Government of Western Australia (2021) Western Australian Renewable Hydrogen Strategy. 18. Department of Jobs, Tourism, Science and Innovation. <https://www.wa.gov.au/system/files/2021-01/WA_Renewable_Hydrogen_Strategy_2021_Update.pdf>.

[116] State of New South Wales (2021) NSW Hydrogen Strategy. 40. Department of Planning, Industry and Environment. <https://www.energy.nsw.gov.au/sites/default/files/2022-08/2021_10_NSW_HydrogenStrategy.pdf>.

[117] DCCEEW (2024) National Hydrogen Strategy 2024. Department of Climate Change, Energy, the Environment and Water, Canberra. 18–33. <https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf> (accessed 13 September 2024).

5.3.2 Government programs

National Reconstruction Fund

The NRF is a $15 billion investment fund established by the Australian Government to facilitate increased flow of finance into the Australian economy to diversify and transform Australian industry. The NRF Corporation (NRFC) is a Specialist Investment Vehicle delivering the NRF as an independent financier, providing finance to drive investments in seven Government identified priority areas of the Australian economy as set out in the *National Reconstruction Fund Corporation (Priority Areas) Declaration 2023*. The NRFC is targeting a funding level over the medium to long term of up to $3 billion for renewables and low emission technologies. This priority area includes opportunities such as manufacturing components of wind turbines, production of batteries and solar panels, and hydrogen electrolysers.[118]

Future Made in Australia

Future Made in Australia is a $22.7 billion package proposed in 2024 to support industry activity and unlock private investment in priority sectors within two streams:

Stream One – Net Zero Transformation

Covers production of green metals, low carbon liquid fuels, and renewable hydrogen. It provides a 10-year Hydrogen Production Tax Incentive of $2 per kg for renewable hydrogen production projects reaching final investment decision by 2030.

Stream Two – Economic Resilience and Security

Covers critical minerals processing and clean energy manufacturing, committing dedicated support for solar and battery programs.[119]

The Future Made in Australia package also includes a $1.7 billion innovation fund. Administered by ARENA, this fund is meant to support the development, translation, and commercialisation of technologies across the two streams.[120]

Net Zero Manufacturing Initiative

Launched in 2024 by the NSW government, this initiative includes $275 million in funding to be distributed across three segments of the overall clean technology development cycle: Clean Technology Innovation (up to $25 million), Low Carbon Product Manufacturing (up to $100 million) and Renewable Manufacturing (up to $150 million). The latter stream focusses on components for renewable energy, specifically including hydrogen electrolysers.[121]

Hydrogen Headstart

Federal Government support for Australia's hydrogen ecosystem is complemented by Hydrogen Headstart, a $4 billion program to advance commercial-scale hydrogen production projects and market uptake. Successful applicants producing hydrogen, ammonia or methanol with renewable energy receive a production credit that covers the difference between production cost and market price. The program's first round was announced in 2023, with a final selection expected by the end of 2024.[122]

Research and Development Tax Incentive

The Research and Development (R&D) Tax Incentive offers tax offsets for eligible R&D expenditure over $AUD 20,000 in the aim of stimulating Australian investment in R&D.[123]

Reducing the cost of R&D could stimulate greater private investment in core and supporting research activities for hydrogen electrolyser manufacturing, encouraging larger companies to pilot electrolysis solutions and Small Medium Enterprises (SMEs) to enter the market.

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[118] Minister for Industry and Science (2023) $15bn National Reconstruction Fund open for business. Media Releases. <https://www.minister.industry.gov.au/ministers/husic/media-releases/15bn-national-reconstruction-fund-open-business> (accessed 12 August 2024); National Reconstruction Fund Corporation (2023) Renewables and low emission technologies. <https://www.nrf.gov.au/what-we-do/our-priority-areas/renewables-and-low-emission-technologies> (accessed 6 August 2024); Australian Government (2022) National Reconstruction Fund: diversifying and transforming Australia's industry and economy. Department of Industry, Science and Resources. <https://www.industry.gov.au/news/national-reconstruction-fund-diversifying-and-transforming-australias-industry-and-economy> (accessed 12 August 2024).

[119] Australian Government (2024) Future Made in Australia National Interest Framework: Supporting paper. 15. Australian Treasury, Canberra. <https://treasury.gov.au/sites/default/files/2024-05/p2024-526942-fmia-nif.pdf>; Australian Government (2024) Hydrogen Production and Critical Minerals Tax Incentives. Australian Taxation Office. <https://www.ato.gov.au/about-ato/new-legislation/in-detail/businesses/hydrogen-production-and-critical-minerals-tax-incentives> (accessed 6 August 2024); Australian Government (2024) Budget 2024–2025. <https://budget.gov.au/content/03-future-made.htm> (accessed 12 August 2024); Bathgate B (2024) New industrial policy: a Future Made in Australia. <https://www.aph.gov.au/About_Parliament/Parliamentary_departments/Parliamentary_Library/Budget/reviews/2024-25/NewIndustryPolicy> (accessed 12 August 2024).

[120] ARENA (2024) ARENA Corporate Plan 2024–25 to 2027-28. Australian Renewable Energy Agency. 8. <https://arena.gov.au/assets/2024/08/ARENA-Corporate-Plan-2024-FIN.pdf> (accessed 30 September 2024).

[121] NSW Government (2024) Net Zero Manufacturing Initiative. Programs, grants and schemes. <https://www.energy.nsw.gov.au/business-and-industry/programs-grants-and-schemes/net-zero-manufacturing> (accessed 13 September 2024).

[122] Australian Government (2024) Hydrogen Headstart program. Department of Climate Change, Energy, the Environment and Water. <https://www.dcceew.gov.au/energy/hydrogen/hydrogen-headstart-program> (accessed 6 August 2024); ARENA (2024) Six shortlisted for $ 2 billion Hydrogen Headstart funding. <https://arena.gov.au/news/six-shortlisted-for-2-billion-hydrogen-headstart-funding/> (accessed 12 August 2024).

[123] Department of Industry Science and Resources, <https://www.industry.gov.au/science-technology-and-innovation/industry-innovation/research-and-development-tax-incentive> (accessed 11 September 2024).

5.4 HEM landscape globally

Today, the main electrolyser manufacturers by nominal capacity mostly reflect the geographic distribution of capacity across China, the United States and Europe (Table 14).

