Supply Chains for Future Road Transport Fuels in Australia

Opportunities and Challenges

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Foresion

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Supply Chains for Future Road Transport Fuels in Australia is part of a series of discussion papers produced by Foresion that aim to holistically explore contemporary supply chain issues and future directions, focusing on logistics, emerging technologies, and environmental sustainability. These papers are aimed at business practitioners, policymakers, and governments as a vehicle for improving integration and visibility along key supply chains.

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Contents

Glossary

kWh	kilowatt hour (1,000 Wh)
MWh	Megawatt hour (1,000 kWh)
GWh	Gigawatt hour (1,000 MWh)
TWh	Terawatt hour (1,000 GWh)
Grey Hydrogen	Hydrogen produced from natural gas, generally through steam reformation
Blue Hydrogen	Hydrogen produced from natural gas, generally through steam reformation and using carbon capture and storing technology
Green Hydrogen	Hydrogen produced by using renewable electricity to split water into hydrogen and oxygen or by using syngas from renewable feedstock
Electrolysis	Electrolysis is the process of using electricity to split water into hydrogen and oxygen
BEV	Battery electric vehicles
FCEV	Fuel cell electric vehicles
ICE	Internal combustion engine
Smart Charging	A charging system where electric vehicles, charging stations and charging operators share data connections to monitor, manage, and restrict the use of charging devices to optimize energy consumption.
ACT	Australian Capital Territory
NSW	New South Wales
NT	Northern Territory
QLD	Queensland
TAS	Tasmania
VIC	Victoria
WA	Western Australia

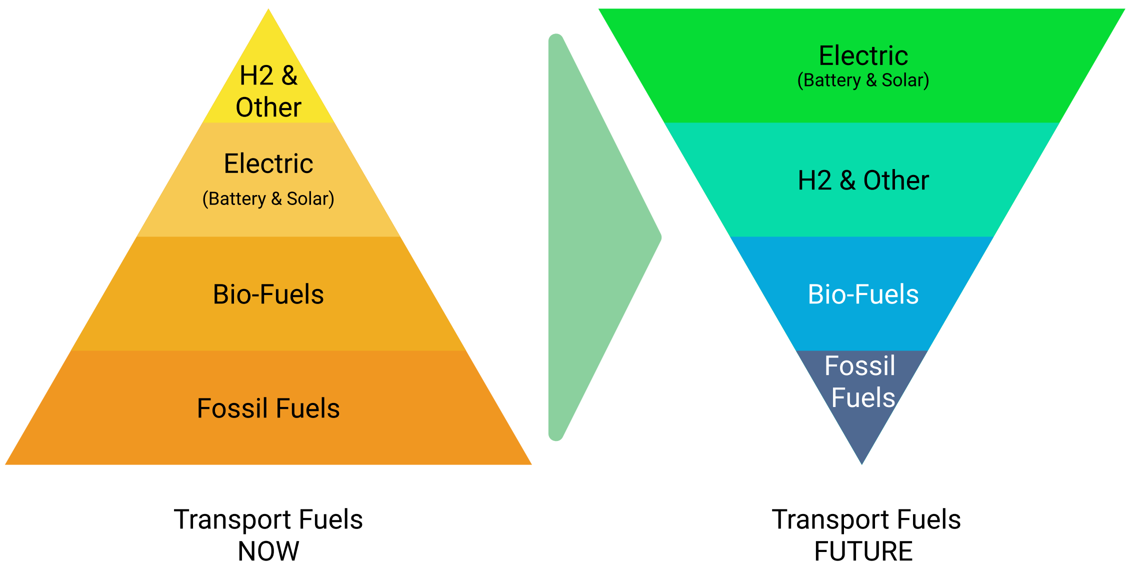

Figure 1 Transport Fuels Now and Into the Future (Foresion, 2021)

Context

The environmental impact of human activity is evident in almost every aspect of our lives as are the implications for future sustainability and prosperity. Transport emissions totalled 8 billion tonnes of CO_2 in 2018[1] and represent close to a quarter of global energy-related emissions. Tackling transport emissions is one of the pathways to addressing man-made environmental impacts.

Contemporary debates around what actions to take to address production, power and sustainability in Western societies is increasingly focused on responses to climate change through electrification of transport and increasing use of renewables. This future vision entails diminishing the role of fossil fuels in favour of batteries, hydrogen, and other renewable fuel sources.

While these actions are certainly a step forward towards a more sustainable future, most initiatives lack integrated perspectives on the supply chains that will enable these visions to be realised. In looking at these supply issues, this paper aims to highlight the **problems** and to suggest potential **solutions** that could ensure sustainability goals are achieved without sacrificing global supply chains' integrity and risking dramatic reductions in citizens' physical and social mobility.

In this context, this paper examines opportunities and challenges relating to supply chains for future road transport fuels in Australia: total energy consumption, energy logistics and the current and projected environmental impact of transportation.

Executive Summary

The increased adoption of alternative fuels in road transport, such as electricity for battery electric vehicles (BEV) and hydrogen for fuel cell electric vehicles (FCEV) has improved the prospects of decarbonising the sector. Indeed, powering BEVs entirely from renewable electricity promises emissions of just 0.6 kg $CO_{2\text{-}e}$/100km[2], as opposed to 25 kg $CO_{2\text{-}e}$/100km currently emitted by the average Australian gasoline powered car or 20 kg $CO_{2\text{-}e}$/100km indirectly emitted by BEVs. However, entirely renewable energy is a long way away from becoming a reality in much of the world, including many Australian states. While electricity generation is increasingly turning renewable, it is important to understand the energy consumption and emissions of BEVs and FCEVs today and in the near future.

Due to differences in infrastructure and fuel mixes for electricity generation around the world, this report focuses primarily on transportation in Australia.

