Opportunities for Queensland businesses in Japan's hydrogen market

TIQ international market report

October 2019

Trade & Investment Queensland AUSTRALIA

Queensland Government

Contents

About Trade and Investment Queensland

Trade and Investment Queensland (TIQ) is the Queensland Government's dedicated global business agency, helping Queensland exporters take their products to overseas markets and promoting Queensland as the perfect place for investment.

With eight offices across the state and 16 offices around the world, TIQ has one of the largest and most dynamic networks of any Queensland Government agency.

TIQ helps Queensland companies take advantage of export opportunities in markets around the world, and works to attract the world's best investors and entrepreneurs to Queensland.

Executive summary

Recent surveys of global activity and economic modelling suggest that Queensland has an unparalleled opportunity to establish a viable and sustainable export economy for 'green hydrogen'. Green hydrogen is produced using renewable energy from a range of natural materials such as water or biomass.

The global market for hydrogen is projected to expand rapidly from an existing base of $150 billion in sales to a trillion dollar economy by 2050, due predominantly to the drive to decarbonise industries such as transportation, electricity generation and chemicals. The bulk of the future hydrogen market will be for green hydrogen produced by low-cost producers in regions with a high penetration of renewable energy.

Queensland already has a high penetration of renewable energy within its network. The state's solar energy production has significantly increased as a result of solar farm installations (~10x), and will continue to increase, with a pipeline of renewable energy projects amounting to more than 15GW capacity.

Queensland's key export markets for green hydrogen are countries with high population densities in the northern hemisphere, where low-carbon, low-emissions transport and energy are key challenges. Countries rapidly converting to a hydrogen economy include Japan, China and Korea, with electric vehicles – cars, trucks and buses – leading the way in consumer take-up. Hydrogen for energy generation is likely to become viable in these markets after 2030.

Modelled projections for Australian penetration of Northern Asia markets for green hydrogen suggest that, by 2030, the value of exports will exceed $1.6 billion and employ more than 2,500 people. With prudent and measured policy decisions, Queensland is well positioned to be a key player in the Australian green hydrogen export market to Japan, Korea, China and other Asian nations. Japan is a market of particular interest, with Japanese industry committed to making Japan the world's first 'hydrogen-based society', and increasing government support and incentives to achieve this goal. Japan and Queensland have also embarked on a number of joint green-hydrogen projects.

With attention to policy levers and to business growth informed by quality research and development, Queensland has an exceptional opportunity to be a leader in the transition to hydrogen-powered economies. A green-hydrogen production sector can not only grow the domestic economy through lowered dependence on fossil fuels, but also build long-term export markets for Queensland. Japan's growing need for sustainable energy, government support for green hydrogen, and demonstrated interest in collaborating with Queensland on hydrogen research present real business opportunities for Queensland's green-hydrogen sector.

Introduction

Queensland is well positioned to rapidly scale up a hydrogen economy utilising existing infrastructure at key ports such as Gladstone, Brisbane and Townsville. The state's abundant renewable energy sources and technical and research capabilities also make it an ideal location for the development of a green-hydrogen sector.

Japan is a country with limited natural energy resources, and meets a significant proportion of its energy demand through imported sources of energy.

The energy industry in Japan, regulated by the Ministry of Economy, Trade and Industry, has announced that the country is ready to move towards a 'hydrogen-based society'. Recent cabinet decisions and legislation have embedded structural and financial incentives to ensure Japan becomes the first country in the world to realise this goal. Japanese institutions and business have also collaborated with Queensland entities on a number of green-hydrogen projects.

Queensland is ideally placed to establish a viable green-hydrogen industry for both domestic and export use. Japan represents a large potential market for Queensland's green-energy companies, and is a potential purchaser for the state's first major exports in this sector.

Hydrogen and its uses

Hydrogen is a flexible energy carrier with wide-ranging uses across all energy sectors.

Lifecycle evaluations show that hydrogen has many benefits as an energy carrier, including reduction of carbon emissions. Hydrogen is carbon-free, and can aid the transition from industries based on fossil fuels to sustainable, lower-carbon industries using electricity from renewable energy technologies.

Hydrogen is one of the world's most abundant elements and one of only a few potential near-zero-emission energy carriers, alongside electricity and advanced biofuels. In nature, hydrogen is usually found combined with other elements to form molecules such as water (H_2O), ammonia (NH_3) and methane (CH_4). Extracting or generating pure hydrogen (H_2) requires energy.

Once in a pure form, hydrogen can be used as a fuel (eg in fuel cells to produce power for vehicles or households). Hydrogen is also a component (or 'feedstock') for many chemical reactions that produce consumer products, including in petrochemical, chemical and heavy industries. Figure 1 shows the primary energy applications and industry sectors in which hydrogen plays a key role.[1]

Hydrogen can be produced from many primary and secondary energy sources, depending on local availability, technical capability and energy inputs. These sources include biomass, water, and fossil fuels such as natural gas and coal. In each of these cases, energy input is required to produce hydrogen. Hydrogen production can range from household-scale to large-scale regional or international facilities[2] as illustrated in Figure 2.

In general, hydrogen-based technologies for large-scale, megawatt electricity storage are best suited to applications that allow hourly to seasonal storage times.[3] However, hydrogen is not limited to network or large-scale electricity storage applications, as demonstrated by the many new products now using hydrogen fuel cells, including forklifts, passenger cars, buses and trucks.

Hydrogen has one of the highest energy-density values per unit mass, at 120–140MJ/kg. This value is approximately three times that of natural gas or LNG.

Because hydrogen contains no carbon, its only exhaust product when used in a fuel cell or burned in a heat engine is water or water vapour. This attribute is driving global interest in hydrogen-based technologies. If pure hydrogen can also be produced using renewable energy, hydrogen fuel will have exceptional potential to reduce greenhouse gas emissions as global population and energy needs increase.

In the first instance, high growth and new applications of hydrogen are likely to be in the transport and electricity industries, predominantly for low-emissions energy uses.[4] Subsequent growth of a hydrogen economy in Australia – for domestic or export uses – is likely to be in the 'feedstock' industries shown in Figure 1.

In Queensland, production facilities for 'renewable hydrogen' are being developed taking into account a range of considerations, including the potential to export to other nations that are planning to decarbonise their industries.

Figure 1: Primary applications of hydrogen as an energy carrier or feedstock for major industries.

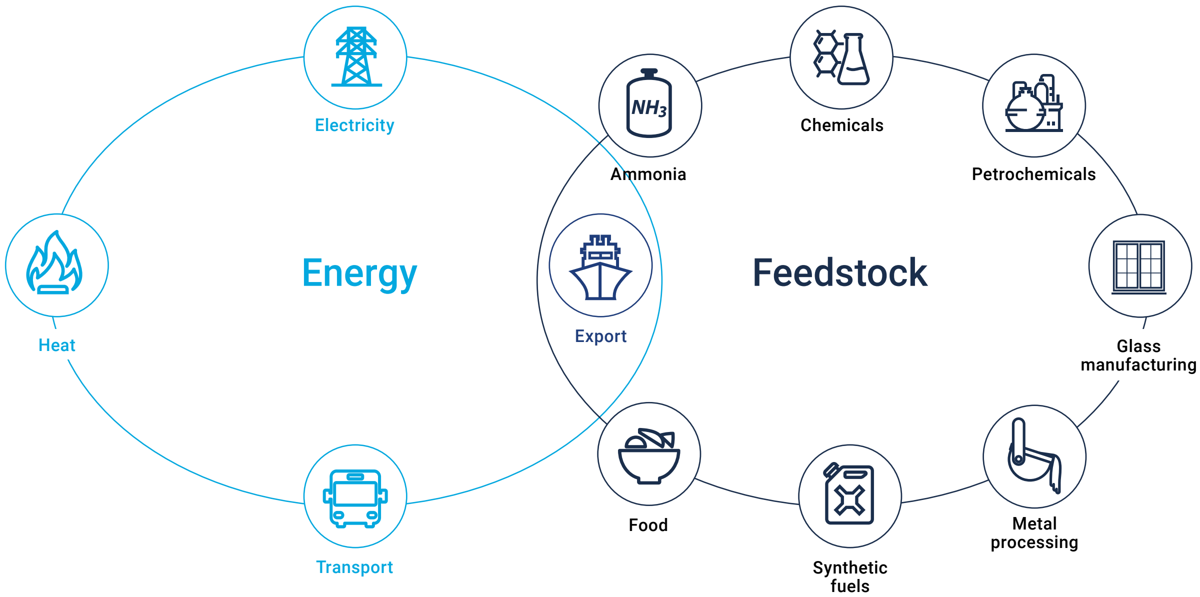
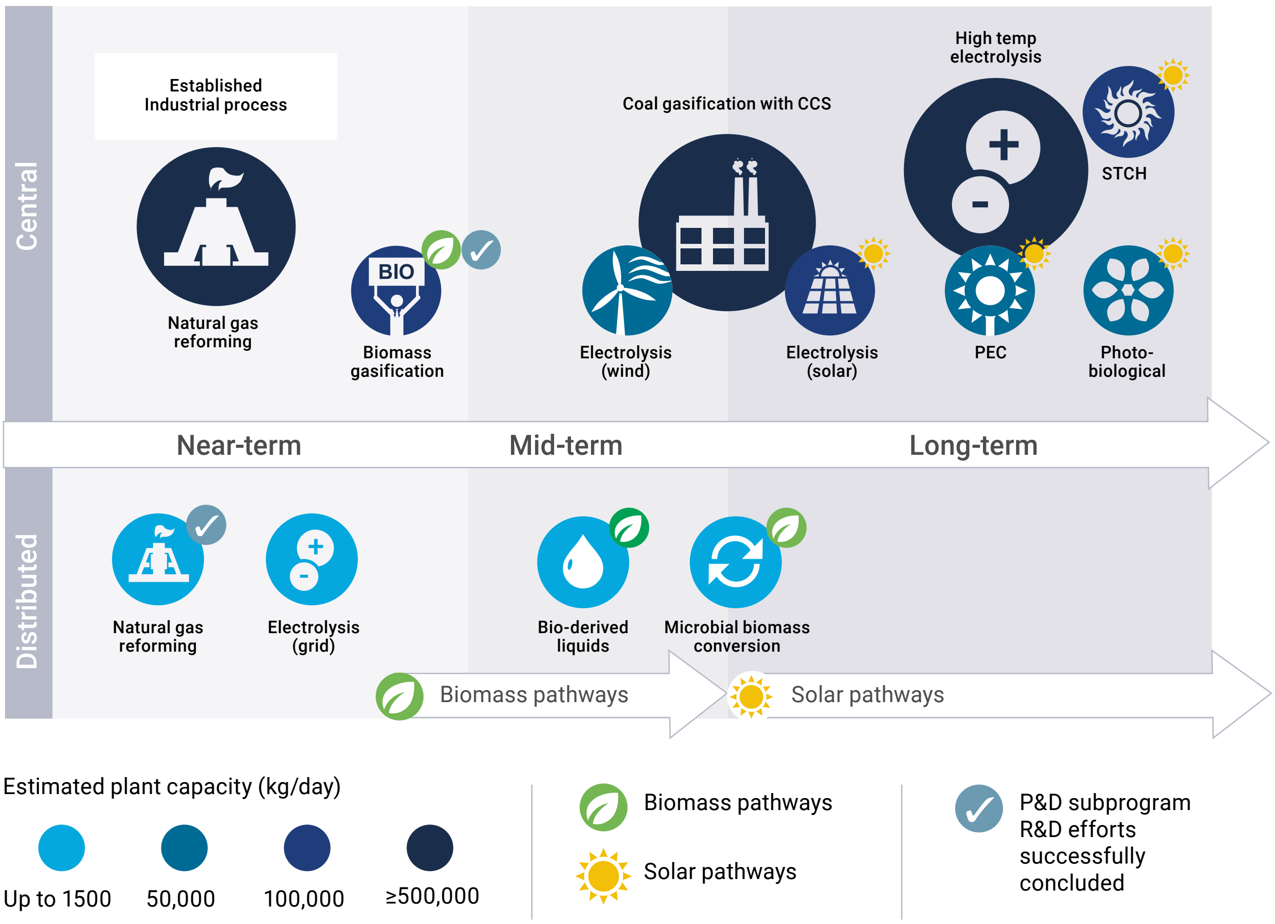