Table 14. Top hydrogen electrolyser manufacturers by nominal capacity as of mid-2024, with their headquarter country.[124]

Ranking	Company	Country (HQ)	Nominal capacity (MW)	Context
1	**Sungrow**	**China**	3,100	Sungrow's primary focus is on large scale production of photovoltaic inverters and systems for energy storage. They also have equipment and digital platform solutions for EV charging, wind energy and hydrogen production (including both alkaline and PEM systems).[125]
2	**Guofuhee**	**China**	3,000	Guofuhee produces equipment for the entire hydrogen supply chain, including electrolysers (both alkaline and PEM); liquefaction units, compressors and tanks for transportation; and vehicular storage and refuelling systems.[126]
3	**LONGi**	**China**	2,500	LONGi specialises in the solar photovoltaic supply chain, including silicon wafer production and panel manufacturing. The company established a subsidiary for hydrogen technology in 2021, offering alkaline electrolyser systems.[127]
4	**Cummins**	**United States**	2,250	Cummins manufactures equipment and components for power systems, across multiple energy sources. Its Accelera division focusses on the zero-emissions segment, including electrolysers (alkaline and PEM) and fuel cells, targeting hydrogen applications in heavy haulage for mining and road, maritime, and rail transportation.[128]
5	**John Cockerill**	**Belgium**	2,200	The John Cockerill Group is active in manufacturing across the energy, defence, industrial production, and environmental solutions sectors. The company produces alkaline electrolyser systems and hydrogen refuelling stations and can deliver fully integrated production facilities.[129]
6	**Bloom Energy**	**United States**	2,000	Bloom Energy focusses primarily on solid oxide fuel cells compatible with natural gas, biogas and hydrogen for use in microgrids and maritime transportation. The company also manufactures solid oxide electrolysers that leverage its technology and systems.[130]
7	**Fortescue Future Industries**	**Australia**	2,000	Fortescue is a large scale iron ore producer and holds additional interest in the metals required for renewable energy technologies. The company is active in electrolyser manufacturing and in the integration of decarbonisation technologies for heavy hauling, rail and maritime transportation (including battery, hydrogen, and ammonia systems).[131]
8	**Ohmium**	**United States**	2,000	Ohmium is dedicated to large scale manufacturing of modular PEM electrolysers, leveraging the supply chain and innovation ecosystem around its production facility in India.[132]
9	**Hygreen Energy**	**China**	2,000	Hygreen Energy produces alkaline and PEM electrolyser systems, conducting stack, balance of plant, and system manufacturing in-house. The company is also developing AEM electrolyser systems.[133]

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[124] Wood Mackenzie Hydrogen Lens (August 2024). Search conducted for hydrogen electrolyser vendors with operational status as of August 2024.

[125] Sungrow (2023) About Sungrow. <https://en.sungrowpower.com/AboutSungrow/1/introduction> (accessed 12 August 2024).

[126] GF Hydrogen Europe GmbH (2023) Complete Solutions Range. <https://www.gfh2.energy/> (accessed 12 August 2024).

[127] LONGi (2024) LONGi Hydrogen. <https://www.longi.com/us/products/hydrogen/> (accessed 12 August 2024); LONGi (2024) About us. <https://www.longi.com/us/development/> (accessed 12 August 2024).

[128] Cummins (2023) Accelera marks start of operations for electrolyzer production in Fridley, Minnesota. <https://investor.cummins.com/news/detail/610/accelera-marks-start-of-operations-for-electrolyzer> (accessed 12 August 2024); Accelera (2024) Applications our technologies support. <https://www.accelerazero.com/> (accessed 12 August 2024).

[129] John Cockerill (2024) 200 years of history. <https://johncockerill.com/en/group/200-years-of-history/> (accessed 12 August 2024); John Cockerill (2024) Products. <https://hydrogen.johncockerill.com/en/products/> (accessed 12 August 2024); John Cockerill (2024) Electrolysers. <https://hydrogen.johncockerill.com/en/products/electrolysers/> (accessed 12 August 2024).

[130] Bloom Energy (2024) How our platform works. <https://www.bloomenergy.com/technology/> (accessed 12 August 2024); Bloom Energy (2024) Applications – Electrolyzers. <https://www.bloomenergy.com/technology/> (accessed 12 August 2024).

[131] Fortescue (n.d.) About Fortescue. <https://fortescue.com/about-fortescue> (accessed 12 August 2024); Fortescue (n.d.) What we do – Green Energy Tech. <https://fortescue.com/what-we-do/green-energy-research> (accessed 12 August 2024); Fortescue (n.d.) What we do - Fortescue Hydrogen Systems. <https://fortescue.com/what-we-do/fortescue-hydrogen-systems> (accessed 12 August 2024).

[132] Ohmium (2024) Our products. <https://www.ohmium.com/our-product> (accessed 12 August 2024); Ohmium (2024) Manufacturing - Gigafactory. <https://www.ohmium.com/gigafactory> (accessed 12 August).

[133] Hygreen Energy (2024) Hygreen Electrolysis – Our Technology. <https://www.hygreenenergy.com/about/ourtechnology/> (accessed 12 August 2024); Hygreen Energy (2024) About Hygreen – Our Manufacturing. <https://www.hygreenenergy.com/about/ourtechnology/> (accessed 12 August 2024).

5.5 Technical targets for electrolyser R&D

Publicly stated targets for each electrolyser type and key R&D area are presented in Table 15 for illustrative purposes. There are differences in the boundary conditions used by each institution to develop their targets, so direct comparisons may be inadequate. Please refer to the original sources for additional context, definitions and disclaimers.

Table 15. Technical targets relevant to future electrolyser R&D, as publicly presented by the US Department of Energy, the EU Clean Hydrogen JU SRIA, and IRENA.