Road Transport Fuels Now And Into The Future (Australia)

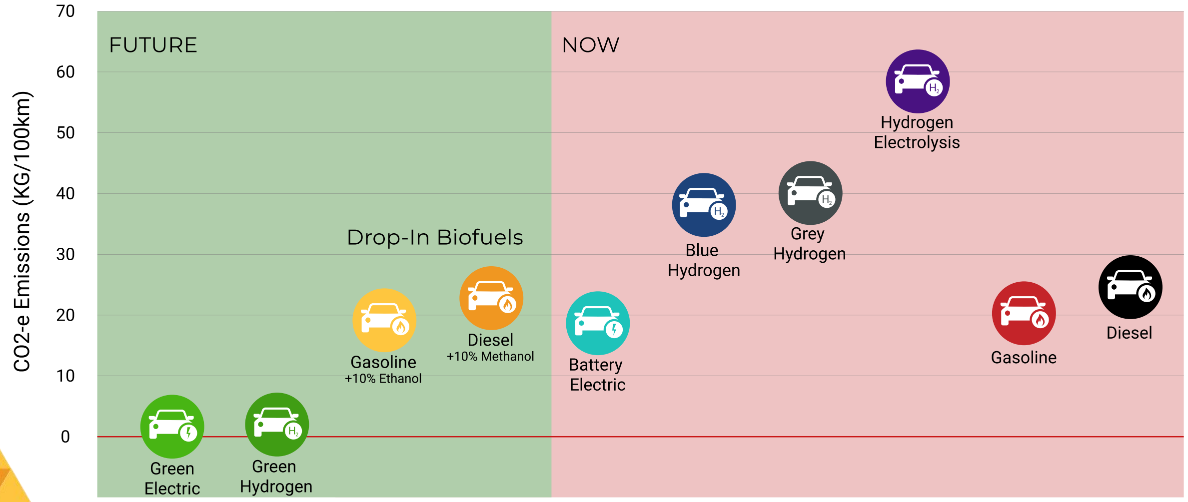

Figure 2 Road transport fuels now and future directions, Australia (Source: Foresion 2022)

The key supply chain challenges for future road transport fuels and energy sources in the Australian context are:

1. **Increased pressure on renewables**.
   Powering the entire road transport sector would require 101 or 315 TWh respectively for BEV and FCEV in addition to the 265 TWh of electricity used in Australia in 2019-20. As fossil fuels are phased out from electricity generation and transportation, renewable generation will not only have to step up and cover fossil fuel generation but also provide additional electricity to power personal vehicles or the entire road transport sector.
2. **Energy logistics**.
   Energy distribution especially for BEV will likely pose several complex challenges due to the charging times. Key questions include: should charging outlets be installed in every street parking spot, or in every parking garage? How will BEV owners charge their vehicles if they do not have access to a home garage? What additional loads will BEV charging place on neighbourhood transformers? How many charging outlets should a charging station have to limit waiting times?
3. **Carbon emissions**.
   The electricity fuel mix determines the environmental impact of BEVs or FCEVs. A 20kWh/100km BEV may emit more $CO_{2\text{-}e}$/100km than a low consumption gasoline car. Conversely, the figures stack up overwhelmingly in favour of BEVs in states like Tasmania or South Australia. Hydrogen for FCEV has a favourable environmental impact if electricity is sourced predominantly from renewables.

The prospect of increasing electricity demand while decreasing fossil fuel reliance in electricity generation together with energy logistics challenges and the current emission footprint generated by BEV or FCEV raise several questions in personal mobility and supply chains space. How should electricity demand be best managed to continue to power industrial, commercial, residential and transportation needs? What is the most efficient way to deliver energy for transportation? How can the promise of lowering transport emission profile be realised? It is unlikely that the answers to these questions will be simple straightforward or one-size-fits-all. However, there are several opportunities which may positively contribute to lowering transport emissions:

1. **Biofuels**.
   Biofuels can contribute immediately to reducing road transportation emissions and potentially achieving environmental outcomes comparable to current BEVs without requiring the additional infrastructure and fleet replacement.
2. **Exchangeable power packs**.
   Exchangeable power packs can circumvent charging times challenges, especially for BEVs. By centralising the charging infrastructure. The electricity demand predictability is significantly increased.
3. **Solar panels on vehicles**.
   Innovations around extendable solar panels may provide vehicles with sufficient self-charging abilities to reduce external energy and charging infrastructure requirements.
4. **Public transportation**.
   Public transportation already uses mature electric power technology and provides a more predictable energy demand pattern and energy efficiency per passenger.

Credit: Futurebridge

Introduction

The increased adoption of alternative fuels in road transport, such as electricity for battery electric vehicles (BEV) and hydrogen for fuel cell electric vehicles (FCEV) has improved the prospects of decarbonising the sector. Indeed, powering BEVs entirely from renewable electricity promises emissions of just 0.6 kg $CO_{2\text{-}e}$/100km[2], as opposed to 25 kg $CO_{2\text{-}e}$/100km currently emitted by an average Australian gasoline powered car or 20 kg $CO_{2\text{-}e}$/100km indirectly emitted by a BEV. However, entirely renewable energy is a long way away from becoming a reality in much of the world, including several Australian states. While electricity generation is increasingly turning renewable, it is important to understand the energy consumption and emissions of BEVs and FCEVs today and in the near future.

Due to differences in infrastructure and fuel mixes for electricity generation around the world, this report focuses primarily on transport in Australia. Therefore, the key questions in this report are:

1. What is the expected energy demand of future road transport fuels?
2. How could future road transport fuels be delivered to users?
3. What is the environmental footprint of current and future road transport fuels?

Approach and Structure

The approach of this report is based on document and statistical analysis as well as projections. The (future) fuels supply chains are analysed in sequence drawing from life-cycle analyses: production, distribution, and use.

- The first section provides background information on Australia's electricity fuel mix and the number of vehicles on Australia's roads to project the potential electricity needs of a fully decarbonised transport sector powered by Li-Ion batteries or hydrogen fuel cells.
- The second section analyses energy distribution models, mainly focusing on electricity, to highlight different issues pertaining to each model.
- The third section models the environmental impact of various fuels (fossil fuels, biofuels, electricity, hydrogen) based on the electricity fuel mix from each Australian state.
- Finally, the last section briefly discusses several opportunities for decarbonising the transport sector on the pathway to transitioning away from fossil fuel.

Powering Future Road Transportation

Powering future road transportation will require vast amounts of electricity if vehicle fleets are converted either to batteries or fuel cells.