Figure 2: Hydrogen production technologies showing relative scales of current and future production.



Queensland Hydrogen Industry Strategy 2019–2024

The *Queensland Hydrogen Industry Strategy 2019–2024* (the Hydrogen Strategy), released on 30 May 2019, sets out the Queensland Government's vision for being at the forefront of renewable hydrogen production in Australia by 2030.

Five focus areas will support the growth of Queensland's hydrogen industry:

- supporting innovation
- facilitating private-sector investment
- ensuring an effective policy framework
- building community awareness and confidence
- facilitating skills development for a new technology.

The Hydrogen Strategy identifies a key role for government in facilitating private-sector investment to establish hydrogen projects in Queensland. Achieving greater efficiency in the production, storage and transport of renewable hydrogen is the key challenge to developing the industry.

To support the Hydrogen Strategy, the Queensland Government has allocated $15 million over four years for a Hydrogen Industry Development Fund (HIDF). The HIDF will provide finance in two funding streams: plant and equipment, and feasibility studies.

In February 2018, the Queensland University of Technology signed an international cooperation agreement to develop joint-venture projects and facilitate joint academic and scientific activities with the University of Tokyo's Research Center for Advanced Science and Technology (RCAST).

In May 2019, the Queensland Premier travelled to Japan and signed a renewed memorandum of understanding with Japan Oil, Gas and Metals Corp, which included continued cooperation to develop hydrogen.

In June 2019, the Queensland Minister for State Development, Manufacturing, Infrastructure and Planning signed a Statement of Intent to Collaborate on the Hydrogen Industry with RCAST, and announced the appointment of RCAST's Professor Masakazu Sugiyama as Queensland's Hydrogen Envoy in Japan.

Hydrogen in Australia

Five important reports on hydrogen as a component of low-carbon technologies were released in Australia and overseas in 2018:

1. a national hydrogen roadmap for Australia[1], outlining pathways to an economically sustainable hydrogen industry, sponsored by CSIRO
2. a report on opportunities for an Australian hydrogen export economy, commissioned by the Australian Renewable Energy Agency[4]
3. a briefing paper to the COAG Energy Council on hydrogen for Australia's future[5]
4. a report by Morgan Stanley on global market projections for the hydrogen economy to 2050[2]
5. a technology outlook by the International Renewable Energy Agency (IRENA), an intergovernmental organisation that supports countries in their transition to a sustainable energy future.[6]

Along with an earlier technology roadmap developed by the International Energy Agency[3], these documents provide the national context for hydrogen projects currently underway in Queensland. They have also been used to inform later sections of this report.

The vision statement in the COAG briefing paper best illustrates the potential significance of a hydrogen economy for Australia.[5]

Our vision is a future in which hydrogen provides economic benefits to Australia through export revenue and new industries and jobs, supports the transition to low emissions energy across electricity, heating, transport and industry, improves energy system resilience and increases consumer choice.

The same briefing paper also notes an export aspiration for Australian hydrogen producers: 'To capture the hydrogen export market and associated benefits in the domestic economy.'

Figure 3: The Sir Samuel Griffith Centre building at Griffith University, Nathan Qld.

Image courtesy of Green Building Council, Australia

Hydrogen in Queensland

Queensland is home to 173 operating or proposed renewable energy projects. Combined, these generate more than 22,500 megawatts annually. These are complemented by exciting new hydrogen-energy projects, demonstrating Queensland's commitment to green, clean energy solutions (Figure 4).

Griffith University

Australia's first large-scale (ie hundreds of kW) installation of hydrogen-based technologies using renewable energy was completed at Griffith University in 2013. The Sir Samuel Griffith Centre is a ground-breaking, multi-purpose 6,150m^2 building powered by solar panels, batteries and fuel cells.

The centre is one of the few hydrogen production and use facilities in Australia driven by renewable energy. Its building is designed to showcase accessibility and transparency and to epitomise Griffith University's identity as one of Australia's leading environmental educators (Figure 3). The centre's design combines the world's first use of solar-hydrogen energy technology with a spatial design that creates a fully self-sustainable, zero-carbon research and learning building.

The building is fitted with over 1,000 solar photovoltaic panels, covering the roof and window shades. On sunny days, this generates more than enough electricity to power the whole building. Energy not used during the day is either stored for later use, or used to chill water for the air-conditioning system the next day.

Solar energy produced by the photovoltaic system is stored in batteries and powers an electrolyser that splits water to make hydrogen. The hydrogen is then stored in a stable form as metal hydrides. When there is no sun, the stored hydrogen can be used to generate electricity via a fuel cell.

Northern Oil

In Gladstone, Northern Oil – a subsidiary of Southern Oil, based in Wagga Wagga, New South Wales – processes waste feedstocks (eg tyres; green, agricultural and forestry waste; bio-solids) into bio-crudes that are ultimately refined into drop-in fuels. More recently, Northern Oil has announced the trial of a hydrogen production process that utilises this bio-crude material. This hydrogen will then be exported to a fuel cell to generate on-site power for the processing plant.

Redlands hydrogen research facility

On 15 March 2019, the state's first ever delivery of green hydrogen to Japan was announced by JXTG, Japan's largest petroleum conglomerate. The hydrogen was produced at the Queensland University of Technology's (QUT) solar photovoltaic facility, located at the Queensland Government's Redlands Research Facility.

QUT and their project partners are also embarking on hydrogen research for Australian conditions. The project will develop a scalable process to evaluate the viability of decentralised renewable energy systems to generate hydrogen from renewable resources. Using two solar array technologies and battery packs, hydrogen will be produced using electrolysis technology. The resulting hydrogen will be used within the facility as well as exported. The facility will allow researchers and industry to optimise the production and use of renewable hydrogen with the aim of scaling up into megawatt scale development.

The Queensland Government has recently committed a significant financial contribution to the research into renewable hydrogen production at the Redlands facility.

