# Hydrogen as a Transport Fuel

## Location options for a freight-based limited initial deployment of hydrogen refuelling stations

Analysis prepared for the National Hydrogen Strategy

Bureau of Infrastructure, Transport and Regional Economics

October 2019

# Contents

# Summary

This paper presents an assessment of potential hydrogen refuelling station locations for an initial limited deployment of refuelling stations, primarily targeted at hydrogen-fuelled freight vehicles.

The analysis presented in this report was prepared by the Bureau of Infrastructure, Transport and Regional Economics (BITRE) at the request of the Department of Infrastructure, Transport, Cities and Regional Development's (DITCRD) Surface Transport Policy Division, to help inform consideration of a National Hydrogen Strategy.[1]

The paper first provides a brief overview of hydrogen and battery-electric vehicle technology, hydrogen refuelling station technology and a brief review of current domestic and international hydrogen-fuel vehicle initiatives. The paper then identifies several high volume road freight markets that could potentially be serviced by hydrogen fuelled trucks and the refuelling station locations that would be required to service the vehicles engaged in those tasks. The paper concludes with some recommendations as to broad potential hydrogen refuelling station locations that would be required to service the identified freight markets.

## Low-emission and hydrogen-fuelled vehicle technology

Zero- and low-emission vehicles (ZEV/LEVs) are vehicles that emit no or low exhaust emissions from the on-board power source(s). Electric-powered vehicles, either fuelled by on-board battery storage—battery electric vehicles (BEVs)—or generated from hydrogen-powered fuel cells (FCEVs), are currently the leading technology for ZEV/LEVs.

Both BEVs and FCEVs currently have higher fixed costs than internal combustion engine vehicles (ICEVs). However, operating costs are expected to become lower for both zero/low emission vehicles types than traditional ICEVs.

FCEVs and BEVs have the potential to serve complementary roles in Australia's road transport task. At the present time, FCEVs have advantages over BEVs in vehicle range, weight and refuelling times, and hence are likely to have an advantage in larger/heavier vehicle applications and in longer-distance operations. BEV's, in contrast, can be refuelled using the existing electricity network and are likely to have cost advantages in light vehicles and short distance applications.

There are currently a range of FCEV and BEV heavy trucks in development, by both major existing freight vehicle manufacturers (such as Freightliner, Kenworth and Volvo) and new entrants (e.g. Nikola and Tesla). Proposed commercialisation dates, range from as early as 2020–21 to 2022–23.

There are also a range of LEV/ZEV programs in Europe, California, China and Japan, among other countries, that are incentivising uptake of FCEVs directly or assisting with the provision of hydrogen refuelling infrastructure to encourage uptake of FCEVs.

## Hydrogen refuelling station location options

The analysis considers the hydrogen refuelling station requirements and location options for an initial limited deployment for two broad hydrogen-fuelled freight vehicle use cases:

- Long-distance inter-capital freight movements
- Urban freight operations.

1. See COAG Energy Council Hydrogen Working Group (https://www.industry.gov.au/about-us/what-we-do/coag-energy-council-hydrogen-working-group).

The selection of these two broad use cases was influenced by road freight volumes and partly by the technology demonstration potential of these two cases, particularly of the long-distance inter-capital option. In identifying refuelling station location options, the analysis has been purposely limited to broad geographic areas only (e.g. suburb or postcode level)—it was beyond the scope of this analysis, and would also be somewhat premature, to attempt to identify specific refuelling locations at any more detailed level.

## Long-distance intercapital freight refuelling station location options

Long-distance road freight volumes are highest between Sydney, Melbourne and Brisbane. In 2013–14, Sydney–Melbourne origin–destination road freight totalled 8.7 million tonnes (both directions), with an average of 1200 freight vehicle trips per day. Sydney–Brisbane road freight was 4.1 million tonnes, which involved an average 556 freight vehicle trips per day. And Melbourne–Brisbane road freight totalled 1.6 million tonnes, involving an average of 220 freight vehicle trips per day. There are also significant additional trucks operating in these corridors between other origin–destination pairs.

Australian capital cities are separated by long travel distances—over 800 kilometres in the cases of Sydney–Melbourne and Sydney–Brisbane, and over 1600 kilometres for Melbourne–Brisbane—hence the location of hydrogen refuelling station infrastructure in initial deployment would have to consider hydrogen freight vehicle range, with refuelling options available near trip origin and also available at one or more intermediate points along each corridor.

The origins and destinations of freight moving between these city pairs tend to be concentrated around several freight and logistics-intensive precincts in each city, which are obvious candidate locations for freight-related hydrogen refuelling stations, close to the start/end of freight trips.

Based on intercapital freight volumes and the origins/destination within each city, locations recommended for consideration as part of an initial hydrogen refuelling station deployment to service intercapital freight include:

*Sydney–Melbourne freight*

- Sydney metropolitan area: Eastern Creek, Wetherill Park, Prospect, Smithfield, Hoxton Park, Ingleburn, and/or Minto
- Melbourne metropolitan area: Western Melbourne: Laverton North, Brooklyn, Altona, Broadmeadows, Campbellfield, Somerton, Epping
- Intermediate locations:
  - Single station option: Tarcutta area
  - Multiple station options: Goulburn, Yass, Tarcutta, Albury-Wodonga, Wangaratta

*Sydney–Brisbane freight*

- Sydney metropolitan area: Eastern Creek, Wetherill Park, Prospect, Smithfield, Hoxton Park, Ingleburn, Minto, Hornsby, Mount Kuring-Gai, Somersby
- Brisbane metropolitan area: Carole Park, Darra, Wacol, Rocklea (Qld), Acacia Ridge, Battle Park, Loganholme, Yatala
- Intermediate locations:
  - Single station option: Near Nambucca Heads
  - Multiple station options: Taree, Port Macquarie, Coffs Harbour, Grafton

*Melbourne–Brisbane freight*

- Melbourne metropolitan area: Western Melbourne: Laverton North, Brooklyn, Altona, Broadmeadows, Campbellfield, Somerton, Epping
- Brisbane metropolitan area: Carole Park, Darra, Wacol, Rocklea (Qld), Acacia Ridge
- Intermediate locations: Shepparton-Mooroopna, Narrandera, Parkes, Narrabri, Goondiwindi, Toowoomba

There is considerable overlap in key urban freight centres involved in intercapital freight movements between Sydney, Melbourne and Brisbane, so refuelling infrastructure provided for one route would also service freight vehicle movements on other routes.

The recommended intermediate refuelling station locations include one or more refuelling sites distributed across each corridor. These recommended locations broadly match existing truck (diesel) refuelling station locations on these networks—the major fuel retailers each operate a network of truck refuelling stations around the country, to accommodate the varying needs of the freight industry. While a single intermediate hydrogen refuelling station rollout may satisfy range requirements, it might not satisfy all potential hydrogen freight vehicle users, and hence the initial deployment will need to consider the optimal number and location of intermediate refuelling stations necessary to meet the objectives of the program.

## Port-based short-haul freight refuelling station location options

Port-based freight movements are another large segment of the Australian freight task—in 2016–17, container volumes through Australia's capital city ports totalled around 7.7 million TEUs (twenty-foot equivalent units), with the majority carried to/from the port via road. A large fraction these containers' first/last movements is between the port and a distribution centre or customer within the greater capital city area.

Port-based hydrogen-fuelled freight vehicle operations would provide a *back-to-base* type example of hydrogen-fuelled freight vehicle operations. (California has plans to build hydrogen refuelling infrastructure to services freight movements between the Port of Long Beach and freight precincts at nearby Wilmington and Ontario (CA).)

The origin/destination locations for port-based containerised freight movements also tend to be concentrated around several freight and logistics-intensive industrial precincts in each city, and again it would appear to make sense to locate freight-related hydrogen refuelling stations near both the port and one or more of these areas.

Based on unpublished import container movements data, locations recommended for consideration as part of an initial hydrogen refuelling station deployment to service port-based container freight include:

*Sydney:* Port Botany, Eastern Creek, Wetherill Park, Prospect, Smithfield, Hoxton Park, Ingleburn, Minto.

*Melbourne:* Laverton North, Brooklyn, Altona, Broadmeadows, Campbellfield, Somerton, Epping

*Brisbane:* Port of Brisbane, Carole Park, Darra, Wacol, Rocklea (Qld), Acacia Ridge

Again, many of these locations overlap with urban locations that are significant origins and/or destinations for intercapital freight movements between Sydney, Melbourne and Brisbane, so hydrogen refuelling infrastructure provided for intercapital freight could also potentially service port-based container movements by hydrogen-fuelled trucks.

## Other considerations

Importantly, planning and zoning restrictions, dangerous goods regulations and proximity to other chemical and hazardous goods have not been explicitly considered in this analysis, except to the extent that prioritised freight refuelling station locations are likely to be most conveniently sited in commercial/light industrial areas, near freight logistics industry precincts. Further analysis, and a more extensive network of hydrogen refuelling stations would be required to encourage widespread commercial adoption of hydrogen fuel cells in freight operators.

# Chapter 1: Introduction

This paper presents an assessment of potential hydrogen refuelling station locations for an initial limited deployment of refuelling stations, primarily targeted at hydrogen-fuelled freight vehicles. The analysis presented in this paper culminates with suggestions as to places where hydrogen refuelling stations are likely to attract significant usage and foster uptake of hydrogen-fuelling vehicle technology in freight vehicles.

The paper has been prepared by the Bureau of Infrastructure Transport and Regional Economics (BITRE)[2], request of the Department of Infrastructure, Transport, Cities and Regional Development's (DITCRD) Surface Transport Policy Division, to help inform consideration of a National Hydrogen Strategy.

Generally, land transport refers to both road and rail segments, for the movements of passengers and freight. This paper focuses on the most likely usage of hydrogen in the heavy vehicle segments of the freight transport sector, as requested by the COAG Energy Council. The view being that demonstration trials and/or testing of mass-transit hydrogen fuelled vehicles are likely to be undertaken by state and territories, and battery-electric vehicles (BEVs) are likely to lead the light (passenger) zero emission vehicle segment.

The two principal technologies for using hydrogen in transport vehicles are hydrogen internal combustion (HIC) and fuel cell electric vehicles (FCEVs). The majority of hydrogen-related transport technology development today is in FCEVs. FCEVs may provide a number of opportunities within Australia's freight transport sector. This paper recommends two options for hydrogen refuelling stations in Australia:

1. Long distance, inter-city freight orientated transport; and
2. Short distance, intra-city heavy vehicle transport

This paper has been prepared on the basis that, at some time in the future:

1. Hydrogen becomes a technically feasible, if not fully commercially viable, transport fuel source in particular applications
2. Hydrogen prices, available volumes and production and storage locations are not insurmountable barriers to future commercial uptake
3. Proposed hydrogen-fuelled technologies for heavy vehicles will be available at their commercialisation dates.

This paper is structured as follows. Chapter 2 provides an overview of the rationale for pursuing low/zero emission vehicles. Chapter 3 provides a short overview and comparison of the principal low-emission transport technologies—battery electric vehicles (BEVs) and FCEVs. Chapter 4 outlines the alternative low-emission heavy vehicle transport technology options and the current state of research and development. Chapter 5 provides a short primer on hydrogen refuelling station technology. Chapter 6 provides an overview of the road freight task and highlights freight intensive origin and destination locations for two cases: i) long-distance inter-city freight movements and ii) short-distance port-based freight movements. Finally, Chapter 7 presents some candidate options for a limited-scale deployment of freight-specific hydrogen refuelling locations. Several appendices provide some additional supporting information.

2. The BITRE is part of the Department of Infrastructure, Transport, Cities and Regional Development, and provides economic analysis, research and statistics on infrastructure, transport and regional development issues to inform Australian Government policy development and wider community understanding.

# Chapter 2: Low emission transport vehicles

## 2.1 Why low emission transport vehicles?

As a signatory to the Paris Agreement, Australia is responsible for promoting a transition to net zero emissions. In the year to December 2018, the transport sector accounted for 18.9 per cent of Australia's national emission inventory, or 101.7 Mt C02-e out of Australia's total 538.2 Mt C02-e (Department of Environment and Energy 2019). Of this, road transport was responsible for 16 per cent of all emissions, with rail, sea and air transport accounting for 3 per cent.

With increasing uptake of renewable sources (solar, wind, hydro, etc.) reducing the emissions contribution of electricity generation and stationary energy production, the transport sector's proportionate contribution to Australia's carbon footprint is likely to attract greater future policy and regulatory scrutiny.

**Table 1: 'Unadjusted' annual emissions, by sector, for the year to December 2017 and 2018**

| Sector | 2017 | 2018 | Change |
|---|---|---|---|
| | (Mt CO2-e) | | (%) |
| Energy - Electricity | 185.5 | 178.9 | -3.5 |
| Energy – Stationary Energy Excluding Electricity | 97.0 | 102.8 | 6.0 |
| Energy – Transport | 99.0 | 101.7 | 2.8 |
| Energy – Fugitive Emissions | 55.4 | 58.1 | 4.9 |
| Industrial Processes and Product Use | 33.7 | 34.7 | 2.9 |
| Agriculture | 71.7 | 69.4 | -3.3 |
| Waste | 11.9 | 12.1 | 1.7 |
| Land Use, Land Use Change and Forestry | -19.5 | -19.5 | 0.4[a] |
| National Inventory Total | 534.7[b] | 538.2[b] | 0.7[b] |

a. Actual change is a small increase in net emissions of less than 0.1 Mt C02-e.
b All values are rounded, total is derived from full precision data.
Source: Department of Energy and Environment (2019).

## 2.2 Zero/low emission transport alternatives

Zero- and low-emission vehicles (ZEV/LEVs) are vehicles that emit no or low exhaust emissions from the on-board sources of power. Electric-powered vehicles, either fuelled by on-board battery storage—battery electric vehicles (BEVs)—or generated from hydrogen-powered fuel cells (FCEVs), are currently the leading technology for ZEV/LEVs. Both BEVs and FCEVs produce zero tailpipe emissions if the energy is produced from renewable sources. The emissions benefit is less, however, if carbon-based energy sources are used to produce the electricity or hydrogen used in these vehicles.

Both BEVs and FCEVs currently have higher fixed costs than internal combustion engine vehicles (ICEVs). However, vehicle operating costs are estimated to become lower for both zero/low emission vehicles types than for traditional ICEVs (Table 2). The potential for lower operating expenses may appeal to businesses seeking to reduce operating costs and increase productivity. Australian business purchasing behaviour reflects this trend with 63 per cent of total electric vehicles in 2017 being purchased by business.[3]

FCEVs and BEVs have the potential to server complementary roles in Australia’s road transport sector. Each of these emerging technologies have distinct comparative advantages and their short- to mid-term uptake in Australia should be based on specialist advantages in order to maximise potential usage benefits.

**Table 2: Comparative Costs of Fuel Sources**

| Vehicle | Fuel cost (per 100km) |
|---|---|
| Internal Combustion Engine | $15.4[a] |
| Fuel Cell Electric | $6.75[b] |
| Battery Electric | $5.40[c] |

a. Assumes 100 kilometres can be travelled with 10 litres of diesel and diesel price is $1.5 per litre.
b. Assumes 1 kilogram of hydrogen per 100 kilometres travelled and that one kilogram of hydrogen costs $6.75.
c. Assumes 18 kilowatt hours per 100 kilometres travelled at a market price of $0.3 per kilowatt.
Source: COAG Energy Council (2019).

