Port Electrification

Options Assessment

February 2024 Ref: GAENZ136

energy nz experts in energy & carbon

EXECUTIVE SUMMARY

In late 2023, Energy NZ was commissioned by the Energy Efficiency and Conservation Authority (EECA) to undertake a high-level desktop (remote) study of energy use, electrification/decarbonisation options and energy infrastructure requirements within the New Zealand seaport sector. Specific aims of the project were to examine:

- The current nationwide fossil fuel demand and split for major NZ seaports
- Projected increase to electricity demand from port operations electrification
- Discussion of current and future technologies and options to enable electrification of port operations
- Projected increase to electricity demand from shore power infrastructure for in-port vessels with traditional (fossil-fuelled) engine types
- Technology review and discussions with port management of anticipated future changes to vessel fuel sources and timelines for transition
- Discussion of the potential role of sustainable fuels in decarbonising parts of the sea transport sector, such as battery electric or hydrogen vessels, and general implications for these on required electrical and fuelling infrastructure

The study involved obtaining energy-use data and freight throughputs for each major New Zealand seaport, as well as undertaking interviews with key port staff to better understand the views, challenges and expectations within the industry. General research was also undertaken on options for electrification and general decarbonisation of the port and international maritime industries, in the context of their likely future potential and effects on NZ ports.

The current annual energy consumption of New Zealand's major port companies and their core (port) operations is approximately **335 GWh** per year, of which 37% is electricity and 63% is fuels (primarily diesel). This is associated with emissions of approximately **62,600 tonnes CO_2-e** per year, of which 14% is through electricity and 86% through fuels.

Energy Source	Annual Energy Use		Emissions (t.CO_2-e)
	Litres	MWh	
Electricity	N / A	123,000	8,600
Fuels	20,000,000	212,000	54,000
Sector Total		**335,000**	**62,600**

Over 40% of total fuel use at NZ ports is currently used by straddle carriers, despite these only being used at the large container-handling ports. Although these therefore represent the single largest potential for electrification in terms of emissions reductions, ports have thus far focused on more-mature technologies such as electric light vehicles and forklifts, and also some port-specific machinery such as terminal tractors and tugs in very specific instances. There is a strong drive from within port organisations to consider low-emission replacement options when existing equipment comes to end of life. However, as ports are typically capital-constrained, and viable electric options for most of this specialised machinery is just beginning to emerge, the window for this replacement is fairly long.

Provision of shore power to berthed vessels is minimal at present. The cancelled iReX ferry project would have involved substantial shore power for charging, but this would only have affected CentrePort and Port Marlborough, and the future application of such systems is currently uncertain. No major shipping is currently provided shore power within NZ, despite requests from cruise lines for this service for cruise ships.

However, a key finding of this study is that cruise ships are hypothetically the least beneficial class for shore power, due to very high power demands (MW) but relatively low total energy use (kWh) while in port. In contrast, bulk carriers have much-lower individual power demands but much-higher total energy use due to longer overall berthing time. This is a somewhat paradoxical situation, as cruise ships have by far the most occurrence of onboard (existing or via retrofit) potential for accepting shore power, whereas bulk ships have by far the least. For any scale of shore power potential, the major electrical capacities required are a substantial hurdle that may not be possible to overcome economically.

At present, options for alternative "green" fuels for the shipping industry are in their infancy. A moderate proportion of new vessels are being constructed in a "ready" state to use these at some stage, while still using standard fuel oils in the meantime. Methanol currently appears to be the preferred option by shipping lines. However, as major international shipping barely refuels in New Zealand, there appears to be little opportunity for NZ ports to influence this.

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1.0 INTRODUCTION

The future electrification of New Zealand ports represents a significant potential carbon emission reduction. This report looks closely at the ongoing efforts to electrify ports across New Zealand, focusing on things like using electricity instead of traditional fuels for ships while they're docked, and switching to electric-powered equipment within the ports themselves. Additionally, the report explores potential future fuels to replace fossil fuels.

With a total of 13 ports strategically located across the North and South Islands of New Zealand, each port plays a unique role in facilitating the movement of goods, passengers, and resources.

In this report, Energy NZ explores the changes underway, the challenges faced, and the remaining opportunities. The ports included in this study include:

- Northport (Whangarei)
- Port of Auckland
- Port of Tauranga
- Eastland Port (Gisborne)
- Port Taranaki (New Plymouth)
- Napier Port
- CentrePort (Wellington Harbour)
- Port Nelson
- Port Marlborough (Picton Harbour)
- Lyttelton Port Company
- PrimePort (Timaru)
- Port Otago (Dunedin)
- South Port (Bluff)

The scope of this study is limited to major seaports and excludes third-party operations, marinas, ferry terminals, harbours/wharves not associated with major ports, and miscellaneous transport facilities such as offshore buoys and specialised industrial load/offload facilities including Chelsea Wharf (bulk raw sugar offload), Taharoa Buoy (offshore transfer of ironsand slurry), and Portland Wharf (cement transfer and loading).

External organisations based on-port are responsible for some aspects of maritime operations, but are excluded from the scope of this report:

- At Port Marlborough, there is limited publicly available information on fishing fleets' fuel usage as it belongs to other organisations.
- Many ports have log operations that are not under their direct ownership.

This study also does not focus on shore-power use that is already present or can be implemented under business-as-usual conditions due to its small scale, such as shore-powering ports’ own marine vessels (namely tugs) or small client vessels. Furthermore, shore-power and charging projects for ferries, such as the cancelled iReX and planned Bluebridge connections, are also not examined in any detail as they have already been the focus of specific studies.

