Technical appendix to SBC heavy freight report

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MAC results

MAC estimates are on a per-vehicle, discounted net cash-flow basis assuming a WACC of 6%.

Figure 1 – Marginal abatement costs (high electricity cost)

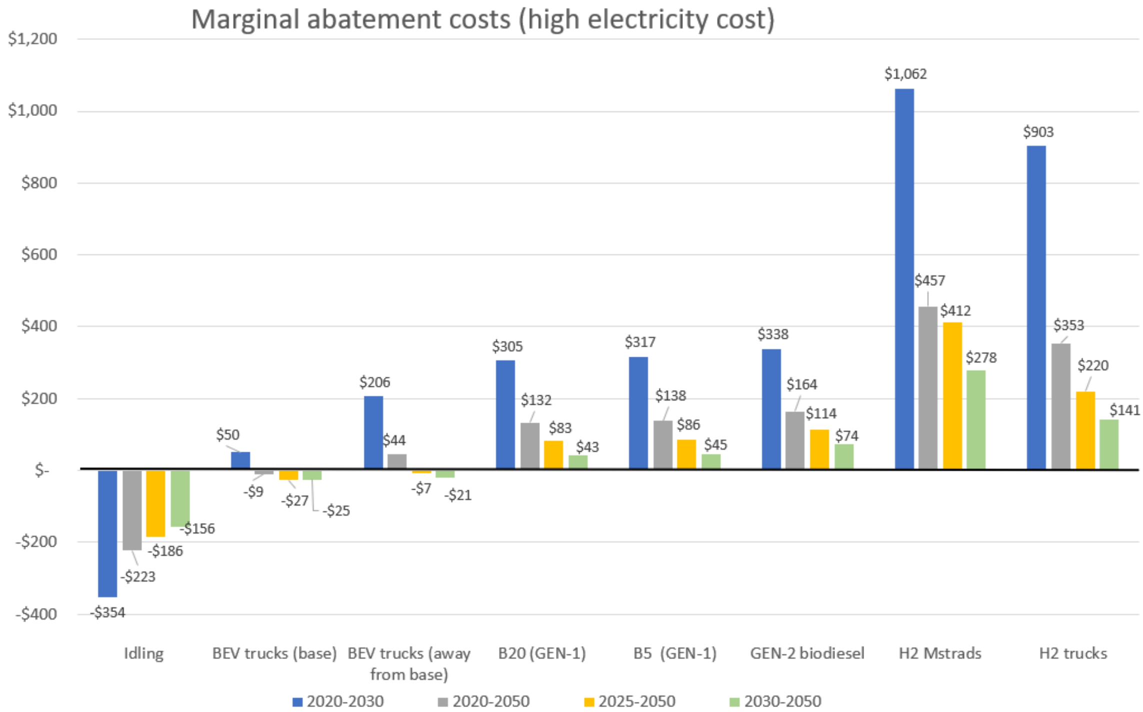
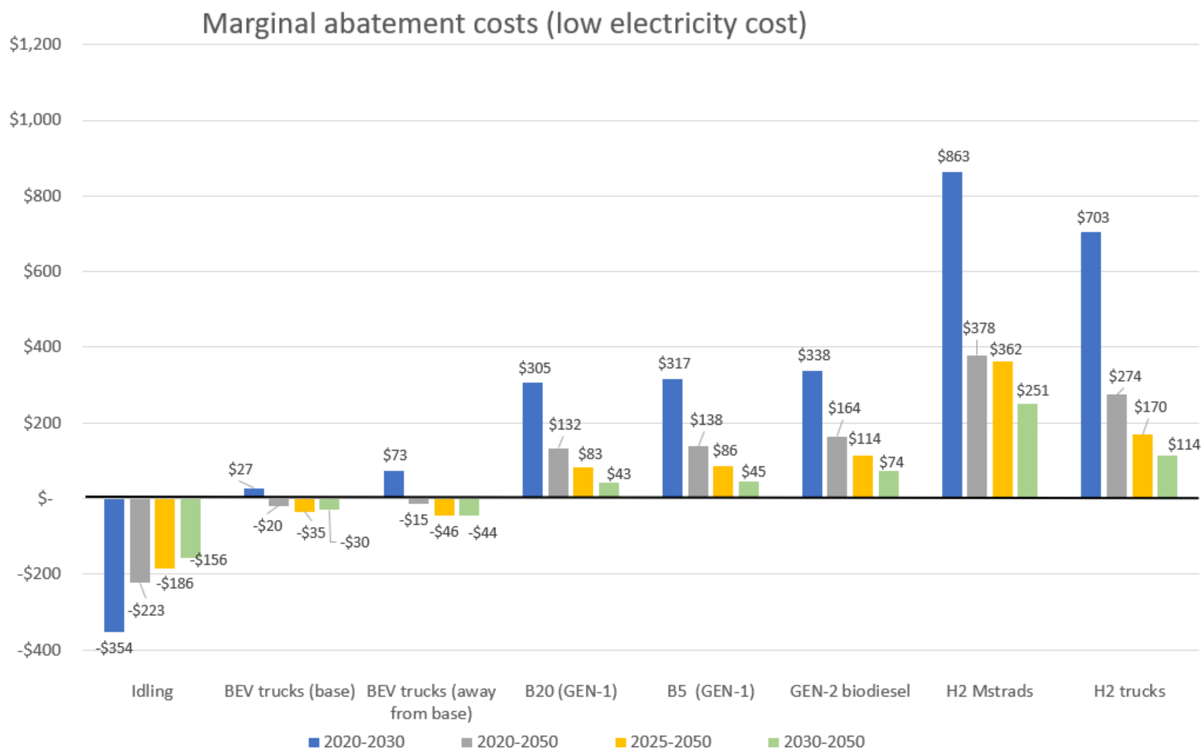