## 2.3 Hydrogen fuel cell electric vehicles (FCEVs)

### Qualities of FCEVs

FCEVs have advantages in range and faster refuelling times over other zero/low emission vehicles. The use of hydrogen as a fuel source also provides considerable weight advantages over current battery technologies. For FCEVs increasing the range, requires increasing the size of the hydrogen tank, which has a low effect on total vehicle weight. This advantage is especially important for heavy vehicles, where under vehicle mass regulations each additional tonne of battery storage reduces the available freight payload by an equal amount, creating opportunity for operators to reduce freight costs per kilometre.[4]

Figure 1 provides a stylised view of the likely impact of vehicle size and typical travel distance on LEV technology choices, which highlights that FCEV’s are likely to have an advantage in larger/heavier vehicle applications—e.g. urban buses, rigid and articulated trucks—and vehicles travelling longer distances where refuelling times are critical.[5]

### Current and Future Usage in Australia

To date, hydrogen usage in the Australian transport sector has been confined to niche roles, such as forklifts and other on-site transport equipment. Most of the FCEV technology development activity is occurring overseas and hence Australia will likely be an importer of overseas vehicle technology standards.

Australia also currently lacks sufficient FCEV refuelling infrastructure to incentivise domestic take up of FCEVs. While the commercial benefits to operators are yet to be proven and the likely potential uptake remain uncertain, there is likely to be little commercial incentive to provide the necessary infrastructure to support a nascent FCEV market, and some assistance may be required to support the necessary refuelling infrastructure while the technology is maturing. Any uptake of light FCEVs in Australia is expected to be greater in

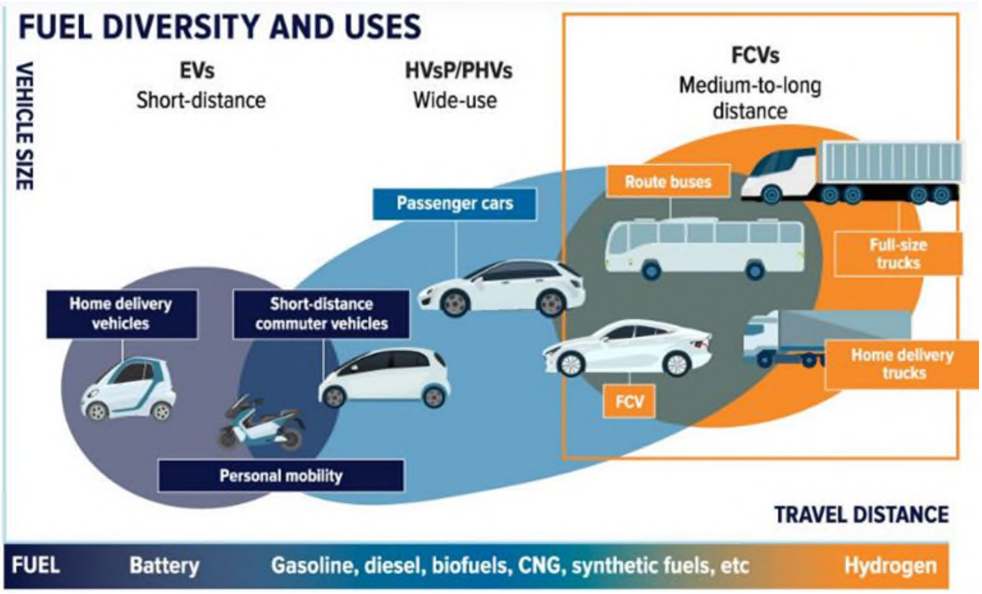
---

3. Climate Works Australia and the Electric Vehicle Council, ‘The State of Electric Vehicles in Australia’ 2018.
4. Earl et al. (2018) analyse the likely battery weight and range of battery electric trucks (BETs) and estimate a semi-trailer with 40 tonne gross vehicle mass (GVM) would require a 4.1 tonnes battery (lithium cobalt oxide) to provide the vehicle with an 800 kilometre journey range. Note that apart from Melbourne–Adelaide, Sydney-Canberra and Melbourne–Canberra, the journey distance for all other capital city pairs exceeds 800 kilometres.
5 For example, Nikola’s heavy truck models currently in development are specified to have a travel distance range of between 500 and 1200 kilometres and refuelling time of no more than 15 minutes (see Chapter 3).

specialist markets, such as government and business fleet sales as less, capital intensive, refuelling infrastructure is required.

Maturation of hydrogen fuel cell technology and greater availability of refuelling infrastructure will assist creating opportunity for hydrogen's utilisation in Australia's transport sector.

**Figure 1 Stylised view of LEV size and travel distance on power-source choice**




Source: Green Car Reports.

# Chapter 3: Heavy alternate fuel technology

This chapter provides a brief overview of current commercial research and development efforts in low/zero emission heavy vehicle technologies. The material attempts to compare and contrast available transport models, their specifications, expected time of commercialisation and any barriers that may affect their integration into Australia's heavy vehicle sector. The same traits and specialisation benefits outlined in Chapter 2 (weight, range and charging/refuelling accessibility) also apply for comparisons between BEV and FCEV heavy vehicles.

## 3.1 Low emission heavy truck technology

There is a wide range of alternative fuel technology development activity being undertaken in the heavy vehicle engine and truck manufacturing sector. For example, established heavy diesel engine manufacturers such as Cummins and Caterpillar have announced hydrogen fuel cell development initiatives[6], Toyota and Hyundai are also actively developing heavy FCEVs. There are also efforts to develop BEV technology for use in heavy vehicles.

Two relevant examples of heavy truck FCEV truck developments are Nikola and Toyota. Nikola is a start-up and catalyst of hydrogen fuel cell usage in heavy vehicles. The company is currently developing three heavy vehicle offerings—the *Nikola One*, *Nikola Two* and *Nikola Tre*—which it is aiming to commercialise by 2023. Toyota are currently partnering with Kenworth in developing 10 zero-emission T680s (a heavy-haul articulated truck prime mover) powered by hydrogen fuel cell electric powertrains, to be operational in the greater

6 Cummins is collaborating with Ceres Power to develop fuel-cell powered heavy vehicle engines, and Caterpillar and FuelCell Energy Inc. are cooperating on development of ultra-low emission Direct FuelCell (DFC(R)) power generation solutions for industrial and commercial use.

Port of Los Angeles region by the end of 2019. Table 4 lists heavy truck FCEVs currently under development.

Innovation is also occurring in adapting BEV technology for more effective usage in heavy trucks. Tesla, a market leader in light vehicles is currently developing the *Tesla Semi*—an entirely battery-electric heavy truck with proposed specifications that are pioneering for BEV technology. Table 5 lists some of the battery-electric heavy vehicles currently under development.

### Table 4: Heavy Truck FCEVs and Advertised Specs[7]

| Brand/Model | Commercialisation | Cost est. | Range | Horsepower | Torque | Charging Time |
|---|---|---|---|---|---|---|
| **Nikola: One** | 2022-23 | $375,000 | 800km -1200km | 1000 hp | 2700Nm | 15 minutes |
| **Nikola: Two** | 2022-23 | $375,00 | 800km -1200km | 1000 hp | 2700Nm | 15 minutes |
| **Nikola: Tre** | 2022-23 | $375,000 | 500km - 1200km | 1000 hp | 2700Nm | 15 minutes |
| **Kenworth: T680 (Toyota)** | 2019 (testing) | N/A | 480km | 670 hp | 1780Nm | N/A |
| **Hyundai/H2 Fuel Cell Electric Truck** | 2019-23 (testing) | N/A | 400km | N/A | 3,400Nm | 7 minutes |

### Table 5: Heavy Truck BEVs and Advertised Specs[8]

| Brand/Model | Commercialisation | Cost est. | Range | Horsepower | Charging Time |
|---|---|---|---|---|---|
| **Tesla: Semi** | 2020 | $215,000 - $260,000 | 480km – 800km | 1000 hp | 30 minutes |
| **Freightliner: eCascadier** | 2021 | N/A | Up to 400km | 730 hp | 2 hours |
| **Volvo: FE/FL Electric** | 2019 (limited release) | N/A | 200km-300km | N/A | 1.5 hours |
| **Freightliner eM2 106** | 2021 | $400,000 | 370km | 480 hp | 1.5 hours |
| **Isuzu FSR/NQR EV** | N/A | N/A | 250km/400km | 174hp/335hp | N/A |

7. Table 4 details FCEV technologies for heavy trucks at the time of writing, models in early development, or without comparable specifications have been excluded.
8. Table 5 lists BEV technologies for heavy trucks at the time of writing, models in early development or without comparable specifications have been excluded.

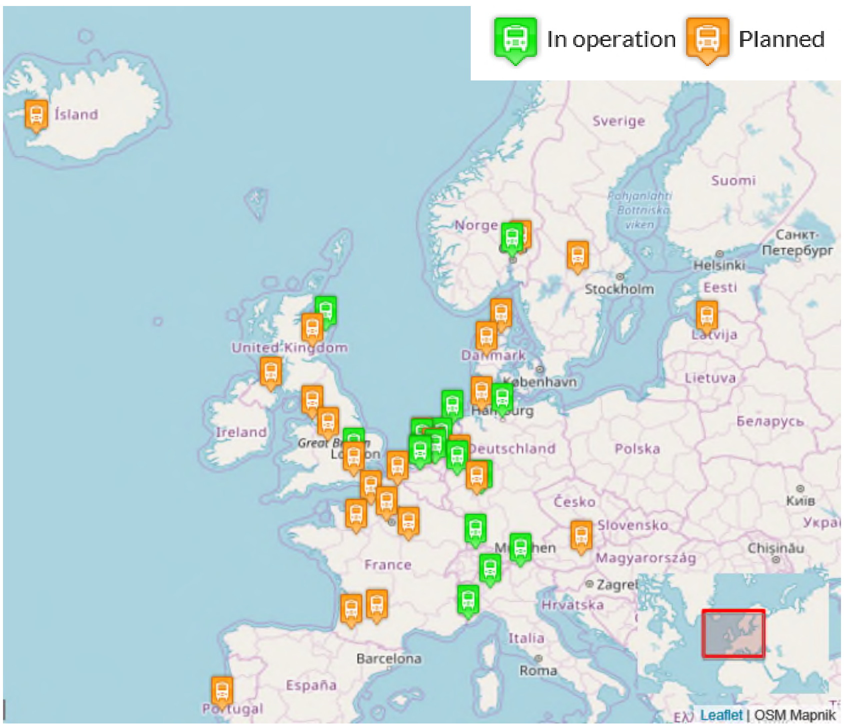
## 3.2 Low-emission public transport (mass transit) vehicle technology

Public transport (mass transit) vehicles operate on well-defined routes, helping make buses suitable for trialling and demonstrating alternate fuel technology. The use of alternate fuel technology on clearly-defined bus routes minimises the constraints that characterise both FCEVs and BEVs. For FCEVs, a clearly defined transport route minimises the expenditure required for refuelling infrastructure, to potentially one refuelling station located at each bus depot. Similarly, for battery electric buses, range restrictions may be potentially somewhat alleviated by being able to build re-charging into the regular schedule of operations.

Hydrogen fuel cell buses are being trialled and demonstrated in Europe, China and the United States. For example, in the United States there are fuel-cell bus demonstration projects in Boston (Massachusetts), San Francisco, Orange County and Thousand Palms (California), Canton (Ohio) and Flint (Michigan) (see Eudy and Post 2018). Transdev, the French-based public transport operator which operates bus services in Sydney, Melbourne, Brisbane and Perth, will be trialling hydrogen-powered buses in France and the Netherlands in late 2019 (Potter 2019). Though there are no current plans to trial hydrogen in Australia, this may provide an opportunity to introduce new technology into urban bus operations in the future.

Figure 2, below, shows the geographical extent of active FCEV public transit demonstrations either currently underway or planned in Europe (which includes the Transdev trials). In particular, there are multiple trials already underway in Germany, Switzerland, Italy, Belgium, the Netherlands and England (London), and trials planned also in France, Portugal, Austria, Northern Ireland and Iceland.

**Figure 2: European Fuel Cell Electric Bus Demonstrations**



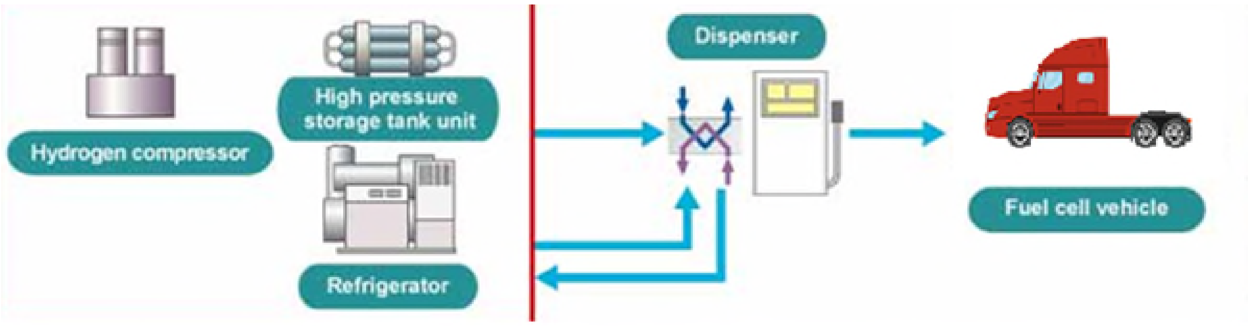

Source: Fuel Cell Electric Buses, knowledge base (https://www.fuelcellbuses.eu/).

# Chapter 4: Hydrogen refuelling station technology

Major progress has been made in the field of hydrogen delivery technologies, especially those for refuelling. Hydrogen delivery technologies and pathways, particularly hydrogen refuelling stations (HRSs), have been demonstrated and tested and are beginning to move toward readiness for initial HRS networks. The greatest challenge for scaling up HRS networks is business case design, which can be difficult due to the potentially long period of underutilisation of stations during the transition to a mass market (IEA & HIA 2015).

The level of hydrogen required by a vehicle dictates hydrogen storage and transportation, as well as general operational activity at the HRS. Monitoring should continue into the safety of HRSs to avoid potential incidents. Developments, both positive and/or negative in this space will be influential in dictating the delivery of HRSs in Australia.

Figure 3: Basic HRS Delivery Functions




## 4.1 Technical Specifications

The Society of Automotive Engineers specifies hydrogen refuelling standards for light vehicles, heavy vehicles and forklifts (Standards: J2601, J2601-2 and J2601-3). These protocols outline hydrogen temperature, pressure and maximum speed, among others during vehicle refuelling at HRSs (SAE 2014).

Overseas government expectations, supported by protocol SAE J2601, targets a refuelling time of three minutes per 5 kilograms of hydrogen (Ball et al. 2016). Assuming a 100 kilometre range per kilogram of hydrogen, this target equates to a 500 kilometre range from three minutes of refuelling time. This charging time is comparable to petrol and diesel refuelling times and significantly quicker than current BEV charging times.

The capacity of the pressurised tank used in an FCEV has considerable impacts on vehicle range. Increasing FCEV driving range requires increasing the size of the hydrogen tank, which has a low effect on total vehicle weight. Generally, a light vehicle will require 5 kilograms of hydrogen to fill its tank, for a heavy bus or truck this requirement can range from between 30 and 100 kilograms of hydrogen (Edwards, 2018).

