AMPC

FINAL REPORT

Renewable Hydrogen (H2) Cost-Benefit Analysis for Australian Red Meat Processors.

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GLOSSARY

AEMO Australian Energy Market Operator

ARENA Australian Renewable Energy Agency

ABS Australian Bureau of Statistics

BEVs Battery Electric Vehicles

CO_2 Carbon dioxide

^{o}C / Deg C Degrees Celsius

EU European Union

FC Fuel cell

FCEV(s) Fuel Cell Electric Vehicle(s)

FTE Full time equivalent

GDP Gross Domestic Product

GHG Greenhouse gas

GJ Gigajoule (10^9 Joules)

H_2 Hydrogen

ICE Internal Combustion Engine

IEA International Energy Agency

IRENA International Renewable Energy Agency

IRR Internal rate of return

kt kilotonne

kW kilowatt

kWt kilowatt of thermal energy

kWe kilowatt of electrical energy

kWh Kilowatt hour

LCoE Levelised Cost of Electricity

LCoH Levelised Cost of Hydrogen

LHV Lower Heating Value

LNG Liquefied Natural Gas

MWh Megawatt hour

NOx Oxides of nitrogen

NPV Net present value

O_2 Oxygen

PEM Proton exchange membrane

PEVs Plug-in Electric Vehicles

PJ petajoule

R&D Research and Development

RMI Red meat industry

RMP Red meat processor

SOEC Solid Oxide Electrolyser Cell

SOx Oxides of sulfur

tkm tonne kilometre

MWh Megawatt hour

UK United Kingdom

US / USA United States of America

1.0 EXECUTIVE SUMMARY

Hydrogen (H_2) provides Australia's red meat industry with the opportunity to simultaneously reduce energy costs, increase energy security and reduce emissions to air associated with fossil fuel combustion. The production of hydrogen is a mature technology due to the long history of electrolysis with H_2 used in petroleum refining, food processing (hydrogenation of fats and oils), welding, glass manufacture, and power stations (alternator / turbine cooling). Recent advancements in hydrogen fuel cell (FC) technology means that the following hydrogen opportunities now exist for red meat processors (RMP):

- Hydrogen as a transport fuel for refrigerated trucks, hook bins, and other heavy vehicles,
- Hydrogen forklifts and light vehicles,
- Power generation for off-grid, peak shaving, and emergency power applications,
- Refueling of transport vehicles (e.g. sale to logistics sub-contractors),
- Sale into the general market as industrial hydrogen for oil refining, metal works, glass manufacture, R&D, etc.

Hydrogen offers the advantages of:

- Lower cost transport fuel compared to diesel, unleaded, and LPG.
- Energy security by producing fuel inhouse and/or domestically thereby reducing reliance on existing liquid fuel supply chains.
- No greenhouse gas (GHG) emissions.
- No particulate, NOx, or SOx emissions when used in a fuel cell thereby offering the opportunity to increase air quality within factories and in local environments.
- Regional / remote area energy storage and utilization.
- Noise minimization when used in a fuel cell vehicle (i.e. the same as an electrified solution).

Key findings:

- Previous works have estimated ~3.2 million liters per annum (p.a.) of direct liquid fuel (diesel, unleaded petrol and LPG) usage by red meat processors [1], however extrapolating data from this project, suggests that this figure may be closer to 120.6 million litres of liquid fuel pa once sub-contractors and other ancillary transportation services are taken into account for livestock transport, transport of finished RMP products to wholesalers, waste management and direct use (i.e. forklifts and on-site activities). Whilst the sample size was smaller, and each company will have its own unique business models, this project highlighted the much larger opportunity to drive down fuel cost and emissions to air throughout supply chain activities directly related to RMPs.

- A feasibility study for RMP-1 determined the potential to utilise 214 tonnes pa of H_2 inhouse offsetting 1.2 million L pa of diesel use under current operational control. Further, truck movements associated with processing activities (B-double livestock trucks and hook bins) contribute a further estimated 1.94 million L pa of diesel bringing the annual demand to 3.15 million L pa of diesel, which equates to approximately 557 tonnes per annum of H_2. To meet total supply chain demand, up to 4.6 MW of electrolysers could be installed; at this larger scale installation at a feedlot could be considered to make use of low cost solar power from a co-located PV array.

[1] AMPC Project code: 2013-5047, "Environmental Performance Review: Red Meat Processing Sector 2015 FINAL REPORT" [data for 2013/14].

- A large number of different hydrogen production scenarios were considered. Two modular scenarios considered were:
    - PEM electrolyser capable of producing 202 tonnes of H_2 pa was designed (4.31 MWe nominal electrolyser load; supported by 5.83 MW PV solar array), which represents ~94% of current diesel demand under direct operational control, or ~36% of total diesel demand when livestock and hook bins are included. The Levelised cost of Hydrogen (LCoH) cost of production of 350 barg hydrogen from 100% renewable co-located solar power ready for vehicle refueling was estimated at $4.17 / kg H_2 [including 8 years of RECs credits and the value of oxygen] or $5.96 / kg H_2 excluding O2 value. This scale is well suited to a feedlot as approximately 13.2 Ha is required for a single axis 5.831 MWp PV solar array.
    - Where a large PV solar array cannot be installed and off-peak grid power is available, hydrogen produced from a 1.0 MW alkaline electrolyser (target of nominal load not dropping below 30% rated electrical load) with power obtained from a co-located 1.352 MWp PV solar array (38.6% of kWh's) plus off-grid power could produce hydrogen for truck refueling at an estimated $3.13 / kg H_2 [including 8 years of RECs credits and the value of oxygen]. This scale is better suited to co-location at a RMP facility as, via the use of fixed roof mounted solar, a higher ground usage factor is obtained thereby only requiring approximately 0.7 Ha for 1.352 MWp PV array.

  Depending upon the efficiency of the fuel cell device, 1 kg of H_2 provides the same brake power (i.e. the output power of a motor) as 5.93 to 6.03 L of diesel; where further improvements of as much as 50% are anticipated as fuel cell technology improves into the future. This equates to ~$6.72 to $7 of diesel fuel per kg of H_2. Hence, it can be seen that in-house H_2 production can provide a lower cost fuel than diesel.

- Payback periods for different hydrogen power generation and mobility devices, utilising hydrogen at $3.13 / kg H_2, took into account the higher cost for a FCEV device versus the lower fuel costs, with the results as follows:
    - 6 years for B-doubles
    - 5 years for forklifts
    - 3 years for semi-trailers.
    - 2 years for a hydrogen fuel cell generating stationary electricity (displacing diesel) and generating hot water (displacing LPG) allowing $1/kg for transport of hydrogen from RMP to feedlot.
    - 7 years for a hydrogen fuel cell providing peak shaving at a RMP facility (i.e. reduction in grid power costs).

- One opportunity uncovered from this stage of works is genset dual-fueling of diesel with gaseous fuels (which could be H_2, LPG, CNG or LNG) which can be made possible by the same engine conversion kit (but would require dedicated and different fuel storage). Assuming LPG at $0.5628 / L and diesel at $0.8756 after allowing for the ATO fuel tax credit for both, and utilizing Gasmastor trial data [2] and excluding the maintenance / life of plant advantages, the payback period for investing in a dual-fuel system for a genset run on diesel-LPG is estimated at 9 months (based upon a fuel saving of $8,269 pa). Once H_2 is available, the same conversion kit can be used to run a diesel-H_2 mix.

  Via improved combustion efficiency, replacing 3.0% of the diesel on an energy basis with hydrogen results in 9.1% lower diesel consumption for the same kWh brake

[2] https://www.gasmastor.com.au/case-studies/stationary-engine-case-studies/, accessed 31 March 2020.

power[3]. Due to these efficiency gains that a small amount of hydrogen provides, the break even value for the hydrogen was estimated at $12.74 / kg H_2. Hence, if H_2 can be produced in-house at $3.13 / kg, the overall payback for in-house H_2 production and dual-fuel conversion of ~20 B-doubles is ~3 years.

- A second feasibility study for RMP-2 determined a potential to utilise 306 tonnes pa of H_2, offsetting 1.815 million L pa of diesel (predominantly for cattle trucks and refrigerated product delivery) and LPG (for forklifts) all under current operational control. Due to the slightly higher off-grid / wholesale power costs in Victoria and slightly lower output from solar panels, the H_2 from a 1 MW alkaline electrolyser is estimated at $3.73 / kg where the oxygen can be utilized.

Hydrogen fuel cells offer the following advantages:

- Zero point source CO2 emissions.
- Zero point source CH4 emissions.
- Zero point source particulate emissions.
- Zero point source NOx emissions.
- Zero point source SOx emissions.
- Water vapour as the only point source emission.
- One of the limited technologies for a zero emissions transport fleet.

Stringent air quality requirements within buildings for worker health in Europe and North America are driving hydrogen forklift sales, in particular where forklifts are used more than one shift per day as the charging time for electric forklifts reduces utilization to the point where electric forklifts are not economically viable.

Each kg of hydrogen used in a fuel cell reduces diesel usage by ~5.9 litres, which equates to a Scope 1 emissions reduction of approximately 16.32 kg. Hence, a RMP replacing 3.149 million L of diesel per annum with hydrogen could reduce Scope 1 emissions by 8,565 tonnes CO_2-e per annum.

In an optimised dual-fuel scenario (i.e. 3% of energy equivalent from H2 delivering a 9.1% overall diesel reduction due to combustion efficiency gains), 1 kg of hydrogen used in a duel fuel engine has been shown to off-set as much as 11.2 litres of diesel. The efficiency ratio is reduced when higher amounts of H_2 is used.

In preparing this report All Energy Pty Ltd has relied upon data, surveys, analysis, designs, plans or other information provided by third parties or as referenced herein. Some of the assumptions made in this report are aspirational in nature (i.e. no opportunity cost assigned to land requirements; diesel prices based upon Q1 2020 data), hence businesses are recommended to undertake project and business specific analyses. No responsibility is accepted for use of any part of this report in any other context or for any other. This report does not purport to provide legal or financial advice; readers should engage appropriate advisers for these purposes.

[3] C. Pana, N. Negurescu, A. Cernat, C. Nutu, I. Mirica, D. FuiorescuExperimental aspects of the hydrogen use at diesel engine, Procedia Eng, 181 (2017), pp. 649-657, 10.1016/j.proeng.2017.02.446

HYDROGEN EXAMPLE SCENARIO: An existing trucking fleet is converted to a “dual fuel” system to be able to run simultaneously on diesel as well as hydrogen (H_2). Replacing 3.0% of the diesel on an energy basis with hydrogen results in 9.1% lower diesel consumption for the same kWh brake power[4]. The dual fueling of hydrogen at these smaller percentages results in improved combustion efficiency, a more homogenous fuel-air mixture, increased brake thermal efficiency, and improved engine performance. Further, less soot is created leading to a cleaner engine combustion leading to reduced maintenance costs, estimated at ~30%. This efficiency gain means that the value of hydrogen in a dual fuel system equates to $12.74 / kg H_2.

A 1.0 MW hydrogen electrolyser is installed with an associated 1.35 MWp PV solar array. Including truck conversion to duel fuel systems, the total capital cost is estimated at $6.26 mil. Some power for the electrolyser is also obtained from low cost off-peak power and/or low cost wholesale electricity via a 11 kV grid connection. The electrolyser produces 121 tonnes of H_2 pa (1.36 mil L pa diesel saving). Annual operating costs are ~$0.48 mil pa (including water, maintenance, grid power and personnel costs), with renewable energy credits worth ~$0.07 mil pa. At the above H_2 value, the simple payback period for the H_2 production facility and truck conversions is approximately 5 to 6 years (not including future increases in diesel costs). The economics are improved where future increases in diesel costs are taken into account and where the H_2 reduces remote area diesel values above the assumed diesel cost of $1.134 / L.

Hydrogen can also be sold to the public, other trucking fleets, backloaded to other points of use (e.g. remote area power) or sold to off-takers for fuel and/or industrial purposes.

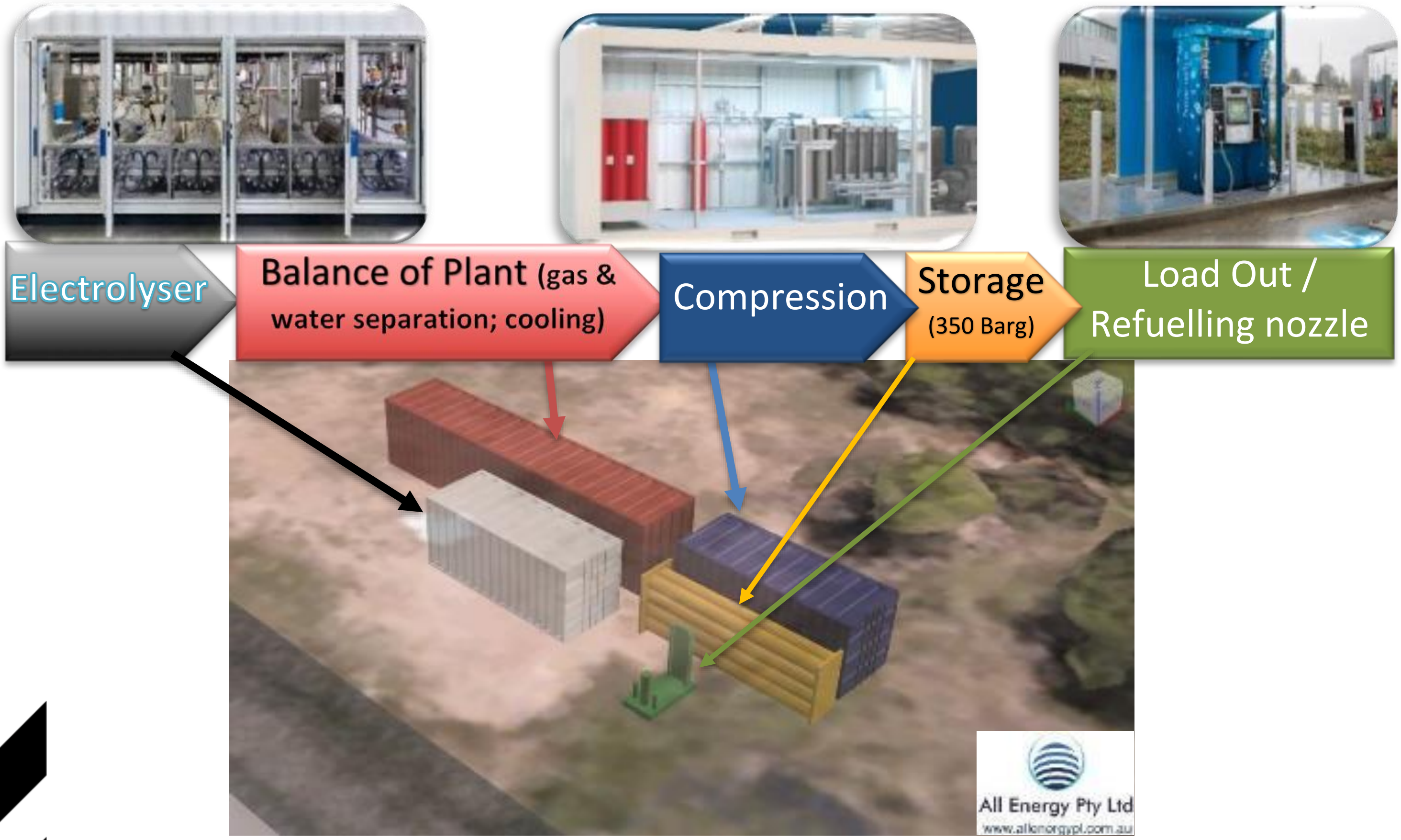


Figure 1: 1 MW electrolyser layout

[4] C. Pana, N. Negurescu, A. Cernat, C. Nutu, I. Mirica, D. FuiorescuExperimental aspects of the hydrogen use at diesel engine, Procedia Eng, 181 (2017), pp. 649-657, 10.1016/j.proeng.2017.02.446

Due to the large number of hydrogen device options, it is recommended that opportunities be analysed in detail with respect to mobility / dual-fuel options and hydrogen demand with an associated calculation of the LCoH at a given production rate of hydrogen. With that in mind, the following Table 1 summarises indicative hydrogen production options with estimated net present value (NPV) and internal rate of return (IRR) calculations with hydrogen off-setting liquid fuel costs increasing at 2.71% per annum, and a discount rate of 1.30%. This calculation excludes the difference in capex between diesel and hydrogen mobility devices.

Table 1: 1 MW Alkaline and 4 MW PEM Electrolyser Feasibility Comparison

Scenario	H_2 usage	CAPEX	NPV	IRR	Discounted payback – years
1.0 MW alkaline electrolyser: solar & off-peak power from 11 kV; 121 t H2 pa.	OCFL fuel cell; 53% feedlot trucks.	$5.76 mil (allowance for stack replacement at ~10 yrs)	$15.7 mil	28%	~4 years (includes future increases in diesel costs)
4.0 MW PEM electrolyser; solar only; 202 t H2 pa.	OCFL fuel cell for power and hot water, CH genset, feedlot trucks.	$13.35 mil	$21.7 mil	13%	~7 years (includes future increases in diesel costs)

Assumptions:

- 20 year life of plant.
- Stack represents 60% of electrolyser costs[5]. Replaced at ~10 years for alkaline system ($540k) run continuously. No replacement required for PEM system run on solar due to lower utilisation.
- Real Discount Rate of 1.30%[6]; annualized annual diesel cost increase of 2.71%[7].
- Other assumptions as outlined throughout the report.

[5] https://arena.gov.au/assets/2016/05/Assessment-of-the-cost-of-hydrogen-from-PV.pdf, accessed 31 March 2020.
[6] Jan 2020 Real Discount Rate, Independent Pricing and Regulatory Tribunal, Ipart.nsw.gov.au, published 20 Feb 2020, accessed 24 April 2020.
[7] https://www.statista.com/statistics/299552/average-price-of-diesel-in-the-united-kingdom/, accessed 31 March 2020.

2.0 INTRODUCTION

2.1 Hydrogen Opportunities for the Red Meat Industry

Hydrogen is a versatile "energy vector" that could be used by red meat processors, in approximate order of 2020 financial viability:

- Hydrogen co-generation replacing diesel gensets,
- Refrigerated heavy vehicles,
- Waste management vehicles (i.e. hook bins; waste collection trucks),
- Light vehicles (i.e. cars),
- Cattle transport in heavy vehicles (i.e. B doubles),
- Forklifts,
- Hydrogen co-generation for peak shaving of grid power,
- Into the future (at a sufficiently low $/kg H2): hydrogen fired boilers, ceramic fuel cells for on-site power and high quality steam generation.

For the wider RMI, additional opportunities include:

- Hydrogen co-generation replacing off-grid diesel gensets and reducing heating fuel at feedlots,
- Feedlot heavy vehicles: trucks for feed, water and scrapings.
- Farming machinery (rapid development occurring for vehicles and devices).
- Hydrogen for fertilizer (liquid ammonia, ammonium nitrate, urea).
- Leasing of land and water access rights (providing wastewater) for utility scale PV solar to generate hydrogen for export.
- Into the future, load balancing for power utilities.

For transport, hydrogen's energy density provides a huge advantage plus the potential to use it in high efficiency (45 – 60%; future developments towards 80%) hydrogen fuel cells (refer section 2.2.1) as opposed to diesel internal combustion engines at around 25% efficiency for light vehicles, towards 30% efficiency in long haul heavy vehicles and towards 38% efficiency in steady speed gensets.

Diesel has an energy density of 45.5 MJ/kg with hydrogen at 120 MJ/kg, almost three times more than diesel; or 33.6 kWh of energy per kg of hydrogen, versus diesel which only holds about 12 – 14 kWh per kg[8].

[8] https://rmi.org/run-on-less-with-hydrogen-fuel-cells/, accessed 3 March 2020.

2.2 Detailed Information on Hydrogen Devices for the Red Meat Industry

2.2.1 Hydrogen for Transport - Summary

The "heart" of hydrogen devices are "fuel cells" (FCs). FCs generate electricity through a chemical reaction of hydrogen gas and oxygen in a fuel cell stack, creating a flow of current, which is used to create electrical power (refer Figure 2 below).

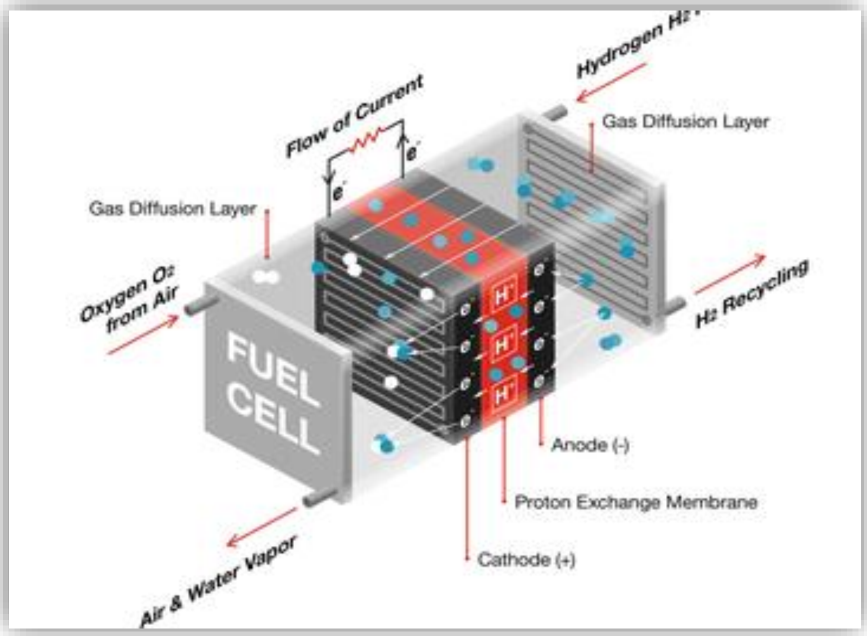


Figure 2: Schematic of a hydrogen fuel cell[9].

FCs are integrated with a power management system and a battery into a Fuel Cell-Electric Vehicle (FCEV; also called a hydrogen FCEV or HFCEV) which enables a more constant power level to be delivered by the FC, permitting downsizing of the FC with associated capex minimisation (refer Figure 3).

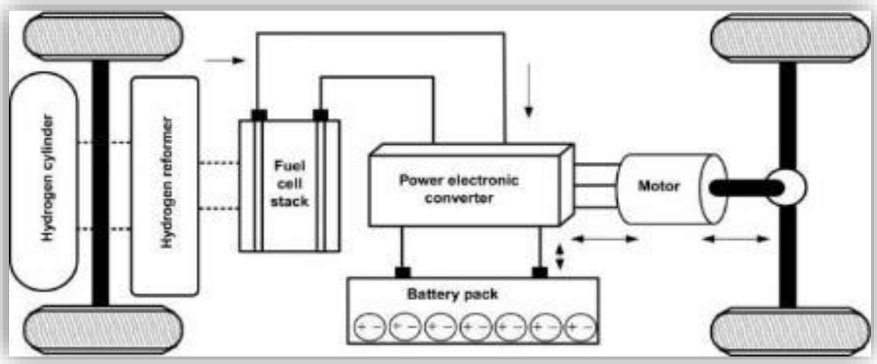


Figure 3: Schematic of a Fuel Cell-Electric Vehicle (FCEV)[10].

[9] https://www.cummins.com/fuel-cells, accessed 28 April 2020.

[10] Fundamentals of Power Electronics Controlled Electric Propulsion, Shailendra Jain, Lalit Kumar, in Power Electronics Handbook (Fourth Edition), 2018.

Summarised in Table 2 below are a range of hydrogen mobility devices using fuel cells (FCs), with some specific images and models. Most vehicles employ a battery to manage the flow of electricity from the fuel cell and, where installed, regenerative braking to then provide power for electric motors (EV) hence these vehicles are FCEVs.

Table 2: Hydrogen fuel cell mobility options.