Figure 2 – Marginal abatement costs (low electricity cost)



Key findings:

Investments in BEV trucks can already deliver emissions abatement at negative costs when viewed over the longer-term horizon, notwithstanding the 9% battery weight penalty assumed by the model. In reality, this penalty would only apply to the heaviest truck fleet, and even within this fleet the limiting factor for many would be space not weight.

Over the shorter-term, the weight penalty could introduce additional costs for BEVs if the RUC exemption is removed. In this case, the MAC particularly for BEV trucks transporting heavier loads over longer distances (charging away from base) could be higher than estimated. Over the longer term, we assume that the marginal impact of RUC is negligible due to improved battery energy density.

We note that the uptake of heavier BEV trucks also largely depends on the availability of away-from-base re-fuelling infrastructure and mass production of heavy EV models. Although the latter issue is being resolved, the former will require significant investment including government support.

On the basis of the above, in our roadmap we assume that 80% of medium fleet (mostly charging at base) can be electrified by 2035, and only 5% is electrified by 2035.

Biodiesel blends can serve as an important transition fuel to reduce 2020-2035 emissions from heavy freight that is difficult to electrify (e.g. due to missing away-from-base infrastructure). We assume that the highest uptake of B5 is reached by 2035, contributing 3.3% to total gross emissions reductions by then.[1]

Due to uncertainty around future feedstock for biofuel blends, and issues around the overall land-use change impact across biomass supply chains, we do not consider generation-1 blends to be a long-term option. We think these will be replaced by advanced biofuels (GEN-2 or renewable diesel) over the long term, either imported or produced locally from biomass grown on marginal land.[2]

From 2030, cost reductions for hydrogen and renewable diesel mean they can both be included in the toolkit of options to reduce heavy freight emissions over the long term. Our MAC estimates are generalised and there will be use cases where specific costs can change the cost relatively of options, e.g. depending on how far biomass for biofuel is transport for, or how electricity is generated to produce hydrogen in a specific location. We also recognise that significant investment will be required to build the infrastructure for hydrogen refuelling. We therefore think that renewable diesel and hydrogen options need to be seen together as a package starting with 2030, whilst allowing for renewable diesel uptake to start earlier in 2025.