Close to 15 million passenger vehicles were registered in Australia which travelled on average 11,000 kilometres in 2020. Light commercial vehicles represent the second largest group of vehicles with more than 3.5 million units which travelled 15,000 kilometres. Half a million rigid and 100,000 articulated trucks travelled on average 21,000 and 78,000 respectively[3].

Powering personal vehicles would require an additional 33TWh of electricity assuming that all vehicles are converted to batteries or 132TWh assuming all vehicles are converted to fuel cells. Powering the entire road transport sector would require 101 or 315TWh respectively for BEV and FCEV (See Table 1 in Appendix for calculation details). To contextualise these figures, in 2019-20 Australia generated 265TWh of electricity[4]. An all-BEV vehicle fleet would require 38% of Australia's electricity. A FCEV vehicle fleet would require more electricity than Australia's current generation. To cope with the additional electricity demand from electric vehicles, Australia's generation capacity will have to increase significantly.

At the same time, both the public and private sectors are endorsing the decarbonisation of electricity generation. Currently, 205TWh or 77% of Australia's electricity is generated from fossil fuels (black and brown coal, natural gas, and oil). As fossil fuels are phased out from electricity generation, renewable sources will not only have to compensate for this phase-out but will also have to provide additional electricity to power personal vehicles or the entire road transport sector. Powering Australia and its transportation sector entirely from renewable sources will require (at least) a five-fold increase in renewable electricity generation.

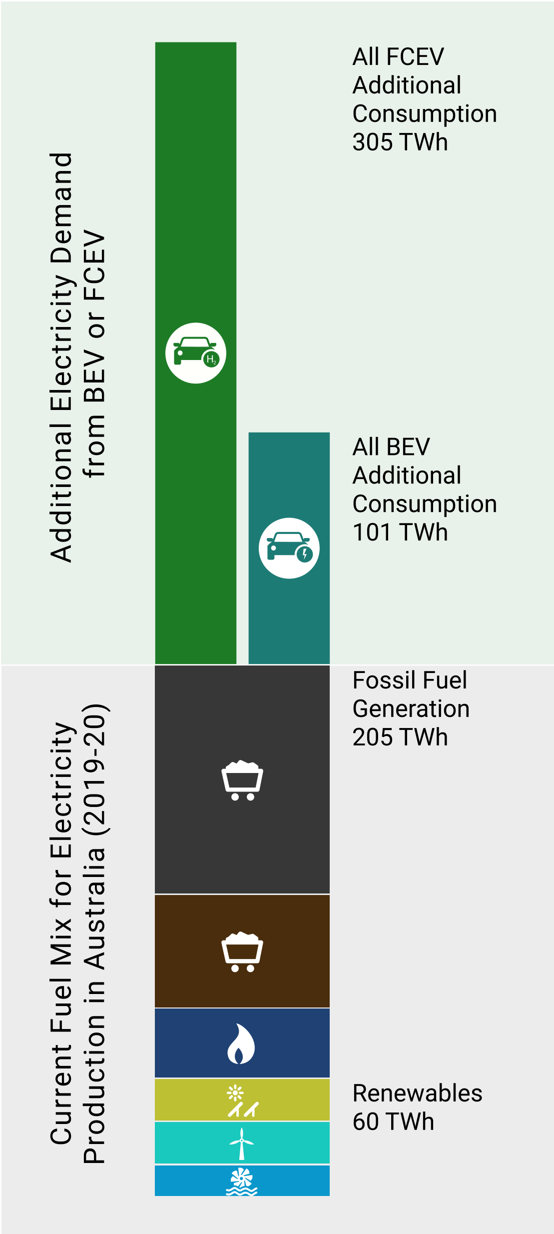

Figure 3 Australian electricity fuel mix and potential electricity demand for BEV and FCEV (Source: Foresion 2022)

Energy Logistics

The logistics chains for traditional fuels are already mature and well established. Re-envisioning logistics chains for future road transport fuels, mainly electricity and hydrogen, poses a new set of challenges. These challenges appear more pressing for electricity delivery than for hydrogen due to battery charging times.

Electricity logistics options range from centralised to decentralised: charging stations, parking garage charges, street charging and home charging.

The key advantage of the **charging station** model is the high charging capacity. Tesla superchargers can deliver up to half of a typical Tesla model S capacity in roughly 20 minutes[5]. However, a typical stop at a charging station lasts between 30 and 40 minutes[6], even with limited numbers of BEVs on the roads. As the number of electric vehicles increases, congestion at charging stations will likely increase as well, leading to significantly longer waiting times.

Parking garage charging increase convenience as vehicles are parked and not in use during charging. This setup seems more viable in cities and will likely require significant investments in grids and charging outlets. However, 1,000 cars charging simultaneously would require 7MWh of electricity or more, depending on charging capacity and, the relatively short stays in parking lots are likely to render *smart charging* infeasible.

Street parking charging is similar to parking garage charging with increased convenience. Street charging will be a necessity for BEV owners that do not have access to a home charger. Therefore, the key issue will likely be, how many chargers and where should they be built?

Home charging is currently the preferred BEV charging approach. A recent survey of New Zealand showed that more than 80% BEV owners charge their vehicles at home[6]. Home charging generally offers the slowest charging speeds. More importantly, at home vehicle charging more than triples the household electricity consumption (a typical Australian household uses 1.5-2.5 kW of electricity per hour[7] while a type 2 charger uses 7 kWh). As the number of electric vehicles increases, local electricity grids will be increasingly under stress due to home charging. Installing solar panels in Australian homes may limit the reliance on the electricity grid but this will require home batteries as generally the sun shines while vehicles are in use.

Importantly, electricity has powered public transportation - trams, trolleybuses, metros, and trains - for decades. The electricity delivery model for vehicles without on-board storage does not seem viable for personal vehicles due to the sheer size of new infrastructure required. Nonetheless, public transportation should play an important role to maintain high levels of personal mobility while reducing emissions. Expanding public transportation networks using established technologies also circumvents battery and fuel cell related raw material availability and toxicity issues.

The supply chains for hydrogen resemble those for traditional fossil fuels. Hydrogen can be delivered to fuel stations by pipelines or trucks. Hydrogen poses an added challenge due to its requirements for high pressure storage which generally increase the costs and complexity of fuelling infrastructure and transport equipment.