Vehicle Description	Image / Information
B-doubles / road trains: - Wester Star with Horizon FC by Hyzon Motors. - Kenworth with Toyota FC Mercedes Econic platform	 
Hook frames for Roll-On/Roll-Off bulk waste hook bin containers e.g. Mercedes Econic platform available in Australia via SuperiorPak.	
Refrigerated delivery: - Mercedes Econic platform - Hino 700 Series platform (not yet available in Australia)	 
Any ridged configuration up to ~30 tonnes - Mercedes Econic platform for cement and waste collection trucks.	
Any truck-trailer combination: - Hyundai Xcient platform to 34 tonnes. - Hino 700 Series platform (not yet available in Australia) to 25 tonnes.	 
Light vehicles: 5 seater Source: - Toyota MIRAI, Hyundai - NEXO FWD SUV	 
Forklifts: - Hyster - Toyota Materials Handling (not yet available in Australia)	 

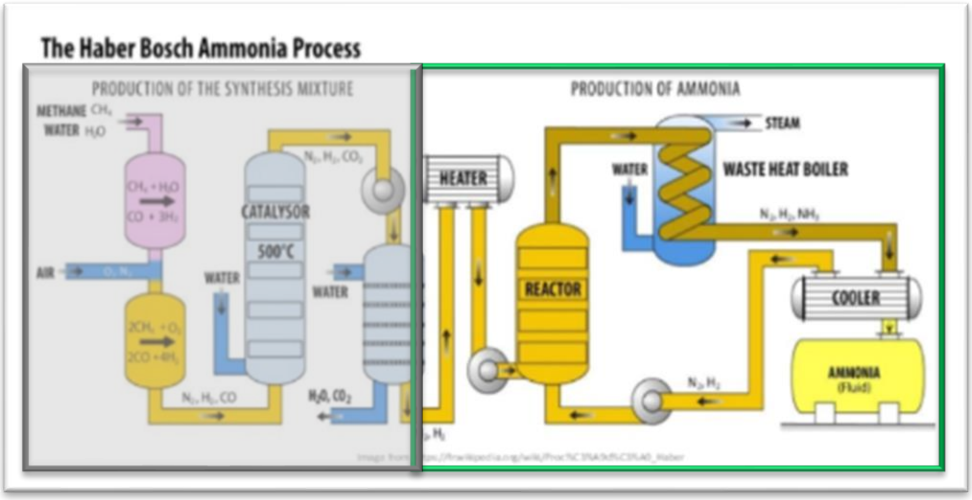
2.2.2 Hydrogen for Stationary Energy and Other Uses

Summarised in Table 3 below are a range of hydrogen mobility devices, with some specific images and models. Section

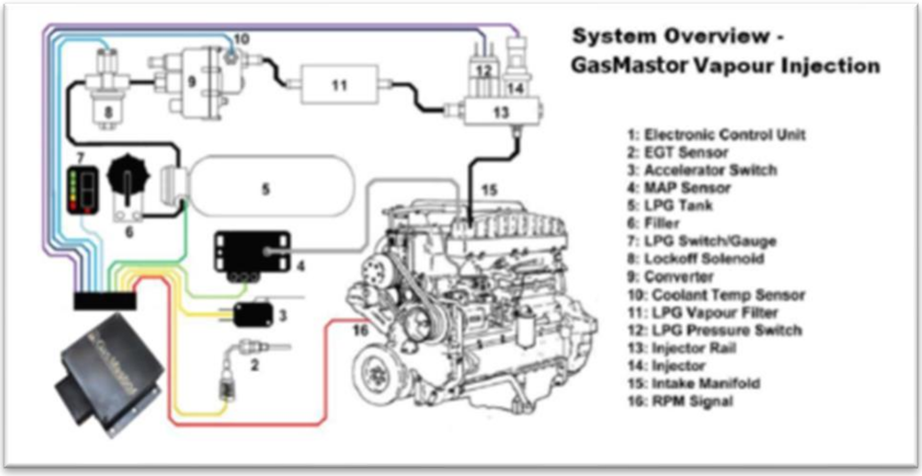
Table 3: Hydrogen stationary and non-fuel cell utilization options.

<table>
<tr><th>Vehicle Description</th><th>Image / Information</th></tr>
<tr><td>Gensets – stationary power generation for:
- Cogeneration (power and hot water).
- Off-grid power
- Peak shaving</td><td>


</td></tr>
<tr><td>Ammonia fertilizer – catalytic conversion of H2 and N2 to NH3; removes need for steam reforming and CO2 removal system. Ammonia can be further processed into ammonium nitrate or urea.

They grey box is replaced by a H_2 electrolyser and air separation unit (to purify N_2 out of air). The green box shows the unit operations to convert H_2 and N_2 into ammonia.</td><td>


</td></tr>
<tr><td>Diesel replacement / efficiency in Internal Combustion Engines.

Pertinent for stationary gensets and transport.</td><td>


</td></tr>
<tr><td>Other industrial uses:</td><td>Oil refining (hydrogenation; desulphurisation), welding gases, glass manufacturing, turbine / alternator cooling; Trains, ships, drones.</td></tr>
</table>

2.2.3 Detailed Information on Hydrogen Devices

2.2.3.1 Introduction on Hydrogen Vehicles

All Energy Pty Ltd has a watching brief of energy fuel costs, markets, uses, and ATO fuel credits to create an analysis of the price point of different fuels for transport.

When considering the economics of transport options, the element of interest is the brake power (calculated in kWh for this analysis) that can be provided per unit cost of each fuel. Brake power is the power provided by the output shaft of an engine and takes into account power lost to friction, energy lost in exhaust gases, and energy lost within the engine itself. Hence, the efficiency for an internal combustion engine (ICE) is low compared to that of an electro-chemical device such as a hydrogen fuel cell (refer to Table 4 below).

The analysis presented in Table 4 takes into account the costs of the fuel, the energy content of the fuel (LHV) and the efficiency of energy conversion by the engine / device into brake power. This calculation therefore takes into account the comparatively high efficiency of a fuel cell to convert energy into brake power. A number of assumptions were made as follows:

- Liquid fuel prices were assumed as the Terminal Gate Price, Brisbane.[11]
- GST was subtracted (refer Table 4 below).
- ATO fuel tax credit taking into account the type of fuel and the use for that fuel was subtracted (refer Table 4 below) [12].
- Lower hating value (LHV) was applied to each fuel.
- Efficiency of conversion for each engine / device.

Summarised in Table 4 below is the cost of brake power output from different motors taking into account the costs of fuel and the different efficiencies. As can be seen, the "low hanging fruit" is for H_2 to offset diesel used in light vehicles however this has a limited application for RMPs, with the larger opportunity being offsetting diesel use in trucks operating on public roads.

Table 4: Analysis of the cost per unit brake power (kWh) provided by different fuels and for different uses

Calculation of $ / kWh of usable energy	ATO Fuel Tax Credit	$/L post-credit (excl. GST)	Efficiency [LHV to brake power]	$/kWh brake power
Diesel fuel for light vehicle public road	**0.00**	**1.292**	**25%**	**0.5164**
Diesel fuel for heavy vehicle public road [high speed engine]	**0.16**	**1.134**	**30%**	**0.3776**
Diesel on private roads	0.418	0.876	30%	0.2916
LPG – non-road (i.e. forklifts)	0.14	0.618	35%	0.2601
Diesel gensets: power only	0.418	0.876	38.0%	0.2302
Diesel Cogen: power and heat	0.418	0.876	38.0% power 40.0% heat	0.2302 power 0.2187 heat
Hydrogen @ $4.05/kg in a fuel cell electric vehicle (FCEV)	-		45%	0.2284
Hydrogen @ $5/kg in a FCEV	-		45%	0.2819
Hydrogen @ $6/kg in a FCEV	-		45%	0.3383
Hydrogen @ $6.70/kg (breakeven price point for H2 in FCEVs compared to diesel ICEs)			45%	0.3776
Hydrogen @ $12/kg in a FCEV	-		45%	0.6766

[11] Aip.com.au, accessed 9 Dec 2019.

[12] https://www.ato.gov.au/Business/Fuel-schemes/Fuel-tax-credits---business/Rates---business/From-1-July-2019/, accessed 9 Dec 2019

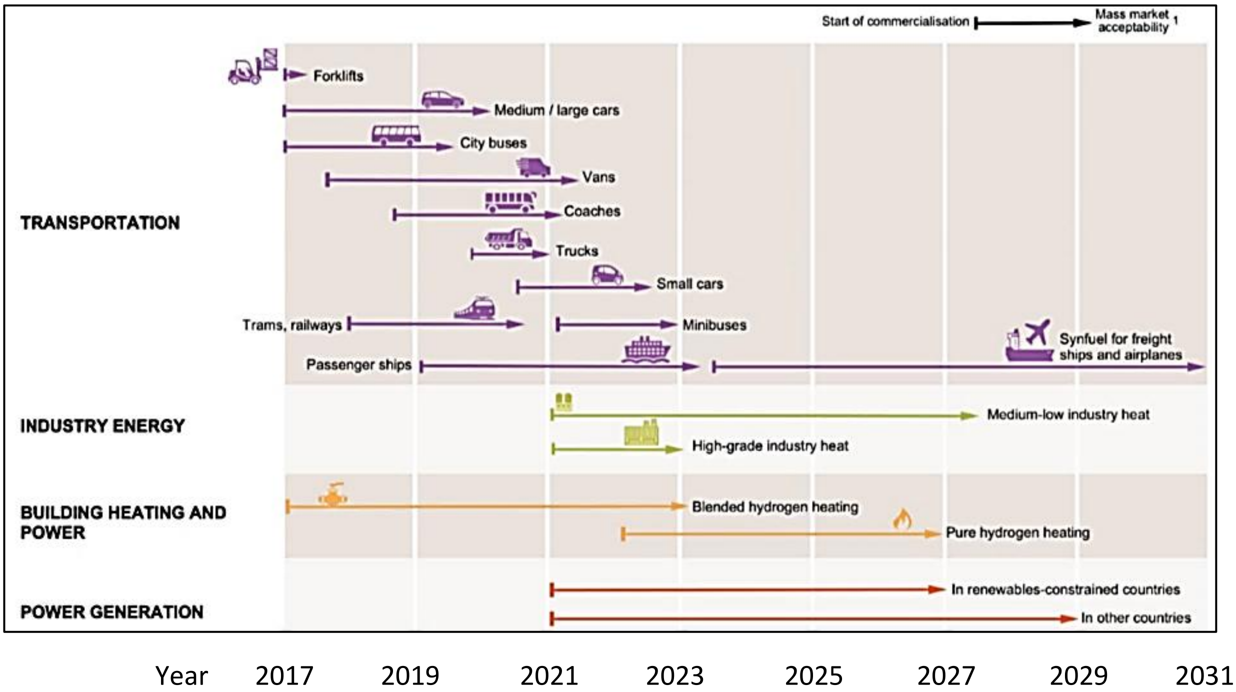
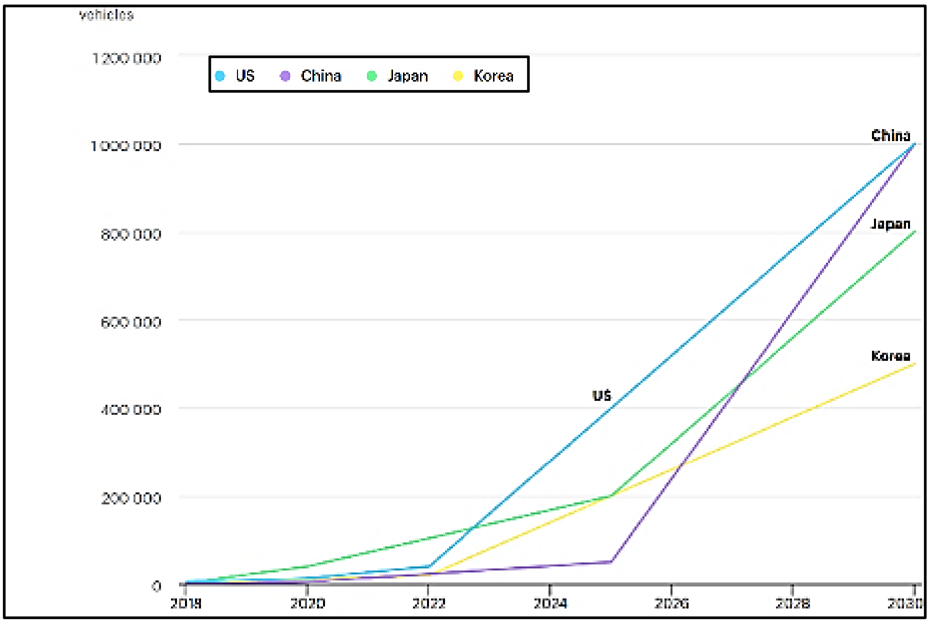


Figure 4: Timeline for commercialization and mass market acceptability of different hydrogen mobility and hydrogen utilization devices

As shown in Figure 4 above, it is expected that competitiveness for different mobility devices will occur at different times. As of Q1 2020, there is a conceited effort for buses and trucks to move towards FCEV propulsion, with a limited expansion of offerings for light vehicles. There is also strong interest in trains and passenger ferries. Figure 4 below shows the accelerated ramp up in fuel cell vehicles. The International Energy Agency reports that by 2030 the number of hydrogen fuel cell vehicles is targeted at 3.3 million in the four countries of US, China, Japan and Korea only[13]; increasing from 11,200 units at the end of 2018. This is an annual compound increase of 60.61% per annum.



[13] https://www.iea.org/data-and-statistics/charts/national-and-sub-national-fuel-cell-electric-vehicle-targets-for-selected-countries-2018-2030

Figure 5: National fuel cell electric vehicle targets for selected countries, 2018-2030 (IEA, 2019).

A detailed economic analysis was performed by the company Ballard comparing hydrogen forklifts to electric forklifts. Over ten years, hydrogen forklifts realize a 24% savings in total lifetime ownership cost. Using this discount rate of 10%, the investment results in a Net Present Value of $US 3.6 million for a fleet of 250 forklifts assuming $US 8 / kg hydrogen costs[14]. One of the key advantages is the long run time efficiency of using hydrogen as opposed to recharging / swapping out batteries.

Ballard supplies fuel cell stacks to systems integrators and material handling equipment manufacturers to be integrated in Class 1, 2 and 3 forklifts. Hydrogen forklifts employing Ballard fuel cells are being used by BMW, Walmart and Bridgestone.

Figure 6: A FCEV forklift is refueled with hydrogen at BMW's South Carolina manufacturing plant (USA)[15].

[14] "Economics of Fuel Cell Solutions for Material Handling", ballard.com, accessed 10 Dec 2019.
[15] https://www.ballard.com/docs/default-source/motive-modules-documents/material-handling/material_handling_case_study_041911.pdf?sfvrsn=2&sfvrsn=2, accessed 1 May 2020.

2.2.3.2 HYZON Heavy Vehicles – Western Star Conversions for B-Doubles

HYZON is an off-shoot of one of the world's main FC fabricators, Horizon. HYZON has had early successes with port container haulage devices in Singapore and throughout China as well as a strong demand for their buses. Presented in the figure below are the main FCs being integrated into FCEVs by HYZON, along with innovative energy design features such as energy recovery from the suspension[16]. Horizon has had over 16 years' experience in FC fabrication.

	VL III-60	VL III-80	VL III-100
Stack Rated Power	60kW	80kW	100kW
Performance	500A@ 120V(150kPa)	500A@ 160V(150kPa)	500A@ 200V(150kPa)
Number of Cells	224	298	372
Power Density by Cell Area	1.08w/cm² (150kpa) 0.8w/cm² (80kpa)	1.08w/cm² (150kpa) 0.8w/cm² (80kpa)	1.08w/cm² (150kpa) 0.8w/cm² (80kpa)
Volume Power Density	5.7kw/L	5.7kw/L	5.7kw/L
Weight Power Density	2.21kw/kg	2.27kw/kg	2.3kw/kg
Stack Size	308mm*410mm*131mm	382mm*410mm*131mm	456mm*410mm*131mm
Stack Operating Temperature	65°C ~85°C		
Operating Environment	-20°C ~ 75°C		
Relative Humidity	0-100% Non-condensing		
Hydrogen Requirement	≧99.95% Dry Hydrogen		
Hydrogen Consumption	≦0.73m3/kWh@ Rated Power		
Startup Time	≦2mins (Normal Temperature) / ≦15mins (-10°C)		
Fuel Cell Module Efficiency	≧47% @ Rated Power		
H2 Pressure	0-170kPa (Relative Pressure)		
Air Pressure	0-80kPa / 0-150kPa (Relative Pressure)		

Figure 7: HYZON Fuel Cell Models

HYZON's basic offering is a 40t GVM 6 x 4 prime mover and an 80t GVM 8 x 4 bonneted Western Star truck (refer Figure below), however Ballard is able to convert most vehicles into FCEV powered systems.

16 https://www.hyzonmotors.com/technology, accessed 30 April 2020.

Figure 8: HYZON H2 Heavy Vehicle (B-double) option.

2.2.3.3 Hyundai Heavy Vehicles

Hyundai is moving at a rapid speed to have 50 trucks deployed in 2020, and 1600 trucks into the Swiss trucking industry by 2025[17]. This new fleet will initially be supported by 2 MW electrolysers utilising renewable hydro power. The range is to be ~400 km.

Table 5: H2 Xcient Fuel cell electric truck specifications (4x2 cargo truck)

Specification	Truck
Gross Vehicle Weight	18 ton (GCW 34 ton with trailer)
Length	9,745 mm
Width	2,550 mm
Height	3,730 mm
Wheelbase	5,130 mm
Driving Range	Approximately 400 km
Hydrogen Refuelling Time	7 min
Tank Capacity / Pressure	32.86 kgH_2 / 350 bar
Fuel Cell Stack Power	190 kW (2 x 95 kW)
Traction Motor	350 kW / 3,400 Nm

Figure 9: Hyundai Hydrogen Truck in rigid and semi-trailer configuration.

[17] https://www.ttnews.com/articles/deployment-hydrogen-fuel-cell-powered-trucks-will-require-fueling-networks-clear-business, accessed 30 April 2020.

2.2.3.4 Kenworth Heavy Vehicles

Kenworth Truck Company and Toyota Motor North America are collaborating to develop 10 zero-emissions Kenworth T680s powered by Toyota hydrogen fuel cell electric powertrains. The first new, jointly developed Kenworth / Toyota Fuel Cell Electric Truck (FCET) was displayed on April 201918. The effort is part of a $41 million Zero and Near-Zero Emissions Freight Facilities (ZANZEFF) grant awarded by the California Air Resources Board (CARB).

Figure 10: Kenworth T680 outfitted with a hydrogen fuel cell electric powertrain from Toyota. The truck uses two of the standard car fuel cells.

This T680 based truck when fully loaded uses 265 L of diesel or 55 kg of H_2 compressed to 700 bar to complete a 563 km run. Refueling time is ~15 minutes versus 2 hours for a commensurate battery. The fuel cells used are simply two pf the Mirai light vehicle fuel cells, however the truck has 670 horsepower due to the larger electric traction motors and onboard battery, which is sufficient for a 36.3 tonne vehicle to take off on a 20 degree gradient[19].

[18] https://www.kenworth.com/news/news-releases/2019/april/kenworth-toyota-pola/

[19] https://www.forbes.com/sites/sebastianblanco/2019/04/23/toyota-kenworth-expand-hydrogen-semi-truck-push-at-los-angeles-ports/#3def1873d762

2.2.3.5 SuperiorPak / Mercedes Heavy Vehicles

Faun, a subsidiary of the Kirchhoff Group, is producing 22 hydrogen fuel cell trucks based upon the Mercedes Econic platform, titled "Bluepower". Faun has been working on battery-electric drives since 2011 and have found that the hydrogen fuel cell option is many times lighter than a comparable battery hence more payload remains available. The FCEV option is also better suited to routes that require highway travel and/or are topographically difficult. In Australia, Faun trucks are available via SuperiorPak.

H2 is generated at a council waste-to-energy plant, providing H_2 for bus and truck refueling. Mercedes-Econic chassis is able to be filled in 8 minutes and can be refilled at all hydrogen stations at a pressure of 350 bar. The Gross Vehicle Weight (GVW) is to be 25 to 40 tonnes, depending upon the usage.

Figure 11: Econic refrigerated box option showing the H2 storage (green Fibre Reinforced Polymermer tanks or FRPs) and the Econic in a semi-trailer format.

One Mercedes Econic Hydrogen option is delivered with the following options[20]:

- 25 to 40 Tons chassis
- 4.200mm wheelbase
- 250 KW Electric motor
- 45KW Fuel cell
- 20KG Hydrogen at 350 bar
- 140kWh battery at 700V

[20] https://www.cleantechnology.nl/trucks.html

2.2.3.6 Scania Heavy Vehicles

On 21 Jan 2020, a roll-out of four (4) Scania hydrogen trucks was announced in Norway. ASKO, Norway's leading grocery wholesaler, installed a H_2 refueling station to support these trucks. Gross Vehicle Weight (GVW) is to be approximately 27 tonnes.

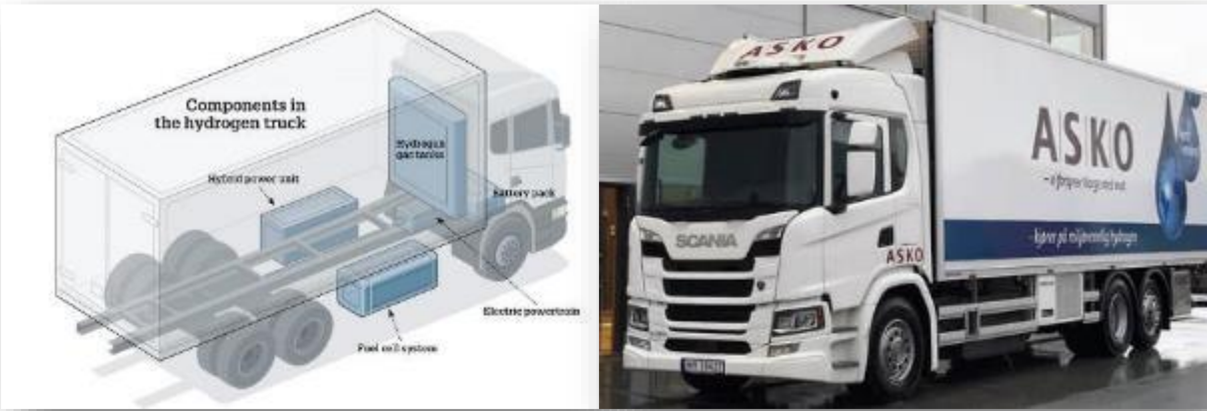


Figure 12: Scania H2 fuel cell truck.

Facts about the truck:

- Gross Vehicle Weight: 26+1 tonnes
- Configuration: 6×2/4
- Powertrain: 290kW electric motor / 210 kW continuous output, 2-speed transmission, 2200Nm peak torque
- Installed battery capacity: 56kWh Li-ion
- On-board charger: 22kW AC with CCS charging interface
- Fuel cell: 90kW PEFC delivered by Cummins / Hydrogenics.
- Hydrogen storage: 33kg @ 350 bar
- Estimated range: 400-500km

2.2.3.7 Cummins Heavy Vehicles

Figure 13: Scania H2 fuel cell truck.

The Cummins zero-emissions class 8, 6x4 day cab tractor is a technology demonstrator suitable for vocational applications, including regional haul, urban delivery operations, port drayage and terminal container handling. The truck was designed and integrated by Cummins in the U.S. and includes a proton exchange membrane (PEM) fuel cell from Hydrogenics. The truck was designed for a 90-kW fuel cell and is scalable in 30 kW or 45 kW increments up to 180 kW, and also has a 100-kWh lithium-ion battery capacity. The truck has a range of 241 to 402 km between filling up, however, that range can be extended with additional hydrogen tanks, by increasing the tank storage pressure or installing additional fuel cells to optimize management of the vehicle load factor.

As Cummins are power train experts, as opposed to chassis specialists, Cummins/Hydrogenics fuel cells have also been integrated into a range of other heavy vehicles.

2.2.3.8 Materials Handling

Hyster demonstrated Australia's first hydrogen-powered forklift in April 2018[21], with more than 16,000 hydrogen fuel cell lift trucks now being used in North America[22]. Since then the company has developed hydrogen fuel cell options with Nuvera to enable integration of hydrogen with the entire Hyster lifting range from 907 to 47,627 kg.

Figure 14: Hyster H_2 Forklift Offerings

A cost benefit analysis utilising a Hyster Hydrogen calculator was completed for a "median" RMP utilising 8 forklifts for 250 days per annum, two shifts per day, 8 hours per shift at an operator rate of $AUS 26.76 / hr[23] (converted to $US), which would deliver an estimated payback of 5 years whilst a 4 year payback is estimated for a fleet of 14 or more. This analysis relies upon production of H_2 at a large scale such as for a B-double fleet with the forklift fuel representing a small fraction of fuel requirement i.e. the economic viability of a H_2 forklift depends upon economies of scale for H_2 production where forklift fuel may only represent 5 – 10% of total H_2 requirements.

[21] https://www.farmmachinerysales.com.au/editorial/details/hyster-launches-hydrogen-forklift-112737/

[22] https://www.hyster.com/north-america/en-us/solutions/white-papers/the-adoption-of-hydrogen-fuel-cell-powered-lift-trucks/, accessed 24 March 2020.

[23] Payascale.com, accessed 24 March 2020.