We should note that if drop-in diesel is produced regionally (from biomass feedstock), it could enjoy further cost reductions due to lower distribution costs compared to fossil diesel that is currently produced at a single location. MfE estimates that this reduced fuel distribution cost advantage could reduce the MAC for renewable diesel by a further $50/tCO2e over the 2020-2030 period (p.85 in (MfE, 2020)).

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[1] Gross emissions exclude resultant emissions from increased electricity generation to power BEV trucks and produce hydrogen.

[2] See (Scion, 2018).

MAC key assumptions

Note: all prices are in 2020 real dollar terms, unless otherwise stated.

Carbon prices

In 2020, we assume a carbon price of $32/tCO2e. For 2030 and 2050 we assume $55/tCO2e and $157/tCO2e respectively, based on the DD-0 scenario from (Productivity Commission, 2018).

Fuel costs

Electricity cost

Electricity cost is the sum of wholesale electricity price and network charges.

High-cost scenario

Average wholesale electricity prices. The 2020 wholesale electricity price is assumed to be $0.108/kWh, which is the average NZ wholesale price over Jan 2018-Aug 2020.

Our price forecast over the long-term reflects an average estimate that accounts for a 22% probability of a dry year (this usually occurs every 4.5 years). Based on our LCOE estimates, we determine that, on average, the lowest cost generation mix required meat peak adequacy and security of supply (dry-year problem) from 2036 is a 22% partially loaded wind and 78% geothermal, resulting in a baseload marginal price of $0.119/kWh in 2036 and $0.126/kWh in 2050. These wholesale price estimates include the carbon cost component associated with geothermal generation. Future price increase reflects increasing carbon prices.

Average network charges. In 2020, network charges constitute 40% of wholesale electricity prices, dropping to 19% in 2039. These proportions are based on (Concept, 2019),[3] with the decline reflecting improved network utilisation as a result of increased future NZ electricity demand.

Off-peak commercial electricity prices are used to estimate electricity cost for BEV trucks charging at base. The wholesale price component for off-peak cost is the average wholesale electricity price above multiplied by a factor of 0.8. This factor reflects the average ratio of off-peak/average wholesale prices based on 2015-2019 EMI data.[4]

Daytime commercial electricity prices are used to estimate electricity cost for BEV trucks recharging at stations during daytime due to longer travel distances than trucks charging at base. The wholesale price component for off-peak cost is the average wholesale electricity price above multiplied by a

[3] Table 1 in (Concept, 2019).

[4] https://www.emi.ea.govt.nz/

factor of 1.13. This factor reflects the average ratio of morning peak/average wholesale prices based on 2015-2019 EMI data.

Low-cost scenario

Wholesale electricity prices. The current wholesale electricity price is 0.075/kWh, increasing at the same rate (in real terms) as in the high-cost scenario (0.6% p.a. to 2036, and 0.4% p.a. subsequently).

Network charges. Same as in high-cost scenario.

Diesel cost

Diesel retail price, excl. GST is used to estimate the MAC for biodiesel for road transport. It is the sum of retail diesel price excluding taxes and the ETS component estimated based on a diesel emissions factor of 2.69 kgCO2e/litre. The 2020 diesel retail price excl. taxes is $1.15/litre, and is the sum of the 2020 average diesel importer cost and retail importer margin as reported by MBIE in its weekly fuel price monitoring.[5]

Diesel commercial price, excl. GST is used to estimate the MAC for straddles. Using MBIE's energy price statistics,[6] we estimate that the commercial price excl. taxes was $0.95/litre in 2019. The delivered commercial price of diesel (excl. GST) is estimated by adding an ETS component as above.

Future diesel prices (excl. taxes) are modelled assuming real price changes in line with oil price forecasts from IEA's Sustainable Development scenario in their 2018 World Energy Outlook (IEA, 2018). This scenario reflects an accelerated global energy transition and is the lower bound of future oil price forecasts. On this basis, the marginal abatement costs with regards to diesel alternatives reflect an upper bound. Specifically, the annual real changes assumed are 0% through to 2025 and -1% thereafter. Note that this is in contrast to a historical real CAGR of 1.1% for diesel importer costs over the 2004-2019 period.