	United States Department of Energy technical targets (2031)[134]		
	Electrical efficiency at the system level (kWh/kg H2)	**Average stack degradation rate (%/1000 h)**	**Uninstalled Capital cost at system level (USD/kW)**
Alkaline	48	0.13	150
PEM	46	0.13	150
Solid oxide	35 (with an additional 7 from heat demand)	0.12	200
AEM	NA	NA	NA

	EU Clean Hydrogen Joint Undertaking Strategic Research and Innovation Agenda (2021–2027) targets (2030)[135]		
	Electrical efficiency at the system level (kWh/kg H2)	**Average stack degradation rate (%/1000 h)**	**Installed Capital cost (EUR/kW)**
Alkaline	48	0.1	400
PEM	48	0.12	500
Solid oxide	37 (with an additional 8 from heat demand)	0.5 (under thermo-neutral conditions, percent loss of production rate at constant efficiency)	520
AEM	48	0.5	300

	IRENA future KPIs (2050)[136]		
	Electrical efficiency at the system level (kWh/kg H2)	**Average stack degradation rate (%/1000 h)**	**Capital cost at the system level (USD/kW)**
Alkaline	< 45	NA	< 200
PEM	< 45	NA	< 200
Solid oxide	< 40	NA	< 300
AEM	< 45	NA	< 200

Meeting these targets will require improvements and innovation across the overall electrolysis system: from individual components and manufacturing processes to cell stacks and balance of plant. Figure 17 aggregates areas for improvement from the different electrolyser types into a set of R&D priorities, which can support the technical targets outlined above. Improving safety and reducing environmental impact is added as another relevant consideration for HEM and for electrolyser use.

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[134] DoE Hydrogen and Fuel Cell Technologies Office (n.d.) Technical Targets for Liquid Alkaline Electrolysis. U.S. Department of Energy. <https://www.energy.gov/eere/fuelcells/technical-targets-liquid-alkaline-electrolysis> (accessed 1 August 2024); DoE Hydrogen and Fuel Cell Technologies Office (n.d.) Technical Targets for Proton Exchange Membrane Electrolysis. U.S. Department of Energy. <https://www.energy.gov/eere/fuelcells/technical-targets-proton-exchange-membrane-electrolysis> (accessed 1 August 2024); DoE Hydrogen and Fuel Cell Technologies Office (n.d.) Technical Targets for High Temperature Electrolysis. U.S. Department of Energy. <https://www.energy.gov/eere/fuelcells/technical-targets-high-temperature-electrolysis> (accessed 1 August 2024).

[135] Clean Hydrogen Partnership (2022) Strategic Research and Innovation Agenda 2021–2027. Annex to GB decision no. CleanHydrogen-GB-2022-02. 152–155. <https://www.clean-hydrogen.europa.eu/system/files/2022-02/Clean%20Hydrogen%20JU%20SRIA%20-%20approved%20by%20GB%20-%20clean%20for%20publication%20%28ID%2013246486%29.pdf> (accessed 26 September 2024)

[136] IRENA (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5°C Climate Goal. 65–66. International Renewable Energy Agency, Abu Dhabi. <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf>.

Catalyst layers 🔵 🟠 🟣

- Optimising or reducing the use of expensive metals (e.g., platinum group elements, rare earth elements) in catalyst layers.
- Developing novel base-metal alloys with enhanced catalytic activity, increased resistance to lower quality feed water and greater overall durability under harsh operational conditions (acidic or alkaline, high temperature, high pressure, frequent ramping in electrical current).
- Improving catalyst ink preparation and coating techniques for greater uniformity, dispersion, surface area, and efficiency in the formation of catalyst layers at scale.

Electrolyte 🔵 🟣 🟢

- Developing non-PFAS membranes with high mechanical strength, greater durability under operating conditions (including higher temperatures), enhanced electrical conductivity and lower resistance to ion movement (H+, OH-, or O2- depending on the case) .
- Optimising membrane materials and designs to minimise hydrogen crossover at reduced membrane thickness, low current densities, and high pressure.

Porous transport layers 🔵 🟠 🟣

- Developing coated base metal layers with increased durability, electrical conductivity, optimised gas-liquid flow, and minimal resistance at the interface with the catalyst layer.
- Trialling fabrication approaches that increase control over PTL structure, increase the efficient use of coating materials, and reduce overall component cost (particularly when expensive metals are still required).

Cell stack 🟠 🟣

- Leveraging improvements at the individual component level to increase overall cell and stack size, which reduce overall cost via economies of scale and reduced system footprint.
- Minimising contamination of key cell components and products resulting from degradation of peripheral stack components (e.g., seals, end plates).
- Developing processes that streamline or aggregate individual fabrication and assembly processes to minimise cost and increase stack quality (e.g., sintering and hydrogen reduction in SOE).

Balance of plant 🔵 🟠 🟢

- Assessing the general design and integration of balance of plant equipment to increase energy efficiency at the system level, reduce footprint, optimise utilisation at larger scales, and reduce capital costs.
- Improving the performance of key equipment (e.g., compressors, cooling units, desalination plants) to increase their individual operational efficiency.
- In the case of desalination plants specifically, additional R&D will be required to facilitate the safe disposal of brine and avoid its environmental impacts.

Utilisation of byproducts and recycling key materials 🟢

- Designing systems that leverage operational byproducts to support balance of plant processes and increase their energy efficiency (e.g., waste heat diverted to water treatment equipment to support distillation).
- Developing stack designs that consider end-of-life disposal and recycling, to facilitate the downstream recovery of valuable materials and minimisation of environmental impacts.
- Advancing recycling processes suitable to the different electrolyser types. Where possible, integrating with the processes used for other renewable energy technologies, in support of more efficient and economically viable recycling operations.

🔵 **Increase energy efficiency**

🟠 **Reduce capital and operational costs**

🟣 **Increase stack durability**

🟢 **Improve safety and reduce environmental impact**

Figure 17. R&D priorities and their relevance to key technical targets.[137]