Table 1 provides a comprehensive overview of various ships calling at the ports, including container vessels, bulk carriers, and cruise ships. It details the frequency of their calls, annual throughput, or number of passengers transferred, as well as the average period of berth time required for shore-to-ship operations. Furthermore, the table enumerates the number of key equipment present in each port, which serves as a foundational resource for evaluating the current state of port operations and identifying areas for potential electrification and efficiency enhancements.

The data presented in this table was sourced from the 2022 Deloitte *Ports* report, annual reports released by each port and direct communication with port authorities. Estimates, indicated in red, are provided for equipment where reliable data is unavailable.

The data provided in the following table is publicly available. The discussions with port authorities only confirmed some of the figures.

	Tauranga	Auckland*	Lyttelton	Taranaki	Napier	Northport	CentrePort	South Port	Eastland	Otago	Nelson	Timaru	Marlborough
Container Ships													
Container Ship Calls	607	514	324	0	242	31	155	46	0	126	132	98	0
Annual Throughput (TEU)	1,200,800	818,200	438,300	0	276,000	13,500	95,753	53,800	0	175,000	105,400	93,900	0
Average Berth Time (h/visit)	19	40	36	0	23	14	18	22	0	25	25	34	0
Bulk Ships													
Bulk Ship Calls	687	330	515	265	343	257	303	285	124	277	649	342	48
Annual Throughput (M tonnes)	12	7	4	5	4	4	3	3	3	2	2	2	0.8
Average Berth Time (h/visit)	75	49	20	51	63	57	49	61	48	30	46	70	55
Cruise Ships													
Cruise Ship Calls	110	110	79	7	64	40	89	32	18	101	7	14	47
Annual Passengers	Unknown	258,444	120,000	Unknown	Unknown	Unknown	137,136	Unknown	Unknown	149,000	2,500	Unknown	Unknown
Average Berth Time (h/visit)	10	15	10	10	8	10	11	23	10	11	10	12	11
In-port Equipment													
Quay Cranes	9	8	4	0	0	0	0	0	0	2	0	0	0
Mobile Cranes	0	0	0	2	6	2	0	2	0	0	4	3	0
Forklifts/Stackers**	0	14	19	2	38	5	20	19	0	11	38	14	0
Straddles	53	62	25	0	0	0	0	0	0	16	0	0	0
Tugs	3	3	2	3	3	4	2	2	0	6	3	2	2
Pilot Launches	2	2	1	2	1	1	2	1	0	6	1	1	1
Light Vehicles	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	20	Unknown	Unknown	33	Unknown	Unknown
Heavy Vehicles	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	1	Unknown	Unknown	16	Unknown	Unknown
Reefer Slots	3,426	945	996	192	1,123	120	Unknown	300	0	1,850	900	650	0

Table 1: Overview of Ship Calls, Throughput, Berth Time, and Key Equipment in New Zealand Ports

* Information provided for Auckland port belongs to 2017. Auckland Port has already replaced a tugboat with a battery electric model.
** Empty container handlers (ECH) and full container handlers (FCH) are assumed to fall under the category of forklifts/stackers.

2.0 EXISTING ENERGY USE AND EMISSIONS

The current total annual energy use of the New Zealand seaport sector is approximately **335 GWh**, having associated CO_2 emissions of approximately **62,600 tonnes**. Of this, 37% of energy use and 14% of emissions are associated with electricity, and the majority 63% of energy use and 86% of emissions are from liquid fuels.

These sector totals are shown in Table 2. Fuels are aggregated for the purposes of this report. The vast majority of fuel use by port operations is diesel, with some small amount of fuel oils used by tugs, petrol by certain light vehicles and pilot launches, and very small (negligible) amounts of LPG by certain forklifts.

Energy Source	Energy Use		Emissions (t.CO_2-e)
	Litres	MWh	
Electricity	N / A	123,000	8,600
Fuels	20,000,000	212,000	54,000
Sector Total		**335,000**	**62,600**

Table 2: Seaport Sector Total Energy and Emissions

It is important to note that these figures are only those associated with port operations, at the main port site and directly by the port company. They do not include other offsite facilities such as depots and freight hubs, nor do they include the energy usage of third-party contractors, operators and tenants at the main port site.

2.1 Energy Use by North/South Island

North Island ports account for 69% of total sector fuel use and 64% of electricity use, as shown in Table 3. In total, they account for approximately 74% of all national container movements and 58% of all bulk shipment.