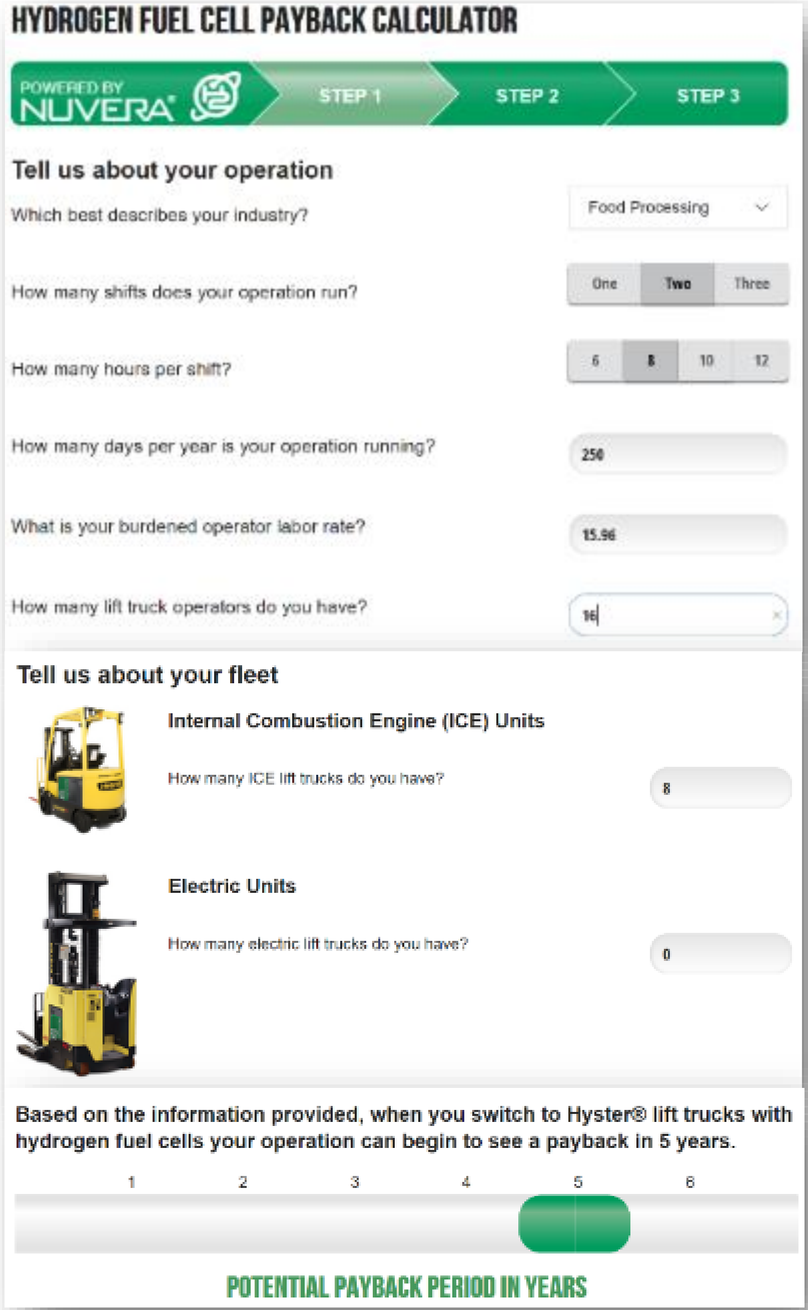


Figure 15: Hyster H_2 Fuel Cell Payback Calculator

Hyster's hydrogen-powered range uses the Nuvera fuel cell systems, which are fast-fuelled power options that replace lead-acid batteries in Class I, II, and III electric lift trucks. The Nuvera fuel cell system was acquired by Hyster-Yale in 2014. The hydrogen fuel cell powered forklifts can be refuelled in as little as three minutes, which saves significant downtime compared with battery-operated forklifts (which can take up to 8 hours to recharge). The key historical barrier to the adoption of more hydrogen-powered vehicles in Australia is a lack of hydrogen infrastructure. Walmart and Amazon in the USA are using H_2 materials handling operations, where productivity is a vital element in maintaining a competitive edge as product and operator utilisation are maximized by providing gains in uptime and productivity. The recharging of the hydrogen-powered forklifts is no different from fueling up a car or truck at the bowser. A hose dispenser connected to the Nuvera hydrogen dispenser system pumps hydrogen into the hydrogen storage tank. The fuel cell re-combines hydrogen and oxygen to generate electricity to power the forklift's electric motor. Unlike a conventional fossil fuel engine, a fuel cell does not burn the hydrogen, but electro-chemically reacts hydrogen and oxygen to produce electricity and water thereby creating an electrical current.

2.2.3.3 Hydrogen Fuel Cells for Stationary Energy

A non-exhaustive list of fuel cell suppliers for stationary power and FCEV vehicles include:

- Ballard (UK / Canada)
- Ceres (UK). Working with Nissan on vehicles.
- Horizon (China)
- Hydrogenics (Canada / Europe)
- Nuvera Fuel Cells (USA). A subsidiary of NACCO Materials Handling.
- SFC Energy (Germany).
- Toshiba (Japan)

Cogeneration from fuel cells works in the reverse of an electrolyser: H_2 and O_2 are electrochemically reacted with associated creation of thermal energy. Assuming a H_2 LHV of 32.71 kWh/kg and a 60% fuel cell efficiency, then 19.63 kWh of electrical output is achieved per kg H_2. Further, around 21% of the HHV can be recovered as hot water (60 to 75 Deg C).

Due to scale up in fuel cell production capacity, the cost per kW is expected to tumble over the coming years to be on parity with and then fall below the cost of internal combustion engines (ICEs). Figure 16 shows the rapid increase in fuel cell installations.

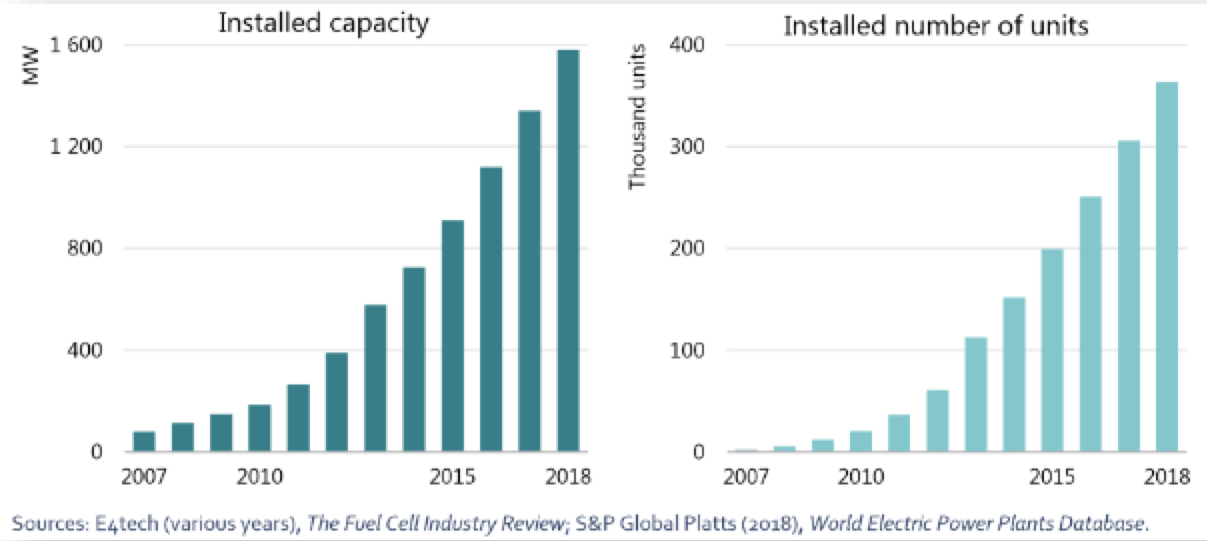


Figure 2: Growth in stationary fuel cell capacity for 2007 to 2018.

2.2.3.4 Farming and Hauling Equipment

A range of companies are able to convert any vehicle to a FCEV power train, however generally, large volumes of conversions are required to reduce the per unit cost. One exception is where a vehicle is based upon a fully electric platform, where the conversion is then simpler as some of the Li-ion batteries are replaced with a FC, thereby increasing the range and reducing the overall vehicle mass, with examples including:

- Scania 27 t GVM platform completed for ASKO,
- Mercedes Econic,
- Komatsu haul trucks (refer case study below).

Figure 17: Case Study of heavy vehicle retrofits with hydrogen fuel cells. The uptake of this technology will drive demand for hydrogen domestically in Australia.

2.3 Hydrogen Production

2.3.1 Introduction to Hydrogen Production

Two key hydrogen production technologies were considered within the scope of this project: alkaline electrolysis and Proton Exchange Membrane electrolysis.

Alkaline electrolysis has been in commercial use for over 150 years[24]. It employs a cathode, an anode and an electrolyte based on a solution of caustic salts. When voltage is applied, water decomposes in the alkaline solution. Hydrogen is formed at the cathode and oxygen at the anode. Between the two electrodes is a membrane that only allows negatively charged ions of oxygen and hydrogen (OH-) to pass through, thus separating the gases. The electrolyte is liquid, which means that the alkaline electrolyser requires more peripheral equipment, such as pumps for the electrolyte, solution washing, and preparation. Of the available electrolysis processes, it has the lowest capex on a nominal capacity (tonnes H2 per hour) basis but has relatively high operating and maintenance costs.

Proton exchange membrane (PEM) electrolysis is a newer technology. It reverses the fuel cell principle and requires no liquid electrolyte. Water is pressed through a stack of two electrodes and a polymer membrane. It only allows positively charged hydrogen protons to pass through. Platinum is usually used as a catalyst in the cell, which contributes to the stack presenting ~60%[25] . The thin cells consisting of a membrane and a pair of electrodes can be arranged in stacks to achieve better performance. Compared to alkaline electrolysis, PEM electrolysis has the advantage of quickly reacting to the power fluctuations typical of renewable electricity generation. This technology is often used for distributed, modular and/or solar powered systems because the equipment is low-maintenance and delivers high-quality gas suitable for use in vehicle fuel cells.

For both alkaline and PEM electrolysis, heat (~20% of total energy input) is generated during the reaction which, when harnessed, increases the overall efficiency of the system. The hydrogen obtained must then be cleaned (to remove O_2 and trace elements that were present in the water such as N_2), dried and compressed if the H2 is used in vehicles or is to be transport to other locations.

Other innovative technologies exist but are many years away from commercial deployment at the scale required hence were not considered within the scope of this project, but are worth noting for potential future use:

- Anion exchange membrane which does not use expensive metals thereby reducing the capex.
- Ceramic membranes that operate at high temperatures, which could also produce steam suitable for RMPs (sterilisation water and steam for rendering), and that offer the potential for direct electrolysis of saline and waste waters without the need for purification. Whilst water purification is not the main capex or opex, impurities are a key contributor to reducing stack life. Further, they provide the opportunity for higher electrical efficiency make incremental efficiency gains.

The price point for H2 production is trending downwards:

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[24] https://www.pv-magazine.com/2020/03/21/the-weekend-read-hydrogen-is-getting-cheaper/

[25] https://arena.gov.au/assets/2016/05/Assessment-of-the-cost-of-hydrogen-from-PV.pdf, accessed 31 March 2020.

- Nikola (USA) have based their business model, commencing from 2021, on $US 2.47 / kg ($AUS 4.07 / kg) whilst east coast USA companies are signing off-takes for sub-$US 4 /kg ($AUS 6.60 / kg).
- 1.50 Euro ($AUS 2.65) / kg once production is automated and scaled-up, which is predicted to occur in 2024[26].
- Enapter (https://www.enapter.com/) utilises anion exchange membrane (AEM) electrolysis and have put forward detailed modelling on capex and opex for hydrogen production, summarised in the following table and figure.

Table 6: H2 production price points

Power Costs $ AUS / kWh	Hydrogen production costs $/kg	CAPEX %	OPEX (Incl. water treatment and maintenance) %	Power %
0.00	3.01	80.0%	20.0%	0.0%
0.0516	5.5384	43.4%	10.8%	45.6%
0.086	7.138	33.7%	8.4%	57.8%

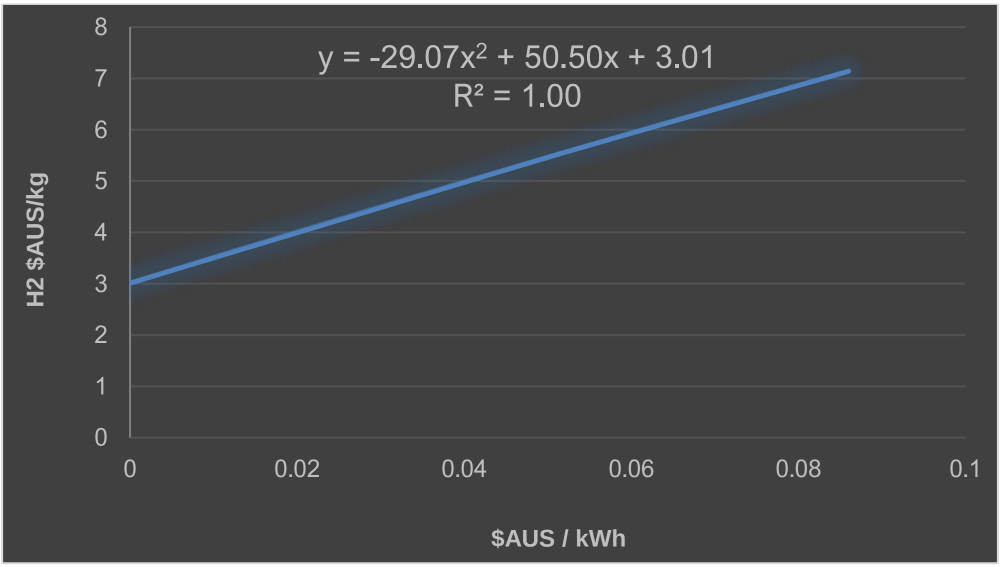


Figure 18: H2 production price points

An interesting outcome of this correlation is to define the electricity cost at which hydrogen is "free" which is at $0.058 / kWh. Whilst this would not occur for large periods of time, there is an increasing percentage of the time where power is at a negative price in the NEM due to power over production from PV solar arrays and power stations not being able to turn facilities off.

A large number of established electrolysis fabrication companies exist, including:

- Hydrogenics (Canada / Europe)
- ITM (UK)
- McPhy (France)
- Nel Hydrogen (Norway)

[26] https://www.pv-magazine.com/2020/03/21/the-weekend-read-hydrogen-is-getting-cheaper/

- Siemens (Germany)
- Thyssenkrupp (Germany)

2.3.2 PRELIMINARY FINDINGS ON H2 PRODUCTION OPTIONS FOR AUSTRALIAN RMPs

There is a rapid rate of change in vehicle OEM offerings, hence the CBA is being updated to reflect new offerings from the market.

IEA priced H_2 in 2018 at $US7.3 to 9.2, with a rapid progression towards $3.6 – 5/kg expected. Since 2010, the cost of electrolysis-produced hydrogen has fallen by 60%, from between USD $10-$15/kg of hydrogen to as low as USD $4-$6/kg today, with a further 60% reduction anticipated over the next 10 years[27]. In the last 10 years fuel cell vehicle costs have reduced by 65%. All Energy Pty Ltd has modelled H2 production at $AUS 5 – 6 / kg.

When investing in hydrogen generating plant, the shortest payback period is achieved by running electrolysers continuously (i.e. 24 hours per day), however the highest net present value (NPV) is achieved by utilising the lowest cost electricity as an input, which has been found to be, in order:

1. Low wholesale electricity spot market pricing (principally available from 07:30 to 17:00 during months of high solar radiation but low power consumption i.e. July - Dec)
2. Co-located PV solar arrays
3. Excess power from biogas-fired reciprocating engines
4. Off-peak power.

The east coast National Electricity Market (NEM) is experiencing increased periods of time of low, zero and negative pricing. However, the electrolysers cannot be run at such a low utilization where operating costs exceed income, hence electrolysers will require a minimum amount of guaranteed low cost power which could be provided by a co-located solar array.

Goal seek analysis determined that when off-setting diesel in a heavy vehicle on a public road, the electricity cost price was $0.063/kWh when H_2 is sold at the break-even price of $8 / kg. Power can be obtained at below this value from wholesale electricity spot market, co-located PV solar, and excess power from biogas fired reciprocating engine.

[27] https://www.linkedin.com/pulse/fuel-cell-price-drop-70-80-production-volume-scales-nicolas-pocard/?trackingId=%2BCPx8JjQtzyDgXWpDYMBkg%3D%3D

2.3.3 Potential benefits of Hydrogen Production to Red Meat Processors

Red meat processors are well placed to access or generate low cost power required for electrolysers. There exists the opportunity to value add wastewater and low cost power into hydrogen for use within the red meat industry supply chain to reduce fuel costs, increase energy security and to reduce emissions. Further, high pressure oxygen (10 to 20 bar) is created as a co-product which can be sparged into aerated waste water treatment ponds and/or dissolved air floatation (DAF) tanks thereby reducing the ongoing kWh and kVA electricity costs, aeration equipment maintenance costs and aeration equipment capex.

A number of scenarios were run to determine the viability of H_2 production at different scales as presented in Table 15 below.

Table 2: Results of four different hydrogen production scenarios for a 1.0 MW alkaline electrolyser using predominantly PV solar [A], PV solar and grid power [B], 4.314 MW PEM electrolyser using PV solar and a 8.627 MW PEM electrolyser using PV solar [D].

#	Technology	Scenario Description	Nominal load MW	Max load MW	PV Solar MWp	kWh pa PV	kWh pa from Grid	kg H2 pa	Nominal kg H2 pa	Utilisation
A	Alkaline electrolyser	PV solar plus grid for minimum 30% of nominal output	1.000	1.250	1.434	2,278,590	1,573,966	**78,767**	162,272	48.5%
B	Alkaline electrolyser	Full utilisation	1.000	1.250	1.434	2,278,590	5,500,000	**159,035**	162,272	98.0%
C	PEM HyLYSER-30-I	PV solar only	4.314	5.831	6.688	10,629,622	0.0	**217,326**	700,000	31.0%
D	2 x PEM HyLYSER-30-I	PV solar only	8.627	11.663	13.376	21,259,243	0	**434,651**	1,400,000	31.0%

#	CAPEX PV	CAPEX H2	TOTAL CAPEX	OPEX pa	Equivalent L diesel for transport	Revenue from H2 sales / Savings via diesel displacement for heavy vehicles on public roads	PAYBACK - Years	Life of plant - Years	$/kg H2 over life of plant
A	1,290,300	900,000	2,190,300	231,206	531,752	621,618	5.6	10.6	5.55
B	1,290,300	900,000	2,190,300	595,542	1,073,646	1,360,310	2.86	5.3	6.36
C	6,019,252	7,764,731	13,783,983	575,502	1,467,163	1,715,113	12.1	16.6	6.47
D	12,038,503	15,529,463	27,567,967	1,151,004	2,934,326	3,430,227	12.1	16.6	6.47

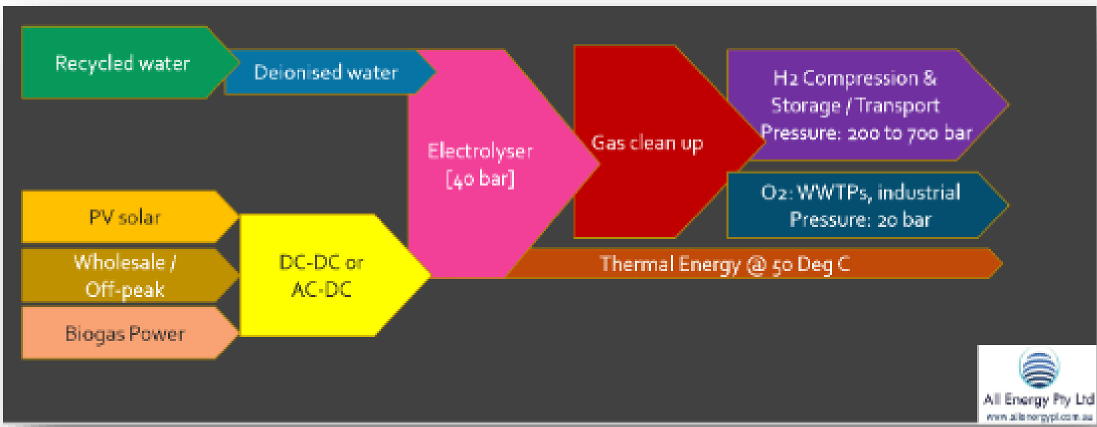


Figure 19: Block Flow Diagram showing production of renewable hydrogen via electrolysis.

2.3.4 Mass and Energy Balance

The scale of the facility takes into account the amount of power required, available surface and rate of hydrogen production. The following basis of design provides an indicative scale for RMPs to conceptualise hydrogen production:

- electrolyser (nominal rating)
- Co-located PV solar array. Final size will depend upon availability of low cost power (refer section 4.4),
- deionised water per annum at nominal rating.
- Economies of scale are able to be achieved at the above scale as this sized unit can be pre-fabricated (e.g. containerized) in order to minimize capex whilst having a good economy of scale. Systems up to modules of 5.4 MW can be procured.
- Whilst a system may have a “nominal” rating, the maximum short term load can be 125 to 160% the nominal rating. Running electrolysers continuous above the nominal rating can damage the electrodes, however vendors have advised that period increases such as for utilization of PV solar do not result in electrode degradation.

The image below shows the approximate size of such as facility, showing from left to right the Refueller, Electrolyser, Compression & High Pressure Storage. Balance of plant equipment not displayed in the image are the cooling system, chilled water and compressed air. The whole facility can be installed within two 40’ shipping containers.

Figure 20: Containerised H_2 facility showing Refueller, Electrolyser, Compression & High Pressure Storage.

2.3.4.1 Implications and Advantages of a H2 Facility Co-located at an RMP

Summarised in the following table are the results of a mass and energy balance for a hydrogen electrolyser operating at different hydrogen outputs.

Table 8: Implications of a H_2 production facility at an RMP.

kg H2 pa	Heat generated: kWt	tonnes O2/h	WWTP O2 requirement head per week equivalent	tpa recycled water required	% Low salinity Recycled water for a 5800 head per week RMP
78,767	152.1	0.073	2,124	1,026	0.63%
159,035	**307.1**	**0.147**	**4,276**	**2,071**	**1.27%**
217,326	419.7	0.201	5,847	2,830	1.73%
434,651	839.3	0.402	11,695	5,660	3.46%
322,700 [Feas. study #1 total H2 demand]	**623.1**	**0.298**	**8,682**	**4,202**	**2.57%**

Table 9: Sources of cleaner, low salinity water that can be used for H2 generation after reverse osmosis and/or de-ionisation.

Amount	Source
499.4 L/head	Sterilisation water at an RMP
68.7 L/head	Viscera table water at an RMP
568.1 L/head	**Total Low salinity water at an RMP**
Amount	**Use in a H2 Facility**
170.4	kg water rejected from reverse osmosis (@ ~30% retentate; suitable for re-use / wash down water)
44.2	kg H_2
353.5	kg O_2

2.3.4.2 Power Options for RMPs

The first rule for cheap H_2 from electrolysis is cheap power. The four cheapest sources of power for RMPs include:

[1] PV solar: this is a reasonably predictable energy source in terms of kWh output on a monthly basis. RMPs should target long term PV solar costs of electricity of $0.03 (large scale system in northern and central regions) to $0.07 (smaller scale system in southerly regions).

[2] Bioenergy: Biogas and biomass. Excluding capex, marginal cost of running engines is $0.03/kWh, hence interested in times of excess biogas / excess generation.

[3] Off-peak power. Marginal cost target of ~$0.06/kWh, whilst not exceeding monthly kVA peaks to avoid access charges. The costs of this power will vary for each site, state and distribution area.

[4] Wholesale power contracts are now available in Australia. This form of power procurement is suited to a variable loads (i.e. H_2 electrolysers) that can be rapidly increased and decreased. The percentage of the year that wholesale electricity is zero to negatively priced is increasing, especially in Qld and SA, hence providing an opportunity for an electrolyser to generate revenue. Long term averages are ~$0.08 to $0.11 (depending upon the state) with access charges and margins paid on top of the wholesale kWh price.

2.3.5 Alternate Hydrogen Production Systems – Reforming

Traditional hydrogen production via steam reforming represents ~95% of all hydrogen production today, however these systems are extremely large to enjoy economies of scale and use natural gas as a key feedstock.

The increasing demand for renewable hydrogen has resulted in smaller, modular reformers utilitising biogas being developed. One Australian company is Hazer, however a commercially viable system requires at least 12,000 m3/day (ideally many times more) and there are a limited number of RMI facilities that would be able to produce this amount of biogas. Bayotech[28] have modules utilising ~9% of the scale required for the Hazer system to produce 200 kg/day of hydrogen at an estimated cost of $US 3 / kg H2 (~$AUS 4.63 / kg H2), and they can supply additional gas treatment technology to reduce sulfur to < 10 ppb in biogas. The smallest module starts at ~994 m^3 nat gas per day (~35 GJ/day; ~1700 m^3 biogas per day). The claimed Bayotech round trip efficiency is ~79% (HHV energy in products divided by input energy i.e. energy in feedstock plus plant parasitic load), whilst for gas to power (via reciprocating engine) to electrolysis to H2 efficiency is in the 20 to 30% range (rising to ~86% where complete thermal energy recovery occurs).