Measuring the Fuels' Environmental Impact

As appealing as emitting just 0.6 kg $CO_{2\text{-}e}$/ 100km[2] from BEVs powered entirely by renewable electricity, this prospect is far from the reality in most Australian states. Currently, only 23% of Australian electricity is produced by renewable sources (hydro, solar and wind), while the remainder is produced by fossil fuels (black and brown coal, natural gas, and oil)[4]. There are significant differences in electricity generation fuel mixes between states: Tasmania relies heavily on hydro and other renewables while more populous states such as New South Wales (NSW), Victoria (VIC), and Queensland (QLD) rely more heavily on fossil fuel generation, mainly coal. The different electricity fuel mixes between states have a significant impact on current and projected BEVs and FCEVs emissions.

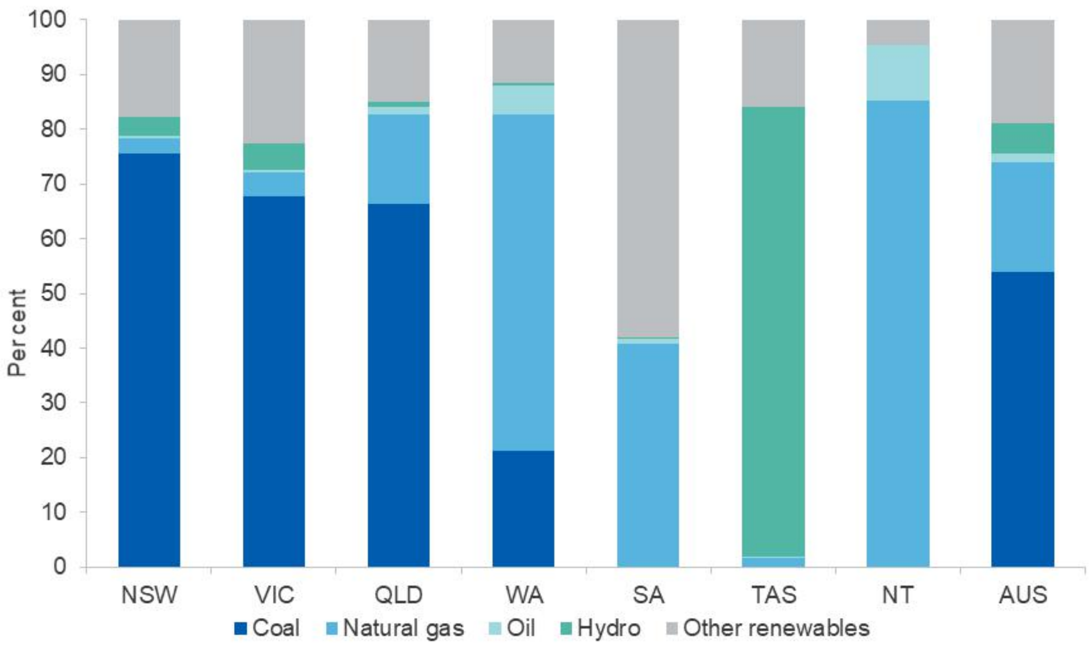

Figure 4 Australian electricity generation fuel mix by state (Source: Department of Industry, Science, Energy and Resources, 2021)

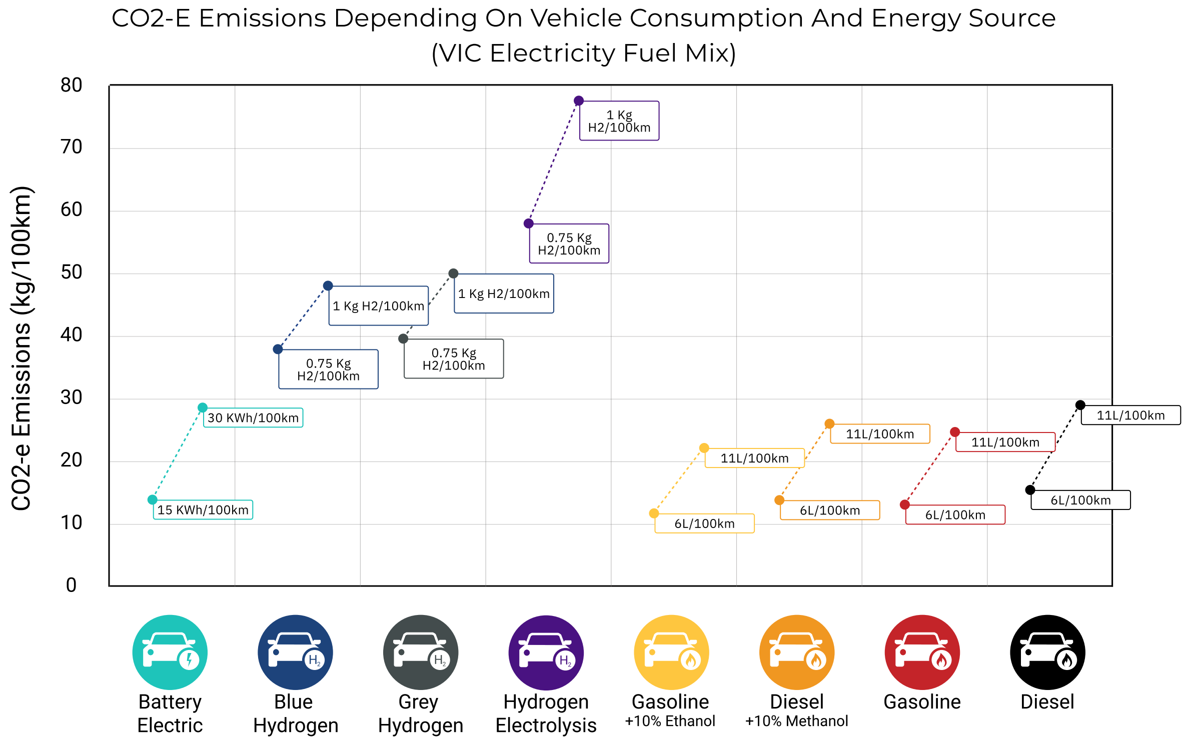

Figure 5 CO_{2-e} emissions depending on fuel source based on VIC fuel mix (Source: Foresion 2022)

This analysis compares the emissions of BEV, FCEV, and internal combustion engine (ICE) vehicles depending on their energy consumption, considering each Australian state's electricity fuel mix. The electricity fuel mix affects the emissions of BEVs as well as FCEVs. Charging and transmission losses are not considered for BEVs. No electricity use is assumed to produce grey and blue hydrogen, however, 30kWh/kilogram of H_2 are used for pressurising and transporting the hydrogen. Grey hydrogen is produced from natural gas. Blue hydrogen is produced from natural gas but uses carbon capture and storing technology. Biofuels such as ethanol and methanol are considered to have no CO_{2-e} emissions because of their biogenic origin. Note, this analysis considers electricity produced within a state and does not include electricity traded between states. The full list of inputs and outputs is detailed in Tables 2 and 3 in the Appendix.