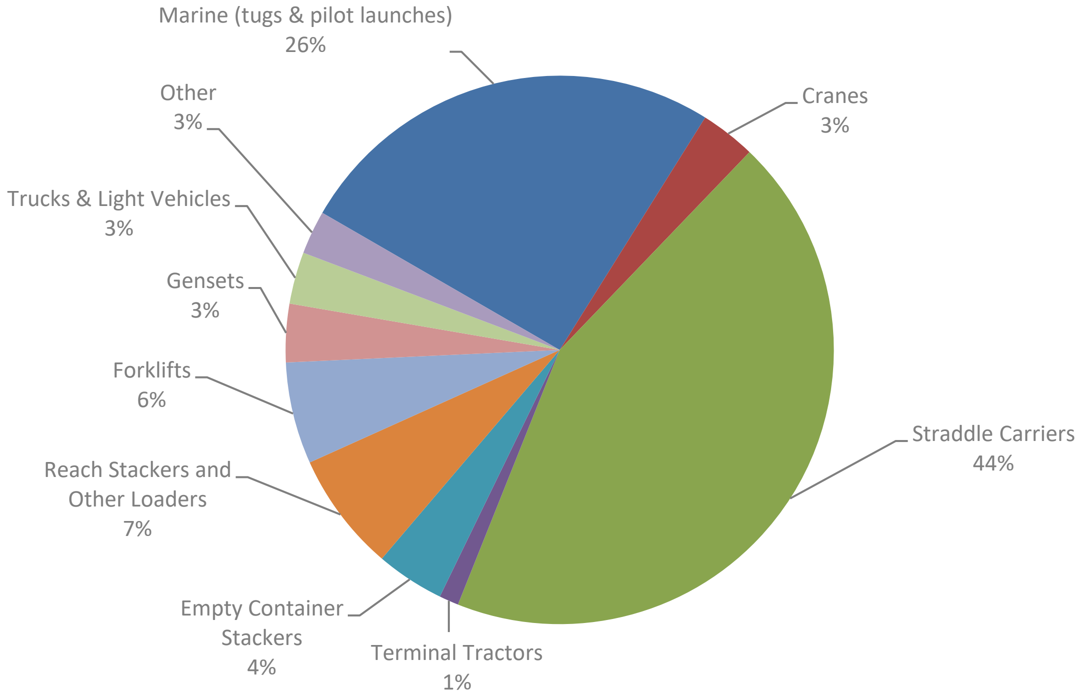
Island	Energy Source	Energy Use		Emissions (t.CO_2-e)
		Litres	MWh	
North	Electricity	N / A	79,000	5,500
	Fuels	13,700,000	145,220	37,000
	North Island Total		**224,220**	**42,500**
South	Electricity	N / A	44,000	3,100
	Fuels	6,300,000	66,780	17,000
	South Island Total		**110,780**	**20,100**

Table 3: Energy and Emissions by Region

2.2 Fuel Use by End User

An indicative breakdown of the sector's fuel use by equipment type is given in Graph 1. Nine of the country's 13 significant seaports provided adequate fuel-use information to contribute to this breakdown. It therefore does not cover all ports; however, those nine ports account for 90% of the total sector fuel use, so this chart is a strong indication of the overall breakdown.

Indicative Sector Fuel Breakdown by End User



Graph 1: Indicative Sector Fuel Breakdown by End User

Key notes to consider when interpreting this breakdown include:

- Despite making up 44% of the total fuel use, straddle carriers are only used in container-handling operations, and only at four of the included nine ports. At the individual ports where they are used, they account for 43% – 69% of total fuel use.
- Cranes are typically electric when used in a static, non-mobile role. As electricity use is not included in this graph, the actual energy use of cranes is a higher proportion of the total. However, the proportion shown in this graph still represents the fuel used by non-electric cranes.
- Marine fuel use is aggregated in this graph, as only some ports have provided a breakdown of it between tugs and pilot launches. Where the breakdown has been provided, the proportion of marine fuel use that is associated with pilot launches ranges from 10% to 33%, averaging 21%. The remaining majority is for tugs.
- Fuel breakdowns of individual ports will vary widely, depending on the nature of the operation and the equipment used to perform it. For example, the three regional ports that do not have container operations (Taranaki, Eastland and Marlborough) have no need for straddle carriers, stackers and other container-handling equipment. Furthermore, not all container ports use straddle carriers to handle containers.

3.0 ELECTRICAL CAPACITY

Ports are not generally major electricity users except where there is significant refrigerated storage onsite, such as reefers (refrigerated containers) or third-party cold stores, so charging of electric vehicles and especially provision of shore power to berthed vessels would represent a major increase in demand.

Of the port operators interviewed during this study, all had discussed capacity availability to some extent with their local electricity network company. Most had little or no spare capacity in the existing connections, or otherwise had the existing spare capacity already earmarked for other projects.

3.1 Seasonal Variation

In instances where significant numbers of reefers are handled in container ports, there is typically a fluctuation in load due to both seasonal ambient temperature variation and changes in the number of reefers present. This is often due to exports of agricultural produce, where these products have a harvest season and are often delivered to port without already being chilled to storage temperature, forcing the reefer to work at high load until this initial chilling is complete. Shipping disruptions or other factors can also result in abnormally large numbers of reefers to be present at a port.

As reefers must remain chilled, and therefore must be powered, it is common practice to use diesel generators during surge periods. The need for these is due to a limited number of grid-powered reefer slots, limited onsite electrical infrastructure, limited total supply capacity to the site, or a combination of these.

Aside from the current need for diesel generators, these seasonal variations in electrical load result in variations in spare capacity. For instance, a port at maximum capacity during times of highest reefer load, may have some substantial amount of spare electrical capacity during other times. However, this seasonality makes the capacity of little/no value for vehicle charging, which requires year-round availability, and the amounts of capacity involved are very small compared to the power requirements of even one berthed vessel. Furthermore, this spare capacity will typically not be where it would be needed — in terms of onsite infrastructure — to be useful for other purposes, so essentially only relates to the total available supply capacity to the site.

For these reasons, most instances of mobile equipment electrification or shore-power projects will need to have new capacity installed, dedicated to those new purposes.

3.2 Battery Storage & Scheduling

Battery storage and scheduling of charging are key characteristics that will affect the added load that electric vehicles or electric heavy equipment place on the electricity network and infrastructure.

Scheduling of charging to off-peak times (where possible), or at least to avoid large numbers of vehicles fast-charging simultaneously, is an obvious method of reducing maximum demands. However, this is not usually compatible with port operations, where vehicles are often “hot-seated”, giving them a continuous requirement for availability and minimal opportunity for recharging during operating hours.

An alternative arrangement is to use swappable batteries, where a vehicle can rapidly trade a depleted battery for a fully charged one. The depleted battery can then be recharged at a slower rate, potentially being scheduled to off-peak times. This does necessitate the purchase of additional batteries, represents a minor operational hurdle in the swap process and introduces the risk of battery damage during transfer, but offers significant improvements in operational and charging flexibility. Such systems are already in place for some vehicles, such as the electric terminal tractors at CentrePort, and are already standard for small forklifts at many industrial sites in NZ.