Current HRS infrastructure allows for utilisation of up to 200 kilograms of hydrogen per day to meet small light FCEV requirements. This market-imposed cap on infrastructure capability meets the current market demand for light vehicles. However, manufacturers of HRS technology are able to address a fuelling demand for light vehicles of 500 kilogram of hydrogen per day and for heavy vehicles 1,500 kilograms of hydrogen per day. In order to meet the quantity of hydrogen demanded by Australia's heavy vehicle/freight transport segment, scaling up HRSs per day hydrogen capacity will be required.

## 4.2 Costs

Currently, the design and delivery of hydrogen refuelling stations are non-standardised. HRS manufacturers have individual specifications (piping, wiring, control panels, dispensers etc.) increasing costs and resulting in a lessening of system compatibility to other situations.

Standardisation of HRS specifications and interfaces will help reduce design and construction costs, shorten construction times and expand the flexibility of equipment combination (Ikeda 2018). The estimated cost of a HRS is estimated at between $2-3 million per station. Standardising the equipment required for HRS is expected to reduce costs by between $700,000 and $1.5 million per station (CSIRO 2018).

## 4.3 Location

There may also be opportunities to align hydrogen refuelling with hydrogen generation and networks to limit the costs associated with transporting hydrogen vast distances to HRS facilities. Co-location would assist creating downward pressure on price for HRS operators and FCEV users.

In order to fuel heavy FCEV vehicles, a mixture of production co-located to delivery and hydrogen transported via road networks to refuelling stations will be required.

# Chapter 5: FCEV developments

There are a wide range of FCEV initiatives already underway in Australia and around the world. This chapter provides a brief outline of domestic initiatives and some of the more notable activities occurring overseas.

## 5.1 Domestic initiatives

### Tests and Pilot Programs

Canberra will be the first Australian city to pilot a publicly-accessible hydrogen vehicle refuelling station. The project is being delivered following the ACT Government's decision to integrate 20 FCEVs into its vehicle fleet.[9] The refuelling station is scheduled to be completed by December 2019.

The West Australian Department of Planning and Infrastructure ran a trial of fuel cell passenger buses between 2004 and 2007. The trial tested three fuel cell public transit buses in the Transperth Fleet and concluded that performance, reliability and operations of the buses exceeded expectations. Fuel and refuelling infrastructure was the primary limitation.

### Proposed Hydrogen Highways

*Hydrogen Highways* describe roads equipped with an integrated network of HRSs to facilitate FCEV transport. Two Hydrogen Highways have been proposed for Australia, the first was the *Hume by Hydrogen* initiative proposed by Hyundai in 2014. The Hume by Hydrogen proposal would connect Australia's two largest capital cities over a distance of 880 kilometres. A second Hydrogen Highway, between Perth and Port Hedland on the Great Northern Highway and covering an estimated distance of 1,950 kilometres, was proposed in 2018. Neither of these proposals have proceeded past the conceptualisation phase.

9. The ACT Government initiative involves 20 new Hyundai Nexo FCEVs (at a cost of approximately $1 million) and a single hydrogen refueling station at Fyshwick.

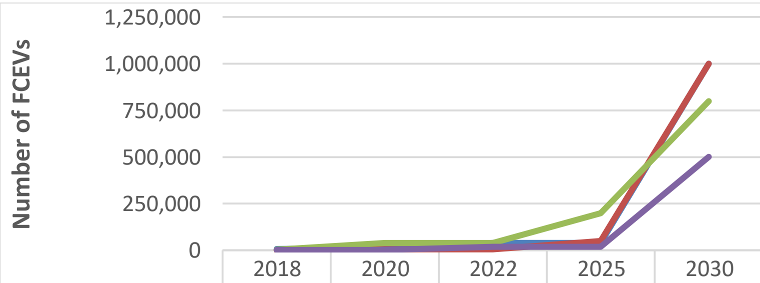
## 5.2 International initiatives

In addition to commercial research and development in FCEVs, there are also a wide range of public-sector initiatives occurring overseas to support FCEV uptake in international markets. Such initiatives have allowed for the rising number of FCEV adoptions discussed in the following passage.

The global FCEV stock reached 11,200 units at the end of 2018, with sales of around 4,000 vehicles in that year, representing an 80% increase in sales since 2017. Most of the sales continue to be Toyota Mirai cars in California, supported by the Zero Emission Vehicle (ZEV) mandate and expanding refuelling infrastructure. China's presence in FCEVs also expanded significantly in 2018, producing an estimated 2,000 small trucks.[10]

While adoption of FCEVs is low compared with BEVs across all markets, several countries have announced ambitious targets to 2030. Figure 4 and 5 outline the current FCEV markets in the United States, China, Japan and South Korea as well as the future national targets in each of these markets.

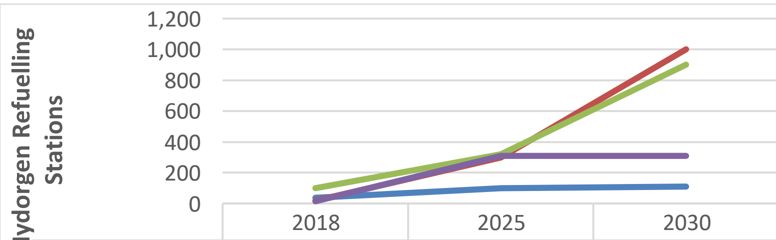
**Figure 4: National Targets for FCEVs (USA, China, Japan and South Korea)**




| | 2018 | 2020 | 2022 | 2025 | 2030 |
|---|---|---|---|---|---|
| USA | 5,900 | 13,000 | 40,000 | 40,000 | 1,000,000 |
| China* | 63 | 5,000 | 5,000 | 50,000 | 1,000,000 |
| Japan | 2,900 | 40,000 | 40,000 | 200,000 | 800,000 |
| South Korea | 900 | 900 | 20,000 | 20,000 | 500,000 |

Source: International Energy Agency

**Figure 5: National Targets for HRSs (USA, China, Japan and South Korea)**




| | 2018 | 2025 | 2030 |
|---|---|---|---|
| USA* | 38 | 100 | 110 |
| China | 20 | 300 | 1000 |
| Japan | 100 | 320 | 900 |
| South Korea | 14 | 310 | 310 |

Sources: International Energy Agency, Japan's Strategic Road Map for Hydrogen and Fuel Cells, the California Energy Commission and China's Hydrogen Fuel Cell Vehicle Technology Roadmap.

10. International Energy Agency 2019, Hydrogen: Tracking Clean Energy Progress. (Note the International Energy Agency reports the number of FCEVs in China for the year 2018 to be 63. Other reports suggest that this number to be higher.)

## Case Study - California

California is the leading FCEV market in the United States and first commenced incentivising zero emission vehicles in 1990 with a 2 per cent sales target for large vehicle manufacturers. The program has evolved over time and complementary policies have been introduced to support refuelling infrastructure.

In 2018 there were 4,411 FCEVs registered in California, 36 operating retail refuelling stations and 28 additional funded stations. In addition, seven bus operators are running a total of 25 active fuel cell electric buses along public transit corridors in California.

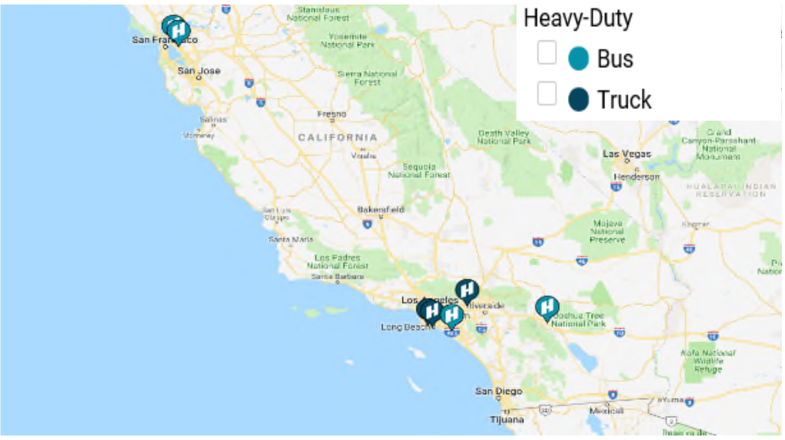
From 2020 onwards, freight transportation will become a focus of California's hydrogen initiatives. Three hydrogen refuelling stations are planned to be opened in 2020, designed specifically for heavy vehicle freight transport. This station network will span a length of almost 100 kilometres and connect primary freight terminals in Los Angeles. Table 6 lists the throughput of each freight terminal that will be connected to California's heavy FCEV refuelling network.

**Table 6: Major Freight Terminals in California 2018**

| | Port of Los Angeles | Port of Long Beach | Ontario International Airport |
|---|---|---|---|
| **Throughput** | 9,458,748 TEU | 8,091,021 TEU | 757,220 Cargo Tonnes |

Note: TEU – Twenty-foot equivalent unit container numbers.
Sources: Data provided by each terminals account of freight/cargo throughput for 2018.

**Figure 6: Hydrogen Heavy Refuelling Infrastructure Station Locations in California**




Source: California Fuel Cell Partnership.

# Chapter 6: Australian freight transport

This chapter outlines the size and scope of the Australian domestic freight transport task and identifies segments of the road freight task that might be suitable for and supportive of early uptake of heavy truck FCEVs.

## 6.1 Heavy vehicle fleet size and usage

There are approximately 500 thousand rigid trucks and 100 thousand articulated trucks on register across Australia (ABS 2018).[11] Rigid trucks are more suitable for inner city deliveries

11. Rigid trucks are motor vehicles with a gross vehicle mass greater than 3.5 tonnes, constructed with a load carrying area. Articulated trucks are motor vehicles comprising a prime mover with no significant load carrying area, but a turntable device which can be linked to one or more trailers.

of small volume freight, whereas articulated trucks are used more in long haul, high-volume freight transport.

Heavy trucks (greater than 4.5 GVM tonnes) dominate the rigid and articulated truck sectors. In 2018, heavy rigid trucks comprised 69 per cent of all rigid trucks—240 thousand trucks between 4.5 and 20 tonnes (i.e. less than 4.5 tonnes gross vehicle mass (GVM), and over 105 thousand rigid trucks above 20 tonnes GVM—while light rigid trucks (i.e. less than 4.5 tonnes GVM) comprised around 31 per cent (160 thousand) of all rigid trucks,. Of the 100 thousand articulated trucks, over 95 thousand are registered to over 40 tonnes gross combination mass (GCM) and 8 thousand to carry more than 100 tonnes GCM (see Table 7).

The number of rigid and articulated trucks on register have grown strongly in recent years, rigid trucks by of 2.7 per cent between 2017 and 2018 and articulated truck numbers by 2.6 per cent over the same period.

**Table 7: Rigid and articulated trucks on register, at 31 January 2018, by gross vehicle/combination mass**

| Rigid trucks | | Articulated trucks | |
|---|---|---|---|
| GVM | Vehicles | GCM | Vehicles |
| 4.5 and under | 158 032 | Over 3 to 20 | 959 |
| Over 4.5 to 8 | 77 539 | Over 20 to 40 | 4 523 |
| Over 8 to 12 | 95 460 | Over 40 to 60 | 36 157 |
| Over 12 to 20 | 67 960 | Over 60 to 100 | 50 723 |
| Greater than 20 | 106 007 | Greater than 100 | 8 332 |
| Total | 504 998 | Total | 100 694 |

Source: ABS (2018)

**Table 8: Rigid and articulated truck vehicle usage, 12 months ended 30 June 2018**

| Vehicle type | Total kilometres travelled | Number of vehicles | Average kilometres travelled | Fuel consumed | Rate of fuel consumption |
|---|---|---|---|---|---|
| | (million km) | (no.) | ('000 km) | (ML) | (L/100 km) |
| Rigid trucks | 10 274 | 495 039 | 20.8 | 2 939 | 28.6 |
| Articulated trucks | 7 917 | 99 705 | 79.4 | 4 369 | 55.2 |

Source: ABS (2019).

Table 8 shows the total and average vehicle utilisation and fuel use of rigid and articulated trucks in the 12 months to 30 June 2018.[12] Rigid trucks travelled a combined 10.3 billion vehicle kilometres in 2017–18 (approximately 20 800 kilometres per vehicle) and consumed approximately 2.9 billion litres of (primarily diesel) fuel (approximately 5900 litres per vehicle per year). Articulated trucks travelled a total 7.9 billion vehicle kilometres in 2017–18 (approximately 79 400 kilometres per vehicle) and consumed approximately 4.3 billion litres of (primarily diesel) fuel (approximately 43800 litres per vehicle per year).

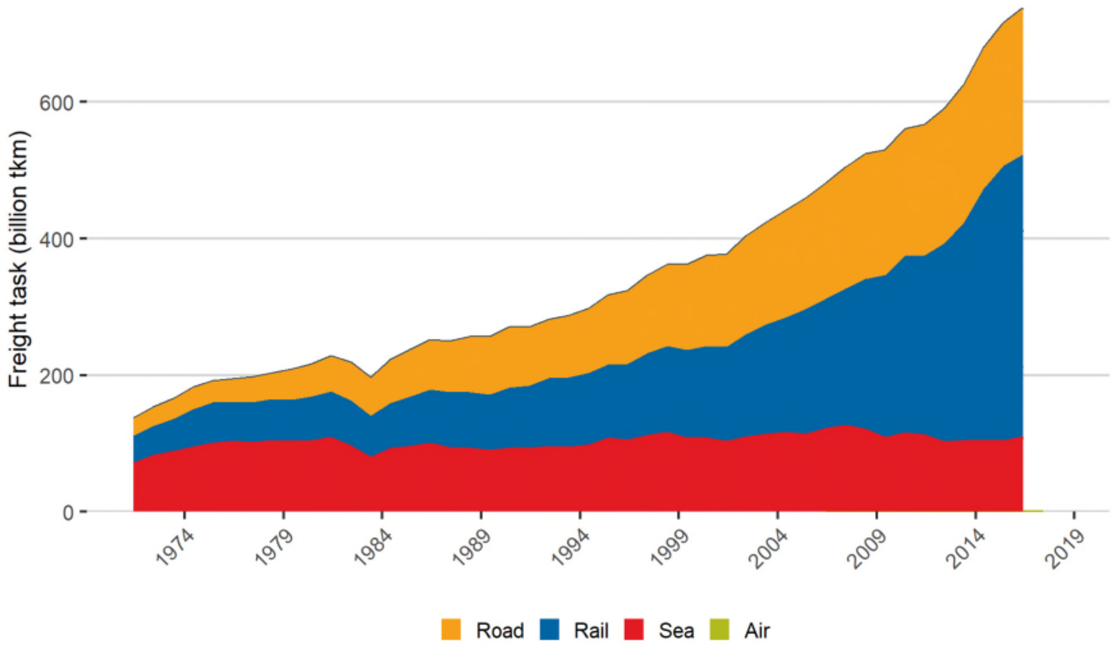
12. Note that the total number of registered rigid and articulated trucks difference slightly between Tables 7 and 8—Table 7 reports the number of vehicles on register at a point in time, whereas Table 8 reports the average number of vehicles on register across the 12 months to 30 June 2018.