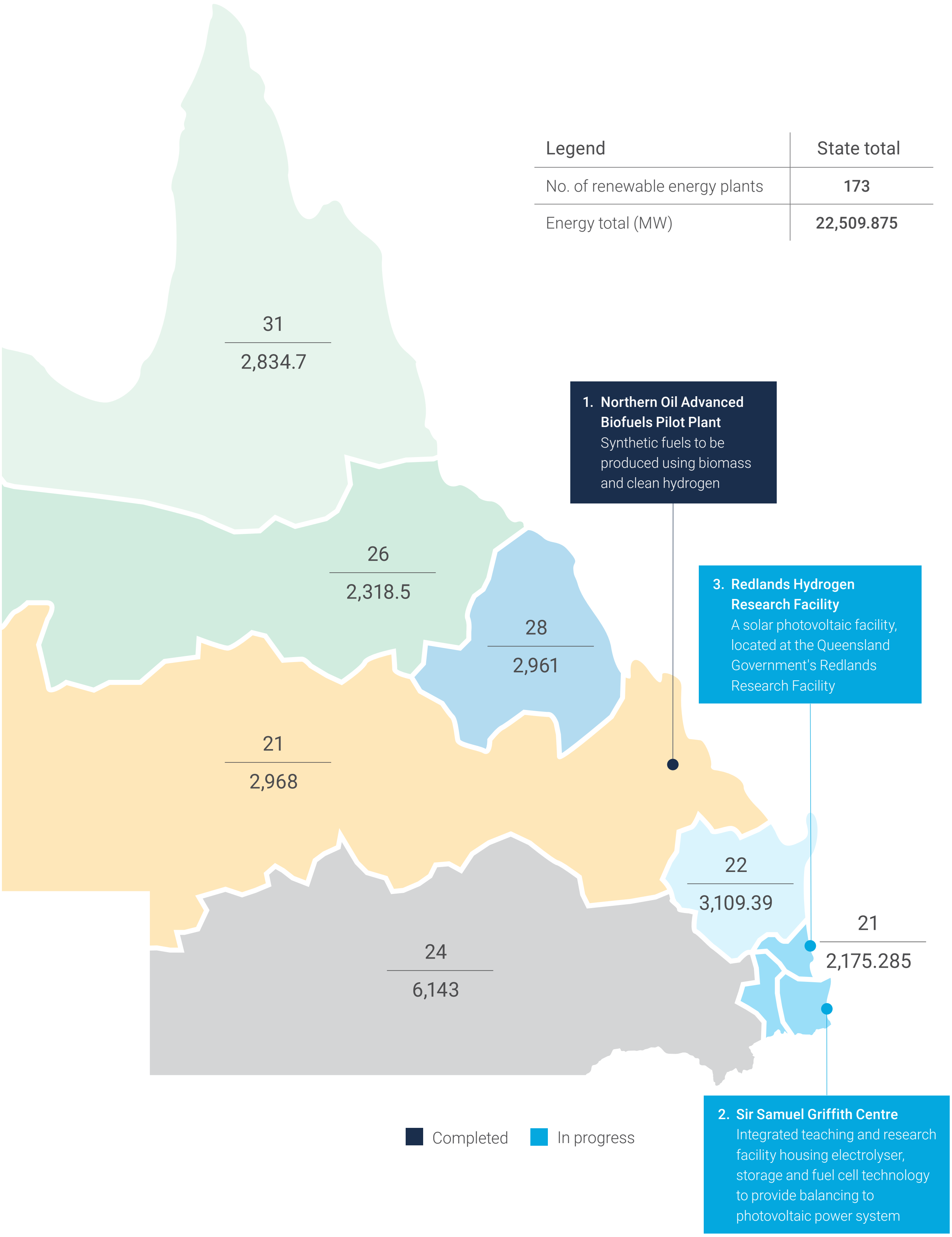
Hydrogen partnership with Japan

More recently, a partnership between Queensland University of Technology, Griffith University, Swinburne University of Technology, the University of Tokyo, Sumitomo Electric Industries and Energy Developments Pty Ltd has been formed to use Queensland-produced solar energy to extract hydrogen from treated non-drinking water, such as seawater.

Solar power will be provided by a concentrated photovoltaic (CPV) array supplemented by commercially available battery packs to extract hydrogen from treated water using electrolysis. Hydrogen will then be fed into a fuel cell and the resultant power returned to the local grid. In this project, funded by ARENA and the partnership, the pilot plant facility will be used to develop optimisation strategies for scale-up and pre-feasibility studies of hybrid renewable energy systems for the production of hydrogen.

Figure 4: Projects using a variety of renewable energy methods.[1]

Legend	State total
No. of renewable energy plants	**173**
Energy total (MW)	**22,509.875**



Source: https://maps.dnrm.qld.gov.au/electricity-generation-map/

Global demand for hydrogen

Demand trends

The ACIL Allen Consulting group report[4] to ARENA provides credible and detailed models, based on verified global data, on the emerging global market for hydrogen.

In general, the trends are consistent with projections developed by Morgan Stanley Research[2], although projections of industry growth by 2050 may diverge due to different modelling approaches.

Nevertheless, all recent roadmaps and modelled projections of the hydrogen market suggest that growth will be substantial over the next 20 years as developing technologies evolve into commercial products and dependence on fossil fuels decreases.

(Please note: Data provided below focuses on future demand for hydrogen for energy-related purposes compared with current usage, which is predominantly for non-energy purposes.[4] For reference, current major uses of non-energy hydrogen and sources of hydrogen are summarised in Figure 5.)

Drivers of hydrogen demand

A common theme in projections for hydrogen demand is the high potential for decarbonisation of specific industries.

The production, use or distribution of electricity is viewed as an early opportunity for rapid growth because production of electricity via renewable energy is established and also price-competitive in some sectors. Integration of renewable energy technologies into a network or a national grid is an acknowledged challenge but use of hydrogen to operate variable-capacity fuel cells now appears to be an option for end-users. Combined with appropriately scaled electricity storage technologies, entry into the power generation and transport sectors may be rapid in some communities. Increasingly, the use of electrolysers generating hydrogen at times when the renewable resource exceeds demand is recognised as a strategy for grid stabilisation. The produced hydrogen can be sold or potentially injected into the national gas grid.

An additional advantage of hydrogen in energy applications is a capacity to replace or reduce liquid hydrocarbons in transport applications. Hydrogen-powered fuel cell electric vehicles (FCEVs) are likely to become a major driver of demand for low-carbon hydrogen in densely populated regions such as Northern Asia (Korea, Japan and China), California and Europe. This demand could be a key early-stage driver of 'green' hydrogen export markets for Australia, provided suitably-scaled means of transportation are developed.

Figure 6 gives an indication of the potential uptake of hydrogen within the transport industry as well as in other sectors.[4] In this figure, existing uses of hydrogen in transportation are identified and the development of additional market segments such as power generation and industry energy are also shown. The figure shows that the transportation sector is an early adopter of hydrogen as a carrier of energy and that, by 2025, many such types of transportation will be commercially viable and accepted in many societies.

The rapid transformation of the passenger and heavy vehicle markets, including those of vehicle manufacturers, suggests that the hydrogen economy will expand beyond existing fossil-fuel requirements. Major jurisdictions such as Europe, North America and Northern Asia have endorsed hybrid and fuel-cell vehicles and implemented legislation that will ultimately lead to zero-emission requirements on new vehicles. These changes as well as recognition that hydrogen may be used for other energy-intensive activities suggest that the market will increase.

Hydrogen also has the capacity to drive turbines for power generation. This is likely to be a major driver for some markets in Asia into which Queensland producers may supply hydrogen.

The drive for lower emissions from the transport sector is due not only to awareness of excessive pollution in many jurisdictions but also because there are broader implications for longer-term global reduction of greenhouse gases.

An indication of the notional emissions benefits from implementing hydrogen as a replacement for diesel fuel is outlined in the ACIL Allen report.[4] For example, if one petajoule (PJ) of hydrogen produced by electrolysis methods coupled to renewable energy (eg solar) was used to replace an equivalent amount of diesel fuel (eg 1PJ), then emissions reductions would be equivalent to 69,337 tonnes of CO^2.

Models of hydrogen demand

The analysis by ACIL Allen builds on earlier international studies to present a sober estimate of likely hydrogen demand based on economic, technical and social factors.

In an extensive analysis, the scenarios developed by ACIL Allen out to 2040 estimate import demand from four key countries with which Australia has established trading practices and a modest share of the rest of the world market. These scenarios are provided in the table below and indicate that a medium demand at 2030 would be 1,025 PJ or 8.5 million tonnes of hydrogen.

For comparison, Australia exported ~60 million tonnes of liquefied natural gas (LNG) in 2017–18, while in 2016–17 estimated exports of LNG from Gladstone were ~16 million tonnes. In the latter case, the bulk of LNG exports went to China, with Korea and Japan also major importers. The value of these exports clearly depends on contract and spot prices for the commodity and this will also be the case for hydrogen.

The Morgan Stanley report suggests that the potential size of the green hydrogen economy will meet ~US$2.5 trillion in sales by 2050.[2]

While this value for market size depends on different assumptions from those identified in the ACIL Allen report, key factors that provide confidence in the emergence of a market include:

Figure 5: Existing hydrogen demand and sources for key industry sectors.