A further alternative to the substantial peak loading caused by simultaneous fast-charging is use of a large-scale stationary battery system for vehicle recharging. As long as the onsite infrastructure is sized to handle the stationary battery recharging loads, the battery system can rapidly discharge to charge the electric vehicles without placing this peak load on the local network. As the stationary battery can then be recharged from the network at a relatively leisurely pace, the additional peak demands and therefore capacity requirements of the port can be reduced significantly, greatly reducing the cost of new infrastructure. These cost reductions need to be weighed against the cost of the battery system to determine whether such an approach is viable, and the best size/capacity of stationary battery.

An additional potential use of a fixed battery system is in supplying shore power to berthed vessels. This can offset some of the intermittent high load on the network caused by supplying shore power, but would in these instances require a much larger utility-scale battery system (50+ MWh) to be able to supply such large loads for many hours. An option of this type was investigated by Port Marlborough in order to supply the new hybrid ferries under the now-cancelled iReX project, as their power demand while in port was higher than the Picton area substation would be able to supply. Use of the battery system would have allowed the ferries to be recharged with much less cost of infrastructure upgrade, and would also have potentially allowed some cruise ships to be supplied from it as well.

3.3 Availability of Network Capacity

The requirement for added electrical capacity for recharging electric light vehicles and smaller forklifts is relatively modest, so long as basic load-management practices like avoiding excessive simultaneous fast-charging are followed — which may or may not be compatible with port operational requirements. This puts these types of upgrade well within the scope of typical network capacity upgrades, and in many cases will not require significant works to the electricity grid to enable them.

The scenario for electrification of all/most of the larger mobile equipment at each port — straddles, larger forklifts, container handlers, stackers, tugs and pilot launches — will almost certainly need substantial new electrical capacity to handle recharging loads. The scope of upgrade could be minimised by use of a stationary battery, but will likely still be required.

Supply of shore power to large ships is a much larger load, some 2x – 20x the existing site electrical capacity, particularly when considering cruise ships and/or multiple vessels simultaneously. Cruise ships are generally very modern vessels, with most new builds having inbuilt capability to accept shore power. In order to maximise sustainability metrics, cruise lines have been increasingly interested in taking shore power whenever possible, and consequently have been enquiring with New Zealand ports about this option. These have led to ports enquiring with local electricity network companies about the availability and costs of obtaining the electrical capacity to be able to supply this.

Feedback from port operators has indicated that these enquiries usually stall when indications of capital cost have been received. Costs quoted for this part of the infrastructure have typically been in the multiple tens of millions of dollars to be able to supply a single cruise ship, as the large size of the load requires substantial network upgrades, often all the way back to the Grid Exit Point and transmission system.

In addition to the cost, this scale of upgrade often has multi-year lead times. Extensive forward planning is therefore required in order to enable this scale of shore-power provision. Beyond this, it is difficult to generalise on the availability and cost of significant added capacity to New Zealand's port sector. Each port connects to a different electricity network, each with its own particular local and regional load dynamics, infrastructure planning, and capacity constraints. Consequently, capacity upgrades need to be a key focus of any site-specific studies to balance each port's capital and operational constraints against the added value from additional capacity in each instance.

More details on Shore Power are outlined in the following section.

4.0 SHORE POWER

In the context of electrifying New Zealand ports, one crucial aspect is the implementation of shore-power solutions, also referred to as shore-to-ship or "cold ironing”.

Shore power systems enable vessels to connect to on-shore electrical grids while berthed, reducing or eliminating the need to run onboard generators, thereby significantly reducing emissions and noise pollution. By providing vessels with access to renewable electricity while at berth, shore-power initiatives contribute to the reduction of global greenhouse gas emissions and support the transition towards a more sustainable maritime industry.

Importantly, shore power requires both wharf-side infrastructure (i.e. the port) and onboard power conversion equipment (the ship owner’s property). Discussions with ports indicate that an industry-wide effort would be needed, with some financial aspects unclear at this early stage, to ensure vessels had capability for shore power. Many vessels that visit NZ will berth at multiple NZ ports.

As part of the electrification power demand analysis for New Zealand ports, ships are categorised into three main types as per port data on vessel visits: cruise ships, container ships, and bulk carriers. Each category presents unique challenges and opportunities in terms of electrification. More details on each type of ship are found in the following sections.

Cruise ships, characterised by their varying power demands due to fluctuating passenger loads and onboard amenities, require flexible and scalable shore power infrastructure to accommodate their needs efficiently. These vessels may require up to 20 MVA of shore power, based on their length, making them the largest consumers of electricity among all other ship types.

Container ships, on the other hand, often have high power requirements for refrigeration units and cargo handling equipment, necessitating robust shore power supply systems capable of delivering high voltage and ample capacity.

Bulk carriers, including log carriers and Roll on/Roll off (RoRo)/vehicle vessels, primarily transport raw materials such as coal, minerals, grain, and logs, as well as oil products. They may have more predictable power demands but still require specific electrification solutions to optimise efficiency and minimise environmental impact.

By understanding the specific power demands of each ship category, New Zealand ports can strategically plan and deploy electrification infrastructure to maximise effectiveness and sustainability across the maritime sector while balancing the necessity of economic viability.

Figure 1 shows different broad types of vessels considered in this study.