## 6.2 Overview of Australian freight transport

In 2015–16, the domestic freight task totalled approximately 738 billion tonne kilometres, which is equivalent to about 30 500 tonne kilometres of freight moved for every person in Australia.[13] Rail transport accounts for approximately 56 per cent of total domestic freight, road freight about 29 per cent and coastal sea freight around 15 per cent. Air freight comprises less than 0.001 per cent of total freight by weight (see Figure 7).

Figure 7 also shows the size of the Australian road, rail, coastal shipping and air freight task since 1971. Road freight has grown seven-fold over that time, from around 25 billion tonne kilometres in 1971 to around 214 billion tonne kilometres in 2016. Rail freight has grown more than nine-fold, from around 40 billion tonne kilometres in 1971 to around 414 billion tonne kilometres in 2016. Coastal shipping volumes have grown approximately 50 per cent since 1971, from around 72 billion tonne kilometres in 1971 to around 110 billion tonne kilometres in 2016. Air freight, which is several orders of magnitude smaller than either road, rail and sea freight, have grown from around 90 million tonne kilometres in 1971 to around 330 million tonne kilometres in 2016.

**Figure 7: Domestic freight task, 1971–2017**




Sources: ABS (2019), BITRE (2018) and BITRE estimates.

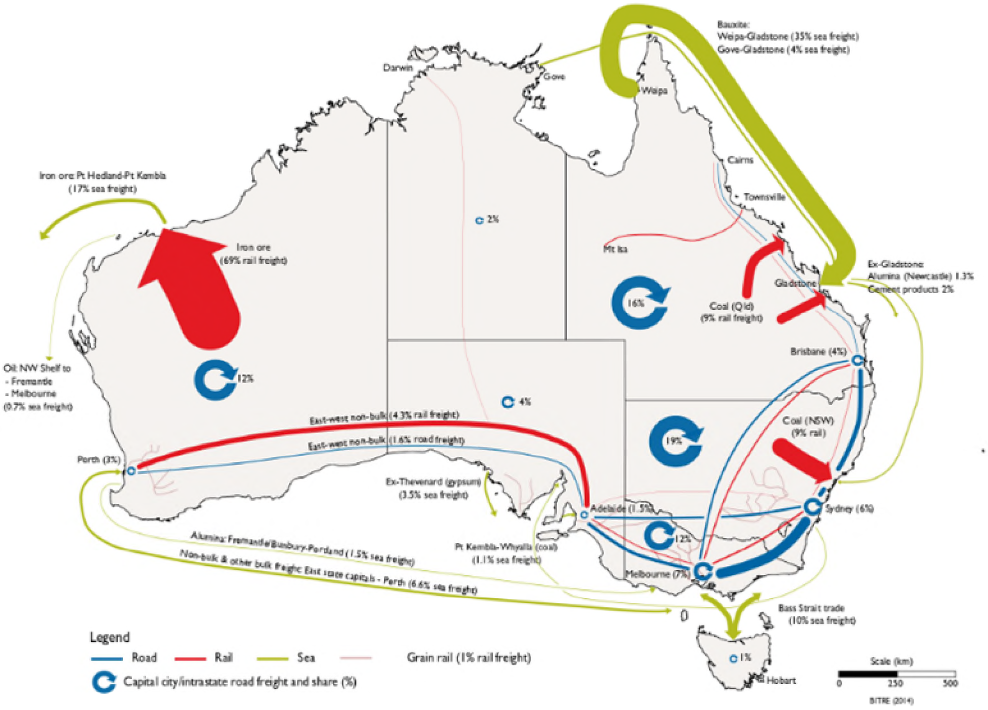
### Movement of freight in Australia

The Australian freight task is also quite diverse and encompasses the movement of bulk export commodities, such as iron ore, coal liquefied natural gas (LNG), grains, the transport of imported motor vehicles, machinery and other manufactured goods, and the transport of finished products for household consumption through distribution centres to retail outlets.

Figure 8 provides a stylistic representation of the major elements of Australian freight movements in 2015-16.

13. One tonne kilometre is equivalent to one tonne moved one kilometre.

### Figure 8: Major freight flows in Australia, 2015-16




Note: Line width shows relative freight volume (tonnes). Share estimates related to freight tonne kilometres.
Source: ABS (2019), BITRE (2018) and BITRE estimates.

## Road freight

While rail carries a larger volume of freight overall, road transport is the main mode of transport for the majority of commodities produced and/or consumed in Australia. Among the notable facts about road freight in Australia:

- Road freight in capital cities accounted for over one fifth of total road freight in Australia in 2015–16, with road freight in other urban areas outside capital cities comprising a further 10 per cent. Inter-capital road freight accounts for approximately 18–19 per cent of total freight movements. The remaining, approximately 50 per cent, comprises freight transported between capital cities and regional areas and other inter-and intrastate freight.
- Over 95 per cent of Australia's road freight is carried in heavy vehicles (i.e. vehicles weighing 4.5 tonnes or more). Articulates trucks account for around 78 per cent and heavy rigid trucks approximately 18 per cent of total road freight, and these shares are little changed over the last decade or so (ABS 2013).
- B-double heavy vehicle combinations are now the most significant road freight vehicle combination, accounting for around 45 per cent of total road freight in 2015–16.

Figure 9 illustrates where road freight moves across the road network, showing road freight volumes across the non-urban transport network in 2013-14—the last time a comprehensive survey of regional road freight movements was undertaken across Australia. The figure highlights the significance of road freight volumes particularly on the Hume Highway (Sydney-Melbourne), Pacific Highway (Sydney-Brisbane) and Newell Highway (Melbourne-Brisbane).

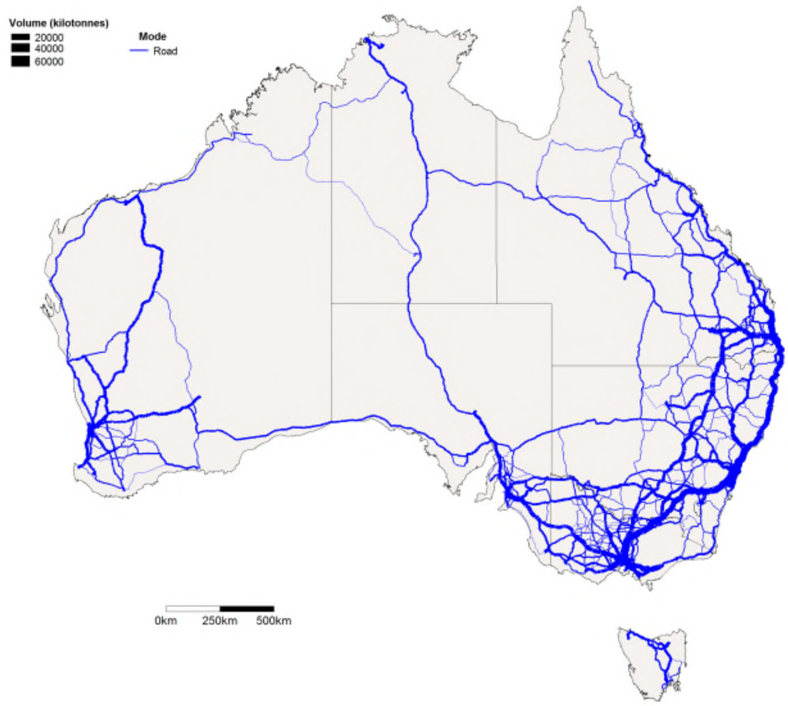
If a long-distance road haul operation were considered for an early trial, then based on freight volumes, Sydney–Melbourne (and nearby centres), Sydney–Brisbane and/or Melbourne–Brisbane are the most heavily trafficked intercapital freight routes. In 2013–14, road freight between Sydney and Melbourne totalled 8.7 million tonnes (both directions), 4.1 million tonnes between Sydney and Brisbane and 1.6 million tonnes between Melbourne and Brisbane (see Table 9). This is equivalent to around 1200 one-way vehicle trips per day Sydney–Melbourne, 550 vehicle trips per day Sydney–Brisbane and 220 vehicle trips per day Melbourne–Brisbane. For reference, the average number of trucks on the Hume Highway between Sydney and Melbourne was around 3970 vehicles per day in 2013–14, 2018 trucks per day on the Pacific Highway/Motorway between Sydney and Brisbane and 898 trucks per day on the highways connecting Melbourne and Brisbane.

**Table 9 Intercapital road freight volumes & distances**

| Intercapital route | Intercapital freight | Implied truck trips | Corridor average trucks trips | Route distance |
|---|---|---|---|---|
| | (Mt) | (vehicles per day) | | (km) |
| Sydney–Melbourne | 8.72 | 1196 | 3974 | 832 |
| Sydney–Brisbane | 4.06 | 556 | 2018 | 914 |
| Melbourne–Brisbane | 1.61 | 221 | 898 | 1684 |
| Melbourne–Adelaide | 2.81 | 385 | 1833 | 727 |

Sources: ABS (2015), BITRE (2016) and BITRE estimates.

**Figure 9: Intercapital and interregional road freight task, 2013-14**




Sources: ABS (2015) and BITRE estimates.

All three routes are more than 800 kilometres in length, necessitating one or more driver rest stops[14] (or driver change) to complete a one-way journey, during which time the truck could

14. Under standard work and rest requirements, truck drivers must not work for more than: i) 5 ¼ hours (in 5 ½-hour period) without a 15 minute continuous rest break; ii) 7 ½ hours (in 8-hour period) without 30 minutes rest (in 15-minutes blocks); and iii) 10 hours (in 11-hour period) without 60 minutes rest (in 15-minutes blocks) (See https://www.nhvr.gov.au/safety-accreditation-compliance/fatigue-management/work-and-rest-requirements for further details.)

be refuelled. In terms of range, both Sydney–Melbourne and Sydney–Brisbane are within the nominal maximum range of the planned Nikola Two (750–1200 km range).

Melbourne–Adelaide, is a shorter intercapital route (approximately 727 kilometres), and accounted for around 2.8 million tonnes of freight in 2013–14, and 385 one-way truck trips per day, and could provide an alternative long-distance route option.

## 6.3 High-volume intercapital freight origins/destinations

If one were to assist implementation of hydrogen refuelling infrastructure to support long distance freight haulage, where might the most appropriate locations to site such stations? Each of the major capital cities has multiple commercial freight intensive precincts. These include, but are not limited to:

- Sydney: Port Botany, Mascot-Alexandria, Wetherill Park, Smithfield, Moorebank, Ingleburn, and Minto
- Melbourne: Port of Melbourne, Altona-Laverton, Somerton, Dandenong and Knoxfield
- Brisbane: Port of Brisbane, Acacia Ridge, Carole Park, Yatala, Carinya Park
- Adelaide: Port Adelaide, Keswick, Wingfield, Dry Creek, Salisbury, Lonsdale.

### Sydney–Melbourne

Table 10, below and Appendix Figure A.1, show the top 10 SA3 region pairs in terms of origin-destination road freight movements between Sydney and Melbourne in 2013-14. Movements to and from Sydney Inner City SA3 and Melbourne City SA3 are predominant.[15] Other key intercapital freight nodes include the commercial/industrial areas in inner and outer western Sydney—Burwood, Liverpool, Fairfield, Mount Druitt SA3s, and Wyndham, Broadmeadows and Hobsons Bay SA3s in Melbourne.

**Table 10: Sydney–Melbourne origin–destination road freight in 2013-14 by SA3 areas**

| Sydney SA3 | Melbourne SA3 | Freight (Mt) | Syd-Mel freight share (%) |
|---|---|---|---|
| Sydney Inner City | Melbourne City | 1.207 | 18.1 |
| Mount Druitt | Tullamarine - Broadmeadows | 0.977 | 14.6 |
| Strathfield - Burwood - Ashfield | Wyndham | 0.588 | 8.8 |
| Liverpool | Wyndham | 0.348 | 5.2 |
| Sydney Inner City | Wyndham | 0.326 | 4.9 |
| Fairfield | Tullamarine - Broadmeadows | 0.317 | 4.7 |
| Fairfield | Hobsons Bay | 0.273 | 4.1 |
| Sydney Inner City | Hobsons Bay | 0.242 | 3.6 |
| Mount Druitt | Hobsons Bay | 0.231 | 3.5 |
| Parramatta | Brimbank | 0.180 | 2.7 |

Sources: ABS (2015) and BITRE estimates.

15. While these inner city regions include some commercial/industrial areas (e.g. Mascot-Alexandria in Sydney Inner City and the Port of Melbourne in Melbourne City), the response appears to be somewhat influenced by survey respondent burden-minimising behaviour (i.e. using shorthand 'Sydney' and/or 'Melbourne' in responses for trips to and/or from some area within Sydney and/or Melbourne and not necessarily Sydney Inner City or Melbourne City specifically).

This analysis does not provide sufficient granularity to make any detailed recommendations about re-fuelling site locations to service the Sydney–Melbourne intercapital freight market, but does provide some broad indications about more significant freight locations in each city. Not surprisingly, these freight-intensive areas lie along Western Ring Road in Melbourne, from the Port of Melbourne out around to Laverton, Derrimut and Tullamarine and Broadmeadows. In Sydney, the freight intensive locations lie along the M5 and M7 Freeways.

Provision of intermediate refuelling sites along the route would depend on resources, hydrogen vehicle uptake and expected utilisation. BITRE has also recently been processing truck GPS telematics data from a small number of road freight firms, and has derived vehicle trip routes and stops. Inspection of Figure 10 shows that trucks can and do stop across a wide number of truck stops and fuel service centres across the corridor. Stop locations do appear concentrated within approximately the middle third of the route—roughly between Yass and Albury in New South Wales. A one intermediate station option would be best placed approximately near half-distance (near Tarcutta, New South Wales). A multiple intermediate hydrogen refuelling station option might also consider locations near Yass and Albury–Wodonga.

Figure 10 also shows freight trip start/end locations, which though from only a narrow set of freight operators, broadly confirms the findings suggested by the freight movement survey data, and highlight the freight significance of commercial/industrial locations in western Sydney and Laverton, Broadmeadows and Dandenong in Melbourne.

**Figure 10: Vehicle GPS-based Sydney–Melbourne truck trips and stops**


Sources: BITRE based on available road freight operator data.

## Sydney–Brisbane

Table 11, below, and Appendix Figure A.2, show the top 10 SA3 region pairs in terms of origin-destination road freight movements between Sydney and Brisbane in 2013–14. Again, movements to and from Sydney Inner City SA3 and Brisbane Inner SA3 account for the largest share of all intercapital freight between these two cities, which may again reflect some response issues in the survey—in particular, Brisbane Inner SA3 appears to have few commercial/industrial precincts or operations. Other key freight nodes for intercapital freight between Sydney and Brisbane include commercial/industrial areas in inner and outer western Sydney—Fairfield, Mount Druitt, St Mary's, and Strathfield SA3s, and in Brisbane Rocklea - Acacia Ridge and Wynnum-Manly, which encompasses the Port of Brisbane.