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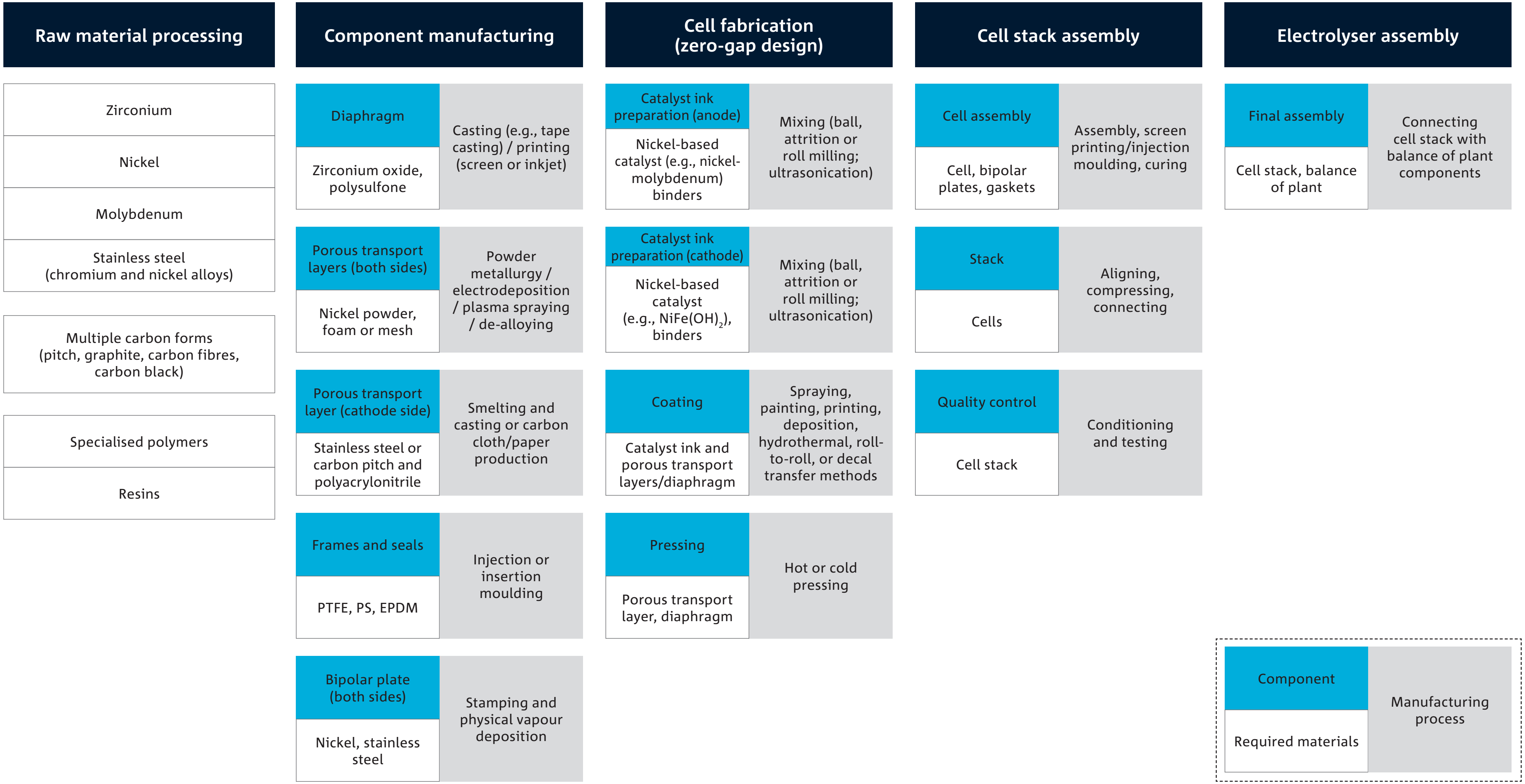
[137] IRENA (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5°C Climate Goal. 32, 57–63. International Renewable Energy Agency, Abu Dhabi; Horizon Europe (2022) HORIZON-JTI-CLEANH2-2022-01-05 – Scaling up of cells and stacks for large electrolysers. <https://www.horizon-europe.gouv.fr/scaling-cells-and-stacks-large-electrolysers-29636> (accessed 15 October 2024).

5.6 Materials, components, and manufacturing processes required for alkaline, PEM, solid oxide and AEM electrolysers



Raw material processing

- Zirconium
- Nickel
- Molybdenum
- Stainless steel (chromium and nickel alloys)
- Multiple carbon forms (pitch, graphite, carbon fibres, carbon black)
- Specialised polymers
- Resins

Component manufacturing

Diaphragm	Zirconium oxide, polysulfone	Casting (e.g., tape casting) / printing (screen or inkjet)
Porous transport layers (both sides)	Nickel powder, foam or mesh	Powder metallurgy / electrodeposition / plasma spraying / de-alloying
Porous transport layer (cathode side)	Stainless steel or carbon pitch and polyacrylonitrile	Smelting and casting or carbon cloth/paper production
Frames and seals	PTFE, PS, EPDM	Injection or insertion moulding
Bipolar plate (both sides)	Nickel, stainless steel	Stamping and physical vapour deposition

Cell fabrication (zero-gap design)

Catalyst ink preparation (anode)	Nickel-based catalyst (e.g., nickel-molybdenum) binders	Mixing (ball, attrition or roll milling; ultrasonication)
Catalyst ink preparation (cathode)	Nickel-based catalyst (e.g., $NiFe(OH)_2$), binders	Mixing (ball, attrition or roll milling; ultrasonication)
Coating	Catalyst ink and porous transport layers/diaphragm	Spraying, painting, printing, deposition, hydrothermal, roll-to-roll, or decal transfer methods
Pressing	Porous transport layer, diaphragm	Hot or cold pressing

Cell stack assembly

Cell assembly	Cell, bipolar plates, gaskets	Assembly, screen printing/injection moulding, curing
Stack	Cells	Aligning, compressing, connecting
Quality control	Cell stack	Conditioning and testing

Electrolyser assembly

Final assembly	Cell stack, balance of plant	Connecting cell stack with balance of plant components

Component	Manufacturing process
Required materials	

Figure 18. Materials, components and manufacturing processes for alkaline electrolyser production[138]

PTFE: polytetrafluoroethylene; PS: polystyrene; EPDM: ethylene propylene diene terpolymer