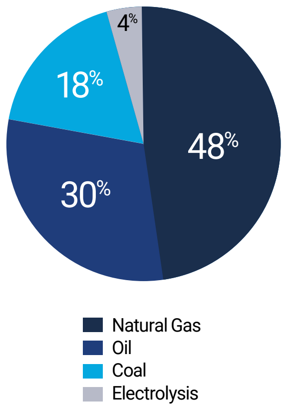
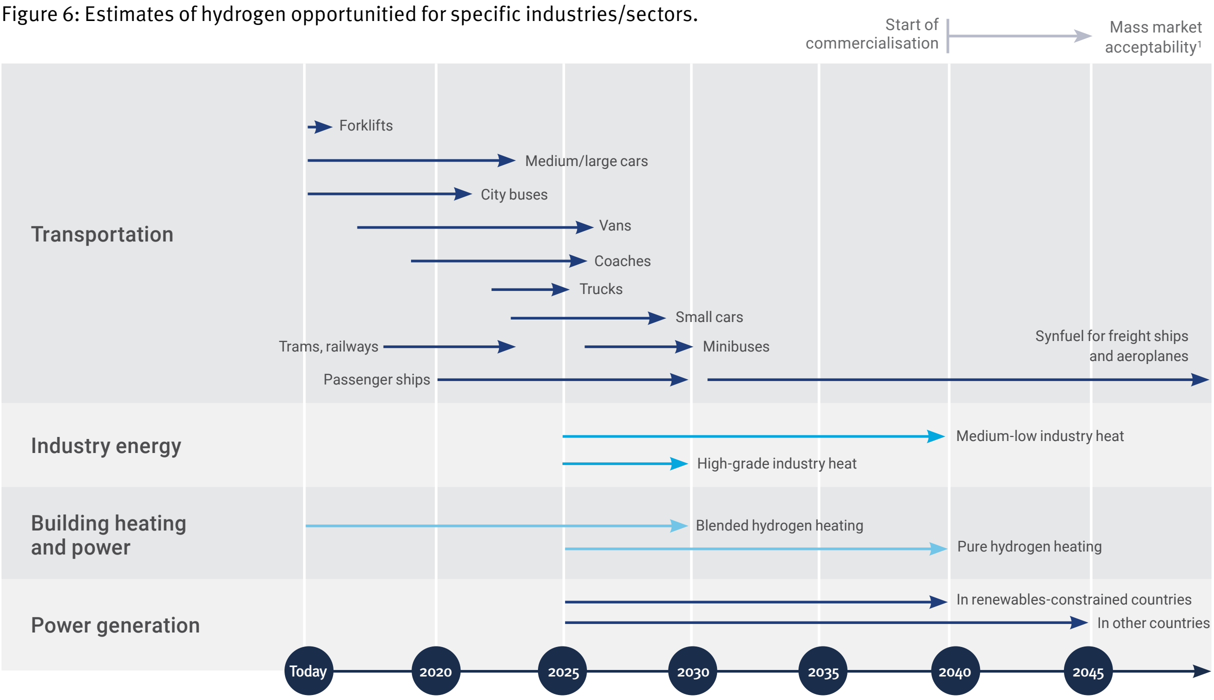
INDUSTRY SECTOR	KEY APPLICATIONS	PERCENTAGE OF GLOBAL H^2 DEMAND	HYDROGEN SOURCES
Chemical	Ammonia Polymers Resins	65%	
Refining	Hydrocracking Hydrotreating	25%	
Iron and steel	Annealing Blanketing gas Forming gas		
General industry	Semiconductor Propellant fuel Glass production Hydrogeneration of fats Cooling of generators	10%	

Figure 6: Estimates of hydrogen opportunitied for specific industries/sectors.



Source: Hydrogen Council (2017), Hydrogen scaling up, a sustainable pathway for the global energy transition

Figure 7: Projected 'green hydrogen' demand and estimated required supply of renewable energy.

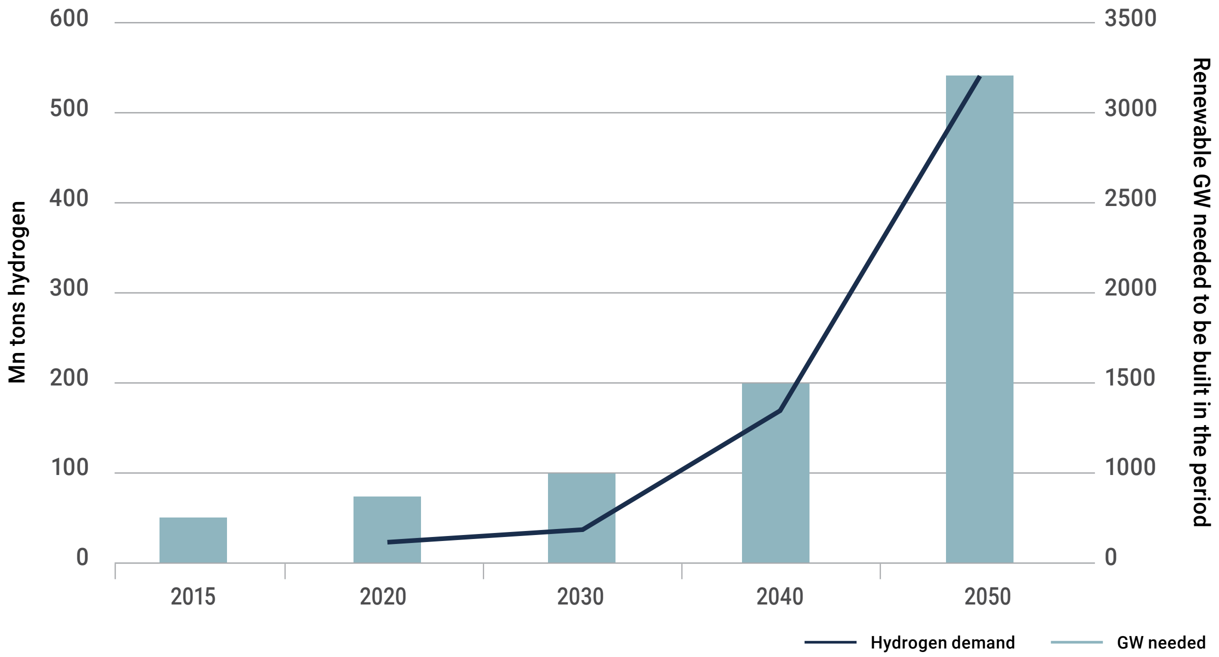


Table 1: Projected global demand for hydrogen (PJ)

Country	2025			2030			2040		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Japan	10.6	62.0	160.7	105.1	211.5	463.3	227.7	496.1	1,149.7
Republic of Korea	8.9	26.7	59.3	44.8	87.4	187.5	120.2	261.2	637.1
Singapore	0.3	1.8	3.8	3.3	6.1	12.4	11.5	20.2	57.7
China	5.8	27.1	83.8	123.5	398.5	841.8	943.1	2,093.3	4,922.7
Rest of the world	11.7	53.8	140.6	126.5	321.6	688.0	595.5	1,312.4	3,093.6
Total	**37.4**	**171.6**	**448.1**	**403.2**	**1,025.2**	**2,193.1**	**1,898.0**	**4,183.2**	**9,860.8**

Source: ACL Allen Analysis

Table 2: Projected global demand for hydrogen ('000 tonnes)

Country	2025			2030			2040		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Japan	88	516	1,338	875	1,761	3,858	1,896	4,131	9,573
Republic of Korea	74	223	493	373	728	1,562	1,001	2,175	5,304
Singapore	3	15	31	27	51	103	96	168	481
China	48	226	698	1,028	3,318	7,009	7,853	17,430	40,989
Rest of the world	98	448	1,170	1,053	2,678	5,729	4,958	10,927	25,758
Total	**311**	**1,429**	**3,731**	**3,357**	**8,536**	**18,260**	**15,804**	**34,831**	**82,105**

Source: ACL Allen Analysis

- there currently exists a global market in hydrogen – predominantly based on methane – which generates sales of approximately $150 billion
- this existing market is likely to generate sales of green hydrogen to industries that are concerned about their carbon footprint and energy efficiency
- price parity between green hydrogen and hydrogen from methane is projected to be achieved by 2030
- transition of the electricity sector to a greener and less energy-intensive model for energy provision and distribution is well underway in many jurisdictions
- evidence is emerging that countries with a higher share of renewables in their energy mix offer good conditions for production of hydrogen.

Morgan Stanley[2] also estimates the renewable power required to generate the production targets proposed by the Hydrogen Council (see Figure 7). In this ambitious scenario, which projects hydrogen to account for 18% of global energy demand by 2050 (or a ten-fold increase in demand), 4,400GW of renewable energy would be required. For comparison, Australia generated ~32GW of power through the national electricity market (NEM) – excluding Western Australia and the Northern Territory – and had an installed capacity of 47GW in 2017. [7]

Queensland is a major contributor to the NEM, with 182 non-household power-production sites and a combined estimated capacity of ~28GW.[7]

Models of hydrogen supply and market size

The cost of hydrogen production for export depends on scale, capacity, transport charges and the source of hydrogen.

The report by ACIL Allen[4] presents a range of scenarios for hydrogen production costs benchmarked against the estimated levelised cost of hydrogen (LCOH) developed by CSIRO for a range of technologies.

These scenarios also include estimates of renewable energy costs as well as projected reduction in production costs and improved capacity factors for hydrogen produced by electrolysis. These costs and estimated capacity to supply the global market by a number of potential suppliers, including Australia, Japan, China and Korea, are considered in the report by ACIL Allen.[4]

These supply parameters are incorporated into a model that estimates Australia's share of the global hydrogen market at ~9% in 2025, reducing to ~3.6% by 2050 as other suppliers enter an expanding market.

Based on this modelling in the ACIL Allen report, potential exports of hydrogen from Australia are likely to range from 265,000 tonnes to 344,000 tonnes in 2025, up to 1 million tonnes in 2030 and up to 3 million tonnes in 2040.[4]

Figure 8: Projected 'green hydrogen' demand for export and impact on the Australian economy.