Different Type of Vessels

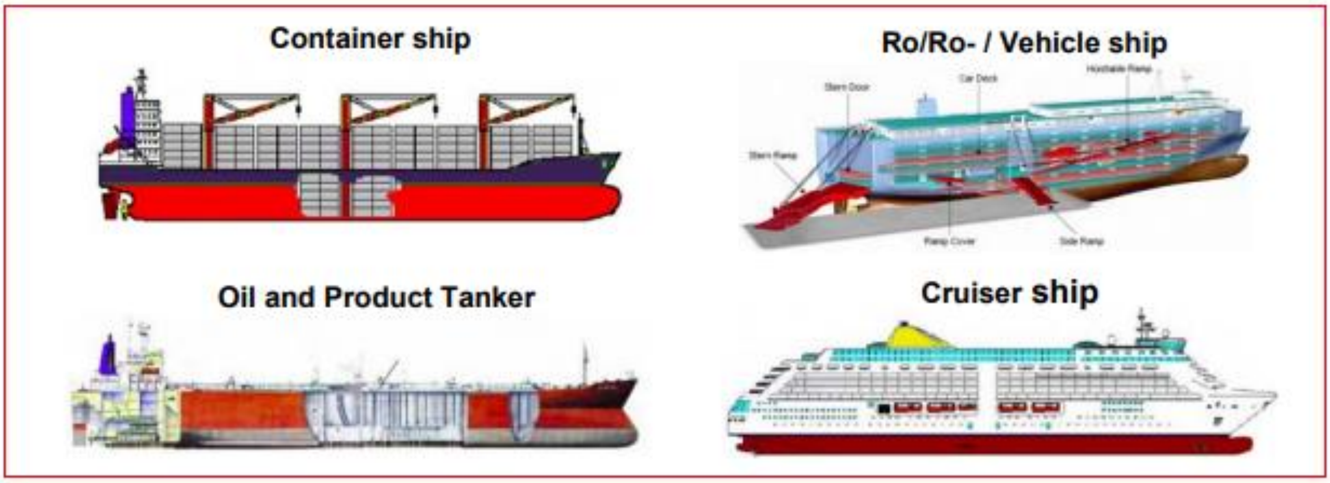


Figure 1: Different Type of Vessels

4.1 Why Shore Power?

Ships need to maintain power to their onboard systems when at berth. These include air conditioning, pumps, compressors, loading equipment, heating/cooling systems, cargo (reefers), etc. For cruise ships, this also includes all the onboard services like laundry, kitchens, pools, lighting, etc.

It appears that most vessels globally, and almost all in New Zealand, simply run their onboard auxiliary generators to provide electrical power when at berth. This consumes fuel, and produces noise, carbon emissions and local particulate emissions. The emissions of shipping/cruise lines is gradually coming under greater scrutiny, for example by the IMO, and shore power is one way to (incrementally) reduce the use of fuel in shipping.

Shore power, where used, is often charged to the shipping line to reflect the electrical energy consumed. However, due to the relatively low cost of marine fuels, and the relatively high cost to bring electricity to wharves — providing a high load for short durations — there is not typically an economic incentive for shipping lines to plug in. It appears that shore power uptake is largely driven by regulations, and to a lesser extent by emissions reduction targets.

4.1.1 Regulatory Factors

There is a split incentive for shore power. The port is likely to be the main investor in infrastructure upgrades, but it is the public that benefits from reduced emissions, reduced noise and improved local air quality. The shipping lines have historically been outside of any carbon emissions targets, although the ship’s fuel use was attributed to the shipping line and not the port. In effect, the port would have to invest to reduce another company’s emissions, and may not be able to recoup its investment. Regulations can help to address this split incentive.

Some jurisdictions have made progress towards requiring shore power connections for vessels at berth. However, this is a difficult endeavour due to a range of vessel designs, electrical system voltages/frequencies, and power draws. It appears that this is most commonly phased in over 10+ years, to allow shipping lines time to retrofit/replace older vessels to ensure compliance with shore power requirements. The State of California is one example of progress in this area, requiring half of container vessels to use shore power. Also, the European Union has adopted regulations which require ports to provide shore power connections at (most) wharves by 2030.

Noise is also a factor at most ports, with those close to residential areas having council noise limits for their operations. Shore power can help reduce the noise of port operations by avoiding most of the vessel auxiliary generator run time when at berth. Again, this has the split incentive of the port benefiting (but not financially) from the uptake of shore power by shipping lines.

4.1.2 Economic Factors

As a very rough indication of the general economics, with marine fuel (fuel oil, or VLSFO) currently around $1,050 per tonne, and energy content of 41 MJ/kg, this gives a fuel energy price of $0.092 per kWh. Running a vessel’s auxiliary generators for onboard electricity, at a typical efficiency of 40%, gives an electricity cost of $0.23 per kWh. This is not too far different from the delivered cost of electricity to most ports already, even without allowing to recoup the costs of shore power infrastructure investment.

Electrical energy from the New Zealand grid is somewhat cheaper than electricity generated from fuel aboard a ship, even in the present system where carbon costs are not applied to ships’ fuels. However, the intermittent, short-stay nature of vessel visits (especially seasonal cruise ships) means that any infrastructure capacity installed solely to provide these vessels with shore power will have very low rates of utilisation. This low utilisation would result in fixed costs making up the majority of total electricity charges, resulting in gross pricing that is higher than the cost of electricity generated onboard. As the ports would need to on-charge the cost of energy to the cruise line, this would result in a net cost increase to shipping operators or cruise lines.

Aside from this price disincentive, the large costs of the initial infrastructure would also need to be recovered for the project to be economically viable, resulting in even higher prices that need to be on-charged to the shipping operators or cruise lines .