A BEV consuming 20kWh/100 km (similar to a Tesla Model S) currently emits similar CO_{2-e}/100km using Victorian electricity as a car consuming 9 litres of gasoline/100km. This profile progressively improves as more renewable electricity is used. In NSW a 20kWh/100km BEV emits the equivalent of a car consuming 7 litres of gasoline/100km. From a carbon emissions perspective, the figures stack up overwhelmingly in favour of BEVs in states like Tasmania or South Australia.

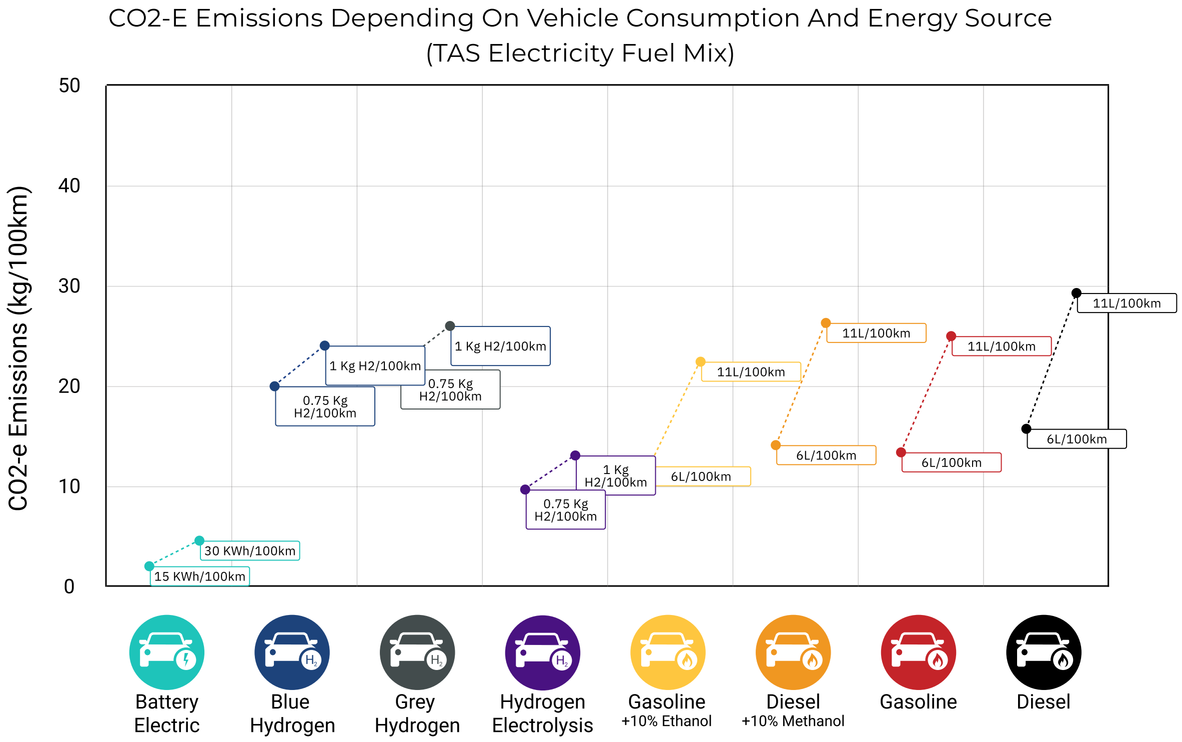

Figure 6 $CO_{2\text{-}e}$ emissions depending on fuel source based on TAS fuel mix (Source: Foresion 2022)

Hydrogen production for FCEV has a favourable environmental impact mainly if electricity is sourced predominantly from renewables (such as Tasmania or South Australia). Otherwise, hydrogen for fuel cell vehicles generally produces more carbon than battery electric vehicles and fossil fuels. FCEVs are unlikely to be an appealing technology from a carbon-perspective alone. Hydrogen FCEV can counterbalance their additional electricity requirements in certain environments when considering other fuel cell technology attributes such as ease and speed of recharge, vehicle range or refuelling infrastructure requirements.