System Specifications

Quality Standard: SAE J2719
Hydrogen Purity: >99.999%
Output Pressure: < 10 bar

BayoTech Model		H2-200	H2-1000
Hydrogen Output	(kg/day)	200	1,000
	(scf/day)	84,500	423,000
	(nM³/hour)	93	463
Utilities			
Natural Gas	(mmbtu/day)	33	165
	(kWh/day)	9,680	48,400
Sulfur	(ppb)	< 10	< 10
Pressure	(psig)	170	170
Power	(kWh/day)	200	950
Water, potable	(gal/day)	525	2,600
Water, discharge	(gal/day)	250	1,250

Emissions:
- CO_2: 8.9 kg/kg H_2
- SO_x: Negligible, removed before conversion
- NO_x: Complies with local limits
- Noise: < 80 decibels at 20 feet

Figure 21: Hazer modular biogas reformer system specifications

Capex supplied is $AUS 2.8 mil for a system that can produce 73 tpa; Capex supplied is $AUS 6.52 mil for a system that can produce 340 tpa. Opex $96k pa. BayoTech has modelled production costs which suggest:

$AUS 4.23 / kg H2 at 73 tpa. (1700 m^3 biogas per day; ~800 kg methane / day)

[28] https://www.bayotech.us/products, accessed 1 May 2020.

$AUS 2.47 / kg H2 at 175 tpa. (4250 m^3 biogas per day; ~2000 kg methane per day)

$AUS 1.87 / kg H2 at 340 tpa. (8500 m^3 biogas per day; ~4000 kg methane per day)

A RMP processing ~5000 head per week could generate ~5000 to 11,000 m^3 biogas per day from a covered anaerobic lagoon, depending upon which streams are captured, stream composition and the conversion ratio of volatiles into biogas (with around 4000 m^3 biogas per day of additional biogas able to be generated where a continuous stirred tank digester is also employed to digest paunch, fats, sludges, etc). Hence, sites processing 2400 head of cattle per week or more are expected to be at a scale where biogas reforming into hydrogen could be more economically viable than electrolysis.

Manure and organic wastes produce methane as it decomposes and contributes to excess nutrients in waterways. Taking the USA as an example: in 2015, livestock manure management contributed ~10% of all methane emissions in the United States, yet only 3% of livestock waste was recycled via anaerobic digesters. When livestock manure is used to produce biogas, anaerobic digestion can reduce greenhouse gas emissions, reduce odors, and reduce up to 99 percent of manure pathogens. The US EPA estimates there is the potential for 8,241 livestock biogas systems, which could together generate over 13 million megawatt-hours of energy each year (1625 MWe for 8000 hrs pa)[29]. The figure below summarises the scale of the biogas opportunity for the USA.

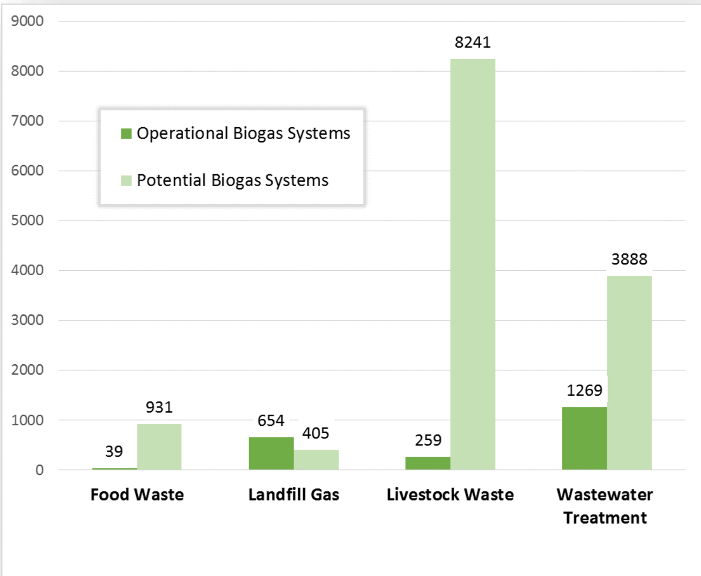


Figure 22: Current number of operational and potential biogas systems in the United States by feedstock.

[29] https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy; https://www.epa.gov/lmop/basic-information-about-landfill-gas, accessed 1 May 2020.

2.4 Hydrogen Status Review and Literature Survey

Hydrogen is the most abundant molecule in the universe and has been an integral part of the energy industry since the mid-20th century when its use became commonplace in oil refining. A review of published works was completed as part of this project to consider the most up to date opportunities and technologies for hydrogen (H_2) production. Existing markets for hydrogen build on its attributes: it is light, storable, reactive, has high energy content per unit mass, and can be readily produced at industrial scale. Today's growing interest in the widespread use of hydrogen for clean energy systems rests largely on two additional attributes:

(1) hydrogen can be used without direct emissions of air pollutants, particulates or greenhouse gases; and

(2) it can be made from a diverse range of low-carbon energy sources such as PV solar.

2.4.1 Australia's National Hydrogen Strategy

A key publication is "Australia's National Hydrogen Strategy" released in 2019 by the Commonwealth of Australia. For a commercial H_2 installation, some points of interest:

- H_2 can be zero emissions when generated from renewable energy.
- The breakeven price of hydrogen in $/kg were calculated as:
  - Petrol at $1.43/L: $13.31/kg H_2
  - Diesel at $1.50/L: $11.21/kg H_2
  - 1 GJ heat via natural gas at $10 / GJ: $1.20/kg H_2

- Figure 23 below (adapted) provides a clear summary of H_2 production and utilization options suited to red meat processors.

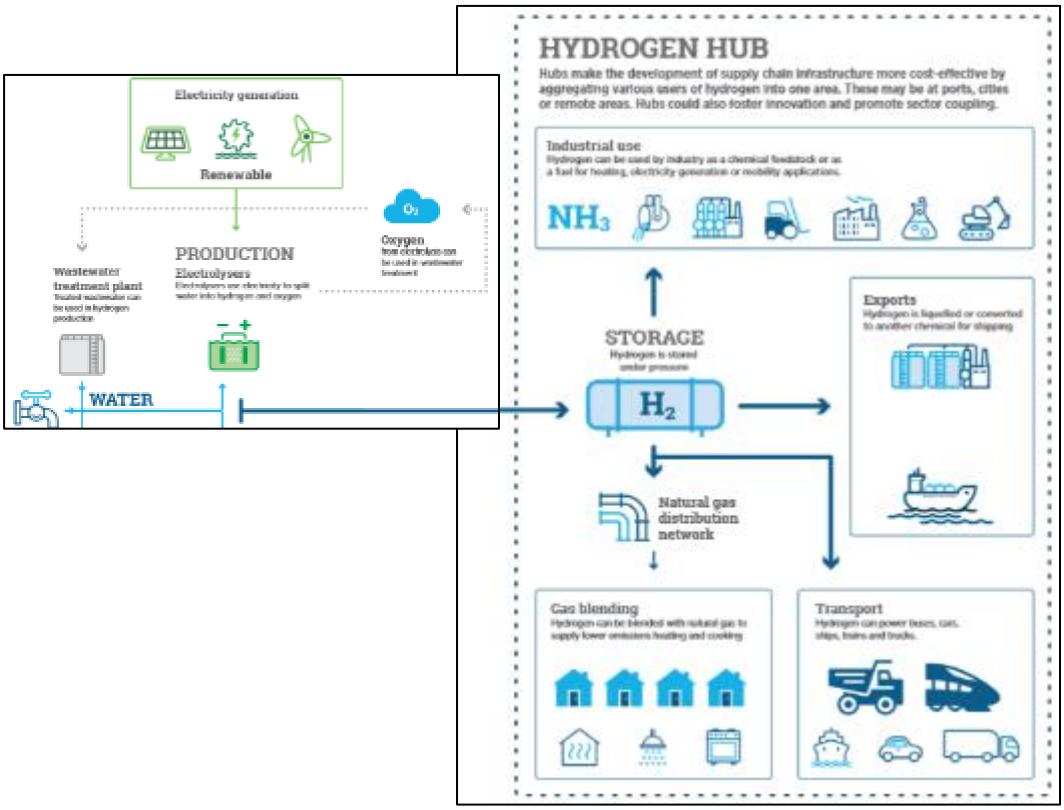


Figure 23: Hydrogen Production and Utilization Options.

- Estimated H_2 production cost of $2 to $3.25/kg by 2030. Assuming no drop in diesel, unleaded or power pricing means that H_2 will replace all of these energy sources on price point alone excluding any carbon pricing mechanism. The forms of energy not cheaper than this price point are direct combustion of natural gas, coal and biomass. However, electrolysis and fuel cells provide the opportunity for “cogeneration” with thermal energy generated at 50 Deg C, which could be used for boiler water pre-heating, potable water pre-heating for warm water and sterilization water at RMPs. Future technology has an aim of fabricating electrolysers that operate at 150 Deg C or higher, hence providing the opportunity to create thermal energy that meets all heating requirements for RMPs.

- Advanced pilots and H_2 hubs ("regions where various users of hydrogen across industrial, transport and energy markets are co-located") are to be supported and accelerated.

2.4.2 Queensland Government Hydrogen Strategy

This AMPC project aligns with the Qld H_2 Strategy by addressing Focus Areas 1, 2, 4 and 5:
[1] Supporting innovation;
[2] Facilitating private sector investment;
[4] Building community awareness and confidence;
[5] Facilitating skills development for new technology.

This report summarized that the global hydrogen production market was valued at $US115.25 billion in 2017 and is expected to grow to over $US200 billion by 2026. This equates to an annual compound growth of 7.13%.

[https://www.dsdmip.qld.gov.au/resources/strategy/queensland-hydrogen-strategy.pdf]

2.4.3 The Australian Renewable Energy Agency (ARENA) - Opportunities for Australia from Hydrogen Exports

This report estimates that for a medium growth scenario, there would be up to 788 direct and indirect jobs created by 2025, up to 2787 in 2030 and 7142 jobs by 2040; with a high demand scenario estimating 16,024 FTEs. The report says that if hydrogen production reaches the higher level of its range of estimates, the job numbers could be comparable to those generated by Liquefied Natural Gas (LNG) and its supply chain. Initially the demand for hydrogen will be driven by non-energy uses such as ammonia production,

This report presents CSIRO data for a 93 per cent capacity for renewable electricity, grid-connected renewables at A$0.04/kWh with a 100 MW electrolyser, producing hydrogen at $5/kg and at an installed capital of $3.765 mil / MW. By 2025 with capital of $1.005 mil / MW and power at A$0.04/kWh, hydrogen production was estimated at $1.80 / kg.

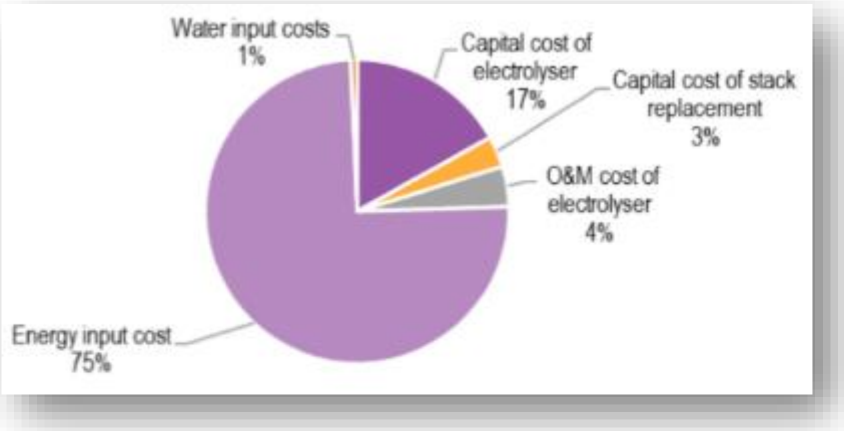


Figure 24: Annualised Cost of Hydrogen Production[30].

This ARENA-funded study found hydrogen exports could contribute $1.7 billion per annum to the economy and provide 2800 jobs by 2030, driven by growing demand from Japan, South Korea, China, and Singapore.

[30] *CSIRO NATIONAL HYDROGEN ROADMAP 2018*

2.4.4 International Energy Agency – The Future of Hydrogen (2019)

According to the International Energy Agency (IEA) 2019 "The future of Hydrogen report, a PEM electrolyser provides the key advantages of:

- 0 to 160% electrical load relative to nominal load. This means that it is better suited to intermittent power sources such as solar and spot market pricing.
- Small footprint,
- Moderate capex.
- Products of higher purities are obtained as PEMs are more effective in separating the gases.
- PEM are more suited to renewable electricity as the response to the variable input is faster.
- Safety and simplicity are improved by the absence of caustic electrolyte circulation.

Solid Oxide Electrolyser Cells (SOEC) have not yet been commercialized hence will not be considered in this project. SOECs use ceramics as the electrolyte and have low material costs. They operate at high temperatures and with a high degree of electrical efficiency. The waste heat could be recovered to produce steam for use within RMP for rendering and sterilization water. Unlike alkaline and PEM electrolysers, it is possible to operate an SOEC electrolyser in reverse mode as a fuel cell, converting hydrogen back into electricity, which means it could provide peak shaving for a RMP. This would increase the overall utilisation rate and economic viability of equipment. A key challenge for those developing SOEC electrolysers is addressing the degradation of materials that results from the high operating temperatures.

Table 30: Comparison for two commercial electrolyser technologies alkaline and proton exchange membrane (PEM) electrolysis with the developing technology of Solid Oxide Electrolyser Cells (SOECs).

	Alkaline electrolyser			PEM electrolyser			SOEC electrolyser		
	Today	2030	Long term	Today	2030	Long-term	Today	2030	Long term
Electrical efficiency (%, LHV)	63–70	65–71	70–80	56–60	63–68	67–74	74–81	77–84	77–90
Operating pressure (bar)	1–30			30–80			1		
Operating temperature (°C)	60–80			50–80			650 – 1 000		
Stack lifetime (operating hours)	60 000 – 90 000	90 000 – 100 000	100 000 – 150 000	30 000 – 90 000	60 000 – 90 000	100 000 – 150 000	10 000 – 30 000	40 000 – 60 000	75 000 – 100 00
Load range (%, relative to nominal load)	10–110			0–160			20–100		
Plant footprint (m^2/kW_e)	0.095			0.048					
Electrical efficiency (%, LHV)	63–70	65–71	70–80	56–60	63–68	67–74	74–81	77–84	77–90
CAPEX (USD/kW_e)	500 – 1400	400 – 850	200 – 700	1 100 – 1 800	650 – 1 500	200 – 900	2 800 – 5 600	800 – 2 800	500 – 1 000

As can be seen in Figure 25 on the following page, the PEM has been the dominant technology of the past 4 years, with an average unit size of 980 kW.

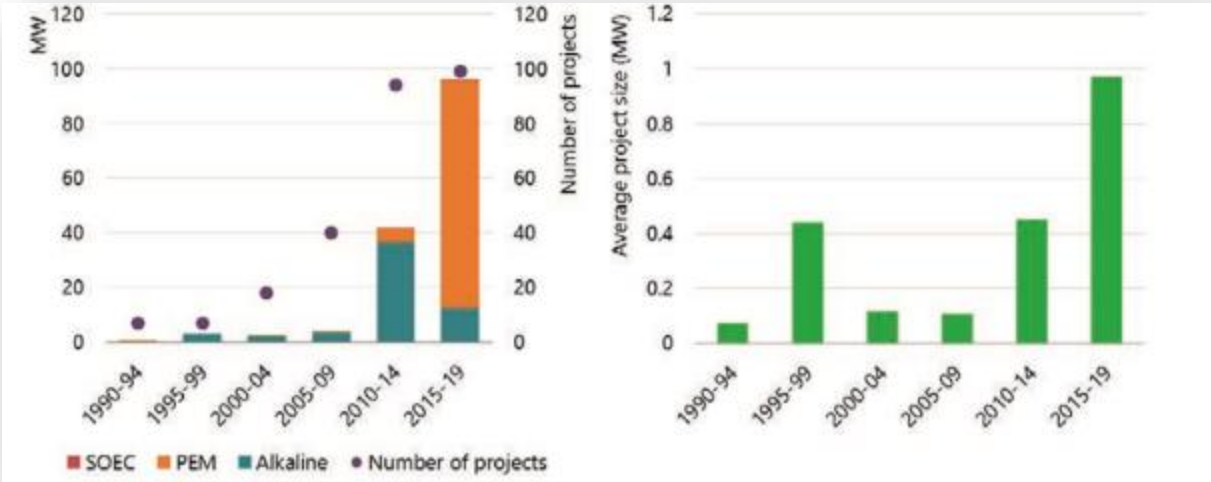
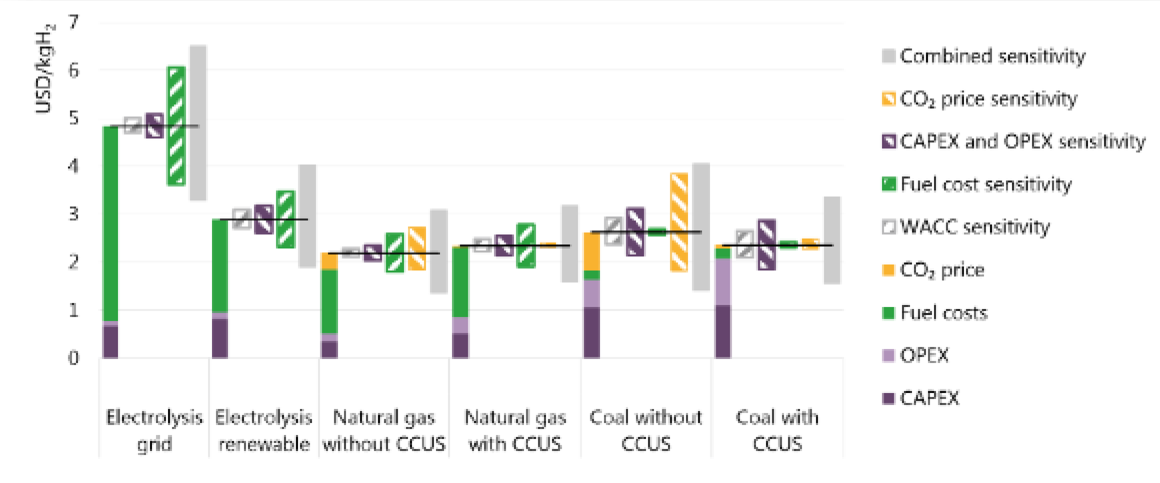


Figure 25: Development of electrolyser capacity for energy purposes and average unit size for the period 1990 to 2019.

The IEA report provides a correlation, presented in Table 11 below, between the hours of electrolyser utilization and relative cost of hydrogen production, normalized to “1.00” for 8000 hours per annum operation.

Table 4: Correlation between the hours of electrolyser utilization and relative cost of hydrogen production, keeping all other parameters the same.

Hours of electrolyser operation	Relative cost factor per unit mass of H2 [compared to 8000 hpa]
1000	1.26
2000	1.18
4000	1.08
6000	1.02
8000	1.00



Notes: WACC = weighted average cost of capital. Assumptions refer to Europe in 2030. Renewable electricity price = USD 40/MWh at 4 000 full load hours at best locations; sensitivity analysis based on +/-30% variation in CAPEX, OPEX and fuel costs; +/-3% change in default WACC of 8% and a variation in default CO_2 price of USD 40/tCO_2 to USD 0/tCO_2 and USD 100/tCO_2. More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

Figure 26: Hydrogen Production Costs for Different Technology Options; 2030 basis.

The International Energy Agency has found that hydrogen costs correlate linearly with the cost of electricity. The following image from USA National Renewable Energy Laboratories (NREL), 'Techno-economic Analysis of PEM Electrolysis for Hydrogen Production" (2014) corroborates the IEA's findings of an approximately linear relationship between electricity costs and hydrogen production costs.

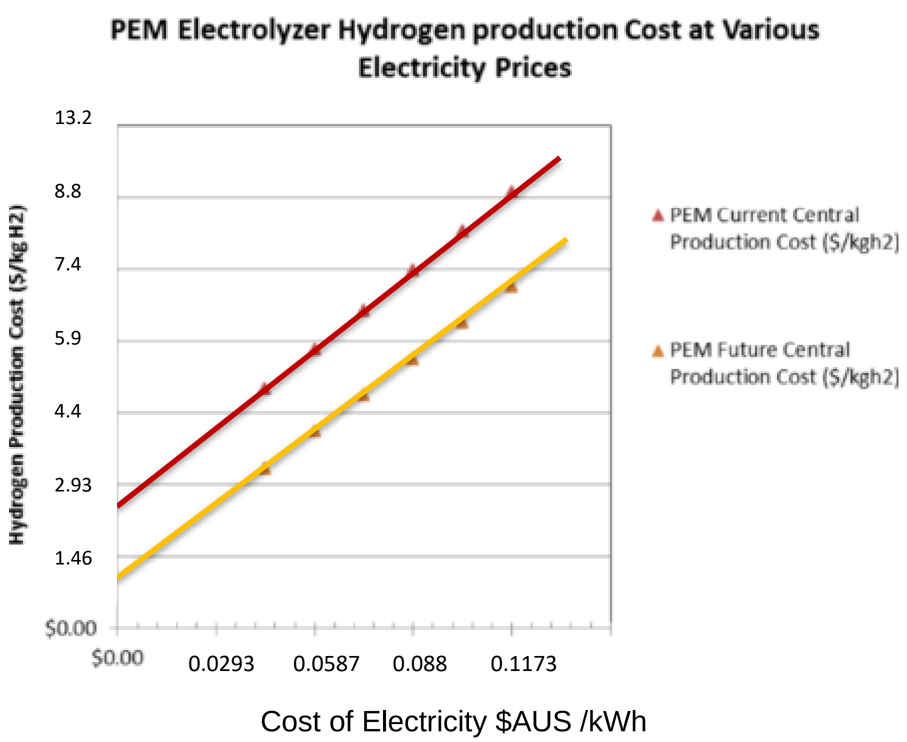


Figure 27: Hydrogen production costs as a function of the cost of electricity. Converted from $US to $AUS ($US 1 = $AUS 1.46; 10 Dec 2019).

2.4.5 Examples of Hydrogen Projects – Global Summary

A review was undertaken to provide a snapshot of the various electrolyser activities occurring for hydrogen production around the world, as presented in Table 12 below.

Table 52: Snapshot of electrolyser projects around the world.

PROJECT TITLE	Location	Size: MW electrolyser	Size: Tonnes H_2 p.a.	Use for H_2	Use for O_2	Source of Power
Dyno Nobel Green H_2	Moranbah, Queensland	160 MW - Proposed	~9000	Ammonium nitrate	TBA	210 MW solar
Incitec Pivot Green H_2	Moura, Queensland	Proposed	3600	Ammonium nitrate	TBA	Solar
Westkueste 100	North west Germany - refer next page for more information.	700 (30MW by 2025) - Proposed	254,435	Hydrogen reacted with CO_2 to make kerosene for jet fuel	Oxyfuel in cement kiln; energy for district heating	Wind
REFHYNE project	Germany	10 MW - Proposed	1,300	Oil refining, industry, power generation, heating for buildings, and transport.	Cement manuf.	Business Park excess power
Jemena Western Sydney Green Gas Project"	Sydney, Australia	0.5 – Under construction	170	Used to power NSW homes and businesses	Vented to the atmosphere	Unknown for electrolysis however for gas and water clean-
Air Liquide Nevada Hydrogen Scheme	Nevada, USA	$150 mil	10,958	Liquid hydrogen mobility and transport in California. Wants to use in cars/trucks. $US 150 mil.	Unknown (at early development stages)	Biogas; Power
BOC	Port of Brisbane, Queensland	0.2 MW – Under construction	TBA	Industrial and transport – providing hydrogen for	TBA	Grid
Stanwell	Rockhampton, Qld	10 to 25 MW - Proposed	TBA	Support local hydrogen economy.	TBA	Stanwell power station
Fukushima Hydrogen Energy research Field	Fukushima, Japan - refer next page for more information.	10 MW with 20 MW solar farm.	808	Trucks, buses, cars and grid balancing without batteries.	N.A.	Solar with grid balancing.

By far and away the most ambitious project is the 700 MW Westkueste 100 project (refer Figure 28 below) to create hydrogen, export the oxygen to cement manufacturing, then recombine the hydrogen and carbon dioxide from the cement production into methanol which can then be refined into jet fuel and synthetic petrol. A key motivator is to find a use for excess wind power that is currently costing the German government 500 million Euros per annum in payments due to wind farms that cannot export power into the grid. Excess heat can be used in an adjacent business park.