Biodiesel cost

B100. In 2020, a price of $2.5/litre is assumed, based on international market analysis. The premia over retail diesel price (incl ETS, excl GST), is assumed to drop by 50% by 2035, and a further 50% by 2050. The resultant prices are $2.2/litre and $2.4/litre by 2030 and 2050 respectively.

B20. In 2020, a premium of $0.239/litre is assumed over the diesel retail price excl. GST but incl. ETS cost. This was determined based on the B100 premium, and savings in the ETS cost component of diesel price. Future premia drop to $0.151/litre and $0.034/litre in 2030 and 2050, reflecting ETS cost savings due to increasing carbon prices.

B5. In 2020, a premium of $0.06/litre is assumed over the diesel retail price excl. GST but incl. ETS cost. This was determined based the B100 premium, and savings in the ETS cost component of diesel price.

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[5] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/weekly-fuel-price-monitoring/

[6] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/

Future premia drop to $0.038/litre and $0.008/litre in 2030 and 2050, reflecting ETS cost savings due to increasing carbon prices.

Hydrogen cost

We estimated hydrogen costs for two scenarios:

- On-site production, storage and use for straddles
- Station re-fuelling for trucks.

Road transport scenario (trucks). The hydrogen cost for trucks include a station overhead charge, which essentially reflect retailing costs alongside profit margin. Based on (Concept, 2019), we assume a station overhead charge of $1.3/kg.

The hydrogen cost for trucks is the hydrogen production cost in the off-road transport scenario (see below), plus the station charge.

Off-road transport scenario (straddles). Hydrogen production cost in this scenario is the average of production costs for manual and automatic straddles. Manual straddles are less fuel efficient, i.e. they require more hydrogen p.a. than automatic straddles resulting in an increased utilisation of the hydrogen production assets, and therefore a lower hydrogen cost on a per-kg basis.[7]

Key assumptions used to estimate small-scale hydrogen production are shown in the table below.

Table 1 – Key assumptions used to estimate hydrogen production costs

	Unit	2020	2030	2050	Source
Cost of water	$/1,000 litres	$1.6	$2.0	$3.3	2019 Auckland Council estimate for non-domestic water use. Assumes 2.5% annual growth
Compressor capex	$/kW	$84	$70	$33	Previous Sapere analysis based on lit review
Electrolyser capex	$/kW	$1,338	$850	$700	(Concept, 2019), (IEA, 2019)[8]
Storage tank, 700 bar	$/kWh	$35.75	$26.36	$14.34	Previous Sapere analysis based on lit review
Compressor opex	% capex	5%	5%	5%	Previous Sapere analysis based on lit review
Electrolyser opex	% capex	3%	3%	3%	Previous Sapere analysis based on lit review

[7] This assumes that the increment in capital costs for an additional straddle is the same regardless of whether the straddle is manual or automated.

[8] Both of these studies assume a capex of $1,400/kW in 2019.

	Unit	2020	2030	2050	Source
Storage tank opex	% capex	5%	5%	5%	Previous Sapere analysis based on lit review
Electrolyser efficiency	%	70%	72.6%	75%	(Concept, 2019), (IEA, 2019)
Electricity network losses	%	4%	4%	4%	(Concept, 2019)
Compression losses	%	10%	10%	10%	(Concept, 2019)
Engineering studies / civil works	% compressor + electrolyser capex	70%	70%	70%	Previous Sapere analysis based on lit review
Station overhead	$/kg	$1.3	$1.3	$1.3	(Concept, 2019)
Network connection cost	$, one-off cost	$3m	$3m	$3m	Previous Sapere analysis based on lit review

High electricity costs

We estimate that the hydrogen delivered costs currently, in 2030 and in 2050 are $12.44/kg, $10.95/kg and $10.68/kg respectively. We note that these estimates are generally higher than those from (Concept, 2019) and (Castalia, 2020)[9], as shown in Table 2 and Figure 1. We think this is largely due to the higher electricity costs we have assumed, although there are also differences on what these hydrogen costs include. Note also Castalia assume a WACC of 8%, whereas we and Concept assume 6%.