Much higher rates of capacity utilisation, namely by providing shore power to other classes of ship that have longer, more-frequent and non-seasonal rates of berthing like bulk carriers and container vessels, would change the economic situation significantly. Although there would still be significant infrastructure costs upfront, the larger quantity of energy delivered per unit of capacity would substantially reduce the gross electricity price by reducing the impact of fixed charges on each unit of energy delivered. For this same reason, recovering the initial capital costs of the infrastructure would be easier by spreading it across a larger amount of energy delivered. Maximising the utilisation of shore-power infrastructure will therefore be key if it is to be economically viable, which means that cruise ships alone cannot justify it.

4.2 Cruise Ships

For cruise ship shore power at New Zealand ports, accommodating the high power demands of these vessels presents a multifaceted challenge. Cruise ships, renowned for their luxurious amenities and varying passenger capacities, require a very high capacity shore power connection to meet their electrical loads.

As cruise ships are generally modern vessels, and the vast majority of new builds have inbuilt power conversion systems for shore power, cruise ships appear to be currently the most capable class of vessel for accepting shore power, if it is available.

With average power demands on the order of 4 – 10 MVA, up to a peak of 20 MVA for large vessels, cruise ships present the most substantial individual power demand and capacity requirement among all ship types. In contrast, their seasonal summer-weighted nature, relative infrequency and short length of stay mean that their actual electrical energy needs while in port are the lowest of any of the three ship categories studied.

In spite of this, cruise lines have initiated discussions regarding shore power at NZ ports, as a means to reduce emissions and contribute to sustainability targets. As a group, cruise lines appear to be the vessel type most interested in shore power.

Average and peak electricity demand, frequency, and voltage requirements for cruise ships of varying lengths are summarised in Table 4.

Vessel Type	Average Power (MVA)	Peak Power (MVA)	Frequency (Hz)	Nominal Voltage (kV)
Cruise Ships < 200 m	4.1	7.3	50 or 60	6.6 and/or 11
Cruise Ships > 200 m & < 300 m	7.5	11	50 or 60	6.6 and/or 11
Cruise Ships > 300 m	10	20	50 or 60	6.6 and/or 11

Table 4: Average and Peak Electricity Demand, Frequency, and Voltage Requirements for Cruise Ships of Varying Lengths

4.3 Container Ships

Container ships, pivotal in global trade, often possess substantial power demands attributed to onboard equipment and refrigeration for cargo.

Feedback from New Zealand ports has indicated that container-line operators are the second-most interested in shore power, although as a general comment the container vessel 'fleet' are less capable of accepting shore power compared to cruise lines. However, they are a more practical class for provision of shore power to due to lower individual vessel loads, more regular (and, critically, non-seasonal) visits, and for longer berthing durations. Retrofits appear to be a relatively simple exercise for this class due to the availability of shore power equipment in containerised format.

Average and peak electricity demand, frequency, and voltage requirements for container ships of varying lengths are summarised in Table 5.

Vessel Type	Average Power (MVA)	Peak Power (MVA)	Frequency (Hz)	Nominal Voltage (kV)
Container Ships < 140 m	0.2	1.0	50 or 60	6.6
Container Ships > 140 m	1.2	8.0	50 or 60	6.6

Table 5: Average and Peak Electricity Demand, Frequency, and Voltage Requirements for Container Ships of Varying Lengths

4.4 Bulk Ships

In the context of this analysis, 'bulk ships' refer to vessels primarily designed for the transportation of large quantities of unpackaged cargo, typically in the form of raw materials such as coal, minerals, grain, logs, and oil products. This category encompasses a diverse range of vessel types, including log carriers, RoRo/vehicle vessels, and ships dedicated to carrying oil products.

Due to the nature of their cargo and operational requirements, bulk ships may have lower and more predictable power demands compared to other vessel types but still require specialised electrification solutions to ensure optimal efficiency and environmental sustainability.

Discussions with New Zealand ports have indicated that bulk vessels are likely to be the last class of ship to have either the interest or capability for shore power. The fleet is generally old, often in poorer repair, and unlikely to be the focus of retrofit investment that has benefits only in perceived sustainability or longer-term economics. It appears to be an industry driven more directly by profit margin. However, the analysis in this report identifies that if these types of vessels could all use shore power, this would provide the largest impact in terms of offsetting international vessel fuel use and hence carbon emissions at NZ ports, although their existing fuel use at berth is not currently counted by any NZ emissions inventory.

Average and peak electricity demand, frequency, and voltage requirements for bulk ships of varying lengths are summarised in Table 6.