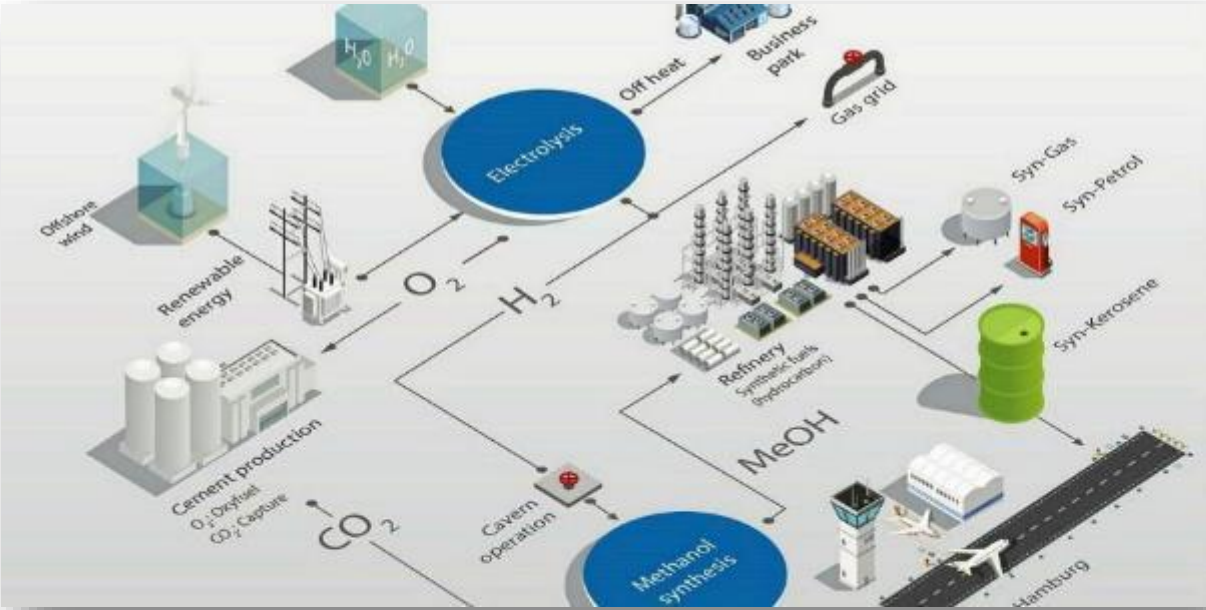


Figure 283: 700 MW electrolyser utilising wind power to produce jet fuel from hydrogen and carbon dioxide.

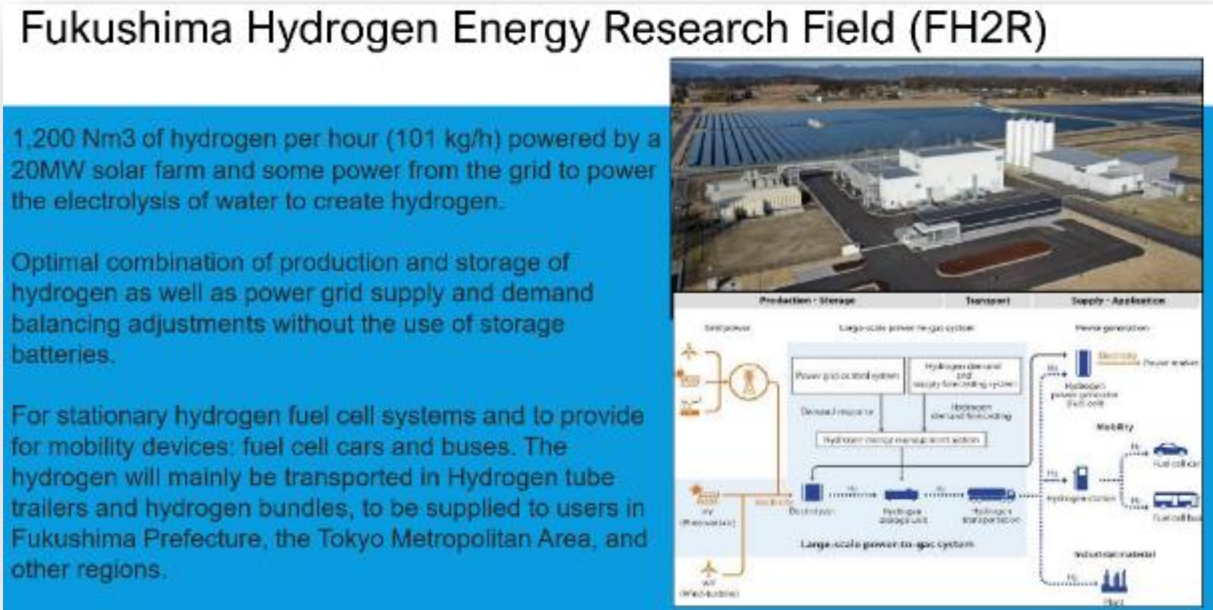


Figure 29: Case study of a recently commissioned 10 MW electrolyser in Japan.

2.4.6 Previous Analytics – Hydrogen Value

An analysis completed by All Energy Pty Ltd in Q2 2019 showed the price point that hydrogen needed to reach to be on the same price parity as a range of different energy sources. This image shows that the “lowest hanging fruit” if for light vehicles using petrol and diesel on public roads, followed by diesel on public roads. The reason for this is that Australian Tax Office fuel tax credit has different rates applied to different fuels, hence there are different price points for different uses of the same fuel.

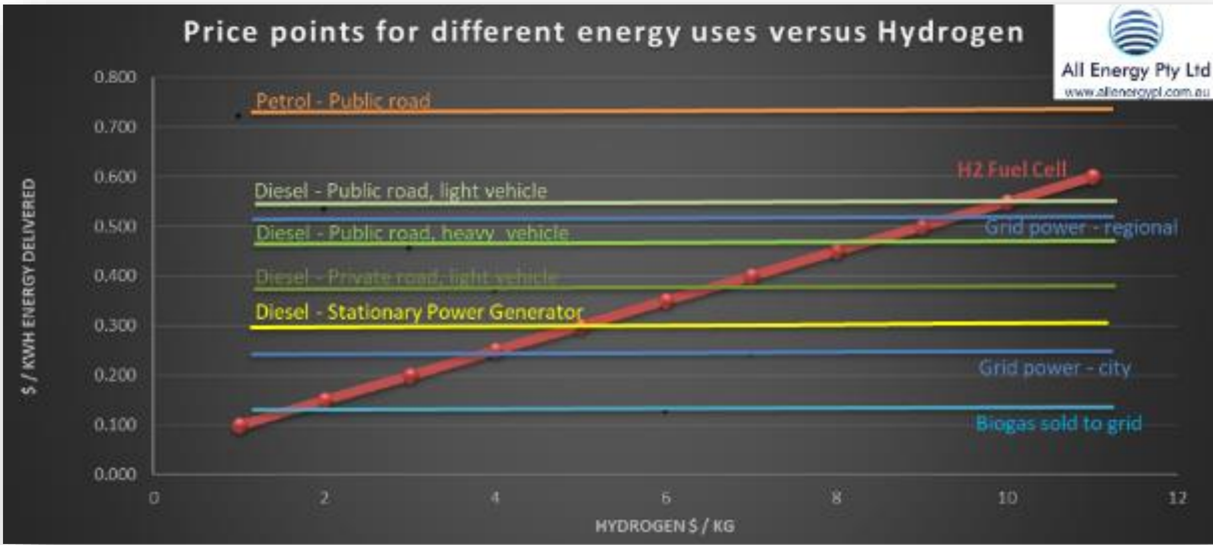
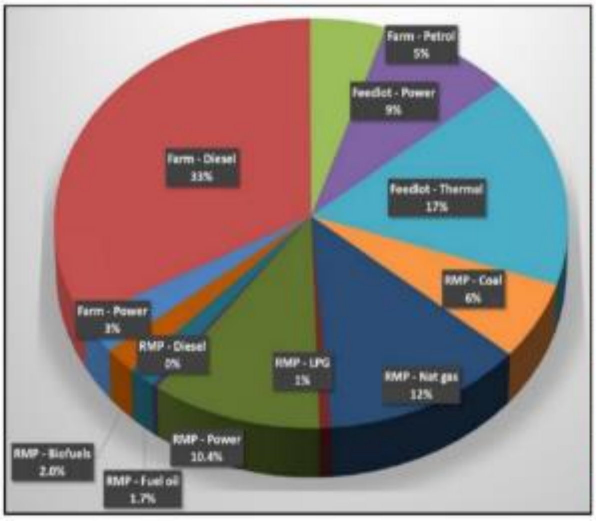


Figure 30: All Energy Pty Ltd analysis of Q2 2019 price points for different fuels in Australia taking into account the type of fuel, the use of the fuel and hence the ATO fuel tax credit. Where each line crosses the red “H2 Fuel Cell” lines shows, along the x-axis, the price point parity in $ / kg hydrogen. For example, hydrogen will break even with diesel for heavy vehicles at approximately $8 / kg.

When considering the red meat industry supply chain, the greatest opportunities for RMPs lie in off-setting transport fuel use of diesel, petrol and LPG; the next opportunities are around cogeneration and energy storage / peak shaving / emergency power at RMPs.



Area of Energy Use	$ pa energy cost	GJ pa
Farm - Power	71,187,726	1,335,244
Farm - Diesel	298,337,099	15,689,117
Farm - Petrol	44,410,528	2,336,677
Feedlot - Power	273,415,322	4,101,230
Feedlot - Thermal	238,836,326	7,961,211
RMP - Coal	15,137,898	2,845,925
RMP - Nat gas	74,680,295	5,849,956
RMP - LPG	10,091,932	316,214
RMP - Power	277,990,032	4,901,315
RMP - Diesel	3,198,393	158,107
RMP - Fuel oil	7,568,949	790,535
RMP - Biofuels	Excluded	948,642
TOTALS	1,314,854,499	47,234,172 (47 PJ)

Figure 4: Annual energy use and estimated spend for energy throughout the RMI supply chain. The updated 2019 estimate has power costs at $1.6 billion per annum.

2.5 Business Models

Hydrogen fuel cell trucks will initially be more expensive than diesel. However, as they use an electric drive platform, HFCVs will be cheaper to refuel and cheaper to run (less maintenance, less filter changes, etc). Truck manufacturers are aware of this hence are offering a number of business models to assist H_2 uptake:

2.6.1 Pay Per Use e.g. Hyundai

Hyundai is introducing a unique pay-per-use model, where they offer the technology change to fuel cell without any risk to our customers.

Based on the driving profile, the usage of the vehicle and the annual mileage, a flat rate per kilometer will be charged. The benchmark here is the current cost of diesel trucks – in terms of the Total Cost of Ownership (TCO). The fee per km includes the complete operation of the truck, including hydrogen refueling, service of the vehicle and any repairs (including replacement of the fuel cell if necessary) covered within a contract for 8 years with no deposit. At the time of writing, the “pay per use” option not yet available in Australia[31].

The big advantage of a long term pay per use model is the lower maintenance costs contributing to a TCO that will be close to diesel options.

2.6.2 Managed Leasing Model e.g. Nikola

Where a third party purchases the truck, manages all of the maintenance costs then leases the truck back to the fleet. Low cost funding is available via the Australian Federal Government’s Clean Energy Finance Corporation for equipment leasing of clean tech such as H_2 production, fuel cells and HFEV vehicles. The company will offer the fuel cell trucks on a per-mile basis. Customers will sign all-inclusive 7-year leases now pegged at 100,000 miles (160,934 km; 41 km per day) a year, but Nikola may lower the miles threshold. As a take or pay lease, customers who fall short on use still must make the minimum miles payment to

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provide the revenue stream Nikola needs to build out a network of filling stations. The leases will match the total cost of ownership for a comparable diesel truck.

As for the pay-per-use option, a managed lease can deliver a TCO close to diesel options due to the lower maintenance costs for FCEVs.

2.6.4 Operating / Equipment Leases and Outright Purchase e.g. Hyzon, Hino, SuperiorPak

Leasing and outright purchasing are more traditional procurement options, however direct procurement from the fabricator can provide interest options lower than market rates. Hyzon Motors offers a scenario of 30% down payment followed by monthly installments over 5 years.

Due to the perception that the higher initial outlay will deter the uptake of FCEVs, many OEMS are only offering long term pay per use and managing leasing options (i.e. 7 years or more).

3.0 PROJECT OBJECTIVES

The objectives of the Project 2020-1014 “Renewable Hydrogen Cost-Benefit Analysis for Australian Red Meat Processors” were:

- Provide clarity on the key parameters impacting the economic and technical viability of hydrogen as an on-site option for processors to offset their heat and power costs.
- Define current interest in hydrogen among Australian RMI processors whilst mapping out options and collaborations for hydrogen.
- Feasibility study for a specific case study site considering how scale, power consumption and peak demand, and fuel usage, and water availability impacts CapEx and economic viability for hydrogen projects; associated cost-benefit analysis.
- Communicate findings via reports, articles, snapshot, workshops and other suitable.

4.0 METHODOLOGY

4.1 Methodology Overview

The following methodology was employed for completion of the feasibility studies:

- Aggregation of the annual demand for liquid fuels, including diesel for generators, trucking, other vehicles and forklift requirements.
- Taking the requirements for individual devices into account, determination of the mass of hydrogen required to displace diesel usage.
- Design of a modular hydrogen facility to provide hydrogen at the approximate scale required to determine $ / kg H_2 produced.
- Calculation of the payback period for different hydrogen power generation and mobility devices.

4.2 Hydrogen for Heavy Vehicles

Shown in Table 13 below are heavy vehicle options utilising hydrogen fuel cells in order to displace diesel trucking. This analysis was used for completion of the CBA. ATO fuel tax credit assumed at $0.165 / L for HVs on public roads; $0.423 / L for all other business activity (ATO rates to 30 June 2020[32]); hence average diesel bowser price assumed to be $1.299 / L with a net cost to a business after accounting for ATO fuel credit of $1.134 / L.

Table 13: Hydrogen Mobility Options for Heavy Vehicles.

Vehicle Description	NOTES	$ / tonne	CAPEX ICE	Annual fuel cost – Diesel $ p.a.	CAPEX H_2 FC	Annual fuel cost – H2 $ p.a.	Simple payback – years
B-Double Livestock Trucks. ~62.5 GVM	42.5 tonne payload (net average daily delivery [excludes trailer capex / opex]).	$ 55.40 / tonne	$AUS 322,572	$ 170,608 [218,040 km pa; 69 L / 100 km][33]	$US 485,000 (6x4 prime mover; $AUS 818k)	$93,984 to 117,262 [Saving: $76,624 to $53,346 pa]	6.5 to 9.3
Heavy rigid - Hook frames; feedlot feeding and water trucks. ~27.5 GVM	24 tonne net average daily delivery, 35 cubic metre; ave. speed 25 km/hour, double shift 5 days per week.	$112.57 / tonne	$AUS 180,000	$ 42,012 [92,000 km pa; 32 L / 100 km][34]	TBA	TBA	TBA
Semi-trailer delivery vehicle – side curtain. ~37.5 GVM	24 tonne net average daily delivery.	$ 70.88 / tonne	$AUS 276,210	$ 110,327 [207,000 km pa; 47 L / 100km][2]	$US 188,174 [35] ($AUS 318k)	$96,561 [Saving: $13,766 pa]	3.0

[32] www.ato.gov.au, accessed 8 April 2020.
[33] Business.vic.gov.au, "Haulage, prime mover and B-Double Trailer", accessed 26 March 2020.
[34] Australian Trucking Association, Technical Council, 12 Sept 2016.
[35] https://nikolamotor.com/NikolaInvestorPresentation3-3-2020.pdf, accessed 26 March 2020.

Table 14: Hydrogen Mobility Costs versus Diesel.

FUEL COST EX GST	Units	Cost	GJ per unit	Units per 100 km	Fuel costs $ / 100 km
B-DOUBLES					
Diesel – B-Double	$/L	1.134	0.0386 GJ / L	111.11 L / 100 km [36]	125.99
Hydrogen Fuel Cell – B-double	$/kg	5.60 4.05	0.1199 GJ / kg	9.6 kg / 100 km [37]	53.76 38.88
SEMI-TRAILERS					
Diesel – Semi-trailer.	$/L	1.134	0.0386 GJ / L	50 L / 100 km [38]	56.70
Hydrogen Fuel Cell – Semi-trailer; 26.3 t GVM	$/kg	5.60 4.05	0.1199 GJ / kg	8.29 kg / 100 km[39]	46.40 33.57
LIGHT VEHICLES					
Unleaded Fuel - light vehicles	$/L	1.294	0.0342 GJ / L	10.8 L / 100 km [40]	13.97
Hydrogen - light vehicle	$/kg	5.60 4.49	0.1418 GJ / kg	0.84 kg / 100 km [41]	4.70 3.77

The conversion between diesel and H_2 is based upon:

60 tonne GVM: ~9.6 kg H_2 / 100 km (200 kW fuel cell)[3]. [Ratio H_2 kg / diesel L = 0.139]

For heavy vehicles, the breakeven H_2 cost is $13.12 / kg H2.

Nikola TCO target: $US 1.61 / mile; $1.01 / km taking into account truck costs, servicing, maintenance and fuel. For a commensurate diesel truck in Australia (refer Appendix 2) after removing the cost of driver, the TCO equates to $1.74 / km. Hence, the Nikola offering suggests a 42% saving in the TCO.

Nikola: 16.33 tonne payload, GVM 26.3 tonnes [5 axle rigid]. 8.29 kg / 100 km.

At an ICE efficiency of 25% and a FC efficiency for a vehicle of 40%, 1 kg of H2 equates to 5.93 L of diesel. The Nikola ratio equates to approximately 6.03 L of diesel equivalent per kg of H2, hence the more conservative figure of 5.93 L diesel per kg H2 equivalent is used for this report.

[36] http://www.freightmetrics.com.au/, accessed 11 Dec 2019.
[37] HYZON, personal communication 20 March 2020.
[38] http://www.freightmetrics.com.au/, accessed 11 Dec 2019.
[39] https://nikolamotor.com/NikolaInvestorPresentation3-3-2020.pdf, accessed 26 March 2020.
[40] Abs.gov.au, 9208.0 – Survey 12 months ended 30 June 2018, accessed 26 March 2020.
[41] https://h2.live, accessed 26 March 2020.

4.4 Hydrogen Transportation

Local storage at the point of hydrogen generation (i.e. compression into tanks for truck load out) is accounted for in the capital cost estimates, however the following storage cost estimates [42] provide indicative costs for storage and confirms the use of pressurised containers as the most economically viable option:

- Salt caverns: $0.37 - $0.18 / kg (geographically limited)
- Depleted gas fields: >$3 (geographically limited)
- Rock caverns: $1.16 - $0.37 / kg (geographically limited)
- Pressurized containers: $0.31 - $0.28 / kg (not geographically limited)
- Liquid hydrogen: $7.44 - $1.55 / kg (not geographically limited)
- Ammonia: $4.61 - $1.42 / kg (not geographically limited)
- LOHCs: $7.32 - $3.03 / kg [liquid organic H2 carrier] (not geographically limited).

Transportation costs for hydrogen are summarised in $US in Figure 32 below, with the assumption transportation of up to 10 tonnes per day of H2 over distances up to several hundred kilometres equates to ~$AUS 1 / kg.

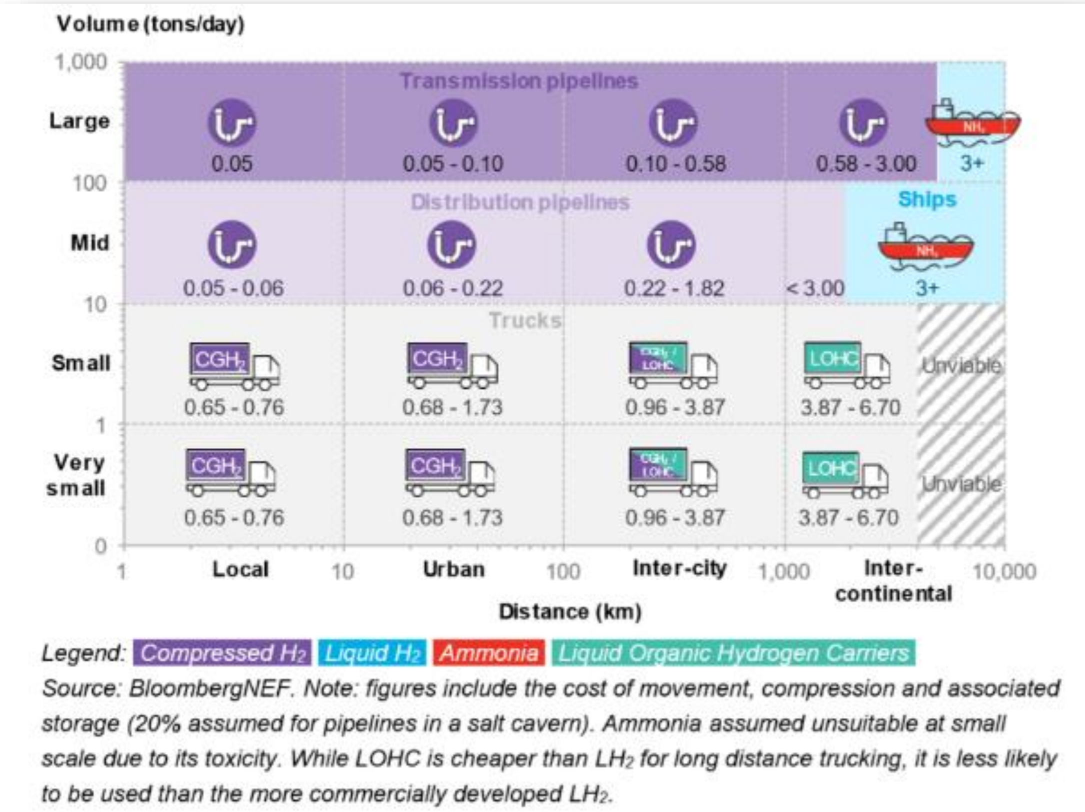

Figure 5: H2 transportation costs by volume and transport vehicle

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[42] Hydrogen Economy Outlook Key messages, BloombergNEF, March 30 2020.

5.0 PROJECT OUTCOMES

5.1 Feasibility Study #1

5.1.1 Basis of Design – Current Diesel Usage and Potential H2 Utilisation RMP-1

Summarised in Table 15 are the liquid fuels consumed currently within operational control and, secondly, liquid fuel part of the supply chain that could be influenced.

Table 15: Hydrogen Mobility Options for RMP-1.

Vehicle Description	Image	# Vehicles required	Average L fuel used: [1] p.a. [2] per vehicle per annum	Approximate H_2 to displace liquid fuel
Currently under operational control				
Feedlot trucks (water, feed)		(assumed based on fuel usage; TBC)	859,164	152,072 kg p.a.
Forklifts - LPG		4 (assumed based on fuel usage; TBC)	[1] 42,853 [2] 10,713 (5.34 L / hour, 2000 operational hpa)	[1] 12,300 kg p.a. [2] 3,075 kg per vehicle p.a.
Gensets – stationary power generation / cogen.		CH: emergency and peak shaving OC: 3 x sychronised gensets	CH: 70,791 OCFL: 235,525	CH: 12,530 kg p.a. OCFL: 41,688 kg p.a. at 45% efficiency (); 114 kg/day.
SUB-TOTAL under direct operational control			1,208,333 L p.a.	213,875 kg p.a.
Sub-contractors not under operational control				
B-Double Livestock Trucks		12 – service provided by contractor.	[1] 1,805,371 [2] 150,448	[1] 319,551 kg p.a. [2] 26,629 kg per vehicle p.a.
Hook frames for Roll-On/Roll-Off bulk waste hook bin containers		2 – paunch and sludge collection service provided by contractor.	Excluded [1] 135,593 [2] 67,797	Excluded. [1] 24,000 kg p.a. [2] 12,000 kg p.a. (500 km per day, 250 days per annum)
General waste collection, delivery, etc.			Excluded	Excluded
SUB-TOTAL sub-contractors not under direct operational control			1,940,964 L pa	343,551 kg H2 pa
TOTAL			3,149,297 L pa	557,426 kg H2 pa

5.1.2 Fuel Cell for Remote Area Co-generation Displacing Diesel and LPG

The table below summarizes the economic viability of a 200 kW H_2 fuel cell with heat recovery for a feedlot. Once H_2 at a low cost is available, an allowance of $1/kg has been made for compression and transport.

Table 16: 200 kW H_2 Fuel Cell with Heat Recovery Viability

Data / Assumption	Metric
$ 160,000	CAPEX installed
769,324	kWh PA
32,533	kg H_2 pa ~60% eff.
48%	utilization
164,290	$ pa H_2 ($4.05/kg plus $1/kg transportation costs)
206,234	$ pa fuel saving versus diesel
341,922	kWh pa 20% heat recovery as hot water
1231	GJ pa hot water
$36,930	$ pa avoided diesel costs
$78,875	TOTAL REVENUE $ p.a.
2.0	PAYBACK PERIOD - YEARS

Figure 63: Ballard 100 kW Fuel Cell Module[43]

[43] https://www.ballard.com/docs/default-source/spec-sheets

Figure 37: Containerised 200 kW and 1 MW Fuel Cell Modules with Pressurised H_2 Storage[44]

5.1.3 Fuel Cell for Peak Shaving

The table below summarizes the economic viability of a 200 kW H_2 fuel cell with heat recovery for a RMP, operating grid parallel in order to reduce peak loads thereby reducing kVA charges plus some value in kWh and thermal energy costs. *This does not include the value in emergency / uninterrupted power and the value in avoided capital such as not increasing transformer capacities.*

Table 17: 200 kW H_2 Fuel Cell with Heat Recovery – Viability at a RMP for Peak Shaving

Data / Assumption	Metric
$ 160,000	CAPEX installed
75000	kWh PA [average of 1.5 hours per operational day]
3,172	kg H2 pa ~60% eff.
4%	utilization
$ 12,845	$ pa H2 ($4.05/kg)
$ 9,118	$ pa kWh savings
$ 26,345	$ pa kVA savings
25,000	kWh pa 20% heat recovery as hot water
90.01	GJ pa hot water
$ 450	$ pa avoided coal
23,068	TOTAL REVENUE
6.9	Year payback

[44] https://www.hydrogenics.com/

5.1.4 Fuel Cell for Emergency / Uninterrupted Power

The table below summarizes the economic viability of a 200 kW H_2 fuel cell with heat recovery for a RMP, operating as an emergency power system when grid power is not available and power is otherwise received from a diesel generator.