	Year	DIRECT IMPACT	+	INDIRECT IMPACT	=	TOTAL IMPACT
Value added	2025	$118m	+	$355m	=	$473m
	2030	$417m	+	$1.256m	=	$1.672m
	2040	$1.068m	+	$3.219m	=	$4,287m
Employment (FTE)	2025	191	+	597	=	788
	2030	677	+	2,110	=	2,787
	2040	1,734	+	5,408	=	7,142

Japan: a hydrogen case study

Japan is a country with limited natural energy resources that meets a significant proportion of its energy demand through imported sources.

The energy industry in Japan, which encompasses electric power, gas and other energy resources, is regulated by the Ministry of Economy, Trade and Industry (METI).

The fourth Strategic Energy Plan for Japan 9 adopted in April 2014 stated, 'Since technological innovation has progressed, now is the time to conduct comprehensive deliberation on a "hydrogen-based society", which uses hydrogen as an energy.'

Subsequently, in June 2014, the Council for a Strategy for Hydrogen and Fuel Cells, comprising experts from industrial, academic and government sectors, compiled the Strategic Roadmap for Hydrogen and Fuel Cells. Progress in the development of hydrogen use led to revisions to the roadmap to include quantitative targets for residential fuel cells, FC(E)Vs and independent hydrogen refuelling stations. More recent cabinet decisions and legislation have embedded structural and financial incentives to ensure Japan becomes the first country in the world to realise a hydrogen-based society.

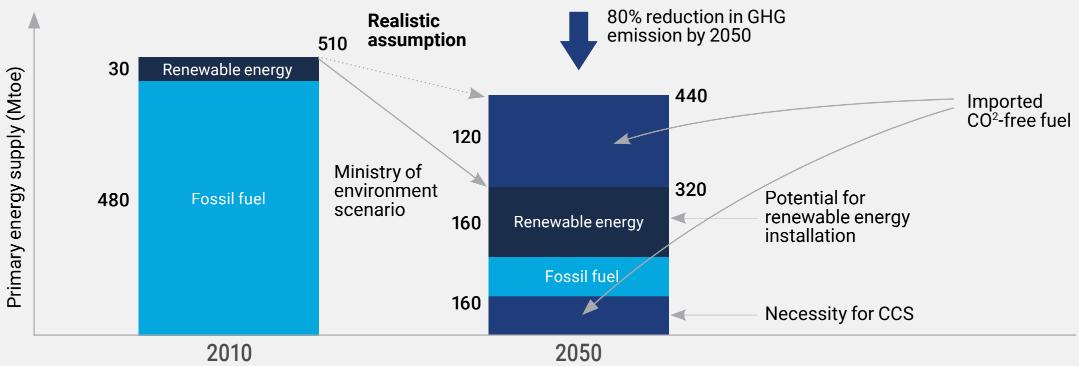
The New Energy and Industrial Technology Development Organisation (NEDO) estimates the likely demand for hydrogen in Japan in 2030 will be ~3,000M Nm^3/year (270,000 tonnes/year) or equivalent to 1GW of power generation and 800,000 fuel cell vehicles (FCVs) on the road. By 2050, with up to 20% of power generation from hydrogen, the estimate is 100,000M Nm^3/year (9 million tonnes/year). If Australia meets the projected export potential of 3 million tonnes of hydrogen by 2040, Japan's demand may comprise a significant proportion of this business.

METI has an aggressive hydrogen scenario that requires total energy demand be reduced from 510 million tonne oil equivalent (MTOE) in 2010 to 320 MTOE by 2050. A further element of this scenario is that the supply of energy from fossil fuels will decrease from 480 to 160 MTOE in this timeframe. Half of this fossil-fuel-sourced energy is also expected to be managed by carbon capture and storage (CCS) associated with hydrogen production. However, given the geological setting of Japan, the capacity to implement CCS in-country is limited due to the challenge of defining stable formations that can contain CO_2. This requirement implies that CCS must be implemented in countries that export hydrogen to Japan if a 'green' provenance is required. Thus, opportunities for export of green hydrogen by methods that do not utilise CCS may further increase in Japan. The 80 MTOE allocated by METI to import hydrogen produced with CCS may prove to be an additional aspirational target for exporters of pure renewable energy hydrogen production.

Figure 9 presents the breakdown of potential and aspirational renewable energy production of hydrogen for export to Japan in order to meet an 80% reduction in emissions by 2050. A realistic scenario is that the total energy demand is only reduced to 440 MTOE by 2050, with 200 MTOE of this being sourced from imported CO_2-free fuel (ie includes 80 MTOE aspirational target without CCS). Another 160 MTOE would then be locally sourced renewable energy.

This scenario would enable Japan to reduce fossil fuel use, target an 80% reduction in GHG emissions and provide viable market opportunities for exporters by 2050.

Figure 9: Need for hydrogen supply to Japan based on METI targets projected to 2050.



Source: Mr Kidoshi, Japan Research Institute

These estimates are a relatively small proportion (< 1%) of the ambitious targets proposed by the Hydrogen Council.[8] Nevertheless, ACIL Allen has estimated the value-add to the Australian economy of such an export scenario as shown for the 'medium' case in Figure 8.

These economic models evaluate both direct and indirect impacts for three time periods, showing that the total impact by 2040 could be $4.2 billion and as high as $10 billion. An important additional impact would be a substantial reduction in greenhouse gas emissions. For example, if existing methane-sourced methods to produce hydrogen for export were implemented, an additional 380,000 tonnes of CO^2 equivalent would be emitted to meet the medium scenario for 2030. Thus, renewable energy production of hydrogen for export not only generates revenue and employment benefits but can reduce greenhouse gas emissions.

The potential additional renewable energy generation required to meet these projected targets is substantial but not impossible to achieve. For example, ACIL Allen estimates the additional generation required to meet the medium scenario shown in Figure 8 at between 15GW and 68GW, with a median value of 32GW by 2030. This median increase in generation capacity approximates the current size of the existing supplied capacity of the NEM today.

Queensland is well positioned to provide a significant share of this additional generation capacity, with efficient, consistent solar power from dedicated solar farms and capture of excess capacity during low network-demand periods.

The case for Queensland

Development of an export capacity for green hydrogen in Queensland is highly prospective because the fundamental raw resources and infrastructure exist or are developing.

Furthermore, past experience with building an LNG gas export market in the state provides reliable guidance on best practices and the pitfalls to avoid for an expanded industry sector.

Policy settings within the state are aligned with the measured development of a hydrogen export industry, although some policy adjustments to deal with new technologies may be required. Similar scenarios may be possible in other Australian states with due consideration of available resources and policies. However, Queensland is well positioned to rapidly scale up an export industry using existing infrastructure at key ports such as Gladstone, Brisbane and Townsville.

Geography

More than other Australian states, Queensland is decentralised along the coast, with viable agricultural, resources and chemicals/process industries located around Bundaberg, Gladstone, Rockhampton, Mackay, Townsville and Brisbane.

Each of these cities is serviced by shipping and transport hubs, and Gladstone has substantial capital invested in gas-export facilities. Inland towns and cities (Toowoomba, Roma, Emerald, Moranbah) also contribute to the potential resources pool, including a skilled workforce, for an export hydrogen industry. A development strategy that recognises the respective contributions to be made by these locations to development of a hydrogen export industry will maximise return on investment.

Australia has one of the largest values for Direct Normal Irradiance (DNI) in the world, second only to parts of Africa. DNI is the amount of solar radiation received per unit area on a surface that is perpendicular to the rays of the sun. In general, electricity is generated by solar panels of two forms: conventional Si-photovoltaics (PVs) and the more recently developed concentrated PVs (CPVs).

Each method of solar energy harvesting has specific advantages depending on geographic location. CPV technology, which tracks and focuses light from the Sun, offers around twice the collection capacity per unit area compared to Si-PVs in regions of high DNI value.

This performance difference drops off with latitude (eg for southern Australian installations) where Global Horizontal Irradiance (GHI) values can be higher. Si-PV solar farms are able to collect light from any direction and so offer capacity with lower efficiency per unit area. The ratio between GHI and DNI provides the best indicator of places in the world where the greatest amount of solar energy can be harvested for a given land area.

While Japan has a high GHI and low DNI, Australia has both a high GHI and DNI, placing Australia in a competitive position to collect solar energy with substantial efficiency performance. Recently, the performance of a CPV array has been shown to be more efficient per unit area (~2.3x factor) than a Si-PV array at Redlands, Brisbane where DNI values are among the lowest in Queensland. In general, installation of CPV arrays in Northern Australia would provide a substantial energy efficiency advantage over other locations using Si-PV arrays.

Renewable energy capacity

The *Powering Queensland Plan* established by the Queensland Government provides strategic direction for the short-term and long-term direction of renewable energy practices in the state. This plan builds on a substantial history of innovative strategies to diversify the state economy and to build long-term resilience – social, environmental and financial – into the future. Recent examples of these strategies include the development of a coal-bed methane industry with exceptional export capacity via Gladstone as well as the emerging biofuels and bioproducts industry guided by the Biofutures Plan.[10]

A vibrant and versatile renewable energy sector in Queensland, linked closely to other forms of energy generation, distribution and export, can play a part in the measured transformation of the economy from dominantly fossil fuel dependence. A significant advantage of geography is the high potential to utilise solar power – supplemented by commensurate energy storage practices – to produce hydrogen by renewable methods. Queensland already has a high penetration of renewable energy within its network and has a pipeline of renewable energy projects amounting to more than 15GW capacity.[11] Current renewable energy generation by solar on a typical spring day amounts to more than 1.3GW – the bulk of which is from small household installations. In addition, a further 1.5GW of solar farm capacity is under construction at 20 sites with expected completion dates by the end of 2019.[11] More importantly, a further 11–13GW of renewable energy capacity (including solar) has been proposed for Queensland.