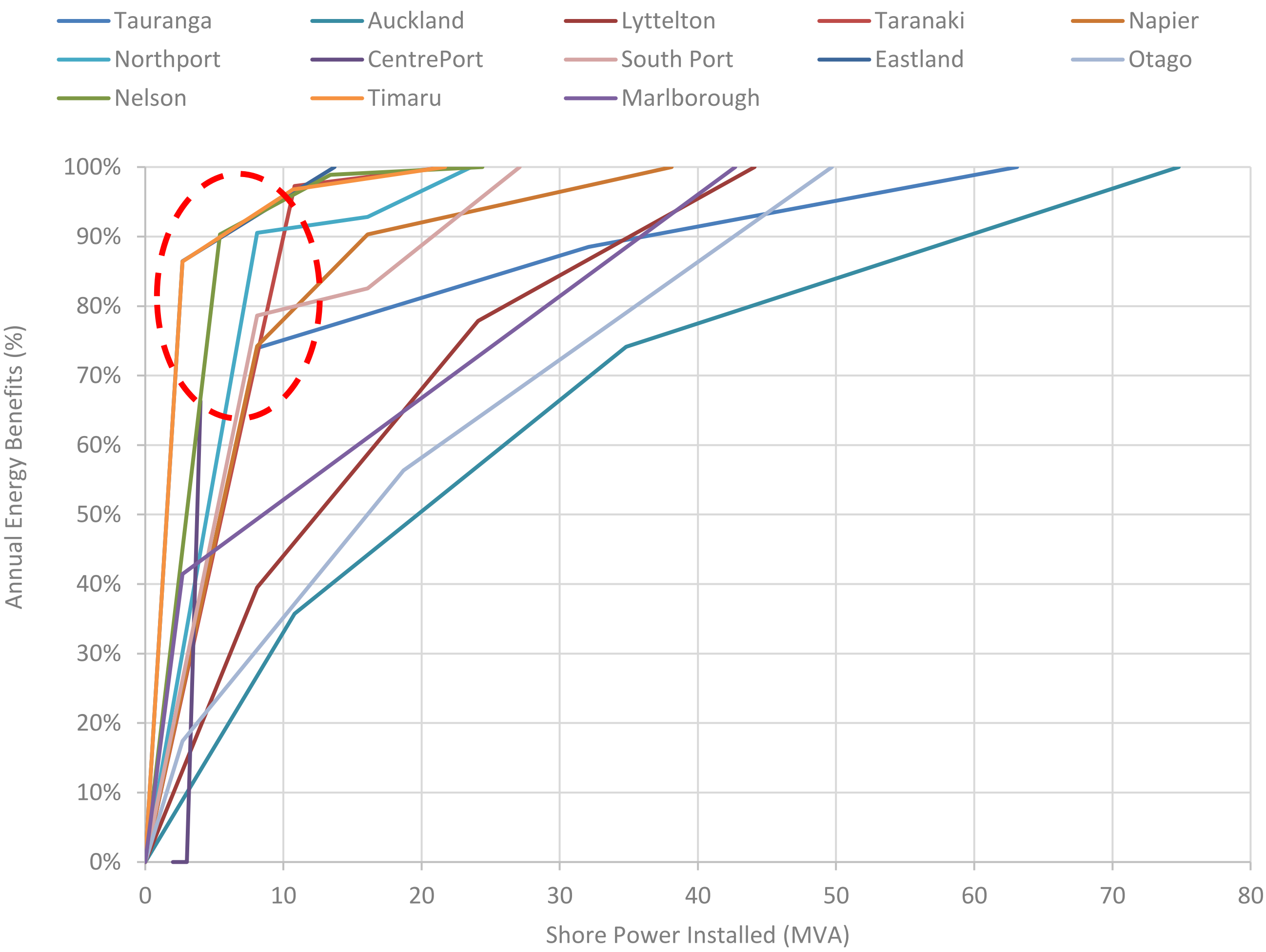
Vessel Type	Average Power (MVA)	Peak Power (MVA)	Frequency (Hz)	Nominal Voltage (kV)
Bulk Ships	1.5	2.7	50 or 60	Varies

Table 6: Average and Peak Electricity Demand, Frequency, and Voltage Requirements for Bulk Ships of Varying Lengths

4.5 NZ Ports Shore Power Demand Analysis

The analysis shows that for most ports, in the hypothetical situation where all vessels can take shore power at all wharves, most of the benefit can be achieved for a small fraction of the installed capacity, as depicted in Graph 2. This is mostly related to the fact that bulk vessels provide the biggest benefit (the most shore power energy delivered) for the smallest incremental capacity requirement, while cruise ships require the most capacity but provide only a very small amount of benefit (shore power energy delivered).

Hypothetical Shore Power Energy vs. Capacity Comparison at New Zealand Ports



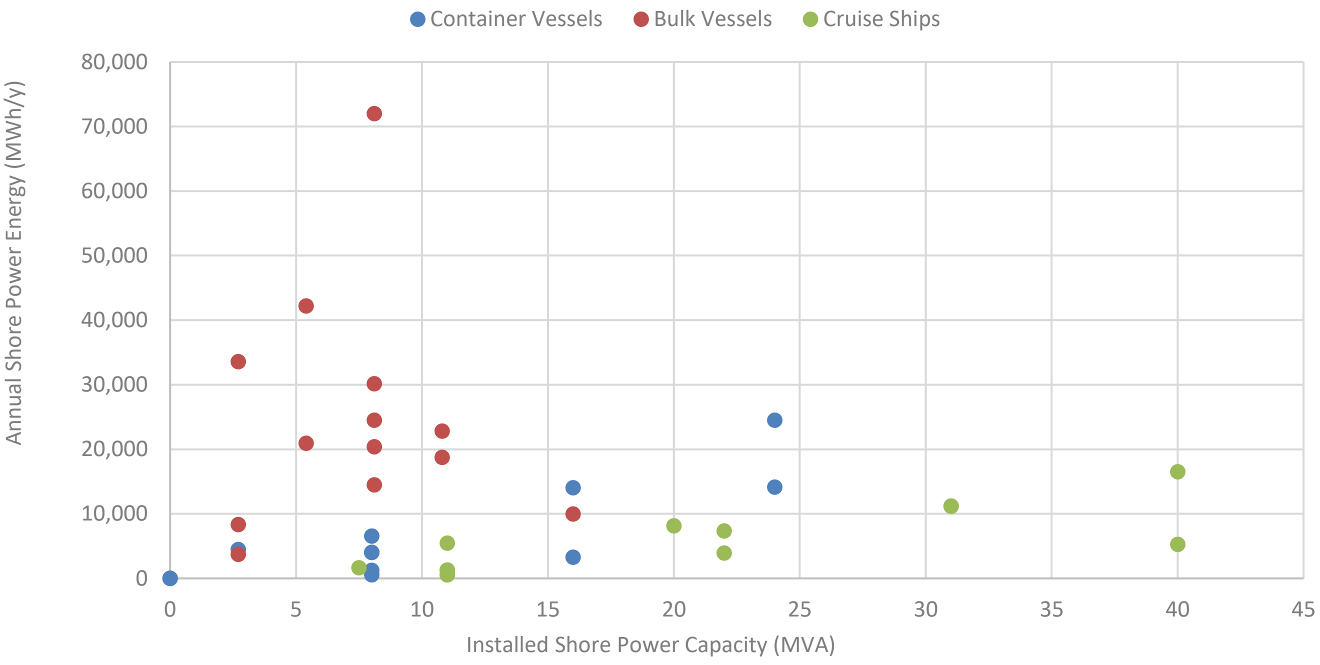
Graph 2: Hypothetical Shore Power Energy vs. Capacity Comparison at New Zealand Portss