The "Concept adjusted" estimate reflects the original estimate by (Concept, 2019), adjusted for our higher electricity costs.[10]

Note that our hydrogen production costs start to increase from 2040 reflecting an increase in electricity costs as a result of higher carbon prices that affect geothermal generation.

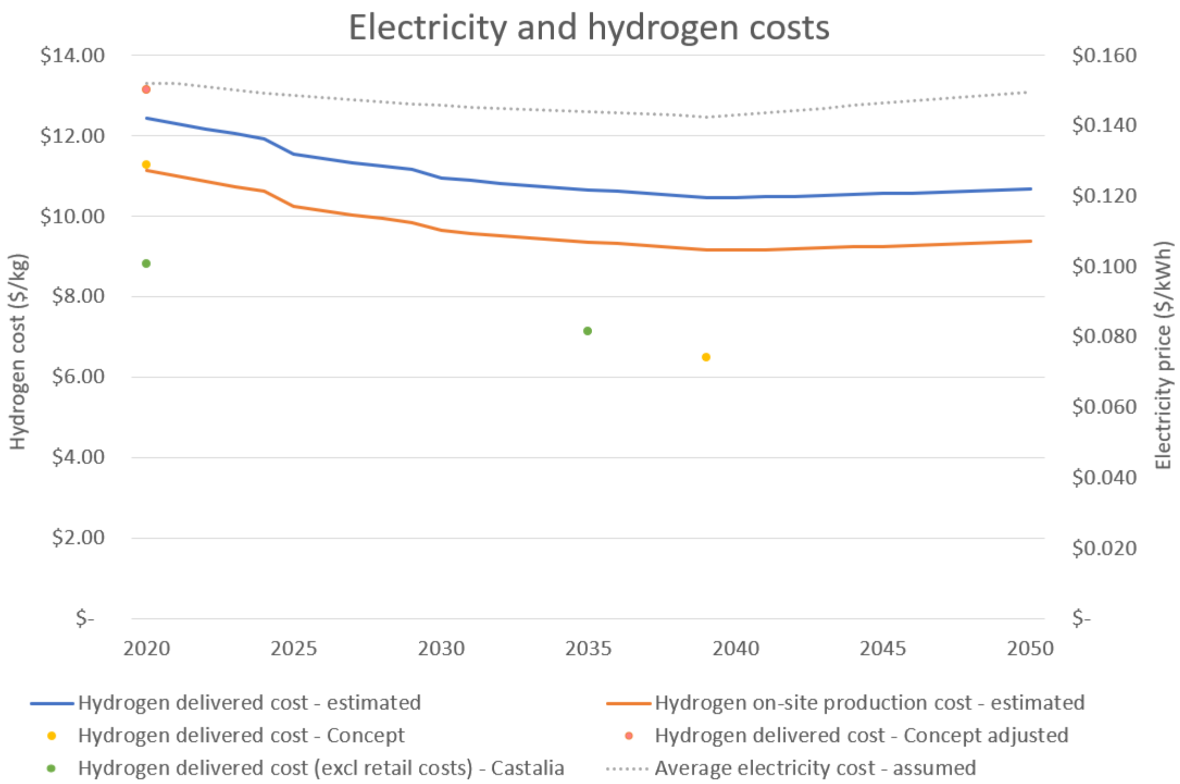
Table 2 – Summary of hydrogen cost estimates, $/kg (high electricity costs)

Estimate by	Scenario	2020	2035	2039	2050
Sapere – delivered cost	Small-scale generation, station re-fuelling	$12.44	$10.66	$10.48	$10.68
Sapere – production cost	Small-scale on-site production and use	$11.14	$9.36	$9.18	$9.37

[9] We also used 2020 estimates provided separately by Castalia in email communication on 23rd Sep 2020.
[10] Concept assume a wholesale electricity price of $0.075/kWh throughout over the entire time horizon.