The combined existing, planned and under-construction solar capacity for Queensland is thus substantial and offers excellent potential to utilise variable, or excess, capacity to support the strategic development of a green hydrogen industry. If this potential capacity were implemented, appropriately supported by distribution and storage infrastructure networks at regional and local scale, a green hydrogen production industry could provide a significant proportion to export markets.

Of note is that the first occurrence of negative electricity pricing in Queensland occurred during the winter of 2018.[12] This condition occurred during a five-minute window in the middle of the day but is perhaps a harbinger of the future for Queensland.

The current policy platforms of the Queensland government, planned solar capacity to 2020 and high potential for significant increases in solar capacity suggest that utilisation of excess solar power, added incrementally to strategic installations or purpose-built, would enable effective and efficient use of solar power to drive a hydrogen export industry.

Emerging technologies

Technology roadmaps for evolution of hydrogen economies are well documented including those mentioned in this report. In general, these roadmaps describe technologies that are well down the technology readiness path – from TRL 4–5 to TRL 7-8.[13] These reports provide certainty that the industry is dynamic, the innovation is ongoing and the roadmaps are useful indicators for a five-year term at most.

On the horizon, there are many exciting developments in the science and engineering of hydrogen-based technologies largely due to impressive levels of investment by governments and corporations around the world over the past 10 years. Significantly increased levels of investment in the hydrogen sector are also committed into the future.

Use of a microbial electrolysis cell (MEC) is an emerging technology for energy and resource recovery during waste treatment. MECs can theoretically convert any biodegradable waste into hydrogen, biofuels and other value added products.[14] The system efficacy can vary significantly when using different substrates or when operated under variable environmental conditions. However, progress has been made in utilisation within urban environments[15] as well as with solar-assisted microbial electrolysis.[16] While scale-up of these technologies with higher efficiencies is the focus of attention, it is likely that this technology will become another viable method to sustainably produce hydrogen. This technology may also become a future focus of Queensland's Biofutures Roadmap and policy agenda.[10]

Finally, evolution of existing technologies to generate higher efficiencies or new approaches to hydrogen production through the development of new materials and/or advanced manufacturing methods are current foci of research and development in the hydrogen sector. For example, new materials for turbines or pipelines offer substantial improvements in energy generation via hydrogen combustion and transport. Improvements in the efficiencies of both types of electrolysis methods are also projected to increase operating lifetimes and improve efficiencies substantially by 2025.[6]

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Appendix 1: Japan's hydrogen market

The following summary provides details of key companies in Japan that are actively engaged in the production, use or distribution of hydrogen and in the manufacture of primary components for the hydrogen market. Many of these companies are global operations with significant marketing or sales activities in developing and developed markets around the world.

Table 1 identifies key consortia that function to develop markets or to vertically integrate activities across broad industry sectors.

Queensland businesses may wish to consider how to establish similar consortia for 'green hydrogen' export to Japan. Alternatively, it may be possible to join one or more of the consortia listed in Table 1.

Table 1: Active hydrogen-based consortia in Japan

Consortium	Companies	No. in Consortia and function	Comment
Hydrogen Mobility Japan	Toyota Motor Corp; Nissan Motor Co. Ltd.; Honda Motor Co. Ltd.; JXTG Nippon Oil & Energy Corp; Idemitsu Kosan Co. Ltd.; Iwatani Corp; Tokyo Gas Co. Ltd.; Toho Gas Co. Ltd.; Air Liquide Japan Ltd.; Nemoto Tsusho K.K.; Seiryu Power Energy Co. Ltd.; Development Bank of Japan Inc. JA Mitsui Leasing Ltd.; Toyota Tsusho Corp.; Sompo Japan Nipponkoa Insurance Inc.; Sumitomo Mitsui Finance and Leasing Co. Ltd.; NEC Capital Solutions Ltd.; Mirai Creation Fund (SPARX Group Co. Ltd.)	~20 To develop hydrogen refuelling station network for FCVs.Target: 160 stations serving 40,000 FCV by 2020.	Known as 'JHyM'
Hydrogen Energy Supply Chain	Kawasaki Heavy Industries; J Power; Iwatani Corp; Marubeni Corp.	4 To deliver hydrogen derived from brown coal deposits in Victoria Australia.	Known as 'HESC'
Advanced Hydrogen Energy Chain for Technology Development	Chiyoda Corp; Mitsubishi Corp; Mitsui & Co. Ltd., Nippon Yusen K.K	4 To develop a demonstration-scale gas liquefaction plant in Brunei; 210 tonnes of H2 by 2020 to refuel 40,000 FCVs.	Known as 'AHEAD'
Carbon Capture and Re-use	Hitachi Zosen Nikki, Inpex; Mitsui Chemical; Sumitomo Corp; Tokyo Gas; Osaka Gas; Itochu Ltd; Asahi Kasei; TEPCO.	>9 To produce methane domestically and to capture/re-use CO^2.	Early stages

Table 2: Active hydrogen-based companies in Japan

Sector	Company	Technology/product focus	Comment	Total revenue (JPY)	Employee numbers
Vehicle manufacturer	**Toyota Motor Corp**	Vehicle peroduction and sales		¥29,379 billion (FY2018)	369,124 (2018)
	Honda Motor	Vehicle production and sales		¥14.60 trillion (FY2016)	208,399 (2016)
	Nissan Motor Corp	Ethanol-based fuel cell vehicle		¥11.38 trillion (FY2014)	142,925 (2014)
Hydrogen refuel stations	**JHyM**	Consortium for hydrogen mobility	See Table 1		
	Chiyoda Corporation	Engineering construction; on-site conversion of MCH		¥603.7 billion (FY2016)	6,097 (2015)
	Kawasaki Heavy Industries	Storage of liquefied hydrogen; mobile transport of liquid H2		¥1.3 trillion (2011)	34,010 (2013)
	JXTG Energy	Existing fossil fuel refuelling stations; adding infrastructure and services for hydrogen refuelling stations		¥ 7,523 billion JPY (FY 2008)	13,290 (2007)
	Iwatani Corporation	H2 testing facilities; liquid H2 handling and use		¥670,792M (March 2018)	1,236 (2018)
	Osaka Gas	Utilises reforming technology to convert methane to H2 for refuelingrefuelling stations; compact units that offer range of H2 production rates		¥1,294 billion (FY2012)	19,818 (2012)
	Tokyo Gas	Using its city gas pipeline network to build efficient refuelingrefuelling stations		¥1,535 billion (FY2011)	16,832 (2013)
Hydrogen conversion and fuel cells	**Chiyoda Corp**	Recovers hydrogen from methyl cyclohexane (MCH) and vice versa	Part of transport value chain	¥603.7 billion (FY 2016)	6,097 (2015)
	Panasonic Corporation	Residential fuel cells that generate power from hydrogen extracted from natural gas	At ~5kW scale	¥7.982 trillion (2018)	257,533 (2017)
	Mitsubishi Hitachi Power Systems	Power generating systems; large-scale H2 + CH4 mixes for gas turbines; also SOFC+gas turbine systems	Uses other gases to operate SOFC		
	JXTG	Developing catalyst to produce MCH from toluene	At R&D stage	¥11 trillion (2013)	24,691 (2012)

Hydrogen Transportation	**Kawasaki Heavy Industries**	Hydrogen liquefaction and transport via ships and trucks	Ship under construction; due for launch in 2021	¥1.3 trillion (2011)	34,010 (2013)
	Chiyoda Corp	Produces methyl cyclohexane (MCH) from toluene for safe, efficient transport	Liquid MCH similar to oil for easy transport/ use	¥603.7 billion (FY 2016)	6,097 (2015)
Hydrogen production	**HESC**	Supply chain: To deliver hydrogen derived from brown coal deposits in Victoria Australia	See Table 1		
	Toshiba Corporation	Alkaline electrolysis units (>100kW); hydrogen storage units (~5MW)		¥5.668 trillion (2016)	187,809 (2016)
	Hitachi Zosen	PEM electrolysis at MW scale	200Nm3/hr in mobile container	¥376,437M March 2018)	
	Asahi Kasei	Alkaline electrolysis at MW scale	Delivered to Fukushima facility; in conjunction with Germany	¥1,897 billion (FY 2014)	34,670 (2018)
	Kobelco	Small scale hydrogen production units		¥1.696 trillion (FY 2016)	36,018 (2013)
Design, construction, management	**Shimizu Corporation**	Developed H2 utilisation and smart management system combined with metal hydride storage		¥ 1,416 billion FY 2012)	15,616 (2013)
	Takenaka Corporation	Established 'decarbonised' integrated technical demonstration examples in Koto-ku, Tokyo; developed virtual power plant		¥1,284 billion (consolidated, fiscal 2015)	7,473
	Obayashi Corporation	Construction and JVs including use of geothermal power to produce hydrogen		¥1,901 billion (FY 2018)	14,359 (2018)
	Marubeni Corporation	With Hitachi and others established demonstration of hydrogen fuel cell use in local government environment including households		¥192,286 billion (March 2017)	39,126 (2013)