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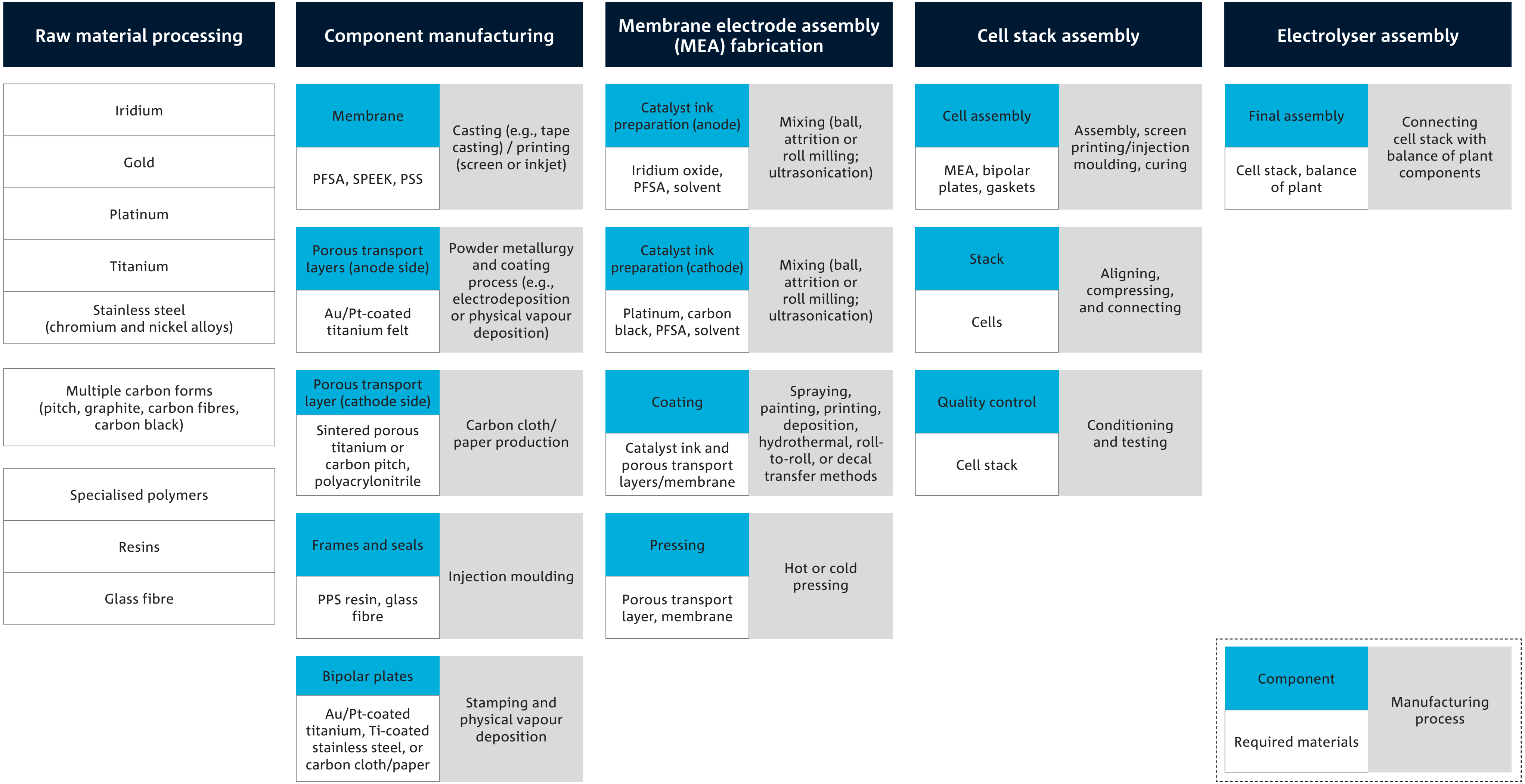
[138] James B, Huya-Kouadio J, Acevedo Y, McNamara K (2021) Liquid Alkaline Electrolysis Techno-Economic Review. Strategic Analysis. <https://www.energy.gov/sites/default/files/2022-02/7-TEA-Liquid%20Alkaline%20Workshop.pdf> (accessed 4 August 2024); Ruth M, Mayyas A, Mann M (2017) Manufacturing Competitiveness Analysis for PEM and Alkaline Water Electrolysis Systems. National Renewable Energy Laboratory, Fuel Cell Seminar and Energy Expo. <https://www.nrel.gov/docs/fy19osti/70380.pdf> (accessed 4 August 2024).



Raw material processing

- Iridium
- Gold
- Platinum
- Titanium
- Stainless steel (chromium and nickel alloys)

- Multiple carbon forms (pitch, graphite, carbon fibres, carbon black)

- Specialised polymers
- Resins
- Glass fibre

Component manufacturing

Membrane	PFSA, SPEEK, PSS	Casting (e.g., tape casting) / printing (screen or inkjet)
Porous transport layers (anode side)	Au/Pt-coated titanium felt	Powder metallurgy and coating process (e.g., electrodeposition or physical vapour deposition)
Porous transport layer (cathode side)	Sintered porous titanium or carbon pitch, polyacrylonitrile	Carbon cloth/ paper production
Frames and seals	PPS resin, glass fibre	Injection moulding
Bipolar plates	Au/Pt-coated titanium, Ti-coated stainless steel, or carbon cloth/paper	Stamping and physical vapour deposition

Membrane electrode assembly (MEA) fabrication

Catalyst ink preparation (anode)	Iridium oxide, PFSA, solvent	Mixing (ball, attrition or roll milling; ultrasonication)
Catalyst ink preparation (cathode)	Platinum, carbon black, PFSA, solvent	Mixing (ball, attrition or roll milling; ultrasonication)
Coating	Catalyst ink and porous transport layers/membrane	Spraying, painting, printing, deposition, hydrothermal, roll-to-roll, or decal transfer methods
Pressing	Porous transport layer, membrane	Hot or cold pressing

Cell stack assembly

Cell assembly	MEA, bipolar plates, gaskets	Assembly, screen printing/injection moulding, curing
Stack	Cells	Aligning, compressing, and connecting
Quality control	Cell stack	Conditioning and testing

Electrolyser assembly

Final assembly	Cell stack, balance of plant	Connecting cell stack with balance of plant components

Component	Manufacturing process
Required materials	

Figure 19. Materials, components and manufacturing processes for PEM electrolyser production[139]

MEA: Membrane electrode assembly; PFSA: perfluorosulfonic acid, SPEEK: sulfonated poly(ether ether ketone); PSS: polystyrene sulfonate; PPS: polyphenylene sulfide