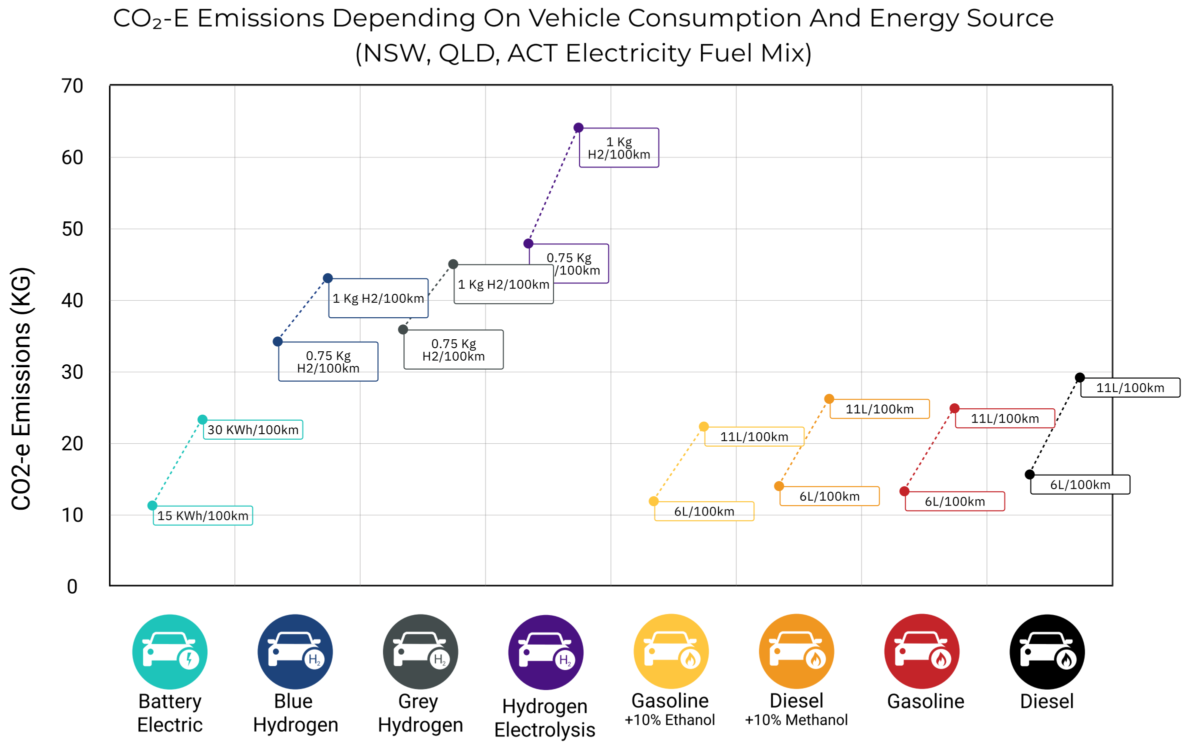

Figure 7 CO_{2-e} emissions depending on fuel source based on NSW, QLD, and ACT fuel mix (Source: Foresion 2022)

Increasing the biofuels percentage in fossil fuels can reduce carbon emissions to comparable levels as some BEVs. Increasing the ethanol proportion in gasoline by 10% reduces calculated CO_{2-e} emissions by 1.5-2.5 kg/100km. Similarly, increasing the methanol proportion in diesel fuels by 10% reduces calculated CO_{2-e} emissions by 2 to 3 kg/100km. These reductions bring many biofuel-powered ICE vehicles to more a comparable with BEVs and can immediately reduce transportation's carbon footprint. C

Currently, QLD and NSW are the only two Australian states which have imposed biofuel mandates of 3 and 6% respectively[8].

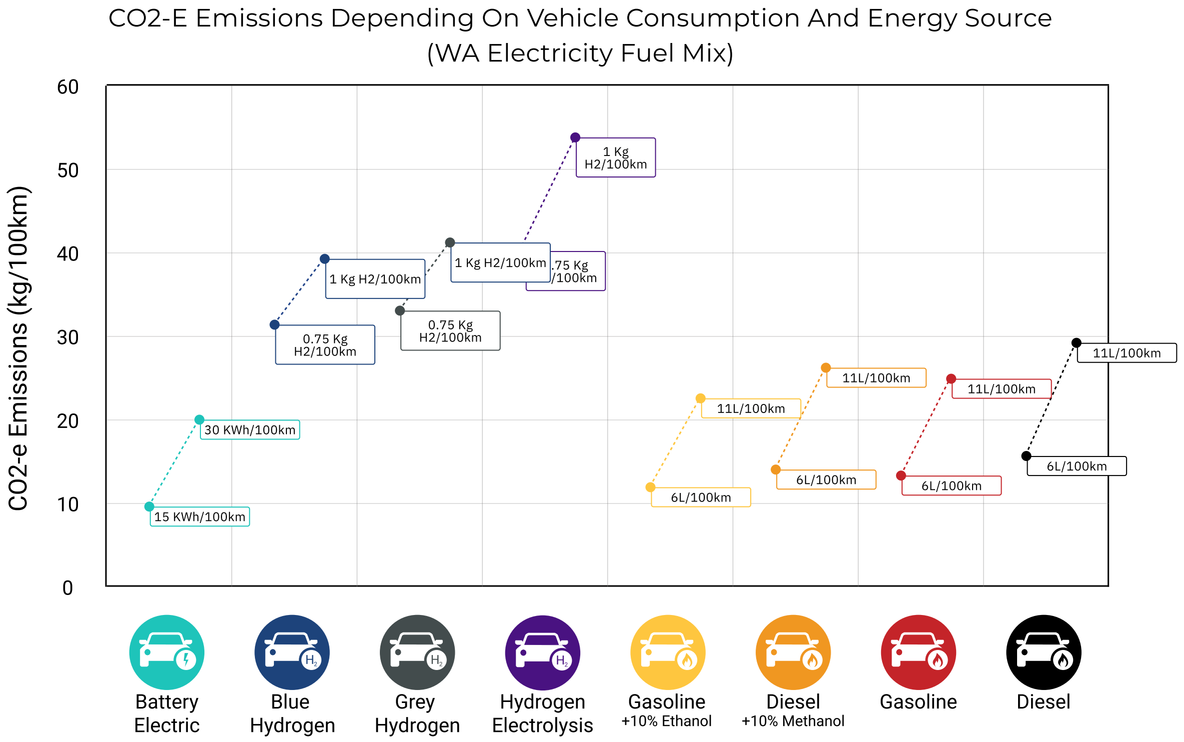

Figure 8 $CO_{2\text{-}e}$ emissions depending on fuel source based on WA fuel mix (Source: Foresion 2022)

Importantly, not all BEVs are the same. A high consumption BEV is just as or even more impacting than a fossil fuel powered vehicle. Vehicles using 30kWh/100 km can generate emissions similar to or greater than the average gasoline powered vehicle. From a carbon-equivalence perspective, BEVs present a stronger case than ICE vehicles and FCEVs in most Australian states. However, carbon equivalence is a unidimensional measure for a multi-dimensional problem.

A significant amount of metals, chemicals and energy are required to produce powertrain elements of BEV. These materials pose other environmental risks such as acidification, human toxicity, particulate matter (PM) production, photochemical ozone formation and resource depletion. Life-cycle comparisons between BEVs and ICE vehicles have highlighted that the break-even point in acidification can be reached after a vehicle drives more than 180,000 kilometres while a break-even for toxicity particulate matter or resource depletion cannot be reached[9].