**Table 11: Sydney–Brisbane origin–destination road freight in 2013-14 by SA3 areas**

| Sydney GMA SA3s | Brisbane GMA SA3s | Freight (Mt) | Syd-Bne freight share (%) |
|---|---|---|---|
| Sydney Inner City | Brisbane Inner | 0.715 | 22.9 |
| St Marys | Rocklea - Acacia Ridge | 0.537 | 17.2 |
| Sydney Inner City | Rocklea - Acacia Ridge | 0.186 | 5.9 |
| Wyong | Brisbane Inner | 0.180 | 5.8 |
| Fairfield | Rocklea - Acacia Ridge | 0.171 | 5.5 |
| Campbelltown (NSW) | Wynnum – Manly | 0.150 | 4.8 |
| Mount Druitt | Wynnum – Manly | 0.128 | 4.1 |
| Strathfield - Burwood - Ashfield | Rocklea - Acacia Ridge | 0.122 | 3.9 |
| Mount Druitt | Forest Lake - Oxley | 0.111 | 3.5 |
| Sydney Inner City | Ipswich Hinterland | 0.109 | 3.5 |

Sources: ABS (2015) and BITRE estimates.

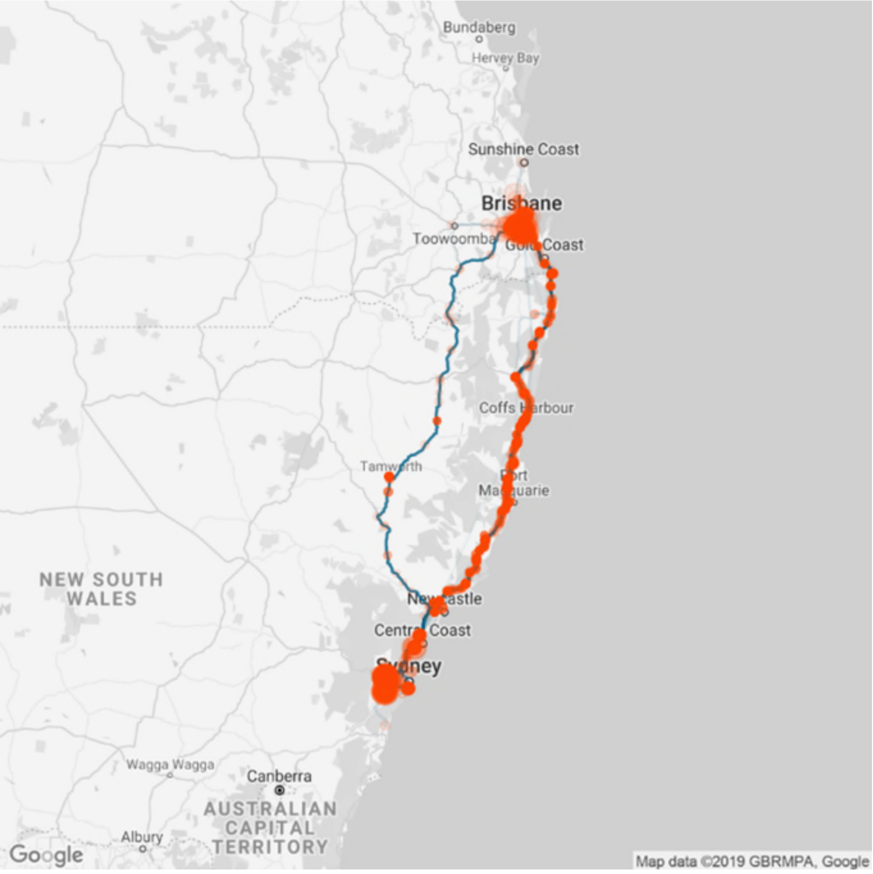
Unlike Sydney–Melbourne, where there is generally a single freight access corridor that connects between the major freight locations in each city and services the intercapital freight movements between the two cities, in the case of Sydney–Brisbane road freight the major freight locations in Brisbane are quite geographically dispersed and, at first blush, would require multiple refuelling sites in Brisbane to conveniently meet industry's needs.

Similarly, in Sydney, the most likely optimal route for freight heading north from around Port Botany and surrounds is likely to be via the M1/A1 (Pacific Highway) before joining the Pacific Motorway, and the most convenient route for freight coming from or going to outer Western Sydney will be via the M7/M2 to the Pacific Motorway. Again, this is likely to required require multiple refuelling sites in different part of Sydney to conveniently meet industry's needs.

Again, provision of intermediate refuelling sites along the route would depend on resources, hydrogen vehicle uptake and expected utilisation. Figure 11 shows freight routes and stops for freight vehicle trips between Sydney and Brisbane. Immediately apparent is that there are two main alternative routes for Sydney–Brisbane origin–destination trips—i) via the coast on the Pacific Motorway/Highway and ii) inland via the New England Highway.

There are far fewer trips on the inland corridor route and fewer stops—the most common stop locations in the sample are at Tamworth and near Armidale. There are many stop locations on the coastal route, all along the entire route. Again, there appears to be a high concentration of stops in the middle third of the route, between Taree and Grafton. A single intermediate refuelling station option might be best placed near half-distance, which is around Nambucca Heads, New South Wales. A multiple intermediate hydrogen refuelling station option might also consider locations near Taree and Grafton.

**Figure 11: Vehicle GPS-based Sydney–Brisbane truck trips and stops**




Source: BITRE based on available road freight operator data.

## Melbourne–Brisbane

Table 12, below, and Appendix Figure A.3, show the top 7 SA3 region pairs in terms of origin-destination road freight movements between Melbourne and Brisbane in 2013-14. The two largest SA3-level origin–destination freight volume movements, between Wyndham–Rocklea - Acacia Ridge and inner Melbourne and inner Brisbane each accounted for around 300 thousand tonnes of freight. Other key freight nodes for intercapital freight between Melbourne and Brisbane include Brimbank (west) and Frankston (southeast) in Melbourne and Forest Lake (southwest) and Wynnum – Manly (Port of Brisbane) in Brisbane.

Figure 12, below, shows GPS-based freight trip start/end and intermediate vehicle stop locations, which, though not immediately obvious from the scale, broadly reinforces the findings suggested by the freight movement survey data—i.e. highlighting the significance of commercial/industrial locations in western and south east Melbourne and southwest Brisbane and the Port of Brisbane for Melbourne–Brisbane origin–destination freight.

Like the case of Sydney–Brisbane, there are two main alternative (almost equidistant) routes between Melbourne and Brisbane—i) inland via the Newell Highway and ii) via Sydney using the Hume and Pacific Freeway/Highways. Again, the provision of intermediate refuelling sites along the route would depend on resources, hydrogen vehicle uptake and expected utilisation. The distance, approximately 1700 kilometres, would likely require more than at least two or three intermediate refuelling stations on one or both routes.

**Table 12: Melbourne–Brisbane origin–destination road freight in 2013-14 by SA3 areas**

| Melbourne SA3 | Brisbane SA3 | Freight (Mt) | Syd-Mel freight share (%) |
|---|---|---|---|
| Wyndham | Rocklea - Acacia Ridge | 0.299 | 30.6 |
| Melbourne City | Brisbane Inner | 0.298 | 30.5 |
| Frankston | Forest Lake - Oxley | 0.120 | 12.3 |
| Monash | Rocklea - Acacia Ridge | 0.095 | 9.8 |
| Melbourne City | Wynnum - Manly | 0.063 | 6.5 |
| Brimbank | Rocklea - Acacia Ridge | 0.055 | 5.6 |
| Melbourne City | Narangba - Burpengary | 0.046 | 4.7 |

Sources: ABS (2015) and BITRE estimates.

**Figure 12: Vehicle GPS-based Melbourne–Brisbane truck trips and stops**


Source: BITRE based on available road freight operator data.

## Melbourne–Adelaide

Table 13, below and Appendix Figure A.4, show the top 10 SA3 region pairs for origin-destination road freight movements between Melbourne and Adelaide in 2013–14. The two largest SA3-level origin–destination freight volume movements between Brimbank–Port Adelaide – West and Melbourne and Adelaide City, were around 870 and 670 thousand tonnes, respectively. Freight volumes for all other Melbourne–Adelaide SA3 area pairs were concentrated in the northern and western industrial areas of each city and were less than 100 thousand tonnes per annum.

**Table 13: Melbourne–Adelaide origin–destination road freight in 2013-14 by SA3 areas**

| Melbourne SA3 | Brisbane SA3 | Freight (Mt) | Syd-Mel freight share (%) |
|---|---|---|---|
| Brimbank | Port Adelaide - West | 0.874 | 38.6 |
| Melbourne City | Adelaide City | 0.665 | 29.4 |
| Hobsons Bay | Salisbury | 0.109 | 4.8 |
| Dandenong | Salisbury | 0.093 | 4.1 |
| Melbourne City | Salisbury | 0.088 | 3.9 |
| Casey - North | Port Adelaide - West | 0.082 | 3.6 |
| Hobsons Bay | Port Adelaide - West | 0.074 | 3.3 |
| Melton - Bacchus Marsh | Salisbury | 0.070 | 3.1 |
| Wyndham | Port Adelaide - West | 0.060 | 2.7 |
| Wyndham | Salisbury | 0.060 | 2.6 |

Sources: ABS (2015) and BITRE estimates.

BITRE does not currently have comparable GPS telematics data for Melbourne–Adelaide freight trips and stops, however based on route distance it is provision for hydrogen fuelled vehicles is likely to require at least one intermediate refuelling stations along the main road freight route (Western and Dukes Highways) between the two cities.

## 6.4 Port-based urban heavy vehicle transport

The second set of potential hydrogen refuelling scenarios considered are a set of urban *back-to-base* type operations involving movement of containers to and from the port in each of Sydney, Melbourne and Brisbane. Container volumes through Australian ports totalled around 7.7 million TEUs (twenty-foot equivalent units) in 2016–17, with the majority carried to/from the port by road freight vehicles.

The estimates are based on unpublished Department of Home Affairs custom declarations for import consignments for calendar 2017.[16]

### Sydney import containers

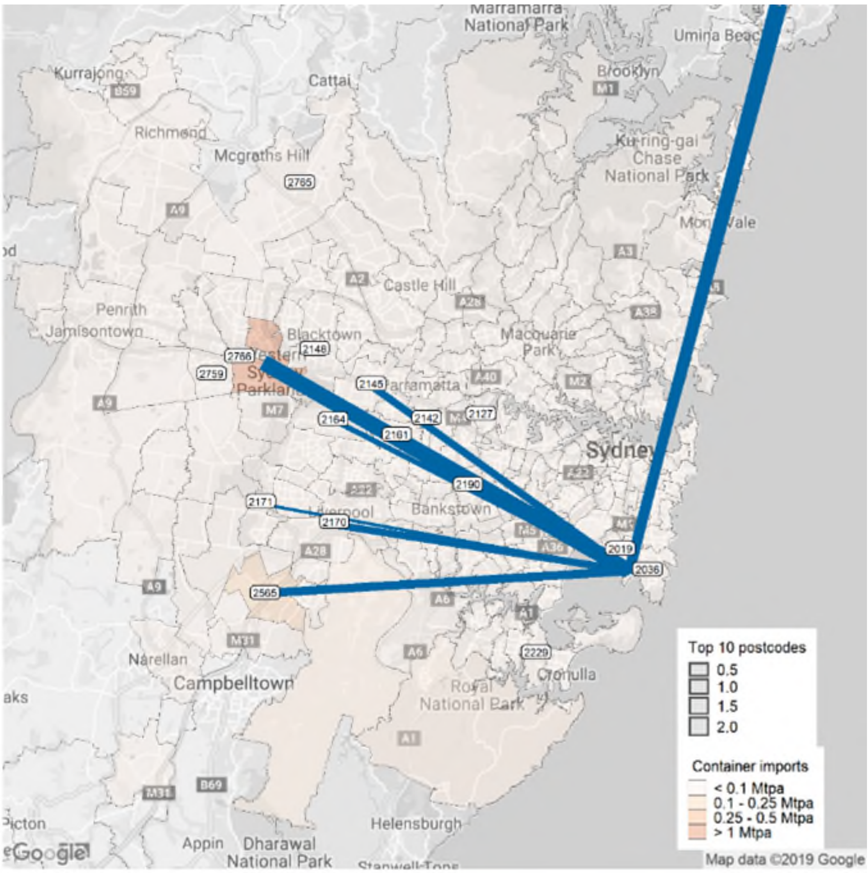
Figure 13 shows the density of import container movements from Port Botany to the first delivery postcode, for containers first destined within the Sydney Greater Metropolitan Area, including the top 8–10 destinations, and Table 14 lists the top 8 destination postcodes and some of the commercial/industrial suburbs overlapping with those postcode areas.

The top Sydney import container destination postcode is 2766, which covers some major industrial/commercial suburbs in outer western Sydney, such as Eastern Creek, Erskine Park, Glendinning, Huntingwood, Horsley Park, Minchinbury and Prospect (NSW). Other major import container destinations include postcodes covering other major industrial areas, such as Ingleburn, Minto, Campbelltown, Yennora, Ingleburn, Smithfield (NSW), Wetherill Park, Revesby, Chipping Norton, among others.

16. Note the raw customs data contains errors of unknown magnitude. While BITRE has taken steps to correct for obvious raw data errors, some may still remain and hence the estimates here are subject to revision.

While an increasing share of container movements may in the future be moved by rail direct from the port, road freight vehicles are still likely to account for the majority of port-based container movements. The location of refuelling stations to service a fleet of hydrogen-powered trucks dedicated to import/export freight movements within the Sydney Greater Metropolitan Area, could comprise a few as two sites, one at Port Botany and another located in outer western Sydney. This appears to be the California strategy outlined in Chapter 5.

**Figure 13: Sydney import container volumes by postcode and top 8-10 destination postcodes, 2017**




Source: BITRE based on unpublished customs data.

**Table 14: Top 8 first destination postcodes and suburbs for Sydney import containers, 2017**

| Rank | Postcode | Commercial/industrial suburban coverage |
|---|---|---|
| 1 | 2766 | Eastern Creek, Erskine Park, Horsley Park, Glendinning, Huntingwood, Minchinbury, Pemulwuy, Prospect (NSW) |
| 3 | 2565 | Ingleburn, Leppington, Minto |
| 3 | 2145 | Smithfield (NSW), Wetherill Park |
| 4 | 2170 | Bankstown Aerodrome, Lansvale, Liverpool, Moorebank, |
| 5 | 2036 | Banksmeadow, Chifley (NSW), Port Botany |
| 6 | 2164 | Horsley Park, Smithfield (NSW), Wetherill Park, Yennora |
| 7 | 2161 | Smithfield (NSW), South Granville, Yennora |
| 8 | 2171 | Hinchinbrook (NSW), Hoxton Park, West Hoxton |

Sources: BITRE estimates based on unpublished customs data.