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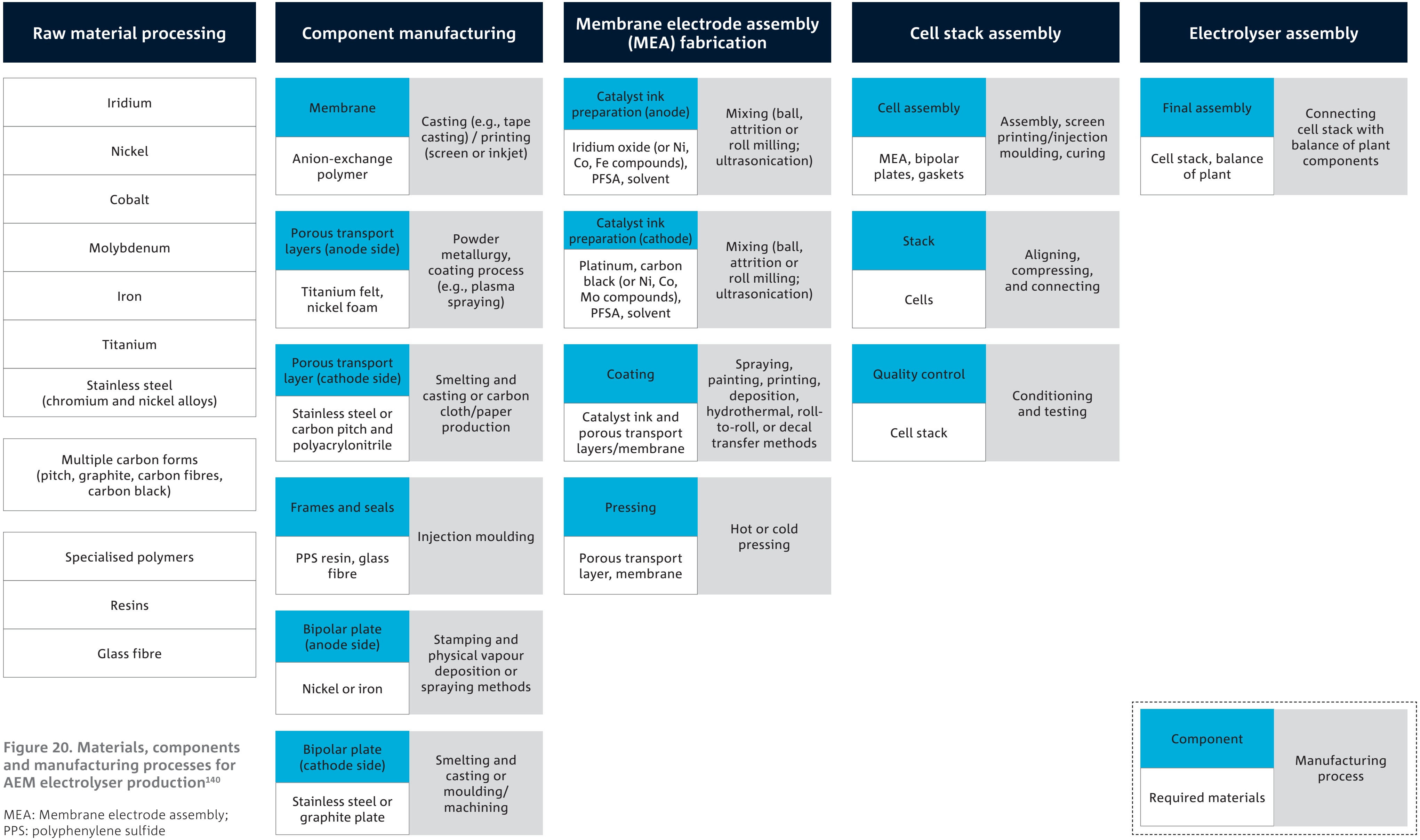
[139] Lagadec MF, Grimaud A (2020) Water electrolysers with closed and open electrochemical systems. Nature Materials 19, 1140; Lin X, Seow JZY, Xu ZJ (2023) A brief introduction of electrode fabrication for proton exchange membrane water electrolyzers. Journal of Physics: Energy 5, 034003; Mayyas A, Ruth M, Pivovar B, Bender G, Wipke K (2018) Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers. National Renewable Energy Laboratory, Golden, CO. <https://www.nrel.gov/docs/fy19osti/72740.pdf>; Umicore (2024) Pioneering platinum coating of Porous Transport Layers (PTL) and Bipolar Plates (BPL) made of titanium. News. <https://mds.umicore.com/en/electroplating/news-media/news/pioneering-platinum-coating-of-porous-transport-layers-ptl-and-bipolar-plates-bpl-made-of-titanium/> (accessed 14 October 2024); Yu HN, Lim JW, Kim MK, Lee DG (2012) Plasma treatment of the carbon fiber bipolar plate for PEM fuel cell. Composite Structures 94, 1911.



Raw material processing

- Iridium
- Nickel
- Cobalt
- Molybdenum
- Iron
- Titanium
- Stainless steel (chromium and nickel alloys)

- Multiple carbon forms (pitch, graphite, carbon fibres, carbon black)

- Specialised polymers
- Resins
- Glass fibre

Component manufacturing

Membrane	Anion-exchange polymer	Casting (e.g., tape casting) / printing (screen or inkjet)
Porous transport layers (anode side)	Titanium felt, nickel foam	Powder metallurgy, coating process (e.g., plasma spraying)
Porous transport layer (cathode side)	Stainless steel or carbon pitch and polyacrylonitrile	Smelting and casting or carbon cloth/paper production
Frames and seals	PPS resin, glass fibre	Injection moulding
Bipolar plate (anode side)	Nickel or iron	Stamping and physical vapour deposition or spraying methods
Bipolar plate (cathode side)	Stainless steel or graphite plate	Smelting and casting or moulding/ machining

Membrane electrode assembly (MEA) fabrication

Catalyst ink preparation (anode)	Iridium oxide (or Ni, Co, Fe compounds), PFSA, solvent	Mixing (ball, attrition or roll milling; ultrasonication)
Catalyst ink preparation (cathode)	Platinum, carbon black (or Ni, Co, Mo compounds), PFSA, solvent	Mixing (ball, attrition or roll milling; ultrasonication)
Coating	Catalyst ink and porous transport layers/membrane	Spraying, painting, printing, deposition, hydrothermal, roll-to-roll, or decal transfer methods
Pressing	Porous transport layer, membrane	Hot or cold pressing

Cell stack assembly

Cell assembly	MEA, bipolar plates, gaskets	Assembly, screen printing/injection moulding, curing
Stack	Cells	Aligning, compressing, and connecting
Quality control	Cell stack	Conditioning and testing

Electrolyser assembly

Final assembly	Cell stack, balance of plant	Connecting cell stack with balance of plant components

Component Required materials	Manufacturing process

Figure 20. Materials, components and manufacturing processes for AEM electrolyser production[140]

MEA: Membrane electrode assembly;
PPS: polyphenylene sulfide

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[140] Lim A, Kim H, Henkensmeier D, Jong Yoo S, Young Kim J, Young Lee S, Sung Y-E, Jang JH, Park HS (2019) A study on electrode fabrication and operation variables affecting the performance of anion exchange membrane water electrolysis. Journal of Industrial and Engineering Chemistry 76, 410; López-Fernández E, Sacedón CG, Gil-Rostra J, Yubero F, González-Elipe AR, de Lucas-Consuegra A (2021) Recent Advances in Alkaline Exchange Membrane Water Electrolysis and Electrode Manufacturing. Molecules 26, 6326; Raja Sulaiman RR, Wong WY, Loh KS (2022) Recent developments on transition metal–based electrocatalysts for application in anion exchange membrane water electrolysis. International Journal of Energy Research 46, 2241; Tricker AW, Lee JK, Shin JR, Danilovic N, Weber AZ, Peng X (2023) Design and operating principles for high-performing anion exchange membrane water electrolyzers. Journal of Power Sources 567, 232967; Xu Q, Zhang L, Zhang J, Wang J, Hu Y, Jiang H, Li C (2022) Anion Exchange Membrane Water Electrolyzer: Electrode Design, Lab-Scaled Testing System and Performance Evaluation. EnergyChem 4, 100087.