Estimate by	Scenario	2020	2035	2039	2050
Concept – delivered cost	Small-scale generation, station re-fuelling	$11.30	--	$6.50	--
Concept – adjusted delivered cost	Small-scale generation, station re-fuelling	$13.16	--	--	--
Castalia – delivered cost (excl. retail charges)	Wind powered large-sale production and transport[11]	$8.82	$7.16	--	--

Figure 3 – Hydrogen cost estimates (high electricity costs)



Low electricity costs

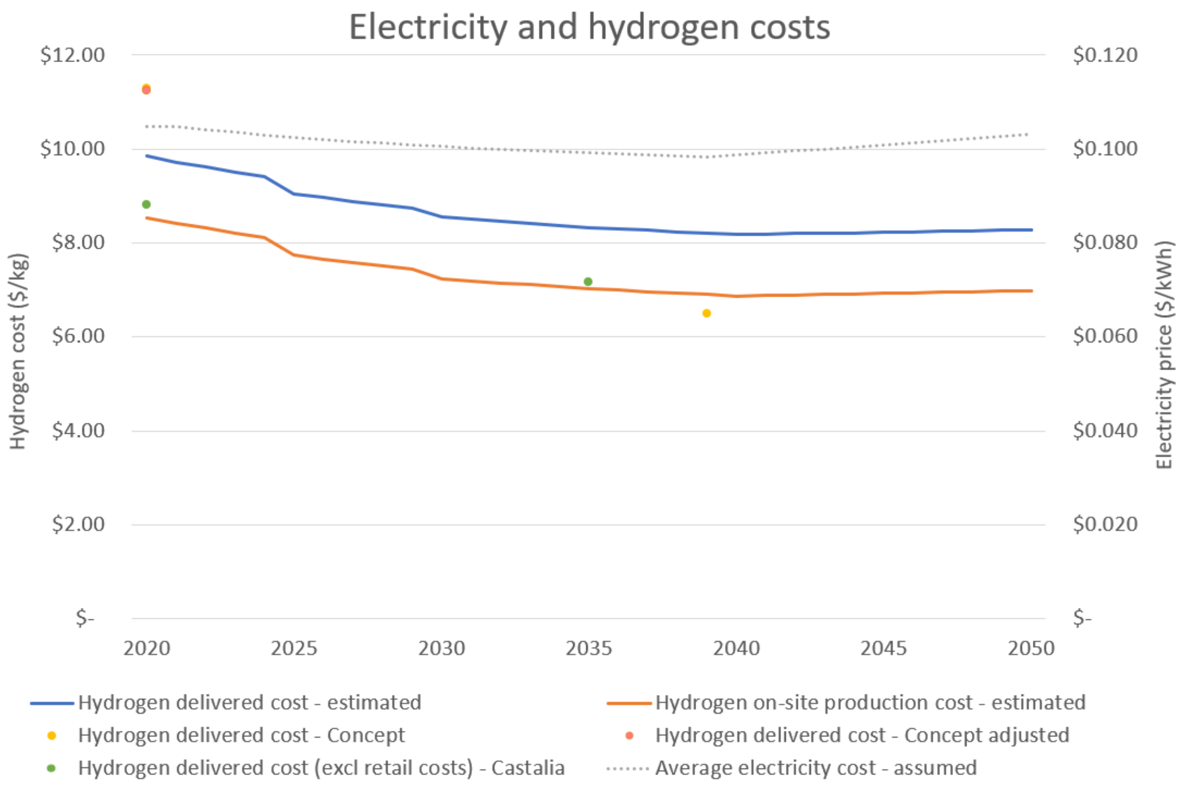
In this scenario, our estimates of hydrogen costs are more aligned with those by Castalia, and by Concept over the long-term.