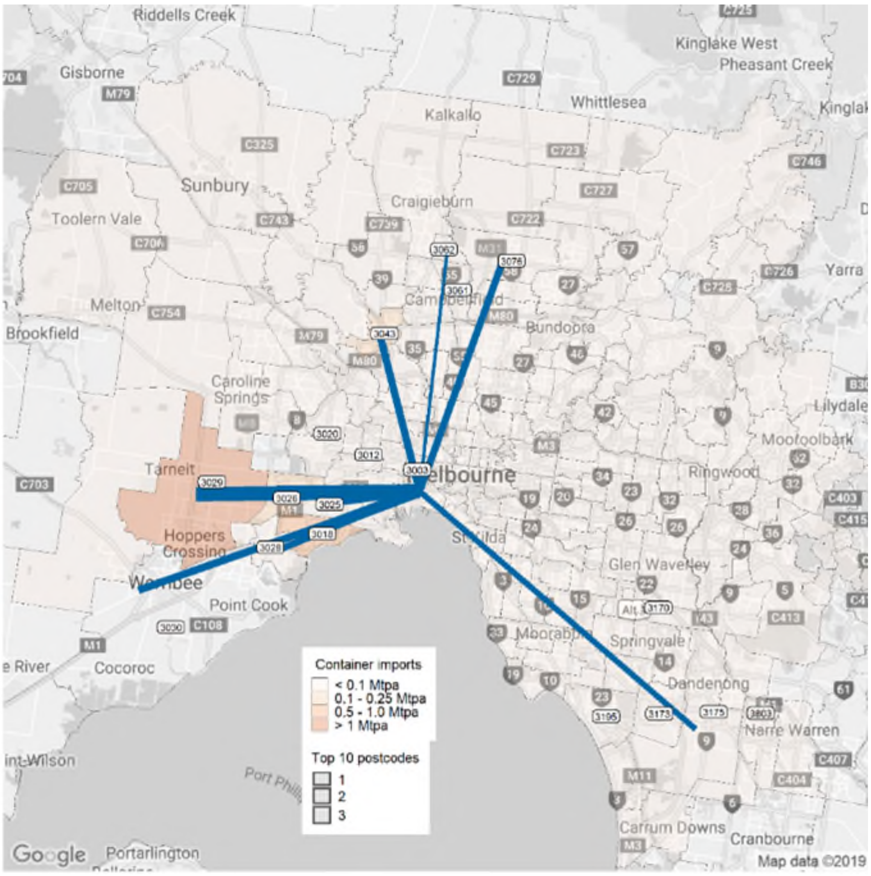
## Melbourne import containers

Figure 14 shows the density of import container movements from the Port of Melbourne to the first delivery postcode, for containers first destined within the Melbourne metropolitan area, including the top 8–10 destinations, and Table 15 lists the top 8 destination postcodes and some of the commercial/industrial suburbs overlapping with those postcode areas.

The top Melbourne import container destination postcodes are 3029 and 3018, which cover some major industrial/commercial suburbs in western Melbourne, such as Derrimut, Hoppers Crossing, Laverton (Vic.), Laverton North, Altona (Vic.), Altona North and Williamstown (Vic.). Other major import container destinations include industrial areas in Melbourne's north, such as Airport West, Broadmeadows (Vic.), Keilor Park, Melbourne Airport, Tullamarine, Campbellfield, Craigieburn, Epping (Vic.) and Somerton (Vic.).

Again, the location of refuelling stations to service a fleet of hydrogen-powered trucks dedicated to import/export freight movements within the Melbourne metropolitan area, could comprise as few as two sites, one at the Port of Melbourne and another located in the industrial areas to the west of Melbourne, but additional sites may be required to service areas to the north and south east of the port.

**Figure 14: Melbourne import container volumes by postcode and top 8-10 destination postcodes, 2017**




Source: BITRE based on unpublished customs data.

Table 15: Top 8 first destination postcodes and suburbs for Melbourne import containers, 2017

| Rank | Postcode | Commercial/industrial suburban coverage |
|---|---|---|
| 1 | 3029 | Derrimut, Hoppers Crossing, Laverton North |
| 2 | 3018 | Laverton (Vic.), Altona North, Altona (Vic.), Altona Meadows, Laverton North, Seaholme, Williamstown (Vic.) |
| 3 | 3043 | Airport West, Broadmeadows (Vic.), Keilor Park, Melbourne Airport, Strathmore Heights, Tullamarine |
| 4 | 3030 | Laverton (Vic.), Derrimut, Sunshine West |
| 5 | 3026 | Laverton (Vic.), Derrimut, Altona North, Altona (Vic.), Brooklyn (Vic.), Laverton North, Sunshine West |
| 6 | 3076 | Campbellfield, Craigieburn, Epping (Vic.), Somerton (Vic.), South Thomastown |
| 7 | 3028 | Laverton (Vic.), Altona (Vic.), Laverton North |
| 8 | 3025 | Altona North, Altona (Vic.), Brooklyn (Vic.), Laverton North, Williamstown North |

Sources: BITRE estimates based on unpublished customs data.

## Brisbane import containers

Figure 15 shows the density of import container movements from the Port of Brisbane to the first delivery postcode, for containers first destined within the Brisbane metropolitan area, including the top 8–10 destinations, and Table 16 lists the top 8 destination postcodes and some of the commercial/industrial suburbs overlapping with those postcode areas.

The top Brisbane import container destination postcode is 4178, which covers the suburb of Lytton, which adjoins the port. Nearby industrial areas in postcode 4174, which includes Hemmant is also a major destination for import container freight. Industrial/commercial suburbs in south-western Brisbane, such as Carole Park, Darra, Oxley (Qld), Richlands (Qld), Sumner and Wacol, are also major import container destinations.

Again, the location of refuelling stations to service a fleet of hydrogen-powered trucks dedicated to import/export freight movements within the Brisbane metropolitan area, could comprise a few as two sites, one at the Port of Brisbane and another located in the industrial areas of southwest Brisbane.

**Figure 15: Brisbane import container volumes by postcode and top 8-10 destination postcodes, 2017**


Source: BITRE based on unpublished customs data.

**Table 16: Top 6 first destination postcodes and suburbs for Brisbane import containers, 2017**

| Rank | Postcode | Commercial/industrial suburban coverage |
|---|---|---|
| 1 | 4178 | Lytton |
| 2 | 4076 | Richlands (Qld), Carole Park, Darra, Sumner, Wacol |
| 3 | 4013 | Banyo, Northgate (Qld) |
| 4 | 4174 | Hemmant, Lytton, Murarrie |
| 5 | 4077 | Richlands (Qld), Darra, Oxley (Qld), Wacol |
| 6 | 4106 | Archerfield, Rocklea (Qld), Salisbury (Qld) |

Sources: BITRE estimates based on unpublished customs data.

# Chapter 7: Hydrogen refuelling station location options

Chapter 6 presented high-level information about the major freight nodes for vehicles involved in transporting interstate road freight between Australia's three largest state capitals, and also the major port-based movements of import containers within those same capital cities. These two areas are among the most heavily concentrated road freight transport tasks in Australia.

These options provide the best potential to maximise the utilisation of freight-targeted HRSs and thereby reduce the required investment costs and operational expenses, and assist in generating public support for future network roll outs. Both options are dependent on developments in technology and overseas markets—the current timeframe of developments overseas suggests that hydrogen is unlikely to be a significant part of the Australian transport fuel mix before 2025.

This chapter summarises the preceding analysis into broad suggestions as to where to locate hydrogen refuelling stations to service each of these two freight tasks. Because the major road freight handling areas in each of the major cities handle both short- and long-haul freight, there is some degree of overlap in the suggested station locations. Safety restrictions and geospatial considerations for designing and delivering HRSs have been considered only to the extent that prioritised freight refuelling station locations are likely to be most conveniently sited in commercial/light industrial areas, and not in areas zoned residential, educational, health and/or parkland.

## 7.1 Long-distance, intercity freight-based hydrogen refuelling station location options

### Sydney–Melbourne freight-related refuelling station location options

As outlined in Chapter 6, the most significant locations for intercapital freight between Sydney and Melbourne lie along the Western Ring Road in Melbourne and outer western and south western Sydney, along the M5 and M7. In Sydney, the freight intensive locations lie adjacent to the M5 and M7 Freeway corridors. Provision of one or more refuelling sites would be required along the route, the number depending on resources, expected hydrogen vehicle uptake and use. A one-station option would suggest a location near the mid-point of the corridor, a multiple station approach would provide more options.

Suggested areas for consideration include:

- Sydney metropolitan area
    - Outer western Sydney: Eastern Creek, Wetherill Park, Prospect, Smithfield
    - South-western Sydney: Hoxton Park, Ingleburn, Minto
- Melbourne metropolitan area:
    - Western Melbourne: Laverton North, Brooklyn, Altona
    - Northern Melbourne: Broadmeadows, Campbellfield, Somerton, Epping
- Intermediate locations (see Figure 16):
    - Single station option: Tarcutta area
    - Multiple station option: Goulburn, Yass, Tarcutta, Albury-Wodonga, Wangaratta

**Figure 16: Sydney–Melbourne freight-related refuelling station location options**


Source: BITRE estimates.

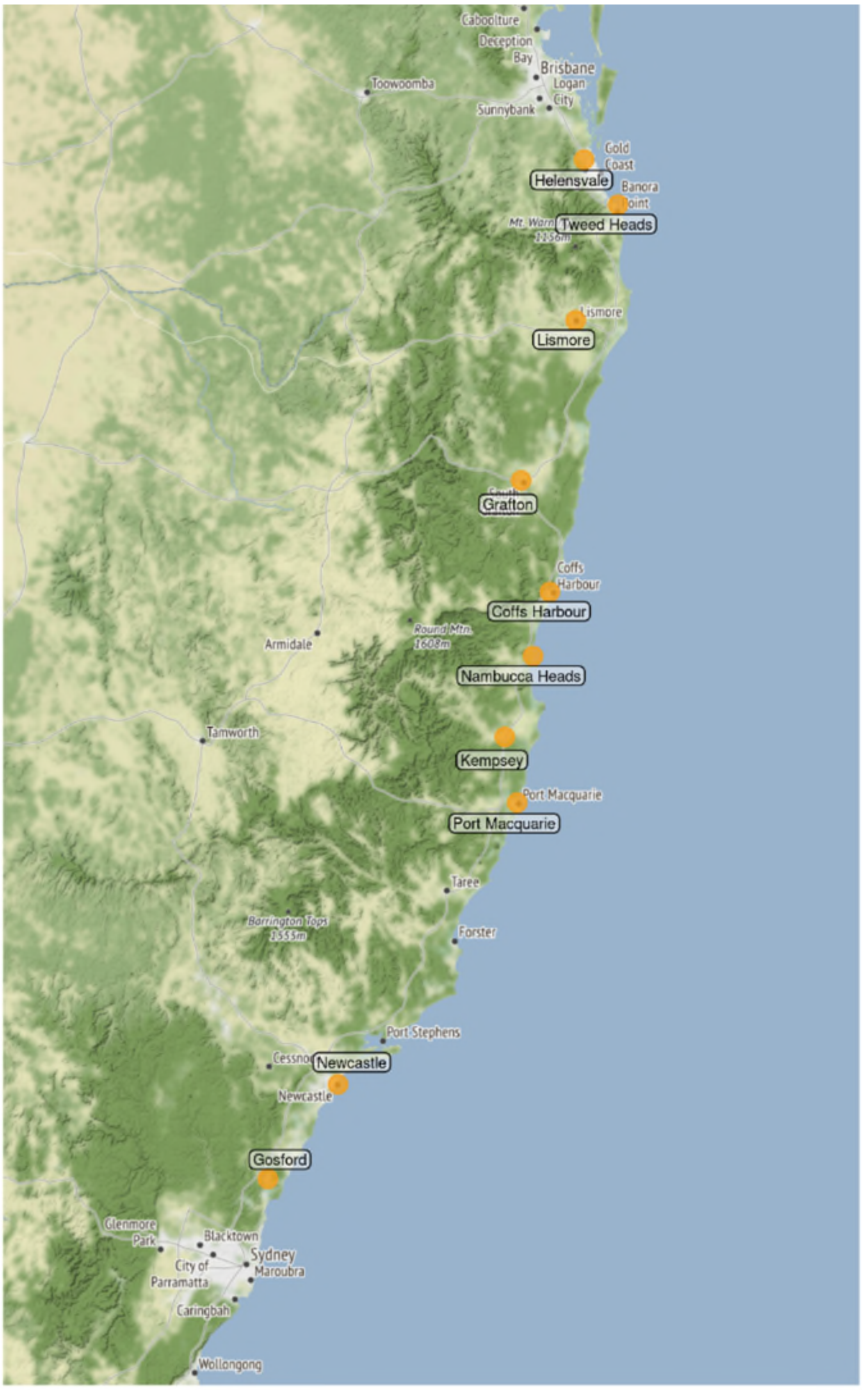
## Sydney–Brisbane freight-related refuelling station location options

The most significant locations for intercapital freight between Sydney and Brisbane are again areas in outer western and south western Sydney (similar to locations suggested for Sydney–Melbourne origin–destination freight) and in Brisbane the industrial and commercial areas in south west Brisbane. However, because the main access corridor to/from Sydney is via the F3 Freeway, consideration could be given to locating a refuelling station in the north of the city, although there are few commercial/industrial precincts in that area. Similarly, in Brisbane, because the main corridor is to the south east via the Pacific Motorway, consideration could be given to commercial/industrial locations near that corridor.

Suggested areas for consideration include:

- Sydney metropolitan area
    - Outer western Sydney: Eastern Creek, Wetherill Park, Prospect, Smithfield
    - South-western Sydney: Hoxton Park, Ingleburn, Minto
    - Northern Sydney: Hornsby, Mount Kuring-Gai, Somersby
- Brisbane metropolitan area:
    - South-west Brisbane: Carole Park, Darra, Wacol, Rocklea (Qld), Acacia Ridge
    - South-east Queensland: Battle Park, Loganholme, Yatala
- Intermediate locations (see Figure 16):
    - Single station option: Near Nambucca Heads
    - Multiple station option: Taree, Port Macquarie, Coffs Harbour, Grafton

**Figure 17: Sydney–Brisbane freight-related refuelling station location options**




Source: BITRE estimates.