Carbon equivalence is a unidimensional measure for a multi-dimensional problem.

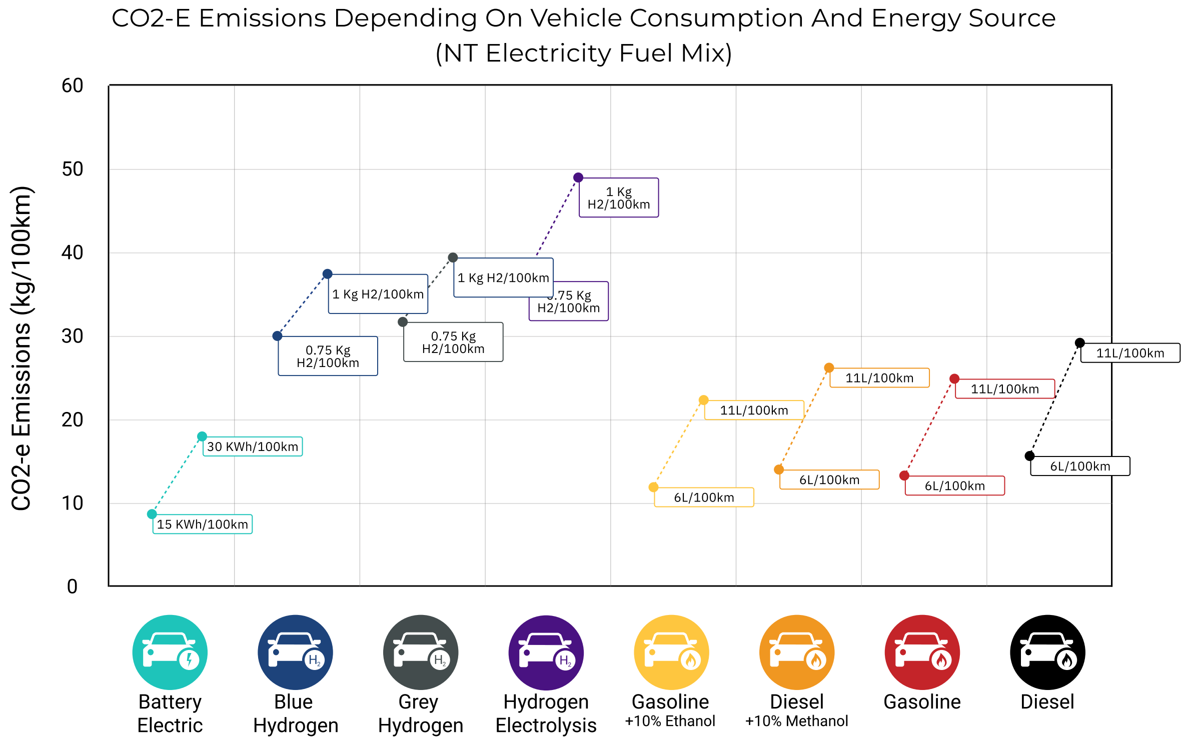

Figure 9 CO_{2-e} emissions depending on fuel source based on NT fuel mix (Foresion 2022)

Although NO_x SO_x and PM_x emissions are counted in carbon-equivalent terms to account for their global warming potential, they also have other effects. PM emissions for instance are "*associated with a variety of adverse health outcomes in the short and long term, such as increased risks of cardiovascular, respiratory, and developmental conditions, as well as an increased risk of overall mortality*"[10]. Heavier BEVs are expected to produce 3-8% more PM2.5 than the ICE vehicle equivalent.

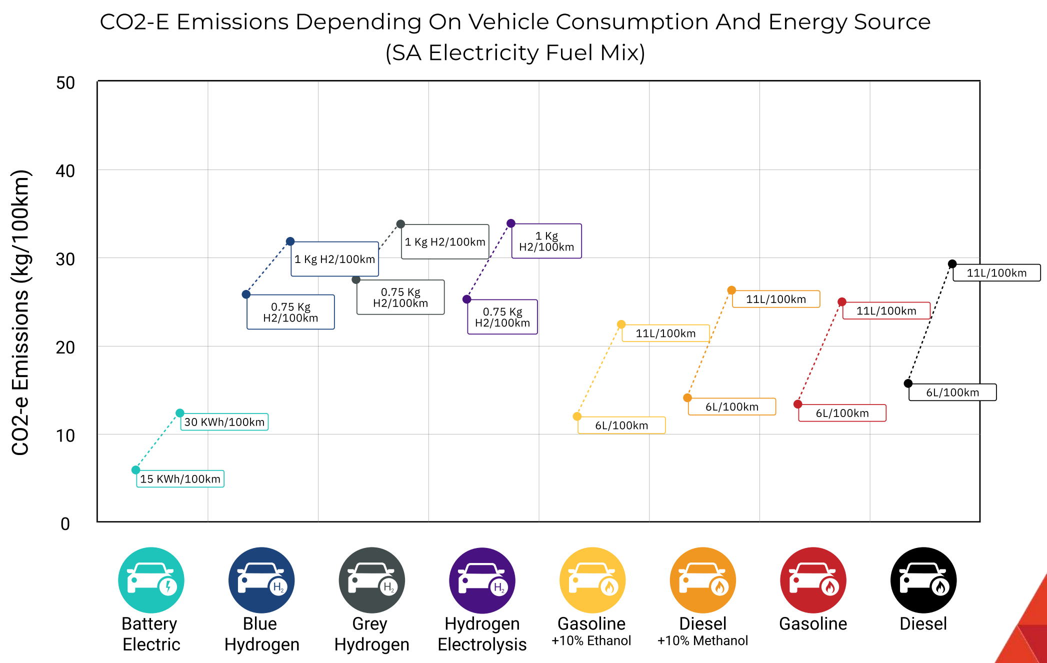

Figure 10 CO_{2-e} emissions depending on fuel source based on SA fuel mix (Source: Foresion 2022)