Raw material processing

- Lanthanum
- Strontium
- Cobalt
- Iron
- Manganese
- Nickel
- Yttrium
- Zirconium
- Gadolinium
- Cerium

- Stainless steel (chromium and nickel alloys)
- Perovskite material

- Specialised polymers
- Resins
- Borosilicate glass (boron and silicon)

Cell fabrication (planar design)

Catalyst ink preparation (anode)	LSCF, LSM or LSM-YSZ, binder and additives	Mixing (ball, attrition or roll milling; ultrasonication)
Catalyst ink preparation (cathode)	Ni-YSZ, binder and additives	Mixing (ball, attrition or roll milling; ultrasonication)
Electrolyte ink preparation	YSZ, binder and additives	Mixing (ball, attrition or roll milling; ultrasonication)
Intermediate layer ink preparation (optional)	GDC or YDC, binder and additives	Mixing (ball, attrition or roll milling; ultrasonication)
Support layer formation	Cathode catalyst or electrolyte ink	Tape casting and sintering
Thinner layer formation	Anode catalyst, intermediates, and cathode/electrolyte catalyst ink	Screen printing / co-casting / tape casting with lamination, drying and sintering

Cell stack assembly

Interconnection manufacturing	Stainless steel, cell	Stamping and etching
Perovskite layer manufacturing	Perovskite material, binders	Mixing, spraying, and sintering
Mounting and assembly	Cells, interconnector layer, glass sealant	Assembly, welding, and sealing
Quality control	Cell stack	Conditioning (compression, and hydrogen reduction) and testing

Electrolyser assembly

Hot-box assembly	Cell stack, balance of plant	Connecting cell stack with balance of stack and heat management components in an insulated unit
Final assembly	Hot-boxes, balance of plant	Connecting with other hot-boxes and balance of plant components

Figure 21. Materials, components and manufacturing processes for solid oxide electrolyser production[141]

LSCF: Lanthanum strontium cobalt ferrite; LSM: Lanthanum strontium manganite; Ni-YSZ: Nickel oxide-Yttria-stabilised zirconia; YSM: Yttria-stabilised zirconia; LSM-YSZ: Composite of LSM and YSZ; GDC: Gadolinium-doped cerium oxide; YDC: Yttrium-doped cerium oxide

Component	Manufacturing process
Required materials	

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[141] Anghilante R, Colomar D, Brisse A, Marrony M (2018) Bottom-up cost evaluation of SOEC systems in the range of 10–100 MW. International Journal of Hydrogen Energy 43, 20309; Ghezel-Ayagh H (2023) Solid Oxide Electrolysis System Demonstration DE-EE0009290. U.S. Department of Energy Hydrogen Program 2023 Annual Merit Review and Peer Evaluation Meeting. <https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review23/ta039_ghezel-ayagh_2023_o-pdf.pdf> (accessed 4 August 2024); Li P, Chen X, Sun Y, Chen T, Zhang B, Li F, Zhou J, Wang S (2023) Fabrication of anode supported solid oxide electrolysis cell with the co-tape casting technique and study on co-electrolysis characteristics. Journal of Power Sources 569, 232912; Nechache A, Hody S (2021) Alternative and innovative solid oxide electrolysis cell materials: A short review. Renewable and Sustainable Energy Reviews 149, 111322; van 't Noordende H, van Berkel F, Stodolny M (2023) Next Level Solid Oxide Electrolysis. Institute for Sustainable Process Technology, Netherlands. <https://ispt.eu/media/20230508-FINAL-SOE-public-report-ISPT.pdf>; Rachau M (2023) Production of Solid Oxide Fuel Cell and Electrolyzer Stacks using HORIBA FuelCon's Sintering Equipment. Feature Article – HORIBA. <https://static.horiba.com/fileadmin/Horiba/Company/About_HORIBA/Readout/R57E/R57E_18_Feature_Article_Mathias_RACHAU.pdf> (accessed 11 October 2024); Ureña V, Ruiz K, Ciaurriz P, Judez X, Aguado M, Garbayo I (2023) Solid Oxide Electrolysis Cells Fabrication: From Single Cells to Batch Production. ECS Transactions 111, 295.

5.7 Bibliometric analysis

Bibliometrics can serve as general indicators of a country's research activity and comparative impact. Table 16 below summarises the results of an analysis for Australia in electrochemistry, the broad category covering electrolysis (alongside multiple other industry-relevant processes), and in a combination of research areas representing materials science.[142]

Table 16. Document counts and citation impact indicators for Australia in the electrochemistry research area

	Web of Science Documents	% Baseline for All Items (Cites)	% Documents Cited	% Documents in Top 1%	Category Normalised Citation Impact	Impact Relative to World
Electrochemistry						
Absolute value	6279	2.41	93.12	2.15	1.32	1.35
Rank	17	14	3	3	2	2
Materials science						
Absolute value	78074	3.49	89.86	2.83	1.49	1.61
Rank	14	10	4	1	2	3

As with other research areas, the Australian publication count in electrochemistry and materials science ranks the country in the top 20 globally. However, publication counts partially reflect population size and research funding in absolute terms, rather than the influence or impact that a country's research is having.

The citation impact of Australian publications, as measured by multiple comparative indicators, ranks the country in the top 3 among the 20 countries with the largest publication counts.

Citation impact metrics like category normalised citation impact (CNCI) use one as a reference. Values above one represent a citation ratio above the world average for the area. See Figure 22 for a comparison of CNCI across the top 20 countries by publication output.