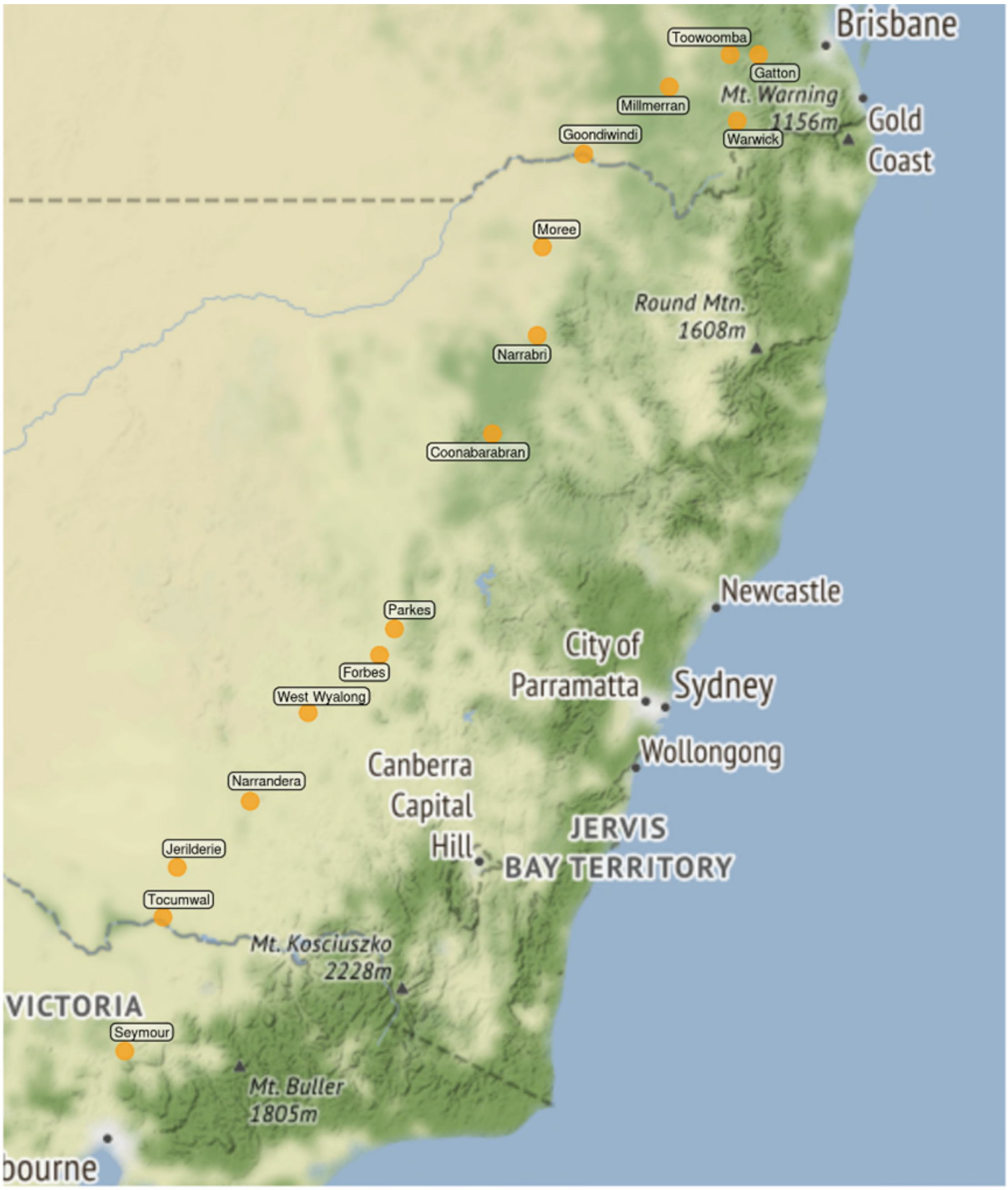
## Melbourne–Brisbane freight-related refuelling station location options

Road freight volumes between Melbourne and Brisbane are much smaller than for Sydney–Melbourne and Sydney–Brisbane and involve far fewer freight vehicles than those corridors. Again, the most significant locations for intercapital freight between Melbourne and Brisbane are around the port and in outer western and northern Melbourne (similar to locations suggested for Sydney–Melbourne origin–destination freight) and in Brisbane the industrial and commercial areas in south west Brisbane. Hence, in Melbourne, the principle refuelling station location options would be the same as for Sydney–Melbourne. In Brisbane, because the main access corridor is via the Warrego Highway to the west, so sites further west could be considered. Because the distance between the two cities is over 1600 kilometres, multiple refuelling station locations would be required along the corridor between Melbourne and Brisbane.

Suggested areas for consideration include:

- Melbourne metropolitan area:
    - Western Melbourne: Laverton North, Brooklyn, Altona
    - Northern Melbourne: Broadmeadows, Campbellfield, Somerton, Epping
- Brisbane metropolitan area:
    - South-west Brisbane: Carole Park, Darra, Wacol, Rocklea (Qld), Acacia Ridge

**Figure 18: Melbourne–Brisbane freight-related refuelling station location options**




Source: BITRE estimates.

- Intermediate locations (see Figure 18):
    - Multiple station option: Shepparton-Mooroopna, Narrandera, Parkes, Narrabri, Goondiwindi, Toowoomba

## 7.2 Short-distance, port-based freight vehicle hydrogen refuelling station locations options

Chapter 6 outlined the most significant destinations for imported container freight in each of Sydney, Melbourne and Brisbane. These locations considerably overlap with the locations of intercapital road freight.

### Sydney port-related freight refuelling station location options

The main import container destination in Sydney are industrial/commercial areas in suburbs in outer western and south western Sydney. In addition to Port Botany, suggested areas of consideration for hydrogen refuelling stations include:

- Port: Port Botany
- Outer western Sydney: Eastern Creek, Wetherill Park, Prospect, Smithfield
- South-western Sydney: Hoxton Park, Ingleburn, Minto.

### Melbourne port-related freight refuelling station location options

The main import container destination in Melbourne are industrial/commercial areas in suburbs in western and northern Melbourne. In addition to the Port of Melbourne, suggested areas of consideration for hydrogen refuelling stations include:

- Port: Port of Melbourne
- Western Melbourne: Laverton North, Brooklyn, Altona
- Northern Melbourne: Broadmeadows, Campbellfield, Somerton, Epping

### Brisbane port-related freight refuelling station location options

The main import container destination in Brisbane are industrial/commercial areas in suburbs in south western Brisbane. In addition to the Port of Melbourne, suggested areas of consideration for hydrogen refuelling stations include:

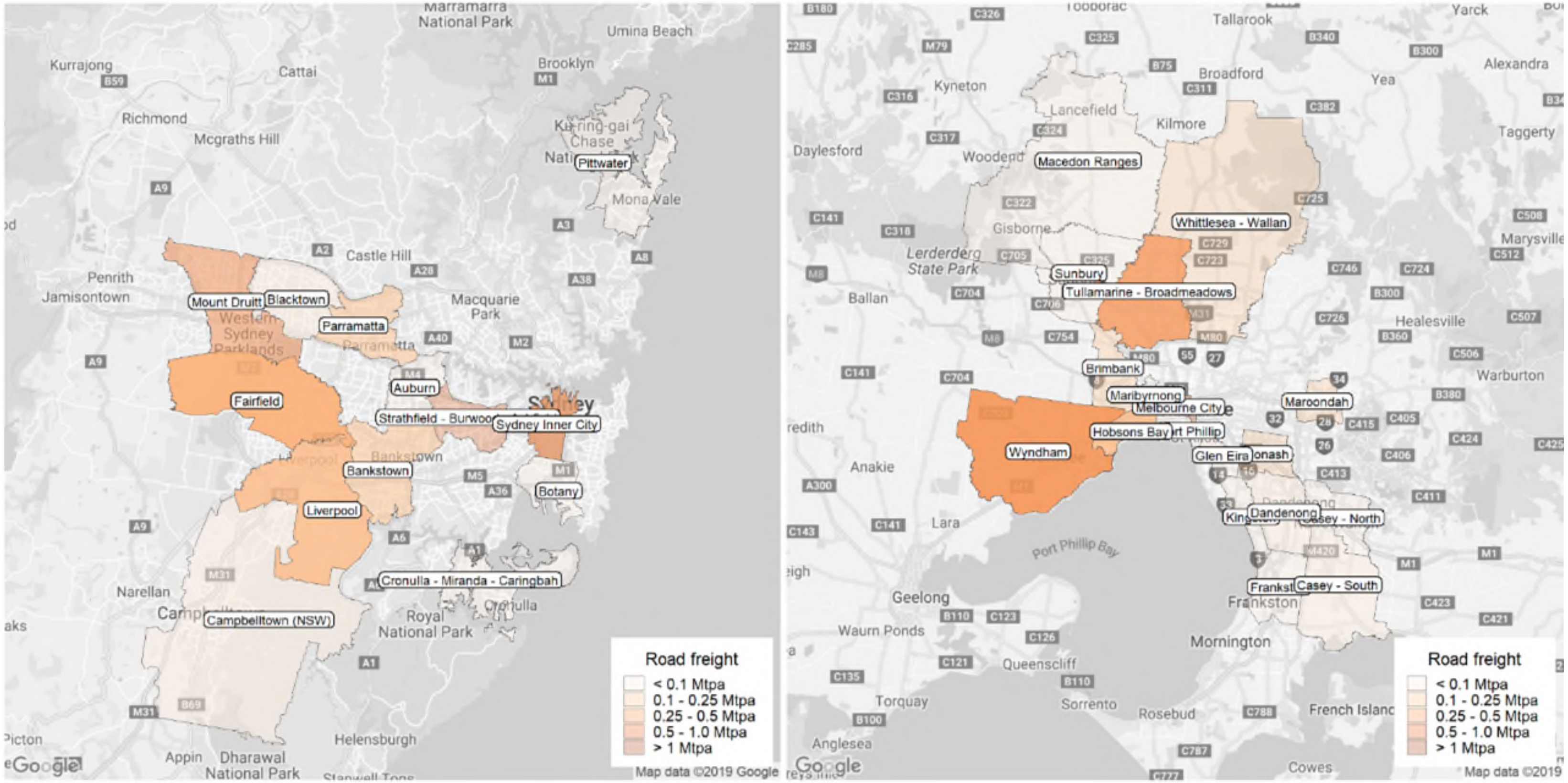
- Port: Port of Brisbane
- South-west Brisbane: Carole Park, Darra, Wacol, Rocklea (Qld), Acacia Ridge

## 7.3 Concluding remarks

This paper has provided a brief overview of hydrogen and battery-electric vehicle technology, hydrogen refuelling station technology and a brief review of current domestic and international hydrogen-fuel vehicle initiatives. The paper has also identified potential broad candidate locations for hydrogen refuelling station locations that would be required to service long-distance intercapital freight markets, between Sydney, Melbourne and Brisbane, and port-based container movements to and from the ports in Sydney, Melbourne and Brisbane.

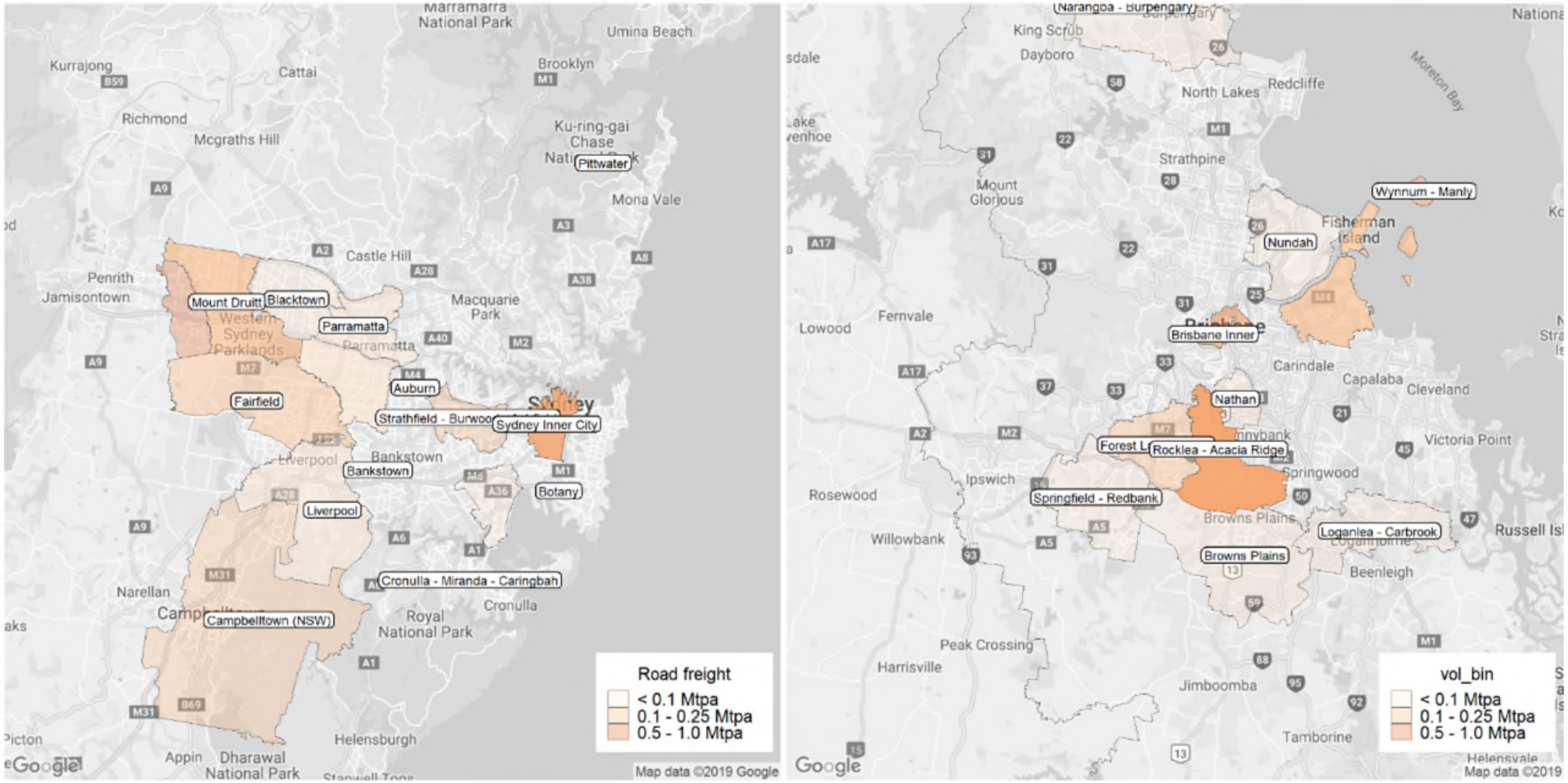
# Appendix A Intercapital freight origin-destination locations

**Figure A.1 Sydney–Melbourne origin–destination road freight in 2013-14 by SA3 areas**




Sources: ABS (2015) and BITRE estimates.

**Figure A.2 Sydney–Brisbane origin–destination road freight in 2013-14 by SA3 areas**

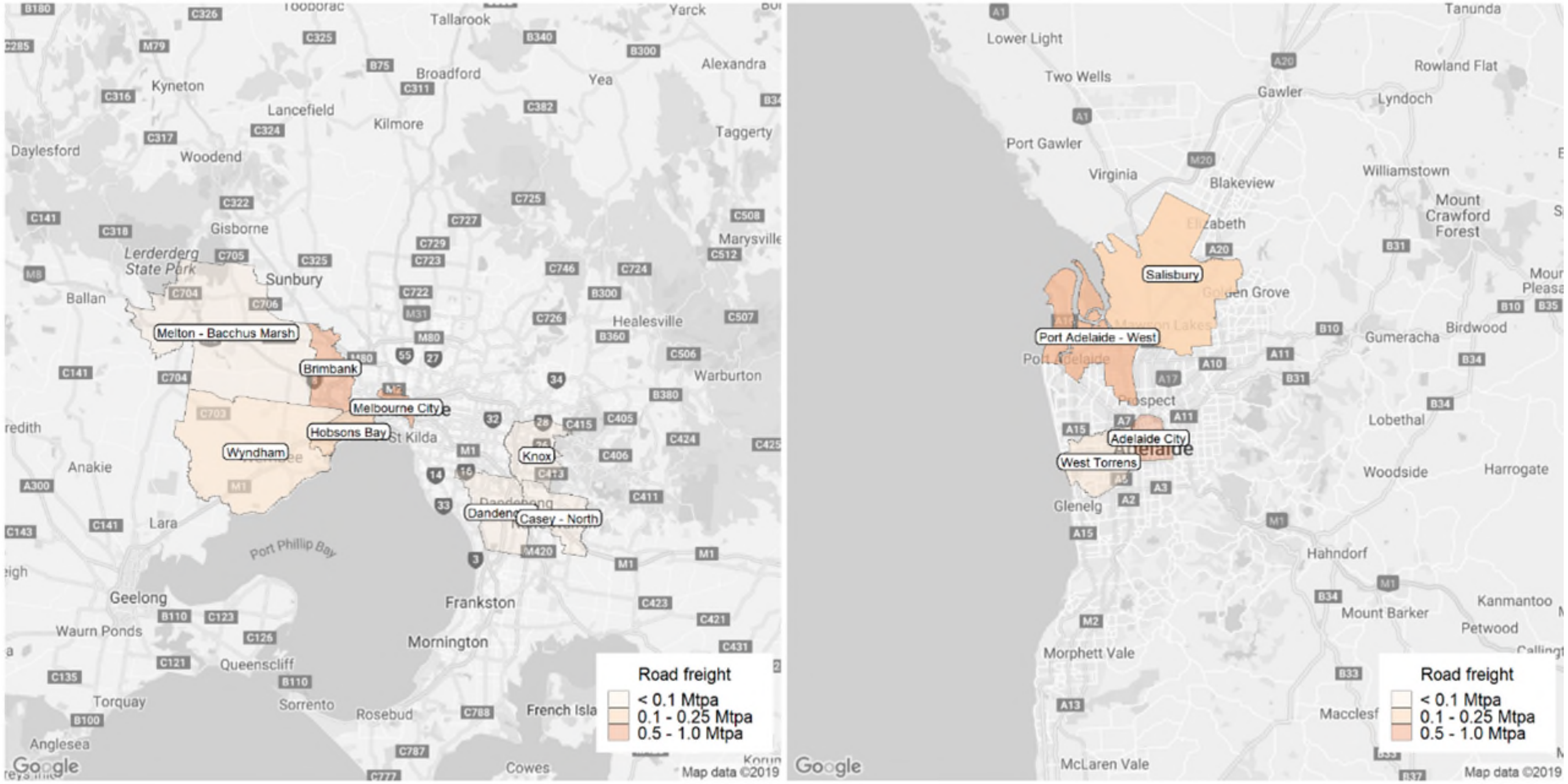



Sources: ABS (2015) and BITRE estimates.