Table 18: 200 kW H_2 Fuel Cell with Heat Recovery – Viability at a RMP for Emergency Power

Data / Assumption	Metric
$160,000	CAPEX installed
150,000	kWh PA [750 hours pa]-
6,343	kg H2 pa ~60% eff.
9%	utilization
$ 25,689	$ pa H2 ($4.05/kg)
$ 60,000	$ pa kWh savings
	$ pa kVA savings
50,000	kWh pa 20% heat recovery as hot water
180.01	GJ pa hot water
$ 900	$ pa avoided coal
35,211	TOTAL REVENUE
4.5	PAYBACK PERIOD - YEARS

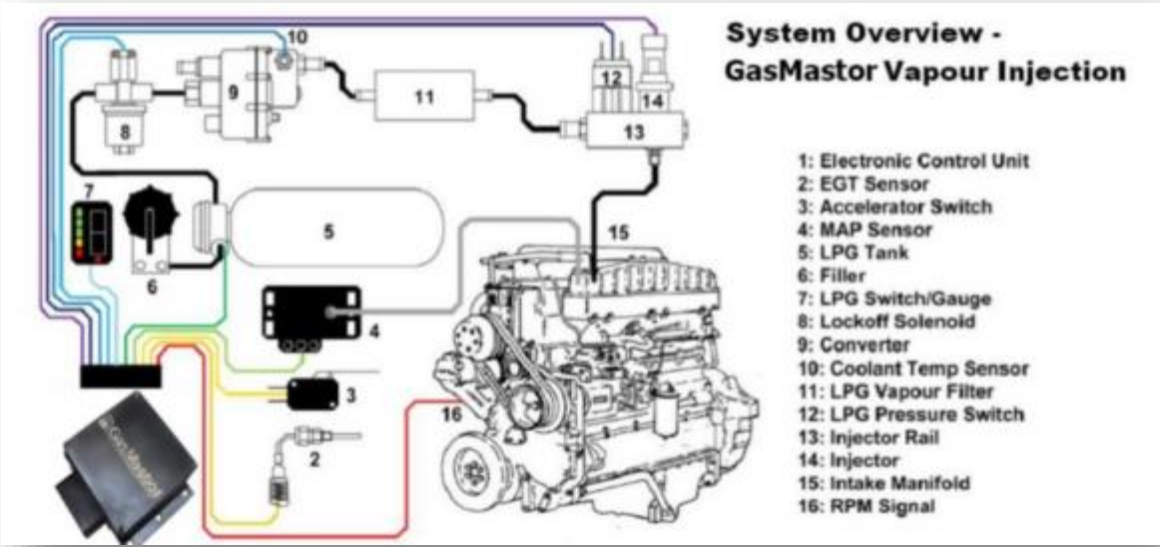
5.1.5 ALTERNATIVE H_2 USAGE OPTIONS – DUAL FUEL

There exists the opportunity to utilize H_2 as a dual-fuel options for existing trucks and gen-sets. Whilst the use of H_2 in an internal combustion engine (ICE) at, say, 30% efficiency means that the efficiency advantages of a fuel cell are not realized (i.e. approaching 50% efficiency), the use of a spark ignition fuel with a higher flame speed such as H_2 (as opposed to a compression ignition fuel like diesel) has been shown to increase diesel combustion from 75% towards 95%+ after optimization / tuning. Further, engine life is increased one third, with an increase in time periods between maintenance cycles also increasing by one third. A further advantage is that the same system can be used for LPG, LNG and/or CNG multi-fueling.

B-Double Duel Fueling with H_2: Assuming H_2 at $4.49 and excluding the maintenance / life of plant advantages, the payback period for investing in a dual-fuel system for a B-double (150,448 L pa) is estimated at 4 months (based upon a fuel saving of $34,427 pa achieved predominantly via efficiency gains).

Genset Dual Fueling with H_2: Assuming H_2 at $4.49 and excluding the maintenance / life of plant advantages, the payback period for investing in a dual-fuel system for a genset at a feedlot (235,525 L pa) is estimated at 3 months (based upon a fuel saving of $53,895 pa achieved predominantly via efficiency gains).

Figure 8: GasMastor System Schematic[45]



Genset Dual Fueling with LPG: The same conversion kit to run a diesel reciprocating engine on H_2 can also be used for LPG. Assuming LPG at $0.5628 / L and diesel at $0.8756 after allowing for the ATO fuel tax credit for both, utilizing GasMastor trial data[46] & excluding maintenance / life of plant advantages, the payback period for investing in a dual-fuel system for a genset run on diesel-LPG at a feedlot (235,525 L pa) is estimated at 9 months (based upon a fuel saving of $8,269 pa).

5.1.6 H_2 PRODUCTION OPTIONS – FROM SOLAR

[45] https://www.gasmastor.com.au

[46] https://www.gasmastor.com.au/case-studies/stationary-engine-case-studies/, accessed 31 March 2020.

The following section details the estimation around H_2 production costs for use in a transport hub and remote energy system.

Technology:	Hydrogenics HyLYSER PEM electrolysis-technology[47].
Power source:	Co-located single axis PV solar.
Nominal load MW:	4.31 MWe
Max load MW	5.83 MWe
PV Solar MWp	5.83 MWp
kWh pa PV	9,883,545 [Brisbane, single axis tracking]
kg H_2 pa:	202,072
Nominal kg H_2 pa:	700,000 kg H_2 p.a. [System rating]
Utilisation:	28.9%
CAPEX PV:	$ 6,039,361
CAPEX H_2:	$ 7,306,546 [allowances for electrolyser, cooling system, installation, compression, storage, refueling]
TOTAL CAPEX	**$13,345,907**
OPEX:	$657,589 p.a. [@9% capex; allowance for insurance, equipment, staffing]
	O_2 opex savings p.a.: $362,217 [aeration energy only; excludes capex, maintenance savings]
Revenue RECs:	$301,448 p.a. [@ $30.5 / MWh[48]]
Revenue hot water:	$120,619 [off-setting LPG, 11.3% thermal recovery, 50 Deg C]
Life of plant:	20 years [stack life ~20 to 25 years; BOP @ 20 year life].
EBITDA $/kg H_2:	$ 4.17 / kg H_2 [including 8 years of RECs and O2 value]
	$ 4.76 / kg H_2 [excluding RECS]
	$ 5.96 / kg H_2 [excluding O2 value]
	$ 6.56 / kg H_2 [excluding RECs and O2 value]
	$ 5.36 / kg H_2 [including thermal energy off-setting LPG and RECs; excluding O2]

The EBITDA $/kg H_2 is a simple metric showing the cost of production accounting for CapEx, OpEx, and revenue / savings before applying interest, taxation, depreciation and amortization; this calculation is referred to in this report as the Levelised Cost of Hydrogen (LCoH). HIGH LEVEL SIMPLE PAYBACK ESTIMATE: 8.2 years [assuming revenue from H_2 for diesel displacement of $1,648,557 pa; assuming H_2 devices at same cost over total equipment life as diesel devices after accounting for opex / maintenance savings].

[47] https://solutions.hydrogenics.com/onsite-hydrogengeneration-hylyzer-pem-electrolysis-technology
[48] http://greenmarkets.com.au/, accessed 27 March 2020.

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5.1.7 H_2 PRODUCTION OPTIONS – FROM SOLAR AND GRID

Where a large solar array cannot be installed or it is desired to reduce the total capital spend, an alternative scenario is to produce hydrogen using an alkaline electrolyser using solar during the day and off-peak power during the evenings.

Technology:	Alkaline electrolysis-technology 1.0 MW nominal load.
Power source:	Co-located single axis PV solar.
Nominal load MW:	1.00 MWe
Max load MW	1.352 MWe
PV Solar MWp	1.352 MWp
kWh pa PV	2,291,178 [38.6% of kVAs; Brisbane, single axis tracking]
kWh pa Off-peak	3,650,000 [42% of time; load managed to limit kVA charges]
kg H_2 pa:	121,469
Nominal kg H_2 pa:	162,272 kg H_2 p.a. [System rating]
Utilisation:	70.5%
CAPEX PV:	$ 1,400,029
CAPEX H_2:	$ 2,052,312 [allowances for electrolyser, cooling system, installation, compression, storage, refueling]. Stack replacement: $540k.
TOTAL CAPEX	**$3,452,341**
OPEX:	$476,708 p.a. [@9% capex; off-peak power @ $0.08 / kWh; allowance for insurance, equipment, staffing]
O_2 opex savings	$271,663 p.a. [~74% offset of aeration energy only; excludes additional advantages of capex and maintenance savings]
Revenue RECs:	$69,881 p.a. [@ $30.5 / MWh[49]]
Life of plant:	20 years [stack replacement @10 years; BOP @ 20 year life].
EBITDA $/kg H2:	$ 3.13 / kg H_2 [including O2 value and 8 years of RECs]
	$ 3.36 / kg H_2 [including O2 value and excluding RECS]
	$ 5.34 / kg H_2 [including RECS and excluding O2 value]

HIGH LEVEL SIMPLE PAYBACK ESTIMATE: 4.1 years [assuming revenue from H_2 for diesel displacement; assuming H_2 devices at same cost over total equipment life as diesel devices after accounting for opex / maintenance savings].

In the 12 months to 1 April 2020, the NEM electricity generation came from 23.8% renewable sources[50], hence the above system would utilize ~53.2% renewable energy. For completely green hydrogen, offsets can be procured at ~$7k p.a.

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49 http://greenmarkets.com.au/, accessed 27 March 2020.

50 www.opennem.org.au, accessed 31 March 2020.

5.1.8 H_2 PRODUCTION OPTIONS – FROM THIRD PARTY VENDORS

As corroboration, Nikola have based their business model, commencing from 2021, on $US 2.47 / kg ($AUS 4.07 / kg) whilst east coast USA companies are signing off-takes for sub-$US 4 /kg ($AUS 6.60 / kg; which allows for production and a margin).

This amount of H_2 (202 tpa) would provide 94.5% of RMP-1's internal diesel requirements or 58.7% the diesel requirements when twelve (12) B-doubles and two (2) hook bins are also included.

With a refueling time of approximately 10 to 15 minutes (accounting for arrival, refueling and departure times), a single re-fueling station can support a fleet of up to 96 to 144 vehicles. Nikola assumes that a 2 MW refueling hub can support 70 trucks on a 10 to 15 min cycle time, which is less conservative than the above assumption[51].

Figure 36: Example Ecosystem of H_2 Transport System

Presented in Figure 37 below is a high level summary on one of the first public H_2 Refueling stations (HRS) to be installed in Australia at QUT's Kelvin Grove campus in Brisbane. The primary aim is to support the Queensland Government's fleet of Hyundai and Toyota FCEV light vehicles. However, there is also the intention for the facility to support buses. Hence, the opportunity to also refuel heavy vehicles. The hydrogen is expected to be provided via a direct off-take agreement with BOC.

As of Q1 2020, market prices for hydrogen are in the double digits per kg hence reducing the wide spread financial viability of hydrogen across all mobility devices, however increased production, especially at the export scale and at large scale electrolysis facilities, will drive the cost of hydrogen from third parties down.

[51] https://nikolamotor.com/NikolaInvestorPresentation3-3-2020.pdf, accessed 26 March 2020.

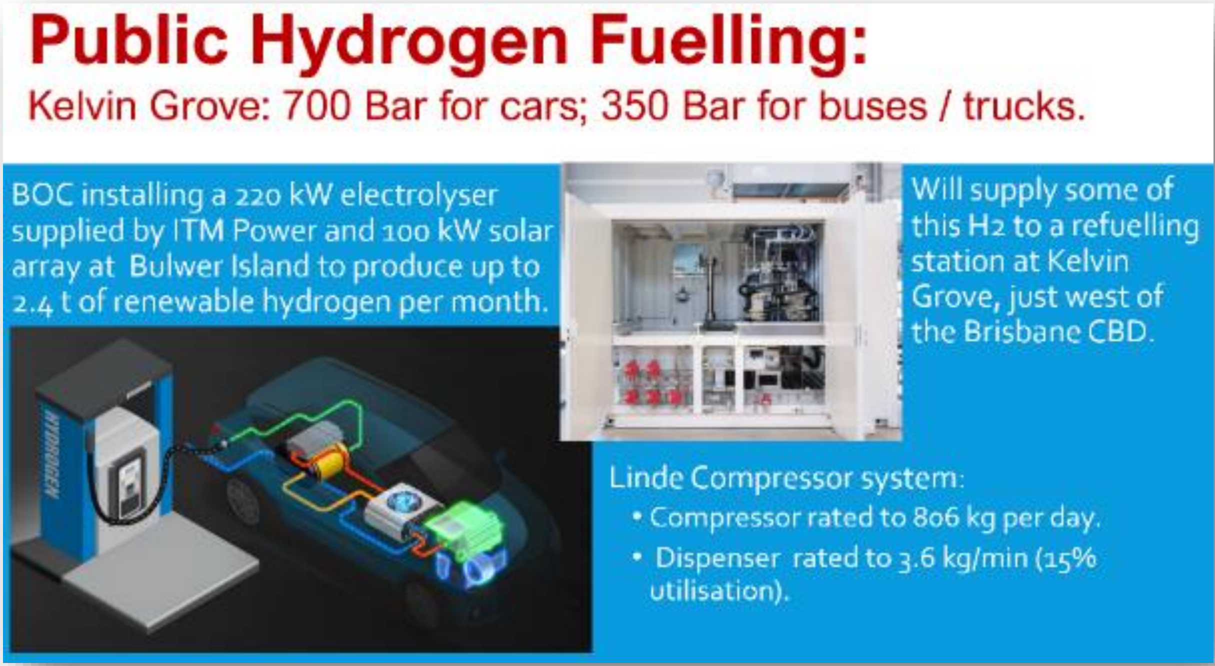

Figure 379: Example Ecosystem of H_2 Transport System

5.1.9 WATER FEEDSTOCK

Water quality is a critical element of ensuring the longevity of the electrolysers, however the water treatment equipment is “off-the shelf” standard industrial equipment. The general strategy is to start with high quality / low salinity waste water such as sterilization water with the following equipment requirements: pre-filtration (150 micron screen filter), Ultrafiltration, Air Scour System, Maintenance Clean System and Cleaning In Place (CIP) / Recovery Clean system for membrane cleaning (refer Figure below).

Table 19: MAK Electrolyser Feedstock Water Pre-Treatment Specifications

Filtrate Recovery Rate	%	90 – 98% (varies according to feed water quality and UF configuration)
Filtrate Turbidity	NTU	<0.1 (typical)
Raw Water Turbidity (max)	NTU	<150
Raw Water TSS (max)	mg/L	<300
Raw Water Temperature	°C	15 ~ 35
Ambient Design Temperature	°C	5 ~ 40 (-15 ~ 45 for insulated containerised system)
Feed Water Inlet Pressure	kPa	>15 (flooded suction)
Permeate Discharge Pressure	kPa	~40 (higher discharge pressures available on request)
Backwash Discharge Pressure	kPa	~40 (higher discharge pressures available on request)
Power Supply	-	AC 380~450 V, 3 Phase, 50/60 Hz

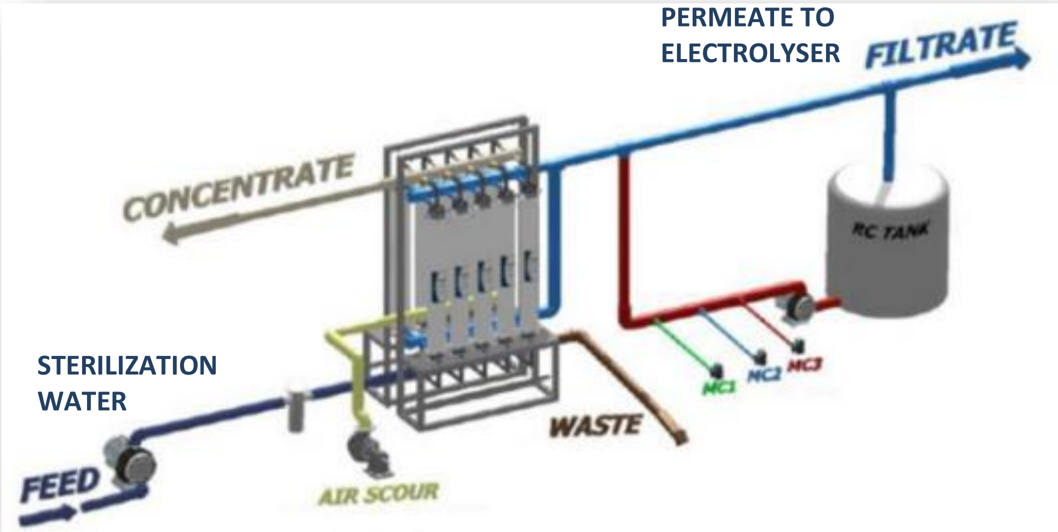

Figure 38: MAK Electrolyser Feedstock Water Pre-Treatment Schematic

Table 20: Hydrogenics Water Quality Requirements[52]

FEED WATER REQUIREMENTS (BEFORE WATER TREATMENT SYSTEM)		
Operating Pressure	bar (psi)	2.75 – 5.50 (40 – 80 psi)
pH	Range	3 – 11
Maximum Temperature	°C	38 °C
Maximum Turbidity	NTU	1.0 NTU
Maximum Silt Density	Index	5.0 (based on 15 min. test time)
Chlorine	ppm	< 0.1 ppm
Maximum TDS	ppm	2000 ppm
Hardness	grains (ppm)	10 grains (170 ppm as $CaCO3$)
Iron	ppm	< 0.1 ppm
Manganese	ppm	< 0.1 ppm
Hydrogen Sulfide	ppm	0 ppm
Langelier Saturation	Index	LSI must be negative
PROCESS WATER (AFTER WATER TREATMENT SYSTEM, TO THE HYLYZER)		
Inlet Water consumption	L/h	~1 L of deionized water per Nm3 of H2 produced.
Required inlet water quality	MΩ.cm	> 1 (ISO 3696 scale 2)
Required inlet water pressure	barg (psig)	0.7 – 6.9 (10 – 100)

[52] https://www.hydrogenics.com/

5.1.10 Off-grid Cogeneration

A scenario was run as follows:

- Diesel genset costs at $0.40 / kWh
- LPG costs at $35/GJ; boiler efficiency at 80%.
- Some load shifting for hay grinding to occur outside of milling hours.
- PFC to reduce kVA.
- Motor speed management and Energy Management System to limit facility load to be power by a 200 kW fuel cell.
- Long run average of 87.76 kW at PF = 0.95. Maximum output of 200 kW.
- Total install CAPEX of $273,000[53] (in 2022 due to scale up of production where stack represents 60% of cost) for a 61.1% electrical efficiency[54], 20% thermal efficiency fuel cell; $727,300 Q1 2020[55].
- H2 cost of $5.02 / kg. Allows $1.00 /kg for transport and storage.
- Generates 769,324 kWh pa

Annual savings:

Thermal energy @ $35/GJ & 80% boiler eff.	$ 39,659
Avoided diesel genset costs	$ 307,729
TOTAL SAVINGS & REVENUE excl. RECs	**$ 347,389**
RECs (TBC if can be claimed)	$ 24,618

H_2 costs @ $5.02 / kg	$ 160,372 pa
PAYBACK – Q1 2020 excl. RECs	3.9 years
PAYBACK – 2022 excl. RECs	1.5 years

H_2 demand of 31.95 tonnes per annum.

[53] $US 230 - 520 / kW for FC ($AUS 126,013 for 200 kWe), "Stack Cost Comparison of 100 kW CHP Fuel Cell Systems", lma.berkeley.edu.
[54] https://sites.duke.edu/svermagcs/files/2019/03/SVerma_FC_Optimization_Paper.pdf
[55] Horizon Fuel Cells, personal communication, Q1 2020.

5.1.12 Grid-parallel Cogeneration for Peak Shaving

A scenario was run for 6 months of 30 min data on an RMP facility to determine the opportunity to reduce peak load costs (kVA charges), kWh costs and heating costs.

Relevant power costs were assumed to be:

- $0.144 / kWh [$0.119 power + $0.023 environmental charges + $0.002 ancillary/network/AEMO]
- $7.699 / kVA/month [11 kV Bus supply]

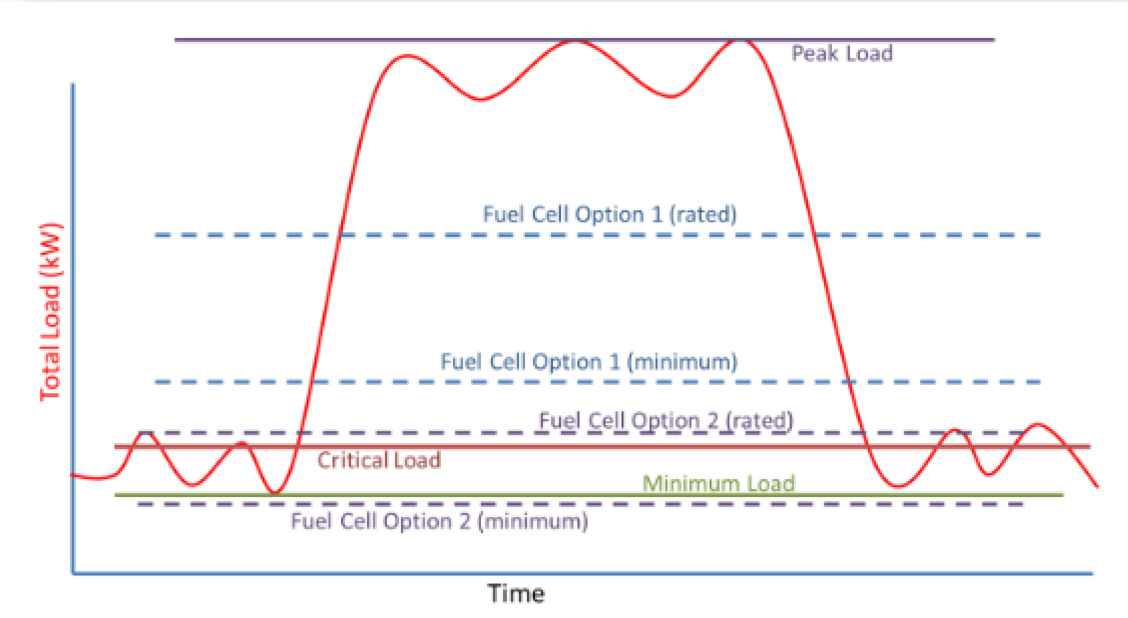

Figure 39: Stylized RMP load during a production shift with impact of embedded generation via a fuel cell.

A scenario was run where the FC is turned on when the plant wide load exceeds a long run average load. A summary of the findings are as follows:
200kW FC fully installed CAPEX: $273,000

Run time: 2447 hours per annum at rated capacity of 200 kW; 489,400 kWh pa.

Cost savings:

Thermal energy @ $5/GJ	$ 3,604 pa.
Revenue kVA reduction	$18,478 pa.
Revenue kWh	$ 70,474 pa.
TOTAL SAVINGS Excl. RECs	$ 94,187 pa.

H2 costs @ $4.02/kg $ 81,697 pa.
As can be seen, due to the relatively low costs for a 11 kV feeder, the economics are not viable (i.e. payback is longer than life of FC).

However, an alternate higher use scenario was run where the fuel cell is run for 4724 hours pa (when loads exceed 1200 kW; H_2 consumption of 48.13 tonnes pa) at a thermal energy value of $35/GJ (LPG costs) **a three year payback was achieved at a kWh value of $0.319 / kWh.** As smaller businesses are currently paying up to $0.36 / kWh, a high utilization fuel cell may be suited to smaller power / thermal energy load where power and heating costs are higher than for a large facility.

The next generation of fuel cells is considered to be solid oxide fuel cells (SOFCs). These cells have an efficiency of over 60%, targeting 80%, when converting H_2 to power and operate at a very high temperature range between 8000C to 1,0000C.

5.1.13 Hydrogen Transportation

The most economically viable hydrogen transport option over 100’s of kilometres is compression (i.e. to 350 barg) for trucking to points of secondary utliisation.