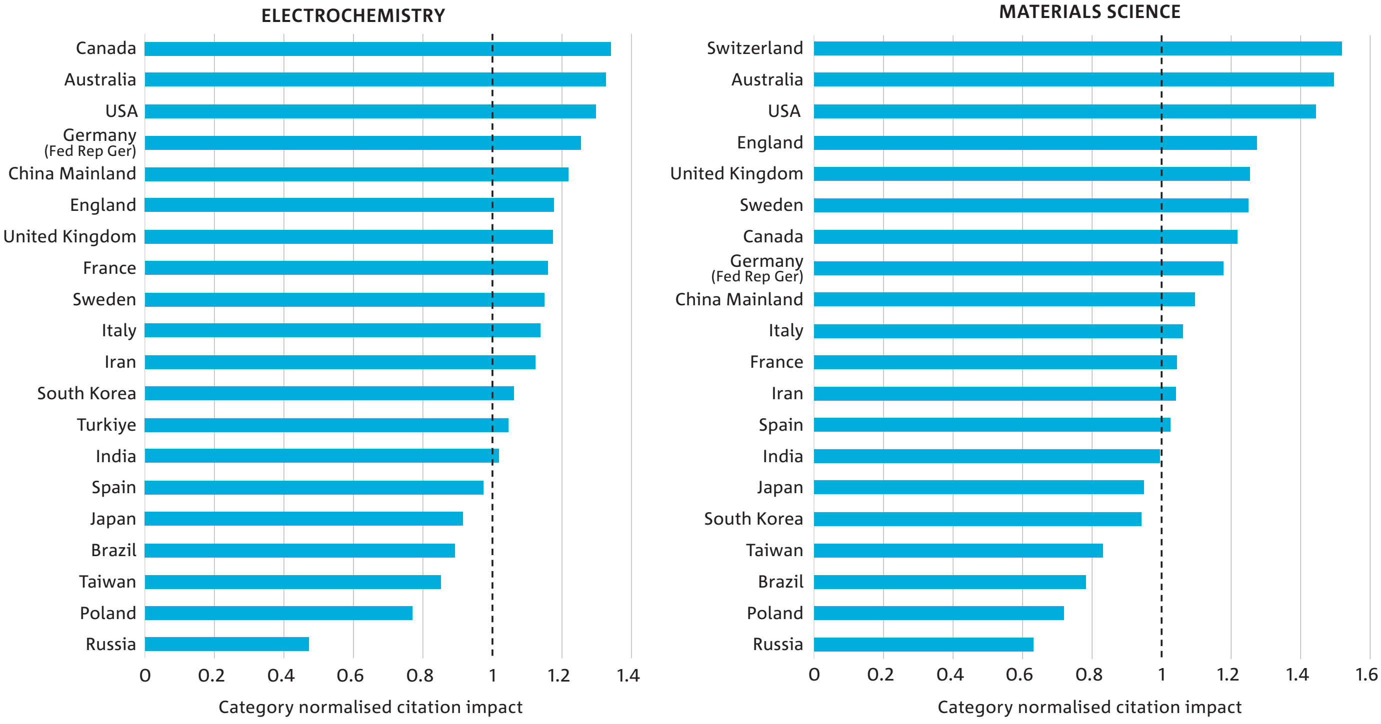

Figure 22. Category normalised citation impact in the electrochemistry and combined materials science research areas, across the top 20 countries by publication output.

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142 The bibliometric analysis by location was conducted using Clarivate's InCites platform. It was based on the InCites dataset, covered all available years (1980 – July 31, 2024), and used 'Electrochemistry', and a combination of 'Materials Science, Composites', 'Materials Science, Coatings & Films', 'Materials Science, Ceramics', 'Materials Science, Characterization & Testing', and 'Materials Science, Multidisciplinary' as research areas in the Web of Science schema.

A separate analysis was performed to specifically assess the four electrolyser types included in this report. Key words representing alkaline, proton exchange membrane, solid oxide and anion exchange membrane electrolysers were collected and used as part of a search strategy in Clarivate's Web of Science. The search focussed on titles and abstracts and included articles published between 1980–2023, excluding all other years and document types.

Two separate samples of articles were assessed to estimate the accuracy of the resulting dataset, with a minimum threshold of 70% established for further analysis. A dataset exceeding this threshold was obtained and exported into Clarivate's InCites platform, where it was sorted to obtain the top 20 countries by publication output. The subset of 20 countries was then exported into Excel for further processing, including data for Country name, number of Web of Science Documents, Times Cited, Percentage of Documents in the Top 1%, Category Normalised Citation Impact, and Citations from Patents. See Table 17 for a summary of the methodology and its results.

Table 17. Document counts and citation impact indicators for Australia for a publications dataset related to alkaline, PEM, solid oxide and AEM electrolysers.

Methodology	
WoS Dataset	Web of Science Core Collection
WoS Search strategy	(TI=("proton exchange membrane" OR "proton-exchange membrane" OR "polymer exchange membrane" OR "PEM" OR "PEMWE") OR TI=("alkaline water" OR "alkaline" OR "AWE") OR TI=("solid oxide" OR "solid-oxide" OR "SOEC") OR TI=("anion-exchange" OR "anion-exchange" OR "AEM" OR "AEMWE") OR (AB=("proton exchange membrane" OR "proton-exchange membrane" OR "polymer exchange membrane" OR "PEM" OR "PEMWE") OR AB=("alkaline water" OR "alkaline" OR "AWE") OR AB=("solid oxide" OR "solid-oxide" OR "SOEC") OR AB=("anion-exchange" OR "anion-exchange" OR "AEM" OR "AEMWE"))) AND (TI=("electrolysis" OR "electrolyser" OR "electrolyzer") OR (AB=("electrolysis" OR "electrolyser" OR "electrolyzer"))) AND (TI=("hydrogen") OR (AB=("hydrogen")))
InCites Dataset size	5827
Estimated accuracy of the dataset	82.5%

Results							
	Web of Science Documents	**% Documents Cited**	**% Documents in Top 1%**	**Category Normalised Citation Impact**	**Impact Relative to World**	**Citations From Patents**	**WoS Documents / Citations from Patents**
Absolute value	218	99.08	14.22	4.12	1.80	40	5.45
Rank	9	3	2	2	2	11	12

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csiro.au

For further information
CSIRO Futures
Vivek Srinivasan
Associate Director, CSIRO Futures
+61 3 9545 8057 | +61 477 391 073
vivek.srinivasan@csiro.au

CSIRO Energy
Dr Patrick G. Hartley
Leader, CSIRO Hydrogen Industry Mission
+61 400 101 154
patrick.hartley@csiro.au

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