**Figure A.3 Melbourne–Brisbane origin–destination road freight in 2013-14 by SA3 areas**


Sources: ABS (2015) and BITRE estimates.

Figure A.4 Melbourne–Adelaide origin–destination road freight in 2013-14 by SA3 areas




Sources: ABS (2015) and BITRE estimates.

# Appendix B Existing fuel station locations

The major fuel retail chains in Australia operate networks of ‘truck stops’ (or truck friendly) and key diesel refuelling stations across the country, including on corridors linking Australia’s major capital cities. The location of existing truck refuelling stations are also likely to provide a guide as to initial hydrogen refuelling station location needs and options. This appendix provides information about truck stops and key diesel refuelling stations for two of the major fuel retailing chains: BP and Shell.

Figure B.1 shows current truck refuelling network locations of BP and Shell servicing the Sydney–Melbourne corridor. Each of these companies operates between 3 and 5 truck stops (including locations with refuelling facilities on each side of the highway) distributed across the route between Sydney and Melbourne. BP’s truck service centres are located at Marulan, Albury/Wodonga, Glenrowan and Wallan. Shell has truck service centres located at Goulburn, Gundagai. Albury and Euroa. These hydrogen refuelling candidate locations identified in Chapter 7 are consistent with the existing truck fuel networks.

Figure B.2 shows current truck refuelling network locations of BP and Shell servicing the Sydney–Brisbane (Pacific Highway) corridor. Each company operates between 6 and 7 truck stops distributed between Sydney and Brisbane. BP’s truck service centres are located at Morisset, Beresfield, Port Macquarie, Kempsey, Valla (Nambucca Heads), Chinderah (Tweed Heads), and the Gold Coast. Shell’s truck service centres are located at Ourimbah, Heatherbrae, Bulahdelah, Kempsey, Nambucca Heads, Grafton, Lismore, and several locations in the Gold Coast.

Figure B.3 shows current truck refuelling network locations of BP and Shell servicing the Melbourne–Brisbane corridor. Each company operates between 10 and 14 truck stops distributed between Melbourne and Brisbane. Between Melbourne and Brisbane, BP operates truck service centres at Wallan (Vic.), Shepparton, Jerilderie, Beckom (Ardelthan), Forbes, Parkes, Tomingley, Gilgandra, Narrabri, Moree, Goondiwindi, Warwick, Toowoomba and Gatton. Shell operates a similar number of sites across the corridor, at Seymour, Tocumwal, Jerilderie, Narrandera, Wyalong, Forbes, Parkes, Dubbo, Narrabri and Goondiwindi.

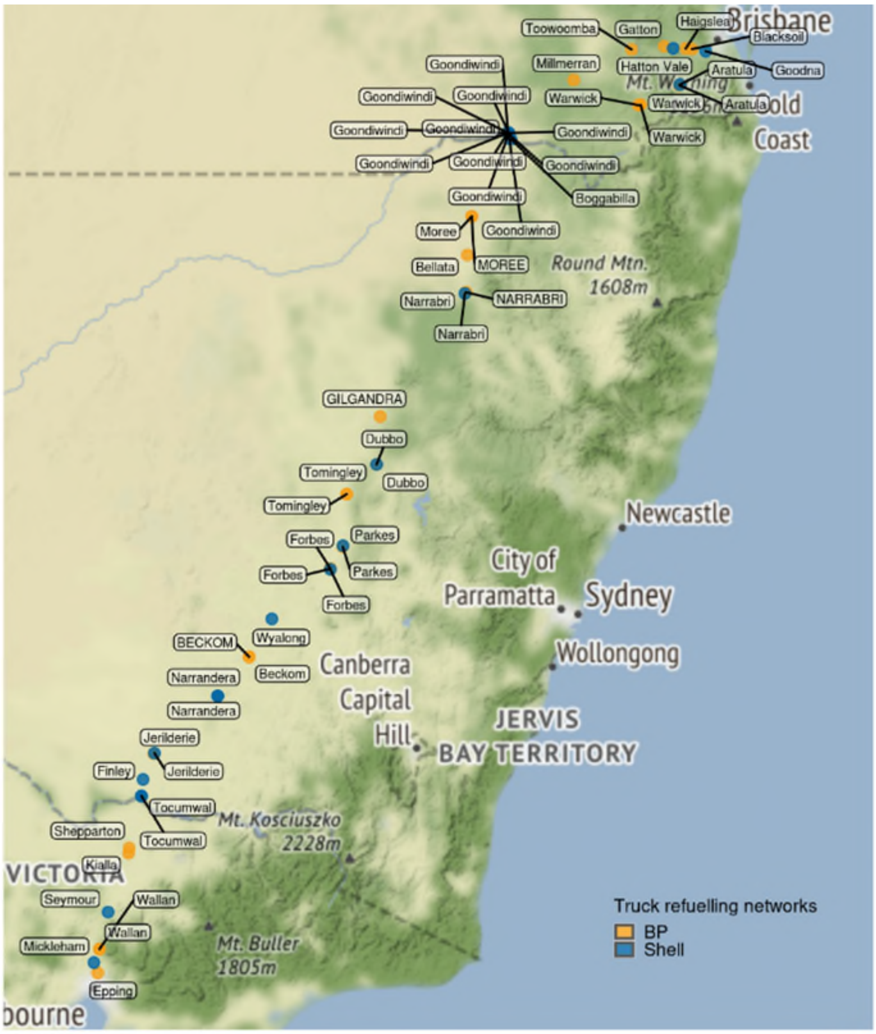
**Figure B.1 National truck refuelling network sites, Sydney–Melbourne corridor, 2019**


Sources: BP Australia Truck Stops (https://www.bp.com/en_au/australia/products-services/service-stations/truck-stops.html), Shell Australia Fuel Finder (https://www.shell.com.au/motorists/fuel-finder.html), August 2019.

**Figure B.2 National truck refuelling network sites, Sydney–Brisbane corridor, 2019**


Sources: BP Australia Truck Stops (https://www.bp.com/en_au/australia/products-services/service-stations/truck-stops.html), Shell Australia Fuel Finder (https://www.shell.com.au/motorists/fuel-finder.html), August 2019.

**Figure B.3 National truck refuelling network sites, Melbourne–Brisbane corridor, 2019**




Sources: BP Australia Truck Stops (https://www.bp.com/en_au/australia/products-services/service-stations/truck-stops.html), Shell Australia Fuel Finder (https://www.shell.com.au/motorists/fuel-finder.html), August 2019.

# References

Australian Bureau of Statistics (ABS) 2015, *Road Freight Movements, Australia, 12 months ended 31 October 2014*, Catalogue no. 9223.0, ABS, Canberra. URL: https://www.abs.gov.au/ausstats/abs@.nsf/mf/9223.0.

—— 2018, *Motor Vehicle Census, Australia 31 January 2018*, Catalogue no. 9309.0, ABS, Canberra. URL: https://www.abs.gov.au/ausstats/abs@.nsf/mf/9309.0.

—— 2019, *Survey of Motor Vehicle Use, Australia, 12 months ended 30 June 2018*, Catalogue 9208.0, ABS, Canberra. URL: https://www.abs.gov.au/ausstats/abs@.nsf/mf/9208.0.

Ball M., A. Basile and T.N. Veziroglu (ed) 2016, *Compendium of Hydrogen Energy Use*, Volume 4: Hydrogen Use, Safety and the Hydrogen Economy, Woodhead Publishing, Oxford.

BITRE 2016, *Traffic on the national road network, 2013–14*, Information Sheet 80, BITRE, Canberra. URL: https://www.bitre.gov.au/publications/2016/is_080.aspx.

—— 2018, *Australian Infrastructure Statistics Yearbook 2018*, BITRE, Canberra. URL: https://www.bitre.gov.au/publications/2018/yearbook_2018.aspx.

California Energy Commission and California Air Resources Board 2019, 'Joint Agency Staff Report on Assembly Bill 8: 2018 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refuelling Stations in California', led by Governor Edmund G Brown Jr, CEC-600-2018-008.

California Fuel Cell Partnership 2019, 'Hydrogen Station Map', URL: https://cafcp.org/stationmap

Council of Australian Governments (COAG) Energy Council 2019, National Hydrogen Strategy – Hydrogen for Transport, URL: https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers/.

CSIRO, 2018, National Hydrogen Roadmap: Pathways to an economically sustainable hydrogen industry in Australia, URL: https://www.csiro.au/en/Do-business/Futures/Reports/Hydrogen-Roadmap

Daimler 2018, 'Electrified on the highway: Freightliner eCascadia and eM2', URL: https://www.daimler.com/sustainability/vehicles/climate-protection/ecascadia.html

Department of Environment and Energy 2019, *Quarterly Update of Australia's National Greenhouse Gas Inventory for December 2018*, URL: http://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/publications/quarterly-update-australias-nggi-dec-2018

Earl, T.L., S. Mathieu, S. Cornelis, C. Kenny, A. Calvo and J. Nix 2018, *Analysis of long haul battery electric trucks in EU*, Amended paper (August 2018) originally presented at the 8th Commercial Vehicle Workshop, 17-18 May 2018, Graz, Austria. URL: https://www.transportenvironment.org/sites/te/files/publications/20180725_T%26E_Battery_Electric_Trucks_EU_FINAL.pdf

Edwards, D. 2018, 'Infrastructure Challenges in the MD/HD Markets', Presentation to the Fuel Cell Truck Powertrain R&D Activities and Target Review Workshop on July 30-31 of 2018 in Chicago. URL: https://www.energy.gov/sites/prod/files/2018/08/f54/fcto-truck-workshop-2018-7-edwards_0.pdf.

Eudy, L. and M. Post 2017, Fuel Cell Buses in U.S. Transit Fleets: Current Status 2018, Technical Report NREL/TP-5400-72208, National Renewable Energy Laboratory, December 2018, Golden, Colorado. URL: https://www.nrel.gov/docs/fy19osti/72208.pdf.

Fuel Cell Truck Powertrain R&D Activities and Target Review Workshop: H2@ Scale End Use Applications, URL: https://www.energy.gov/eere/fuelcells/fuel-cell-truck-powertrain-rd-activities-and-target-review-workshop-h2-scale-end-use

Hydrogen Society of Australia and Innovate Australia 2018, 'The Hydrogen Highway'. Published by the Department of the Treasury, URL: https://treasury.gov.au/sites/default/files/2019-03/360985-InfraNomics-supporting-document.pdf

Hyundai Motor Group, 2018, Hyundai Motor and H2 Energy to bring the world's first fleet of fuel cell electric trucks into commercial operation, URL: https://www.hyundai.com.au/hyundai-info/news/2018/september/hyundai-motor-and-h2-energy-to-bring-the-world-s-first-fleet-of-fuel-cell-electric-trucks-into-commercial-operation

Ikeda 2018, 'Status of Hydrogen Fueling Station Technologies in Japan', presented at the International Hydrogen Infrastructure Workshop, URL: https://www.energy.gov/sites/prod/files/2018/10/f56/fcto-infrastructure-workshop-2018-16-ikeda.pdf

International Energy Agency & Hydrogen Implementing Agreement (IEA & HIA) 2015, 'Large Scale Hydrogen Delivery Infrastructure', Final Report of the Expert Group Task 28, URL: http://ieahydrogen.org/Activities/Task-28/Task-28-report_final_v2_ECN_12_2_v3.aspx

Isuzu 2018, 'Driving Toward the Future', URL: https://isuzu.com.au/news-media/isuzu-electric-vehicles/

Kenworth and Toyota 2019, 'The Kenworth T680 with Integrated Toyota Hydrogen Fuel Cell Technology Stars at Port of Los Angeles', URL: https://www.kenworth.com/news/news-releases/2019/april/kenworth-toyota-pola/

Ministry of Economy, Trade and Industry 2019, 'Formation of a New Strategic Roadmap for Hydrogen and Fuel Cells, URL: https://www.meti.go.jp/english/press/2019/0312_002.html

Nikola 2019, 'Nikola Hydrogen Products: Nikola One, Two, Tre', URL: https://nikolamotor.com/motor

Ontario International Airport 2019, 'Ontario International Airport PAX and Cargo Statistics', URL: https://www.flyontario.com/corporate/statistics

The Port of Los Angeles 2019, 'Annual Container Statistics (by calendar year; includes monthly data), URL: https://www.portoflosangeles.org/business/statistics/container-statistics

The Port of Long Beach 2019, 'Container Trade in TEUs, Yearly TEU Totals', URL: http://www.polb.com/economics/stats/yearly_teus.asp.

Potter, B. 2019, 'Transdev trials hydrogen buses', The Australian Financial Review, 22 March 2019, URL: https://www.afr.com/news/transdev-trials-hydrogen-buses-20190321-h1cmfj.

Society of Automotive Engineers (SAE) 2014, 'Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles', URL: https://www.sae.org/standards/content/j2601_201612/

Strategy Advisory Committee of the Technology Roadmap for Energy Saving and New Energy Vehicles and the Society of Automotive Engineers of China (SAE-China), ' Hydrogen Fuel Cell Vehicle Technology Roadmap', URL: http://www.ihfca.org.cn/file/FCV%20Tech%20Roadmap.pdf

Tesla 2019, "Tesla Semi', URL: https://www.tesla.com/semi

Volvo Trucks Global 2019, 'First electric Volvo trucks delivered to customers', URL: https://www.volvotrucks.com/en-en/news/press-releases/2019/feb/pressrelease-190219.html