Websites

Company	URL address
AHEAD consortia	https://www.ahead.or.jp/en/
Asahi Kasei	https://www.asahi-kasei.co.jp/asahi/en/
Chiyoda Corp	https://www.chiyodacorp.com/en/service/spera-hydrogen/innovations/
HESC consortia	https://hydrogenenergysupplychain.com/
Hitachi Zosen	http://www.hitachizosen.co.jp/english/
Honda Motor	https://automobiles.honda.com/clarity-fuel-cell
Iwatani Corp	http://www.iwatani.co.jp/eng/index.html
JHyM	https://www.jhym.co.jp/en/
JXTG Group	https://www.noe.jxtg-group.co.jp/english/
Kawasaki Heavy Industries	https://global.kawasaki.com/
Kobelco	http://www.kobelco-eco.co.jp/english/
Marubeni Corporation	https://www.marubeni.com/en/
Mitsubishi Hitachi Power Systems	https://www.mhps.com/index.html
Nissan Motor Corp	https://www.nissan-global.com/EN/ZEROEMISSION/
Obayashi Corporation	https://www.obayashi.co.jp/en/business/new_businesses.html
Osaka Gas	https://www.osakagas.co.jp/en/index.html
Panasonic Corp	https://na.panasonic.com/us/
Shimizu Corporation	https://www.shimz.co.jp/en/company/about/sit/topics/topics02/
Takenaka Corporation	http://www.takenaka.co.jp/takenaka_e/
Tokyo Gas	https://www.tokyo-gas.co.jp/en/
Toshiba Corp	https://www.toshiba-energy.com/en/hydrogen/index.htm
Toyota Motor Corp	https://ssl.toyota.com/mirai/index.html

Corporate summaries

Asahi Kasei

Asahi Kasei Europe started a demonstration project for the production of green hydrogen at the Hydrogen Competence Center in Herten, Germany. The project will transform simulated electric power from wind energy into hydrogen. The Japanese company announced that it plans to intensify its activities in the field of hydrogen production in Europe. Based on its chlor-alkali electrolysis technology, the company developed an alkaline-water electrolysis system, which is suitable for use with fluctuating power input such as from renewable energy sources. The system offers scalability up to 10MW, allowing the customer to produce a large quantity of hydrogen with a single unit.

https://www.asahi-kasei.co.jp/asahi/en/

Chiyoda Corporation

Chiyoda Corporation is a global engineering company specialising in oil and gas midstream for gas processing and LNG, downstream refineries, and petrochemical facility design and construction. Chiyoda headquarters is in Yokohoma, Japan and it has engineering offices around the world. Most of Chiyoda's business takes place outside Japan, including in the USA, Canada, Latin America, Middle East, Africa, Russia, the former Soviet Union, South East Asia and Australia.

After obtaining continuous stable performance of the proprietary dehydrogenation catalyst at laboratory scale, a variety of verification tests (including catalyst life and catalyst durability tests) for commercial use were conducted, spanning approximately 10,000 hours from April 2013 to November 2014, at the demonstration plant at Chiyoda's Koyasu Office & Research Park in Yokohama. From the commercial scale demonstration tests, it has been confirmed that MCH can be hydrogenated with toluene with yields of over 99%, while hydrogen is produced from the same MCH with yields of more than 98% through the dehydrogenation process.

Chiyoda Corporation has developed a proprietary technology named SPERA Hydrogen for the storage of hydrogen for long periods of time and its transport over long distances at large scale, both at ambient temperature and pressure in a stable liquid form. The company also claims that conventional infrastructure for petroleum and natural gas can be inexpensively repurposed to store and transport SPERA Hydrogen. This advantage will substantially contribute to lowering capital expenditures in the transition to renewable energy sources.

https://www.chiyodacorp.com/en/service/spera-hydrogen/innovations/

Honda Motor Corp

In Takanezawa, Japan, on 16 June 2008, Honda Motors produced the first assembly-line FCX Clarity, a hybrid hydrogen fuel-cell vehicle. More efficient than a gas-electric hybrid vehicle, the FCX Clarity combines hydrogen and oxygen from ordinary air to generate electricity for an electric motor. The vehicle itself does not emit any pollutants and the only byproducts are heat and water. The FCX Clarity also has an advantage over gas-electric hybrids in that it does not use an internal combustion engine to propel itself. Like a gas-electric hybrid, it uses a lithium ion battery to assist the fuel cell during acceleration and capture energy through regenerative braking, improving fuel efficiency.

The current lack of hydrogen filling stations throughout developed countries will keep production volumes low, and Honda will release the vehicle in groups of 150. California is the only US market with infrastructure for fuelling such a vehicle, though the number of stations is still limited. Building more stations is expensive, as the California Air Resources Board (CARB) granted $6.8 million for four H2 fuelling stations, costing $1.7 million USD each. Honda views hydrogen fuel cell vehicles as the long term replacement of piston cars, not battery cars.

https://automobiles.honda.com/clarity-fuel-cell

Hitachi Zosen

Hitachi Zosen Corporation has developed a solid polymer hydrogen generation system with a capacity of 200 Nm3/hour—the largest in Japan—for enabling the storage of surplus power at megawatt-scale power generation facilities. The company is set to start demonstration tests in the current fiscal year (ending March 2019) toward a target release in the following fiscal year (ending March 2020).

http://www.hitachizosen.co.jp/english/

Iwatani Corporation

in Japan. Establishes unique environment in Japan for low-temperature, ultrahigh-pressure hydrogen testing. Iwatani Corporation has renovated the hydrogen research facilities at its R&D Center (Amagasaki-shi, Hyogo) to become the most advanced facilities in Japan for testing equipment durability, hydrogen-compatible materials and more.

Iwatani first encountered hydrogen in 1941. Its hydrogen business has since accumulated experience and expertise over a long period of time, and we hold a 100% market share for liquid hydrogen. We have seen the liquid hydrogen sales volume increase steadily, especially in recent years. Company share of the Japanese market has nearly doubled to 70% in the past ten years.

http://www.iwatani.co.jp/eng/index.html

JHyM (Hydrogen Mobility Japan)

Japan H2 mobility, LLC,'JHyM', contributes to realise the hydrogen society and aims to develop a hydrogen station network for FCVs (Fuel Cell Vehicles) in Japan. By establishing a hydrogen infrastructure for hydrogen mobility widespread use in Japan, JHyM offers FCV drivers more convenient access to hydrogen stations. In the field of mobility including FCVs, hydrogen is expected to be one of the energies to solve global environmental issues of greenhouse gas emissions and Japanese energy security of stable resources simultaneously.

https://www.jhym.co.jp/en/

JXTG Group

The JXTG Group was formed in April 2017 through a business integration of the JX Group and the Tonen General Group. The JXTG Group comprises three core operating companies under a holding company, JXTG Holdings. The consolidated group contains the following: (i) Energy Business: JXTG Nippon Oil & Energy; Oil and Natural Gas Exploration (ii) Production Business: JX Nippon Oil & Gas Exploration and (iii) Metals Business: JX Nippon Mining & Metals. The JXTG Group is one of Japan's leading corporate groups with sales revenue of 10 trillion yen.

Development of Hydrogen Production Catalyst – The catalyst plays an important role in the process to manufacture hydrogen that is the raw material of a fuel cell. The high performance catalyst that JXTG Nippon Oil & Energy Corporation has developed enables hydrogen to be efficiently produced from petroleum products.

https://www.noe.jxtg-group.co.jp/english/

Kawasaki Heavy Industries

Kawasaki Heavy Industries is a Japanese public multinational corporation primarily known as a manufacturer of motorcycles, heavy equipment, aerospace and defence equipment, rolling stock and ships. It is also active in the production of industrial robots, gas turbines, boilers and other industrial products. The company is named after its founder Shōzō Kawasaki, and has dual headquarters in Chūō-ku, Kobe and Minato-ku, Tokyo.

KHI is known as one of the three major heavy industrial manufacturers of Japan, alongside Mitsubishi Heavy Industries and IHI.

https://global.kawasaki.com/

Kobelco

The Kobe Steel Group has developed important components for hydrogen fuelling stations, such as compressors that utilise ultrahigh pressure technologies amassed in the machinery and engineering fields. Kobe Steel is also contributing to the realization of a hydrogen society through our materials business, having supplied materials used in Toyota Motor Corporation's Mirai fuel cell vehicle* released in December 2014.

http://www.kobelco-eco.co.jp/english/

Marubeni Corporation

Marubeni Corporation and its consolidated subsidiaries use their broad business networks, both within Japan and overseas, to conduct importing and exporting (including third country trading), as well as domestic business, encompassing a diverse range of business activities across wide-ranging fields including food, consumer products, chemical and forest products, energy and metals, power and plants projects, and transportation and industrial machinery. Additionally, the Marubeni Group offers a variety of services, makes internal and external investments, and is involved in resource development throughout all of the above industries.