Figure 10: 1 MW electrolyser indicative layout orthographic views

Figure 11: 1 MW electrolyser indicative layout orthographic views

5.1.13 Indicative Facility Layout

5.1.13.1 Indicative Layout Orthographic View – Option 1

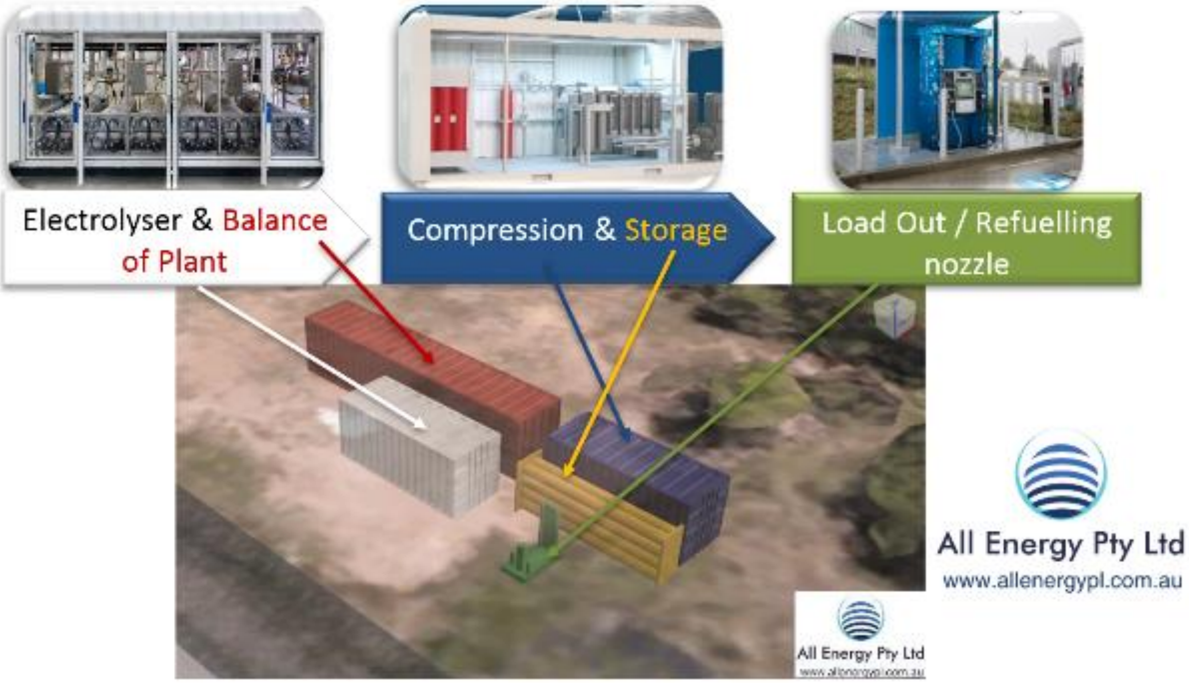

Figure 11: 1 MW electrolyser indicative Option 1 layout orthographic views.

5.1.13.2 Indicative Layout Orthographic View – Option 2

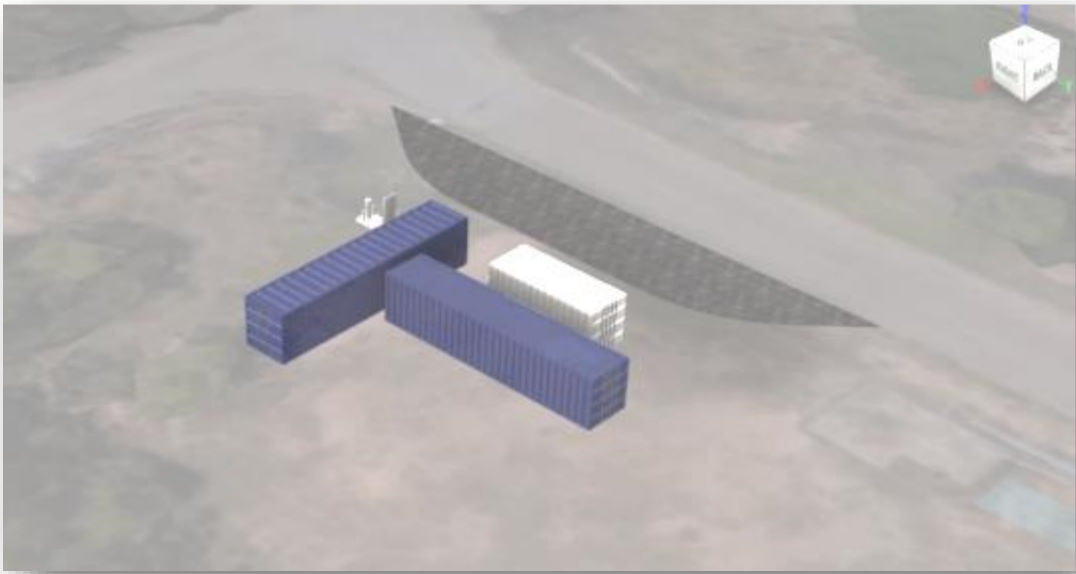

Figure 11: 1 MW electrolyser indicative Option 1 layout orthographic views.

5.1.13.3 Indicative Layout Orthographic View – Option 3

Figure 113: 1 MW electrolyser indicative Option 1 layout orthographic views.

5.1.13.4 Indicative Roof Surface Area Requirement for 1.352 MWp Solar Array.

Figure 12: Indicative area requirement for PV array to power 1 MW electrolyser

5.2 Feasibility Study #2

5.2.1 Basis of Design – Current Diesel Usage and Potential H2 Utilisation by RMP-2

RMP-2's fleet of vehicles include:

- 24 Prime Movers.
- 52 Semi Trailers.
- Refrigerated Pantech's
- Tautliners
- Tankers (i.e. tallow)
- Tippers
- Hook-lift Trucks
- Truck/Dogs
- Stock Crates
- Sheep Crates
- Calf Trucks
- Container Side Loader Trailer
- Container Skel Trailers
- B/Double Configurations
- A/Double Road-train Configurations

The following table summarises the types of vehicles currently being used by RMP-2.

Table 21: Current RMP-2 Group Liquid Fuel Demand.

Vehicle Description	**Image**	**Number of prime movers**	**Average L fuel used p.a.**	**Approximate H_2 to displace liquid fuel**
Currently under operational control				
B-Doubles for Livestock Trucks and tallow tankers **Kenworth T609 (ISX e5, 600hp)**		**~10**	**~886,957 Lpa**	
Kenworth T409SAR		1		
Kenworth T909		1		
Cabover K200s. Main duty: FTE refrigerated B-doubles vans for product delivery to Geelong / Melbourne		**~10**	**~739,130 Lpa**	
Secondary duty: B-double cattle trucks				

Vehicle Description	Image	Number of prime movers	Average L fuel used p.a.	Approximate H_2 to displace liquid fuel
T359s hook trucks (10×4 twin-steer, 10.8 litre Cummins ISMe5 engines set at 440hp @ 1800 rpm, 2000Nm at 1200rpm)		**2**	**~73,913**	
Forklifts - LPG		TBA (~11)	115,000	
TOTAL			**1,815,000**	

5.2.2 H_2 PRODUCTION OPTIONS – FROM SOLAR

The following section details the estimation around H_2 production costs for use in a transport hub and remote energy system.

Technology:	Hydrogenics HyLYSER PEM electrolysis-technology[56].
Power source:	Co-located single axis PV solar.
Nominal load MW:	4.31 MWe
Max load MW	5.83 MWe
PV Solar MWp	5.83 MWp
kWh pa PV	9,799,308 [Mt Gambier, SA[57]; single axis tracking increasing collection by 23% compared to fixed[58]]
kg H_2 pa:	200,350
Nominal kg H_2 pa:	700,000 kg H_2 p.a. [System rating]
Utilisation:	28.6%
CAPEX PV:	$ 6,039,361
CAPEX H_2:	$ 7,306,546 [allowances for electrolyser, cooling system, installation, compression, storage, refueling]
TOTAL CAPEX	**$13,479,366** (1.00% regional construction index applied) [59]
OPEX:	$664,165 p.a. [@9% capex; allowance for insurance, equipment, staffing, water treatment]
Revenue RECs:	$298,879 p.a. [@ $30.5 / MWh[60]]
Revenue hot water:	$119,591 [off-setting LPG, 11.3% thermal recovery, 50 Deg C]
Hours stack life:	64,000 hours

[56] https://solutions.hydrogenics.com/onsite-hydrogengeneration-hylyzer-pem-electrolysis-technology
[57] https://www.lgenergy.com.au/calculator/suburb/compton-sa/5290
[58] "Solar Trackers", solarchoice.net.au, accessed 24 April 2020.
[59] 1.00% Regional Building Index applied for regional areas, Rawlinsons Australian Construction Handbook.
[60] http://greenmarkets.com.au/, accessed 27 March 2020.

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Life of plant: 20 years [stack life 20 – 25 years assuming 28.6% utilisation].

EBITDA \$/kg H_2: \$ 5.19 / kg H_2 [including 8 years of RECs, excluding O2 value]
\$ 6.68 / kg H_2 [excluding RECS & O2 value]
\$ 4.59 / kg H_2 [including RECS & heat; excluding O2 value]

The EBITDA \$/kg H_2 is a simple metric showing the cost of production for the hydrogen accounting for capex, opex, aeration savings to calculate earnings before applying interest, taxation, depreciation and amortization. The cost of production including RECs generated from the PV solar facility (for 8 years; i.e. 2022 - 2030) and excluding RECs is shown.

Assuming that hydrogen devices are at the same capex as diesel devices, the IRR is estimated at 13% and the NPV at \$17.6 mil.

Notes: the value of the oxygen was excluded for this analysis.

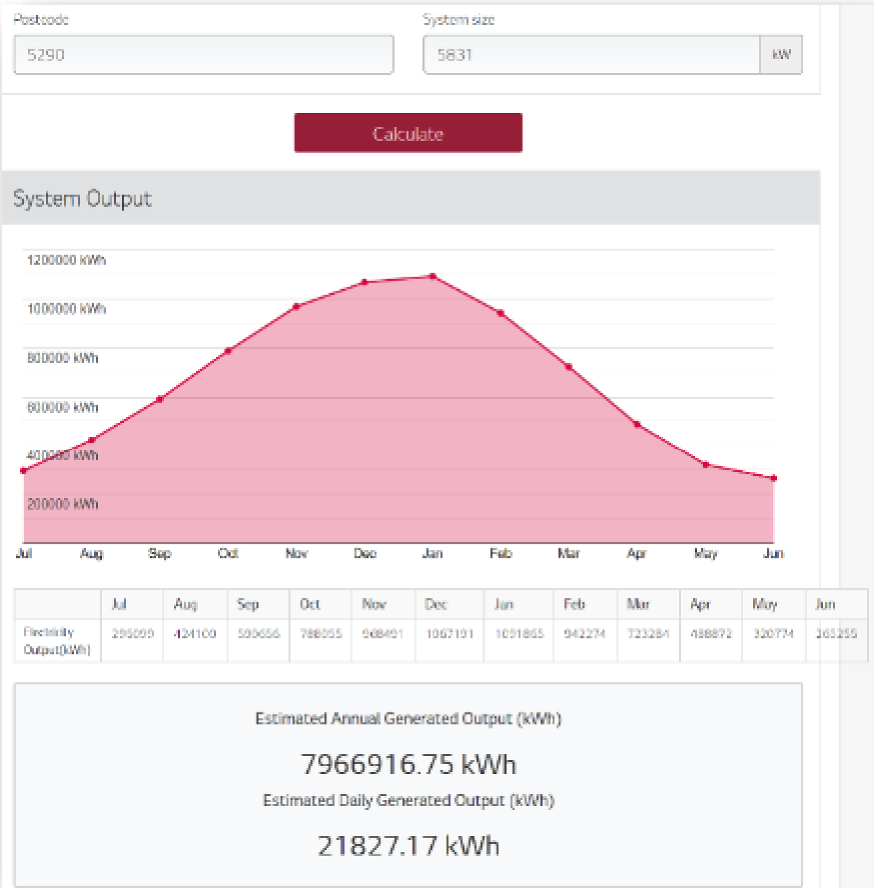

Figure 45: solar PV resource at Mt Gambier, SA.

5.1.7 H_2 PRODUCTION OPTIONS – FROM SOLAR AND GRID

Where a large solar array cannot be installed or it is desired to reduce the total capital spend, an alternative scenario is to produce hydrogen using an alkaline electrolyser using solar during the day and off-peak power during the evenings.

Technology:	Alkaline electrolysis-technology 1.0 MW nominal load.
Power source:	Co-located single axis PV solar.
Nominal load MW:	1.00 MWe
Max load MW	1.352 MWe
PV Solar MWp	1.352 MWp
kWh pa PV	2,271,650 [38.4% of kVAs; single axis tracking in Victoria]
kWh pa Off-peak	3,650,000 [42% of the time; load managed to limit kVA charges; assumed at $0.093 / kWh YTD AER wholesale costs[61], plus $0.025 environmental and ancillary charges]
kg H_2 pa:	121,070
Nominal kg H_2 pa:	162,272 kg H_2 p.a. [System rating]
Utilisation:	70.3%
CAPEX PV:	$ 1,400,029
CAPEX H_2:	$ 2,052,312 [allowances for electrolyser, cooling system, installation, compression, storage, refueling]. Stack replacement: $540k.
TOTAL CAPEX	**$3,486,023** (1.00% regional construction index applied) [62]
OPEX:	$588,055 p.a. [@9% capex; off-peak power @ $0.11 / kWh; allowance for insurance, equipment, staffing]
Revenue RECs:	$69,285 p.a. [@ $30.5 / MWh[63]]
Stack replacement:	$1.23 mil at 64,000 hours.
Life of plant:	20 years [stack replacement @10 years; BOP @ 20 year life].
O2 energy saving	$177,481 pa (estimated surface aeration reduction)
EBITDA $/kg H2:	$ 3.73 / kg H_2 [including O2 value and 8 years of RECs]
	$ 4.31 / kg H_2 [including O2 value and excluding RECs]
	$ 6.52 / kg H_2 [excluding RECS and O2 value]

Assuming that hydrogen devices are at the same capex as diesel devices, the IRR is estimated at 18% and the NPV at $10.5 mil.

In the 12 months to 1 April 2020, the NEM electricity generation came from 23.8% renewable sources[64], hence the above system would utilize ~53.0% renewable energy. For completely green hydrogen, offsets can be procured at ~$7k p.a.

Thermal energy was excluded for this analysis, however where 50 Deg C water can be utilized, the cost reduction in coal / biomass fuel is $12k pa or $72k pa cost reduction in LPG fuel cost.

61 https://www.aer.gov.au/wholesale-markets/wholesale-statistics/annual-volume-weighted-average-spot-prices-regions
62 1.00% Regional Building Index applied for regional areas, Rawlinsons Australian Construction Handbook.
63 http://greenmarkets.com.au/, accessed 27 March 2020.
64 www.opennem.org.au, accessed 31 March 2020.

5.1.8 Indicative Layout

Figure 46 below provides an indicative layout for a 1.0 MW electrolyser at a RMP.

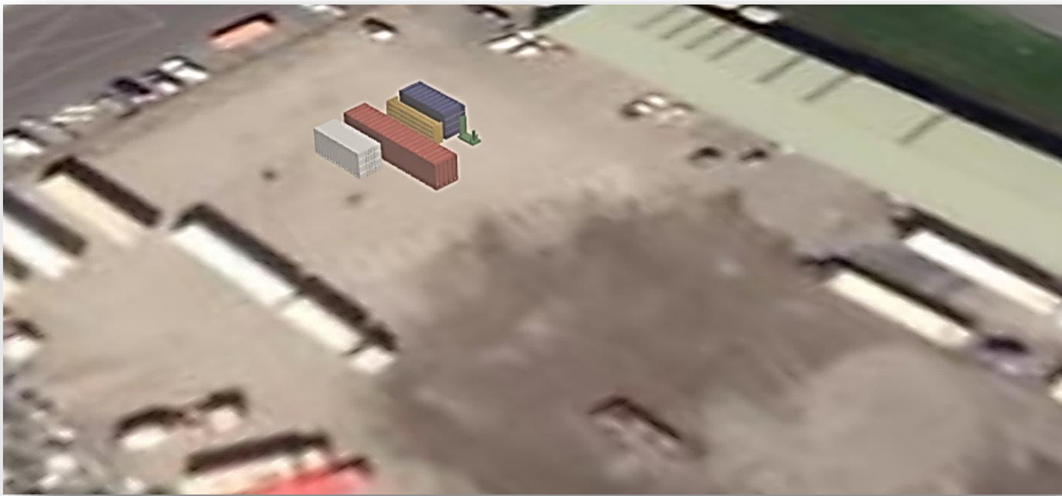

Figure 46: H2 Layout Orthographic and Plan View

Figure 47: PV Solar Array Layout Option for supporting a 1MW Hydrogen Electrolyser.

5.3 Aggregated Results From Expression of Interest (EoI)

EoIs were received from eight (8) RMPs representing 5.14 million L of liquid fuel under direct operational control, and towards double this figure when taking direct sub-contractor fuel requirements into account. Five (5) companies nominated the opportunity for sale of hydrogen to adjacent businesses and seven (7) nominated a use for the oxygen on-site (i.e. in a waste water treatment plant). Six (6) nominated the ability to segregate high quality waste water (e.g. sterilization water). All RMPs nominated roof area or available land for the installation of PV solar.

6.0 DISCUSSION

6.1 Relative Hydrogen Production Costs – CAPEX versus OPEX

As for all capital equipment, the longer the life of plant and higher the plant operating costs, the lower the contribution of the initial CAPEX to overall life of plant costs. This is evidenced in Table 22 below. For the alkaline system that also uses grid power, it can be seen how important it is to manage the ongoing operating costs. The CSIRO National H2 Roadmap (2018) predicted a drop in electrolyser CAPEX of 73.3% from 2018 through to 2025.

One of the key areas of endeavor for electrolyser fabricators is to increase the life of stacks. The estimates presented in this report are based upon a stack life between major overhauls of ~64,000 hours (+/- 15,000 hours). This +/- 23.4% margin is large, but is attributable to a number of chemical and mechanical impacts on electrolysers including impurities in the water "poisoning" the catalysts, oxidation of the catalyst (e.g. hydrous iridium oxide in the membranes due to low open cycle voltages), passivation of membrane and mechanical / physical damage such as particulates clogging the membrane which reduces available membrane surface areas. Advances in materials science will prevent the chemical / mechanical impacts thereby extending the life of the stacks, further lowering the life of plant cost of electrolysers.

Alkaline electrolysers are reasonably mature, hence higher percentage falls are anticipated for PEM electrolysers. PV technology is comparatively mature; hence the greatest percentage savings are expected to occur with the electrolysers.

Table 22: Comparison between CAPEX and OPEX for hydrogen production.

Parameter	CAPEX % Lifetime Costs	OPEX % Lifetime Costs
Alkaline Electrolysis including O2 and RECs value. 38.6% power from PV, 61.4% from off-peak grid power. **20 year life of plant.**	29.5%	70.5%
Alkaline Electrolysis including O2 and RECs value. 38.6% power from PV, 61.4% from off-peak grid power. **25 year life of plant.**	25.1%	74.9%
PEM Electrolyser using PV, including RECs, excluding O2. **20 year life of plant.**	50.4%	49.6%
PEM Electrolyser using PV, including RECs, excluding O2. **25 year life of plant.**	44.8%	55.2%

6.2 Levelised Cost of Hydrogen (LCoH) – Sensitivity Analysis

Presented in Table 23 are findings of how the LCoH is impacted by changes in power OPEX, the PV solar array CAPEX, electrolyser CAPEX and the life of plant. As can be seen, the yearly operating costs dominate the LCoH as the operational life of the plant increases.

Whilst reducing CAPEX is important, a key aim must be to maintain low operating costs.

Table 23: Sensitivity analysis for hydrogen production.

Parameter	**% Change**	**% reduction in H2 cost (LCoH)**	**$ / kg H2**
Base case – Alkaline Electrolysis including O2 and RECs value. 38.6% power from PV, 61.4% from off-peak grid power.			3.13
Alkaline Electrolyser CAPEX reduction	- 50% electrolyser plant CAPEX (no change in OPEX)	**-13.4%**	**2.71**
Alkaline Electrolyser power OPEX reduction - Grid power	- 50% (i.e. grid power drops to average of $0.04 / kWh)	**-38.3%**	**1.93**
Alkaline Electrolyser power OPEX reduction – uninterrupted power innovation (e.g. supercapacitors)	- 80% (i.e. uninterrupted power drops and/or grid drops to average of $0.016 / kWh via new power storage technology)	**-61.3%**	**1.21**
Grid power cost and PV CAPEX reduction for an Alkaline Electrolyser using PV and Grid	- 50% (i.e. grid power drops to average of $0.04 / kWh; PV array at half current CAPEX)	**-47.2%**	**1.64**
Extended electrolyser life from 64,000 to 80,000 hrs	+25% life of plant (from 20 to 25 years)	**-9.0%**	**2.848**
Base case – PEM Electrolysis including RECs value, excluding O2 and heating value. All power from PV.			5.96
PEM Electrolyser using PV	- 50% electrolyser CAPEX reduction (no change in OPEX)	**-15.0%**	**5.06**
PEM Electrolyser using PV	- 50% PV CAPEX reduction	**-12.5%**	**5.21**
Extended electrolyser life from 64,000 to 80,000 hrs	+25% life of plant (from 20 to 25 years)	**-9.1%**	**5.42**

6.3 Power Cost Trend

The future trend is for moderately priced wholesale power on a $/kWh basis compared to previous years (refer Figure 49 below). Another trend, as shown in Figure 50, is for wholesale power to be free or at a negative cost for longer periods each year due to the increasing fraction of generation provided by solar (displayed in Figure 51).

Figure 49: ASX Electricity Futures Data for eastern seaboard in $/MWh.

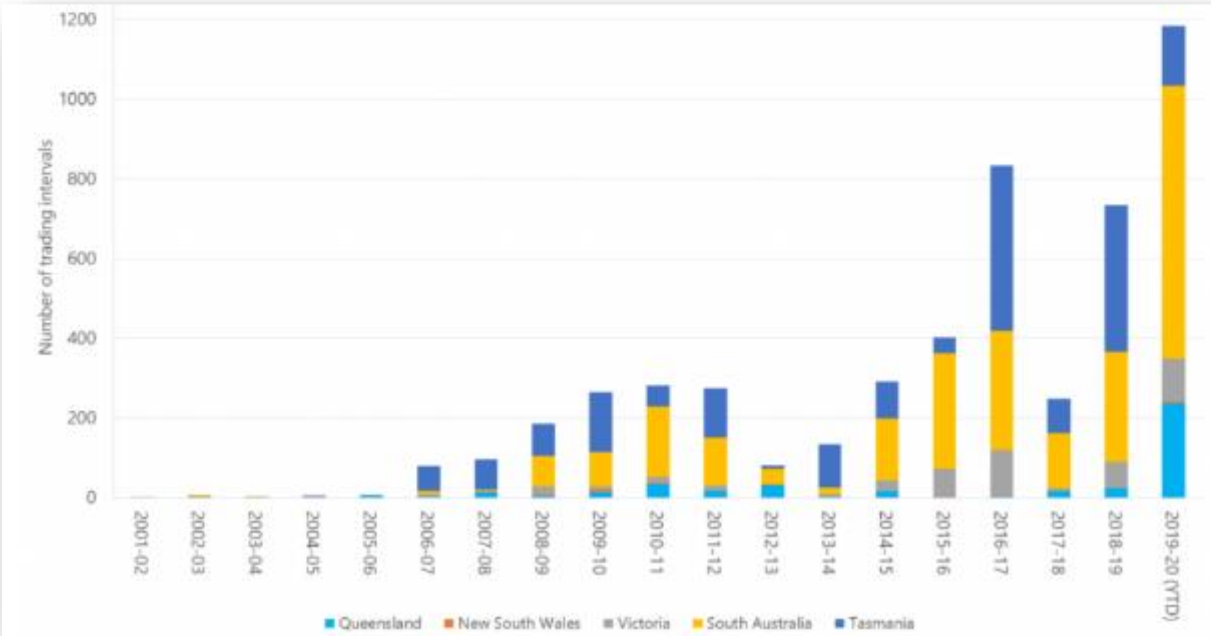

Figure 50: Annual count of spot prices below $0/MWh (each count equates to 30 minutes).

The Australian Energy Regulator (AER) data in Figure 50 does not capture the number of ramp-back / curtailments also put in place by AEMO to stabilise the grid, resulting in PV solar farms "spilling" or wasting power.