[11] Captive wind powered co-located hydrogen electrolyser at largest scale + compression + trucking 200km (mid-point estimate). Does not include additional losses and energy costs from compressing to the high pressures needed for heavy vehicle refuelling at a service station - this is additional to the actual service station costs if these are based on existing diesel refuelling stations.

Table 3 - Summary of hydrogen cost estimates, $/kg (low electricity costs)

Estimate by	Scenario	2020	2035	2039	2050
Sapere – delivered cost	Small-scale generation, station re-fuelling	$9.84	$8.33	$10.48	$8.29
Sapere – production cost	Small-scale on-site production and use	$8.54	$7.03	$9.18	$6.98
Concept – delivered cost	Small-scale generation, station re-fuelling	$11.30	--	$6.50	--
Concept – adjusted delivered cost	Small-scale generation, station re-fuelling	$11.25	--	--	--
Castalia – delivered cost (excl. retail charges)	Wind powered large-sale production and transport[12]	$8.82	$7.16	--	--

Figure 4 – Hydrogen cost estimates (low electricity costs)



[12] Captive wind powered co-located hydrogen electrolyser at largest scale + compression + trucking 200km (mid-point estimate). Does not include additional losses and energy costs from compressing to the high pressures needed for heavy vehicle refuelling at a service station - this is additional to the actual service station costs if these are based on existing diesel refuelling stations.

Roading costs

Although the pump diesel price is exempt from excise duties to cover roading costs, diesel vehicles are required to purchase road user charges (RUC) to cover roading costs. Currently, battery electric vehicles are exempt from RUCs, however we expect that they will need to start contributing towards roading costs as the number of BEVs on roads increases. Hydrogen-powered vehicles are not exempt from RUCs, and it is not clear at this stage if such exemptions might be introduced in the near future.

On the basis of above, we exclude RUC from our MAC calculations. Our premise is that roading costs must be levied one way or another to maintain and improve road infrastructure. Because our MAC estimates are on a per-vehicle basis, we assume that RUCs have no impact on a marginal basis for hydrogen-powered vehicles that retain the same weight as diesel-fuelled vehicles. For battery electric vehicles, higher battery weight in the near term could imply higher RUCs per vehicle if the RUC exemption expires. This means that the MAC over 2020-2030 for BEV trucks may be higher than estimated. Over the long term, however, we expect the energy density of batteries to improve significantly (see discussion on weight penalties in the section on BEV costs) such that that the marginal impact of a RUC on BEVs to be negligible from a MAC estimation perspective.

Asset capex and opex

Diesel vehicles

Table 4 – Capex and opex assumptions for dieseltrucks

Item	Unit	2020-2035	Source
Diesel truck capex	$	$206,023	ALSCO case study[13]
Maintenance cost	% capex p.a.	4.3%	Based on ALSCO case study
Fuel consumption: short-haul	Litres/truck/pa	$14,747	Sapere analysis of short-haul freight
Fuel consumption: long-haul	Litres/truck/pa	44,241	Assumes 3 x short-haul consumption
Diesel engine efficiency	%	35%	Sapere analysis

Table 5 – Capex and opex assumptions for diesel straddles

Item	Unit	2020-2035	Source
Manual straddle capex	$	$1.5m	Sapere analysis
Maintenance cost	% capex p.a.	12%	Sapere analysis based on existing literature

[13] https://www.leadingthecharge.org.nz/alsco_leads_the_way

Battery electric vehicles

We investigate two scenarios: short-haul and long-haul freight. In the first case, we assume that the truck can charge back at base taking advantage of off-peak electricity tariffs. By contrast, long-haul transport means that trucks face daytime charges.

We also note that BEV trucks face "productivity penalties" as a result of heavier vehicle weight and longer re-fuelling times for long-haul freight. A penalty of x% means that x% more trucks would be required to deliver the same level of service. Based on (MfE, 2020) and (Concept, 2019), we assume 9% penalty for weight, and 9% penalty for re-fuelling times currently. The weight penalty falls to 3% by 2039 due to improvements in battery energy density.