Hitachi, Ltd., Marubeni Corporation, Miyagi Consumer's Co-operative Society and Tomiya City, Miyagi Prefecture were adopted by the Ministry of the Environment as 'Low Carbon Hydrogen Technology Demonstration Project in Cooperation with Local Government' and prepared a demonstration project to establish a low carbon hydrogen supply chain in Tomiya City. The demonstration used the existing solar power generation system installed at the logistics centre of Miyagi COOP. Solar power is transformed to hydrogen by an electrolyser, and then stored in the form of cassettes containing metal hydride and then delivered through an existing distribution network to three family houses, Miyagi COOP supermarkets and Afterschool Children's Club in Tomiya City. After delivery, the cassette is attached to a pure hydrogen fuel cell and converted to power and heat that the users can utilise as energy. The facilities will be operated for more than 1 year with results to be obtained by March 2020.

https://www.marubeni.com/en/

Mitsubishi Hitachi Power Systems (MHPS)

Animura (CEO) and his colleagues at MHPS succeeded in developing a large-scale hydrogen gas turbine combustor that uses a mix of LNG—the fuel used in gas-fired thermal power—and 30% hydrogen. It burns hydrogen while allowing suppression of NOx emissions to the level of gas-fired thermal power. The technology is compatible with an output equivalent to 700MW (with temperature at turbine inlet at 16000C), and it offers a reduction of about 10% in CO2 emissions compared with GTCC.

https://www.mhps.com/index.html

Nissan Motor Corp

Nissan Motor Corp, is a Japanese multinational automobile manufacturer headquartered in Nishi-ku, Yokohama. The company sells its cars under the Nissan, Infiniti, and Datsun brands with in-house performance tuning products labelled Nismo. The company traces its name to the Nissan zaibatsu, now called Nissan Group.

Nissan is the world's largest electric vehicle (EV) manufacturer, with global sales of more than 320,000 all-electric vehicles as of April 2018. The top-selling vehicle of the car-maker's fully electric line-up is the Nissan LEAF, an all-electric car and the world's top-selling highway-capable plug-in electric car.

https://www.nissan-global.com/EN/ZEROEMISSION/

Obayashi Corporation

Obayashi Corporation is one of five major Japanese construction companies along with Shimizu Corporation, Takenaka Corporation, Kajima Corporation, and Taisei Corporation. It is listed on the Tokyo Stock Exchange and is one of the Nikkei 225 corporations with headquarters in Minato-ku, Tokyo. In 2018, Obayashi was ranked 15th place on ENR's list of Top 250 Global Contractors, the highest rank among Japanese Contractors.

Established in 1892 in Osaka, Obayashi operates in Japan and other countries, especially Southeast Asia and Australia, as well as the USA and Europe. Major landmarks in Japan include the Kyoto Station Building and Tokyo Broadcasting System (TBS) Center in Tokyo, as well as the Tokyo Skytree. Obayashi has 86 subsidiaries and 26 affiliated companies in Japan, Europe, the Middle East, Asia, Australia and North America.

New Zealand and Japan have signed a Memorandum of Cooperation on hydrogen in an effort to no longer rely on fossil fuels. The cooperation agreement between New Zealand’s Ministry of Business, Innovation and Employment and Japan’s Ministry of Economy, Trade and Industry was signed in Tokyo on October 23rd by Minister Woods and Hiroshige Seko, Japan’s Economy, Trade and Industry Minister. A project to pilot the commercial production of hydrogen using renewable geothermal energy has been announced between Taupo-based Tuaropaki Trust and Obayashi Corporation, one of Japan's most successful construction companies. Tuaropaki Trust, the first privately owned electricity generator in New Zealand which opened the Mokai power station, near Taupo, in 2000, will enter into a new venture with Obayashi Corporation.

https://www.obayashi.co.jp/en/business/new_businesses.html

Osaka Gas

The Daigas Group revised its long-term management vision for 2030 in response to dramatic changes in the business climate mainly due to the full deregulation of the domestic Japanese energy market.

We are looking upon this change as an opportunity to become an innovative energy and service company that continues to be the first choice of customers. Our aim is to contribute to the advancement of society, communities, and customers by going beyond customer expectations and business boundaries and corporate boundaries. The company has an extensive domestic consumer business as well as an international business across the value chain for LNG utilisation. The company sells a containerised, modular process that converts methane (LNG) to hydrogen for use in households or refuelling stations.

https://www.osakagas.co.jp/en/index.html

Panasonic Corporation

Panasonic Corporation, formerly known as Matsushita Electric Industrial Co., Ltd. is a Japanese multinational electronics corporation headquartered in Kadoma, Osaka, Japan. The company was founded in 1918 as a producer of lightbulb sockets and has grown to become one of the largest Japanese electronics producers alongside Sony, Hitachi, Toshiba, Pioneer and Canon Inc. In addition to electronics, it offers non-electronic products and services such as home renovation services. Panasonic is the world's fourth-largest television manufacturer by 2012 market share.

https://na.panasonic.com/us/

Shimizu Corporation

Primary business components include contracting for building, civil engineering, machinery and other construction works as well as research, planning, study, evaluation, diagnosis, design, supervision, management and consultancy in connection with construction works. Regional development, urban development, ocean development, space development, resources and energy development, and environmental improvements and the like. Real estate purchase, sale, letting, brokerage, management, appraisal and consultancy as well as construction, sale, letting and caretaking of residential houses and other kinds of buildings and development and sale of land.

Shimizu developed the hydrogen energy utilization system jointly with the National Institute of Advanced Industrial Science and Technology (AIST). The system takes surplus electricity generated by solar power and other renewable energy sources, converts it into hydrogen, and stores it. It is then utilised for power generation as needed. For hydrogen storage, the system uses metal hydride tanks with the property of absorbing hydrogen up to 1,000 times its volume to ensure compact, safe hydrogen storage in buildings. Moreover, Shimizu Smart BEMS (Building Energy Management System) provides the technology to control the production, storage, and utilization of hydrogen, according to the status of renewable energy power generation and the demand for electricity and heat in buildings. The experimental system consists of solar power generation equipment (output of 20 kW), water electrolysis equipment (5 Nm3/h), a hydrogen storage device (approx. 40 Nm3), a fuel cell (output of 3.5 kW), and a storage battery (output of 10 kW). The system was designed specifically for use in a building with a floor space of around 1,000 m2.

https://www.shimz.co.jp/en/company/about/sit/topics/topics02/

Takenaka Corporation

Takenaka Corporation is one of the largest architecture, engineering, and construction firms in Japan. Its headquarters is located in Chūō-ku, Osaka. Takenaka has 8 domestic offices in Japan and overseas offices in Asia, Europe, and the USA.

http://www.takenaka.co.jp/takenaka_e/

The Hydrogen Energy Supply Chain (HESC)

The Hydrogen Energy Supply Chain (HESC) is a world-first pilot project to safely and efficiently produce and transport clean hydrogen from Victoria's Latrobe Valley to Japan. The project could potentially bring billions of dollars of international investment to Victoria and Australia, create a significant number of jobs across pilot and commercial phase construction and operations and position Australia as a global leader in the supply of clean hydrogen energy.

https://hydrogenenergysupplychain.com/

Tokyo Gas

Tokyo Gas engages in development of technology geared toward the establishment of infrastructure as well as advanced utilization of hydrogen that does not release CO2when consumed. Tokyo Gas is using its city gas pipeline network to build two types of hydrogen refuelling stations: on-site mother stations that produce hydrogen from city gas, and off-site daughter stations that are supplied with hydrogen from nearby on-site stations. Tokyo Gas aims to reduce costs and improve operational efficiency by maintaining higher capacity utilization of hydrogen production equipment during the early stages of development of the hydrogen refuelling station network.

Tokyo Gas is operating two on-site hydrogen refuelling stations in Senju (established in January 2016) and Urawa (established in February 2016), and one off-site station in Nerima (established in December 2014). The stations in Nerima and Urawa are commercial hydrogen refuelling stations that also double as Compressed Natural Gas refuelling Stations (CNG station). By sharing some facilities with the CNG station, we are able to reduce costs and operate the stations more efficiently.

https://www.tokyo-gas.co.jp/en/

Toshiba Corporation

Toshiba Corporation is a Japanese multinational conglomerate headquartered in Tokyo, Japan. Its diversified products and services include information technology and communications equipment and systems, electronic components and materials, power systems, industrial and social infrastructure systems, consumer electronics, household appliances, medical equipment, office equipment, and lighting and logistics.

In response to the requirements of varied and large-scale applications, Toshiba is striving to develop technologies that achieve higher efficiency while saving space. An example of this is the Alkaline Water Electrolysis Hydrogen Production System (AEC), which Toshiba has developed as an ideal solution for larger scale applications. Because its electrode substrate does not contain noble metals, the AEC is cheaper than other methods that use noble metals -- making it ideal for large-scale applications. This system can produce 100Nm3 H2 per hour, which is enough to power two fuel-cell vehicles. This mass-production system can be used in various applications involving hydrogen, such as stationary fuel cells, fuel-cell vehicles, and hydrogen generation.

https://www.toshiba-energy.com/en/hydrogen/index.htm

Toyota Motor Corporation (Hydrogen fuel cell)

In 2002, Toyota began a development and demonstration program to test the Toyota FCHV, a hybrid hydrogen fuel-cell vehicle based on the Toyota Highlander production SUV. Toyota also built a FCHV bus based on the Hino Blue Ribbon City low-floor bus. Toyota has built several prototypes/concepts of the FCHV since 1997, including the Toyota FCHV-1, FCHV-2, FCHV-3, FCHV-4, and Toyota FCHV-adv. The Toyota FCV-R fuel-cell concept car was unveiled at the 2011 Tokyo Motor Show. The FCV-R sedan seats four and has a fuel-cell stack, including a 70MPa high-pressure hydrogen tank, which can deliver a range of 435mi (700km) under the Japanese JC08 test cycle. The Toyota Mirai vehicle was launched in 2015.

In 2015, Toyota released 5,600 patents for free use until 2020, hoping to promote global development of hydrogen fuel-cell technology.

https://ssl.toyota.com/mirai/index.html

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