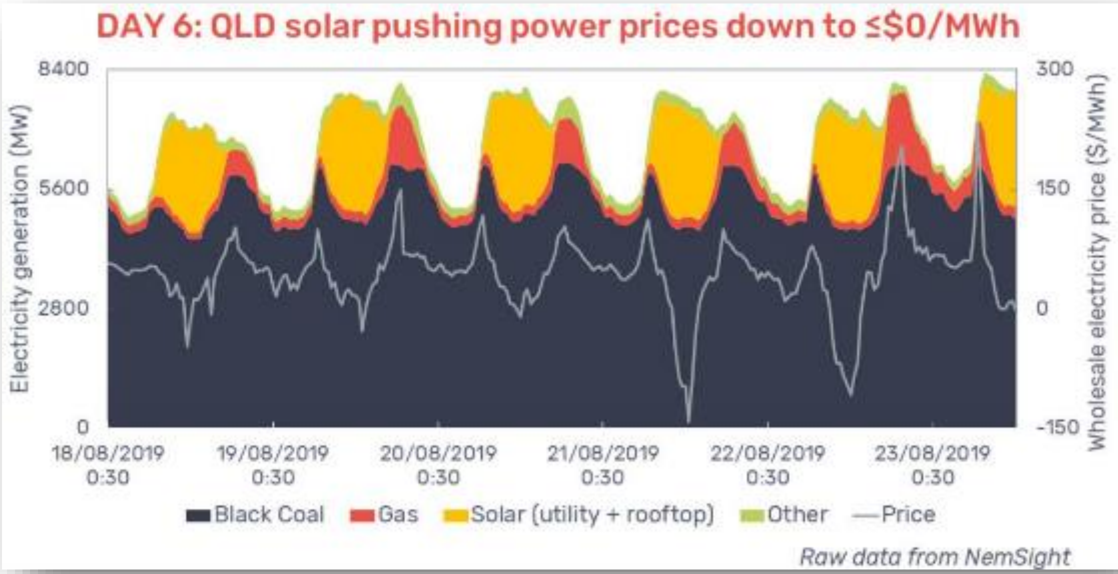

Figure 51: The sum of fossil and renewable generation, showing how the spot price drops below $0 / MWH during periods of high solar PV production.

As in Figure 51 (Queensland), this effect is also observed in South Australia where a significant proportion of power is supplied by highly transient wind farms.

The outcome to draw from available data is that electrical loads that can be varied (i.e. ramped up or down) to respond to the wholesale market have the opportunity to access low cost, free or even cost negative power. A hydrogen electrolyser is a perfect example of fast responding load that can turn the volatility of grid power pricing into an opportunity to generate low cost hydrogen. PV solar can provide a minimum kWh basis, with the grid power providing uninterrupted power and an opportunity to ramp up production when power is at a suitable price point.

6.4 Hydrogen versus Electrification

The general trend in the industry is that passenger vehicles and light commercial with low utilization (i.e. <8 hours per day usage or <~300 km per day, with the balance of the time being available for re-charging) will be electrified, whilst heavy and commercial vehicles are suited to hydrogen fuel cells, in particular trucks that need to maximise tonnage payloads, have large inclines / declines on typical routes and long-haul vehicles.

Figure 52 below shows the high efficiency that can be obtained with electric vehicles. However, Figure 52 fails to show the ***limitations of electrification***:

- batteries are slow to charge and/or can be damaged during rapid charging,
- batteries are heavy and provide a comparatively low kWh per kg,
- batteries cannot provide the kWh storage required for the high payloads of heavy vehicles.

Further, advances in technology mean that electricity can remain as DC, electrolysis efficiency is already >80% and rising, compression and transport parasitic loads are dropping, and fuel cell efficiencies are rising. In 2020, a compressed H2 solution is expected to be closer to ~37 to 38 kWh per 100 kWh renewable electricity.

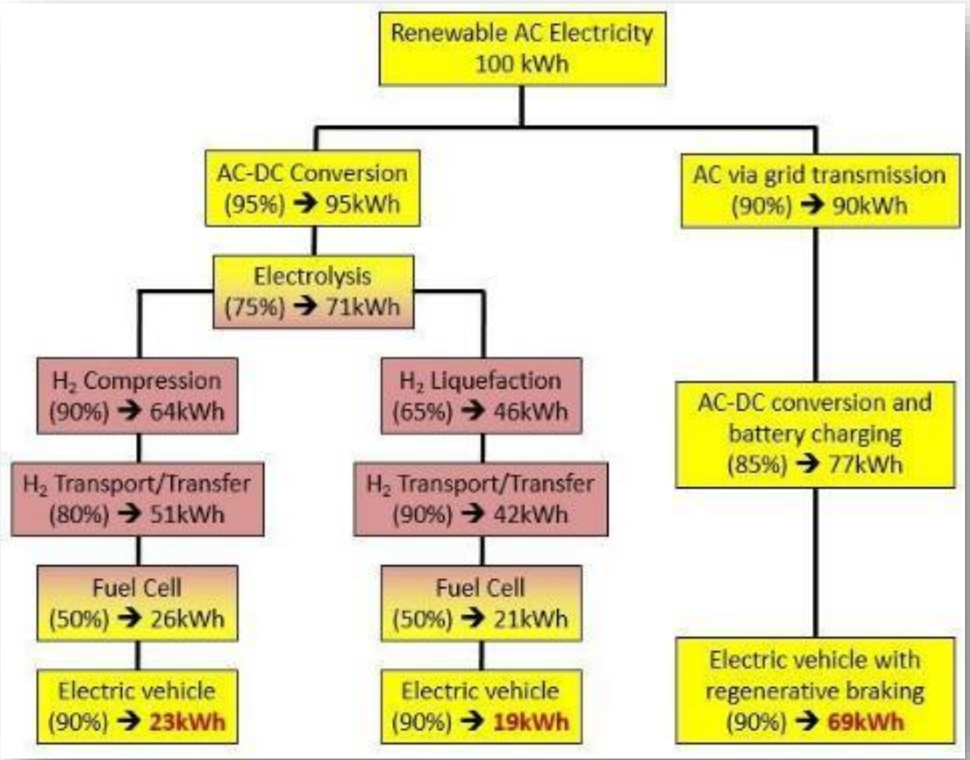

Figure 52: H2 and electric vehicle production routes, energy efficiency comparison

6.5 Emissions to Air Implications

Hydrogen fuel cells offer the following advantages:

- Zero point source CO2 emissions.
- Zero point source CH4 emissions.
- Zero point source particulate emissions.
- Zero point source NOx emissions.
- Zero point source SOx emissions.
- Water vapour as the only point source emission.
- One of the limited technologies available for a zero-emissions transport fleet.

Stringent air quality requirements within buildings for worker health in Europe and North America are driving hydrogen forklift sales, in particular where forklifts are used more than one shift per day as the charging time for electric forklifts reduces utilization to the point where electric forklifts are not economically viable.

Hydrogen used in internal combustion engines reduces CO2, CH4, particulate and SOx emissions. There is evidence that hydrogen increases NOx emissions in an ICE due to the higher combustion temperatures.

Each kg of hydrogen reduces diesel usage by ~6 litres, which equates to a Scope 1 emissions reduction of approximately 16.32 kg CO_2-e. Hence, a RMP replacing 3.149 million L of diesel per annum with hydrogen could reduce Scope 1 emissions by 8,565 tonnes CO_2-e per annum.

The Clean Energy Finance Corporation (CEFC) created the infographic presented in Figure 53 to show the potential for hydrogen throughout the Australian economy to drive down GHG emissions.

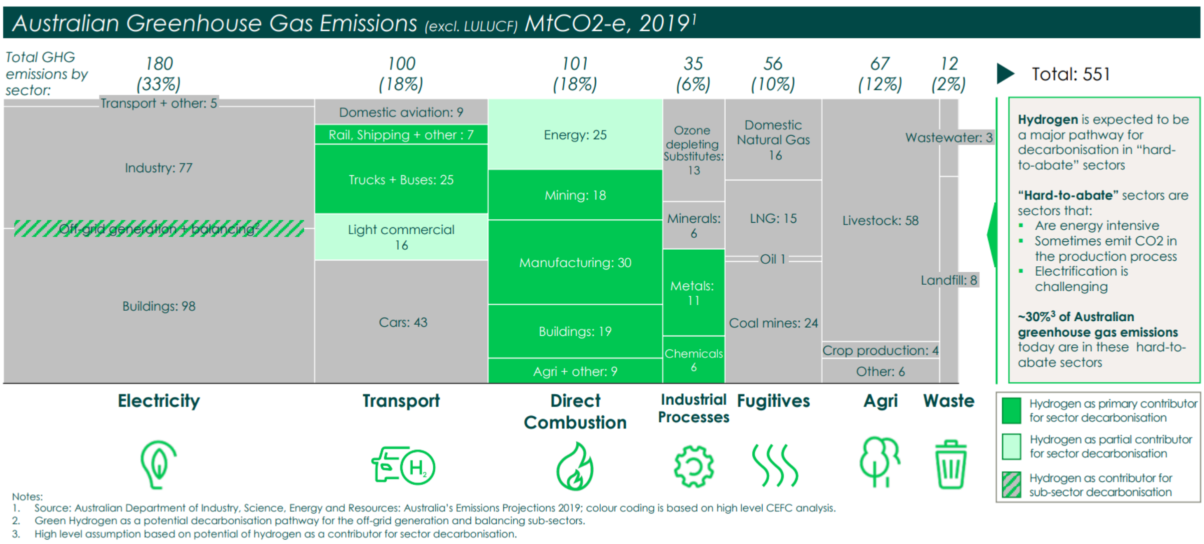

Figure 53: H2 opportunities across Australia and Associated Greenhouse Gas Emissions[65].

6.6 Funding Assistance for Hydrogen

[65] https://www.cefc.com.au/media/iz4keraf/h2-across-australian-greenhouse-gas-emissions.pdf

Funding for hydrogen infrastructure is available from:

- Federal Government's Renewable Energy Target: Large Scale Energy Certificates can be created from PV solar or when power is generated using renewable energy. Credits are generated for registered facilities then required / sold to the market. More information is available here: http://www.cleanenergyregulator.gov.au/RET

- Clean Energy Finance Corporation (CEFC): has put aside $300 mil for projects requiring over $10mil in funding. More information is available here: https://www.cefc.com.au/media/files/cefc-welcomes-launch-of-new-300-million-advancing-hydrogen-fund/

- Northern Australia Infrastructure Fund: for projects from Gladstone and northwards in Qld, NT and the northly half of WA. Concessional funding is available for infrastructure projects, such as hydrogen production. More information is available here: https://naif.gov.au/about-naif-finance/

- Australian Renewable Energy Agency (ARENA): EoIs closing 26 May 2020 for projects >5 MW, however funding is available via ARENA's wider funding scheme the Advancing Renewables Program (ARP). More information is available here: https://arena.gov.au/renewable-energy/hydrogen/

7.0 CONCLUSIONS/RECOMMENDATIONS

Hydrogen provides one of the limited opportunities for de-carbonising “hard to abate” sectors such as heavy vehicle transport, commercial transport, and off-grid 24/7 power generation. Hydrogen is considered an important energy vector for the creation of economically viable and zero emissions supply chains.

The advantages of hydrogen production for RMPs include:

- Lower cost liquid fuel for use in transport, forklifts and for embedded power generation.
- Energy security by generating a fuel “in-house”.
- Zero point source emissions of CO2, CH4, NOx, SOx, and particulate emissions.
- Value adding of low salinity waste water into hydrogen.
- Pressurised oxygen as a co-product which can be sparged into aerated water treatment facilities to reduce power requirements.
- Thermal energy (~50 Deg C hot water) for off-setting the use of fossil fuels for heating water.
- Utilisation of existing and under utilized infrastructure e.g. off-peak power during the evenings and weekend.
- Production of hydrogen to reduce energy costs and for sale to third parties as a new business offering.

A wide range of mobility devices are available offering payback periods of around 3 to 6 years, with internal rates of return estimated towards 28%. When the advantages of O2 are taken into account, the Levelised Cost of Hydrogen (LCoH) production (i.e. over a 20 year life of plant) production costs could be 41% lower than a plant that cannot utilize O2.

Achieving carbon neutrality, such as outlined in the Carbon Neutral by 2030 goal or via the Federal Government’s Climate Active scheme, requires consideration of all emissions from “cradle to grave” taking a rigorous life cycle approach. Whilst previous works suggest direct liquid fuel consumption is ~3.2 million litres, data from this project suggests that when the wider supply chain is taken into account (such as transport services by third parties) liquid fuel consumption could be in excess of 120 million litres. This is both a threat and an opportunity: the threat of energy security, emissions and cost volatility but the opportunity via hydrogen for businesses to generate their own fuels, drive down emissions, save on energy costs and to also supply fuel in the form of hydrogen to other businesses.

The production of hydrogen to meet the supply chain liquid fuel requirements from a feedlot through to warehousing may only require approximately 4 to 5% of the sterilization water generated by an RMP. This is both a weakness and a strength: converting water into hydrogen for in-house use will not consume all of the waste water, however it is a strength in that a RMP could produce excess hydrogen for sale to third parties.

Recommendations for future research:

- Conversion of biogas into hydrogen via reforming. Modelling suggests that sites processing 2400 head of cattle per week or more could be at a suitable scale to produce hydrogen at a lower cost than hydrogen from an electrolyser. Economics are improved where biogas is already available i.e. generated in an existing covered anaerobic lagoon (CAL).
- Support of a trial of hydrogen-diesel dual fuel vehicles.
- Support of a trial of hydrogen fuel cell vehicles.
- Support for a hydrogen refueling hub at a RMP and/or for cattle trucks from feedlots to RMPs e.g. detailed design and approvals.

- Wide reaching hydrogen supply chain study which could consider how RMPs can produce hydrogen for use throughout the RMI e.g. hydrogen for transport, on-farm vehicles, and as a chemical feedstock for fertilizer production (e.g. liquid ammonia).

In preparing this report All Energy Pty Ltd has relied upon data, surveys, analysis, designs, plans or other information provided by third parties or as referenced herein. Some of the assumptions made in this report are aspirational in nature (i.e. no opportunity cost assigned to land requirements; diesel prices based upon Q1 2020 data), hence businesses are recommended to undertake project and business specific analyses. No responsibility is accepted for use of any part of this report in any other context or for any other. This report does not purport to provide legal or financial advice; readers should engage appropriate advisers for these purposes.

8.0 BIBLIOGRAPHY

Reference are provided within the footnotes of the body of the report.

9.0 APPENDICES

Truck Operating Cost Calculator Results

AMPC

Truck Operating Cost Calculator

Country of operation: Australia — *Units: Kilometres, litres, metric tonnes*

Step 1: Fuel

Current Fuel Cost	$	1.30	per Ltr	Australian Institute of Petroleum Fuel Charts National Diesel Average - Click Here
Less Fuel rebate (fuel credit)	$	0.16500	per Ltr	
Fuel Cost including delivery & rebate	$	1.13500	per Ltr	*See ATO for Fuel Credit details- click here*

Step 2: Vehicle Type

Select Type of Truck & Trailer	Flat Top - Road Train (Dble)	
Net Average Daily Delivery	24	Tonne

Step 3: Fuel Consumption

Average Vehicle Fuel Burn Rate	0.90	Km / Ltr (Kilometres per Litre) = 111.11 ltrs per 100km

Step 4: Distance and Working Days

Distance Travelled per Day	750	Kilometres (Per working day)
Days per week vehicle works	6	Days per week
Weeks per year vehicle works	46	(account for driver holidays and service time)
Vehicle Description / Number		
Route Description — From		
Destination		

Step 5: Finance (per vehicle)

Capital Cost - Vehicle (Truck)	$	322,572	
Vehicle Stamp duty	$	9,677	*Based on a rate of 3%*
Capital Cost - Trailer(s)	$	178,000	
Trailer(s) Stamp duty	$	5,340	*Based on a rate of 3%*
Miscellaneous costs	$	15,000	
Less Deposit	$	0	
Principle (Loan - Amount Financed)		$530,589	
Balloon	%	25%	Residual $132,647
Interest Rate	%	9.50%	Paid monthly in arrears
Loan Period		5.0	Years

Loan repayments are calculated based on constant payments and a constant interest rate (averaged).
Balloon is the residual lump sum payment payable at the end of the loan (if selected to be used).

Annual Depreciation	$		*Guide to depreciation:* www.ato.gov.au

Depreciation rates and limits are set by the Tax Office. Speak with your financial advisor for what rate to use.

Step 6: Fixed Costs (per vehicle)

Costs in Step 6 relate only to the costs for a single vehicle

Insurance (Truck & Trailer)	$	18,045	per year	Road Tolls Paid	$	20	per day
Registration (Truck & Trailer)	$	15,897	per year	Mobile Cost	$	120	per month
Accounting / Consultancy	$	500	per year	Telephone Cost	$	295	per month
Depot / Rent for vehicle	$	12,500	per year	Administation Staff	$	1,890	per month
Depot Rates / Insurance	$	1,500	per year	Office Supplies	$	240	per month
Driver Wage (click here to check)	$	278	per day	Miscellaneous	$	82	per day
Workcover/ Workers Insurance		4.70%	(of wage on top of wage)				
Superannuation		9.00%	(of wage on top of wage)				

(Note: The Results Calulation assumes 52 weeks of driver employment for the wages costs).

Step 7: Service / Maintenance

Vehicle Service Cost (Type A)	$	930	per service interval every	18,000	Km
Maintenance Cost (Type B)	$	3,026	per maintenance interval	20,000	Km

(Maintenance includes costs for Brakes / Differential rebuild / Injectors / Alternator / Engine rebuild / Batteries etc.)

Step 8: Tyre Wear

Steer Tyre Cost	$	774	per tyre	Drive and Trailer Tyre Cost	$	700	per tyre
Steer Tyre Quantity		2		Drive and Trailer Quantity		40	
Steer Tyre Life		100,000	Km	Drive and Trailer Tyre Life		160,000	Km

Step 9: Fuel Levy Calculation (only if a base fuel rate is used in contract agreement)

Base Rate Fuel Price (if used)	$	1.00	per Ltr			
Base Rate Less Rebate per Step 1	$	**0.83500**	per Ltr	**Fuel Levy**	***11.67***	%

Using Current Fuel Price of $ 1.3 per Ltr equates to a fuel levy of 11.67% over the base rate fuel price of $ 1 per Ltr

Summary of Estimated Costs - *Click Calculate to Update Figures*

Cost Summary	**Per Annum**	**Per Month**	**Per Work Day**	**Percentage Cost**
Fuel (without fuel rebate included)				***42.77%***
Fuel	261,050.00	21,754.17	945.83	39.5%
Finance - Principle	79,588.37	6,632.36	288.36	**12.0%**
Finance - Interest **	33,303.36	2,775.28	120.66	**5.0%**
Depreciation	0.00	0.00	0.00	**0.0%**
Fixed Costs	107,134.02	8,927.84	388.17	**16.2%**
Driver	98,618.83	8,218.24	357.31	**14.9%**
Tyres	39,429.36	3,285.78	142.86	**6.0%**
Maintenance	31,319.10	2,609.92	113.48	**4.7%**
Service	10,695.00	891.25	38.75	**1.6%**
Total Cost Estimate $	661,138.04	55,094.84	2,395.43	**100.0%**

Distance Travelled	207,000	Km per year - (estimated average)
Service Intervals	12	per year (estimated average)
Maintenance Intervals	10	per year (estimated average)

*** Note: Interest amount varies from year to year. Value is the average of the finance period. (See Rule of 78).*

RESULTS - Based on Current Fuel Price in Step 1

Operating Margin **10.0%**

Estimate Charge per Day ***$ 2,661.59*** *+ GST / Tax (Based on $1.3 per Ltr, less rebate)*

Operating Cost per	*Day*	$ 2,395.43	*Est. Charge per Day*	$	2,661.59	*Margin per Day*	$	266.16
Estimated Cost per	*Tonne*	$ 99.81	*Est. Charge per Tonne*	$	110.90	*Margin per Tonne*	$	11.09
Estimated Cost per	*Km*	$ 3.19	*Est. Charge per Km*	$	3.55	*Margin per Km*	$	0.35

CAUTION: Margin is highly affected by cashflow. Margin shown may not be achieved for various reasons.
Seek accredited financial advice before using these figures.

Margins shown EBITA - (Earnings before Interest, Tax, Amortization)
All Figures exclude GST / Tax considerations.

AMPC

Truck Operating Cost Calculator

Country of operation: Australia — *Units: Kilometres, litres, metric tonnes*

Step 1: Fuel

Current Fuel Cost	$	1.30	per Ltr	Australian Institute of Petroleum Fuel Charts National Diesel Average - Click Here
Less Fuel rebate (fuel credit)	$	0.16500	per Ltr	
Fuel Cost including delivery & rebate	$	1.13500	per Ltr	*See ATO for Fuel Credit details- click here*

Step 2: Vehicle Type

Select Type of Truck & Trailer	Reefer - Single	
Net Average Daily Delivery	16.33	Tonne

Step 3: Fuel Consumption

Average Vehicle Fuel Burn Rate	2.10	Km / Ltr (Kilometres per Litre) = 47.62 ltrs per 100km

Step 4: Distance and Working Days

Distance Travelled per Day	750	Kilometres (Per working day)
Days per week vehicle works	6	Days per week
Weeks per year vehicle works	46	(account for driver holidays and service time)
Vehicle Description / Number		
Route Description From		
Destination		

Step 5: Finance (per vehicle)

Capital Cost - Vehicle (Truck)	$	276,210	
Vehicle Stamp duty	$	8,286	*Based on a rate of 3%*
Capital Cost - Trailer(s)	$	184,411	
Trailer(s) Stamp duty	$	5,532	*Based on a rate of 3%*
Miscellaneous costs	$	15,000	
Less Deposit	$	0	
Principle (Loan - Amount Financed)		$489,440	
Balloon	%	25%	Residual $122,360
Interest Rate	%	9.50%	Paid monthly in arrears
Loan Period		5.0	Years

Loan repayments are calculated based on constant payments and a constant interest rate (averaged).
Balloon is the residual lump sum payment payable at the end of the loan (if selected to be used).

Annual Depreciation $ ____ *Guide to depreciation:* www.ato.gov.au

Depreciation rates and limits are set by the Tax Office. Speak with your financial advisor for what rate to use.

Step 6: Fixed Costs (per vehicle)

Costs in Step 6 relate only to the costs for a single vehicle

Insurance (Truck & Trailer)	$	16,647	per year	Road Tolls Paid	$	20	per day
Registration (Truck & Trailer)	$	6,555	per year	Mobile Cost	$	120	per month
Accounting / Consultancy	$	500	per year	Telephone Cost	$	295	per month
Depot / Rent for vehicle	$	12,500	per year	Administation Staff	$	1,890	per month
Depot Rates / Insurance	$	1,500	per year	Office Supplies	$	240	per month
Driver Wage (click here to check)	$	278	per day	Miscellaneous	$	82	per day
Workcover/ Workers Insurance		4.70%	(of wage on top of wage)				

Superannuation 5.00% (of wage on top of wage)

(Note: The Results Calulation assumes 52 weeks of driver employment for the wages costs).

Step 7: Service / Maintenance

Vehicle Service Cost (Type A)	$	930	per service interval every	18,000	Km
Maintenance Cost (Type B)	$	1,670	per maintenance interval	20,000	Km

(Maintenance includes costs for Brakes / Differential rebuild / Injectors / Alternator / Engine rebuild / Batteries etc.)

Step 8: Tyre Wear

Steer Tyre Cost	$	774	per tyre	Drive and Trailer Tyre Cost	$	700	per tyre
Steer Tyre Quantity		2		Drive and Trailer Quantity		20	
Steer Tyre Life		100,000	Km	Drive and Trailer Tyre Life		160,000	Km

Step 9: Fuel Levy Calculation (only if a base fuel rate is used in contract agreement)

Base Rate Fuel Price (if used) $ 1.00 per Ltr

Base Rate Less Rebate per Step 1 $ 0.83500 per Ltr **Fuel Levy** 6.88 %

Using Current Fuel Price of $ 1.3 per Ltr equates to a fuel levy of 6.88% over the base rate fuel price of $ 1 per Ltr

Summary of Estimated Costs - *Click Calculate to Update Figures*

Cost Summary	Per Annum	Per Month	Per Work Day	Percentage Cost
Fuel (without fuel rebate included)				*26.89%*
Fuel	111,878.57	9,323.21	405.36	24.3%
Finance - Principle	73,415.94	6,118.00	266.00	15.9%
Finance - Interest **	30,720.54	2,560.04	111.31	6.7%
Depreciation	0.00	0.00	0.00	0.0%
Fixed Costs	96,393.74	8,032.81	349.25	20.9%
Driver	98,618.83	8,218.24	357.31	21.4%
Tyres	21,316.86	1,776.41	77.24	4.6%
Maintenance	17,284.50	1,440.38	62.63	3.8%
Service	10,695.00	891.25	38.75	2.3%
Total Cost Estimate	$ 460,323.98	38,360.33	1,667.84	100.0%

Distance Travelled	207,000	Km per year - (estimated average)
Service Intervals	12	per year (estimated average)
Maintenance Intervals	10	per year (estimated average)

*** Note: Interest amount varies from year to year. Value is the average of the finance period. (See Rule of 78).*

RESULTS - Based on Current Fuel Price in Step 1

Operating Margin 10.0%

Estimate Charge per Day $ 1,853.16 *+ GST / Tax (Based on $1.3 per Ltr, less rebate)*

Operating Cost per	*Day*	$ 1,667.84	*Est. Charge per Day*	$ 1,853.16	*Margin per Day*	$ 185.32
Estimated Cost per	*Tonne*	$ 102.13	*Est. Charge per Tonne*	$ 113.48	*Margin per Tonne*	$ 11.35
Estimated Cost per	*Km*	$ 2.22	*Est. Charge per Km*	$ 2.47	*Margin per Km*	$ 0.25

CAUTION: Margin is highly affected by cashflow. Margin shown may not be achieved for various reasons.
Seek accredited financial advice before using these figures.

Margins shown EBITA - (Earnings before Interest, Tax, Amortization)
All Figures exclude GST / Tax considerations.

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