Table 6 – Capex and opex assumptions for BEV trucks

Item	Unit	2020	2030	2050	Source
BEV truck (base)	$	$321,128	$269,371	$209,295	Current cost is 143% of diesel counterpart as per (Concept, 2019). This is then adjusted for a 9% weight penalty. Battery cost reduction based on previous Sapere analysis
BEV truck (away from base)	$	$347,643	$282,316	$212,567	Based on ALSCO case study, adjusted for 18% weight + recharge penalty. Battery cost reduction based on previous Sapere analysis. Current cost is 143% of diesel counterpart as per (Concept, 2019). This is then adjusted for a 18% weight penalty. Battery cost reduction based on previous Sapere analysis
Maintenance cost	% capex p.a.	3.2%	3.2%	3.2%	Sapere analysis based on relative maintenance cost of diesel trucks as per p.37 in (Concept, 2019)
Battery system efficiency	%	81%	81%	81%	Sapere analysis based on existing literature
Base re-charging infrastructure cost (short-haul)_	$/kWh	$0.022	$0.022	$0.022	Based on $/kWh component cost proportions in Fig.30 from (Concept, 2019)
Service station over-head (long-haul)	$/kWh	$0.111	$0.059	$0.033	Based on $/kWh component cost proportions in Fig.30 from (Concept, 2019)

Fuel-cell heavy vehicles

Table 7 – Capex and opex assumptions for hydrogen trucks

Item	Unit	2020	2030	2050	Source
Truck capex	$	$500,000	$347,163	$206,023	$500k in 2019 and 250k in 2039 as per (Concept, 2019)
Maintenance cost	% capex p.a.	3.2%	3.2%	3.2%	Sapere analysis based on relative maintenance cost of diesel trucks as per p.37 in (Concept, 2019)
Vehicle energy consumption	kWh p.a.	297,859	272,789	252,035	Estimated based on relative efficiency of diesel engines and fuel cells
Fuel cell and drivetrain efficiency	%	55%	60%	65%	Sapere analysis based on existing literature

We estimated the cost of hydrogen-powered straddles by subtracting the cost of a generator set from the total capex of a diesel-powered straddle, and adding the cost of on-vehicle hydrogen storage and fuel cells. We estimate that the cost of a hydrogen-powered manual straddle is $1.8m, $1.7m and $1.55m in 2020, 2030 and 2050 respectively.

The key assumptions used are in the following table.

Table 8 – Capex and opex assumptions for hydrogen straddles

Item	Unit	2020	2030	2050	Source
Power of straddle fuel cells	kW /straddle	370	370	370	Sapere analysis
H2 tank capacity	kWh	12,117	12,117	12,117	Sapere analysis
Fuel cell capex	$/kW	$84	$70	$33	Sapere analysis based on existing literature
Diesel gen set	$	$92,466	$92,466	$92,466	Sapere analysis
Maintenance cost	% capex p.a.	12%	12%	12%	Sapere analysis based on existing literature

Emission factors

Long-term power grid emissions factors are based on MBIE's estimated for the Global Low Carbon scenario in their last Energy Insight (MBIE, 2012) , and are consistent with the current NZ policy direction of significantly reducing emissions in electricity sector. Current electricity emissions are based on latest MfE estimate of 0.0977 $kgCO_2e/kWh$ (MfE, 2019).

Table 9 – Emissions factors assumed

	Unit	2020	2030	2050	Source
Grid electricity	kgCO2e/ kWh	0.0977	0.062	0.056	Based on (MfE, 2019) and (MBIE, 2012)
Diesel	kgCO2e/ litre	2.69	2.69	2.69	(MfE, 2019)
B5	kgCO2e/ litre	2.56	2.56	2.56	Estimated based on diesel EF and % blend
B20	kgCO2e/ litre	2.15	2.15	2.15	Estimated based on diesel EF and % blend
Renewable diesel	kgCO2e/ litre	0	0	0	

Idling

For idling MAC estimates, we assume fuel savings of 2.5% across the entire time horizon. This is based on (Foresight, 2019).

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