Credit: IEA

Opportunities for Decarbonising Transportation

The prospect of increasing electricity demand while decreasing fossil fuel reliance in electricity generation together with energy logistics challenges and the current emission footprint generated by BEV or FCEV raise several questions in personal mobility and supply chains space. How should electricity demand be best managed to continue to power industrial, commercial, residential and transportation needs? What is the most efficient way to deliver energy for transportation? How can the promise of lowering transport emission profile be realised? It is unlikely that the answers to these questions will be simple straightforward, one-size-fits-all. However, there are several opportunities which may positively contribute to lowering transport emissions:

1. **Biofuels.**
   While alternative fuel vehicles promise several benefits in the future, many promises depend on renewable electricity generation which may be difficult to achieve in a short timeframe. Biofuels can contribute immediately to reducing transportation emissions. Increasing the biofuel content of gasoline or diesel by just 10% can improve the road transport sector's environmental footprint without requiring the additional infrastructure and fleet replacement. Biofuels may also provide a pathway to reducing the environmental impact of commercial and heavy road transport where batteries and fuel cell vehicles still do not offer viable alternatives to traditional fossil fuels.
2. **Exchangeable power packs.**
   The electricity distribution challenges especially for BEVs stem mainly from the charging times. Exchangeable power packs will circumvent this issue by centralising the charging infrastructure,

therefore providing significant demand predictability on the electricity grid. Moreover, exchangeable power packs could reduce BEV charging times to exchange times, an activity that can be easily automated. Exchangeable power packs will require cooperation and coordination amongst vehicle and power pack manufacturers to ensure common and interoperable standards. A key issue however will be the increased power pack and raw material demand.

3. **Solar panels on vehicles.**
   Innovations around extendable solar panels may provide vehicles with sufficient self-charging abilities to reduce vehicle energy and charging infrastructure requirements. Currently, solar panels on vehicles provide minimal energy to power electric vehicles. However, the average Australian car travels 30km per day, including many vehicles which travel significantly less than the average. Solar panels could provide just enough energy to recharge specifically those vehicles travelling short distances on a regular basis.
4. **Public transportation.**
   Public transportation already uses mature electric power technology, provides a more predictable energy demand pattern and energy efficiency per passenger. Low population densities in and outside the largest Australian cities have typically reduced the appeal of public transportation for policy makers and the public. However, in the context of transitioning away from fossil fuels, public transport may provide a viable, scalable, and energy efficient opportunity to maintain high levels of personal mobility.

Increasing the biofuel content of gasoline or diesel by just 10% can improve the transport sector's environmental footprint without requiring the additional infrastructure and fleet replacement.


Credit: Expatica

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Appendix

Table 1 Australia's vehicle stock and potential electricity demand for transportation (Source: Motor Vehicle Census, Australia, 2021 and Foresion, 2022)

Vehicle Type*	Passenger vehicles	Light commercial vehicles	Rigid trucks	Articulated trucks	Total
Number of Vehicles (million)	14.85	3.52	0.55	0.11	19.03
Total Kilometres Travelled (billion)	163	52	11	8.1	234.4
Average Kilometres Travelled/Vehicle	11,100	15,300	21,100	78,300	
Average BEV Consumption (kWh/ 100km)	20 [a]	85 [a]	85 [a]	144[b]	
Average FCEV Consumption (kg H2/ 100km)	1.0 [a]	2.5 [a]	2.5 [a]	7.6[b]	
Total BEV Electricity Demand (TWh)	**32.97**	**45.77**	**9.91**	**12.39**	**101.04**
Total FCEV Electricity Demand (TWh)	**131.87**	**107.70**	**23.31**	**52.33**	**315.21**

* Motorcycles, busses, and non-freight carrying vehicles excluded from analysis
[a] best estimate
[b] Determined from figures presented in Transport & Environment [11]

Table 2 Fuel environmental impact calculation - key assumptions (Source: Foresion, 2022)

Inputs	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Electricity production emissions (kg CO_2-e/kwh) [12]	0.81	0.98	0.81	0.43	0.68	0.17	0.62	0.81
Grey H_2 emissions (kg CO_2-e/MJ of H_2)[13]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Blue H_2 emissions (kg CO_2-e/MJ of H_2) [13]	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
H_2 energy density (low) (MJ/kg of H_2) [14]	120	120	120	120	120	120	120	120
H_2 energy density (high) (MJ/kg of H_2) [14]	140	140	140	140	140	140	140	140
Electrolysis power required (kWh/kg of H_2) [15]	50	50	50	50	50	50	50	50
H_2 pressurisation & transport (kWh/kg H_2) [15]	30	30	30	30	30	30	30	30
Gasoline (kg Co2e/litre) [12]	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32
Diesel (kg Co2e/litre) [12]	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71

Table 3 Fuel environmental impact calculation - results (Source: Foresion, 2022)

Vehicle Type	Energy Source	Energy Consumption per 100km	CO2-e Emissions							
			NSW	VIC	QLD	SA	WA	TAS	NT	ACT
BEV	Electricity	15 kWh	12.2	14.7	12.2	6.5	10.2	2.6	9.3	12.2
BEV	Electricity	30 kWh	24.3	29.4	24.3	12.9	20.4	5.1	18.6	24.3
FCEV	Grey Hydrogen	0.75 kg H2	36.6	40.4	36.6	28.0	33.7	22.2	32.3	36.6
FCEV	Grey Hydrogen	1 kg H2	45.7	50.8	45.7	34.3	41.8	26.5	40.0	45.7
FCEV	Blue Hydrogen	0.75 kg H2	34.9	38.7	34.9	26.4	32.0	20.5	30.6	34.9
FCEV	Blue Hydrogen	1 kg H2	43.8	48.9	43.8	32.4	39.9	24.6	38.1	43.8
FCEV	Electrolysis Hydrogen	0.75 kg H2	48.6	58.8	48.6	25.8	40.8	10.2	37.2	48.6
FCEV	Electrolysis Hydrogen	1 kg H2	64.8	78.4	64.8	34.4	54.4	13.6	49.6	64.8
ICE	Gasoline + 10% ethanol	6 litres	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
ICE	Gasoline + 10% ethanol	11 litres	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0
ICE	Diesel + 10% methanol	6 litres	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
ICE	Diesel + 10% methanol	11 litres	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
ICE	Gasoline	6 litres	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9
ICE	Gasoline	11 litres	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5
ICE	Diesel	6 litres	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
ICE	Diesel	11 litres	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8