Discussions with ports and with equipment provider Cavotec indicate that different types of vessels (broadly bulk, container and cruise) will likely have different levels of motivation to comply with shore power if not made mandatory.

Graph 3 illustrates the relative annual shore power energy (potential) at each port, grouped by each type of vessel. The installed shore power capacity reflects the hypothetical need to supply shore power to multiple vessels of the same type, if berthed simultaneously at one port.

It is clear that for all ports, bulk vessels have the greatest potential for energy and emission savings from shore power, and also the lowest power requirements compared to container and cruise ships. It is also obvious that cruise ships have the highest capacity requirements and the lowest potential energy delivery.

Shore Power Energy Potential and Capacity Required, by Port



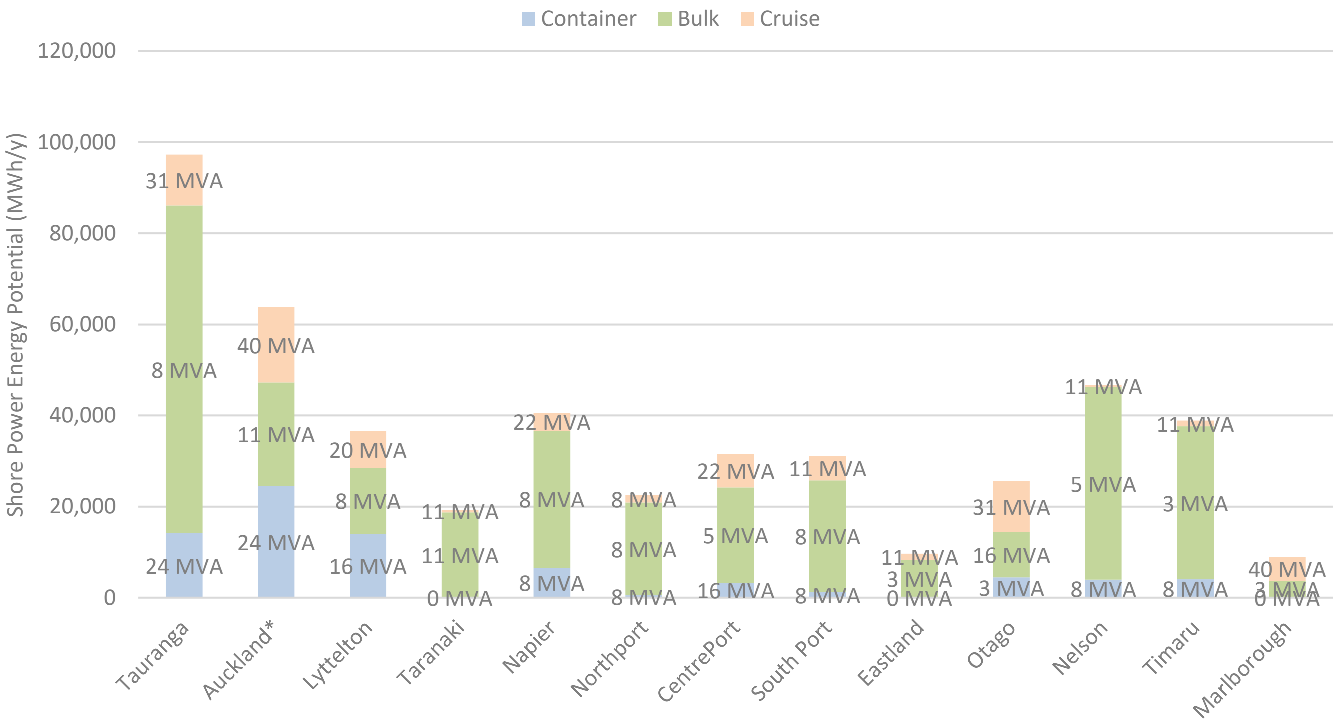
Graph 3: Shore Power Energy Potential and Capacity Required, by Port

The above findings are preliminary only, and require more in-depth analysis for each port. However, the implications in terms of electricity prices for shore power are likely still valid: shore power for cruise ships will be much more expensive to provide than for bulk vessels, due to higher investment costs, higher electricity capacity costs, and lower overall energy consumption.

Graph 4 illustrates the annual electrical energy that is required for shore power, per type of vessel, per port. The labels in grey show the MVA of shore power capacity that might be needed to enable shore power for each vessel type. In reality, installed shore power could be used by any type of compatible vessel, able to berth at a wharf with shore power installed.

As indicated visually in Graph 3 above, bulk vessels consistently present the largest shore power potential (i.e. largest offset of vessel fuel) for the lowest installed shore power capacity (3 – 10 MVA). For all ports, cruise ships present a very small amount of potential shore power electrical energy, for a very large installed shore power capacity (10 – 40 MVA).

Shore Power Energy Potential, and Required Capacity in MVA (by Port)

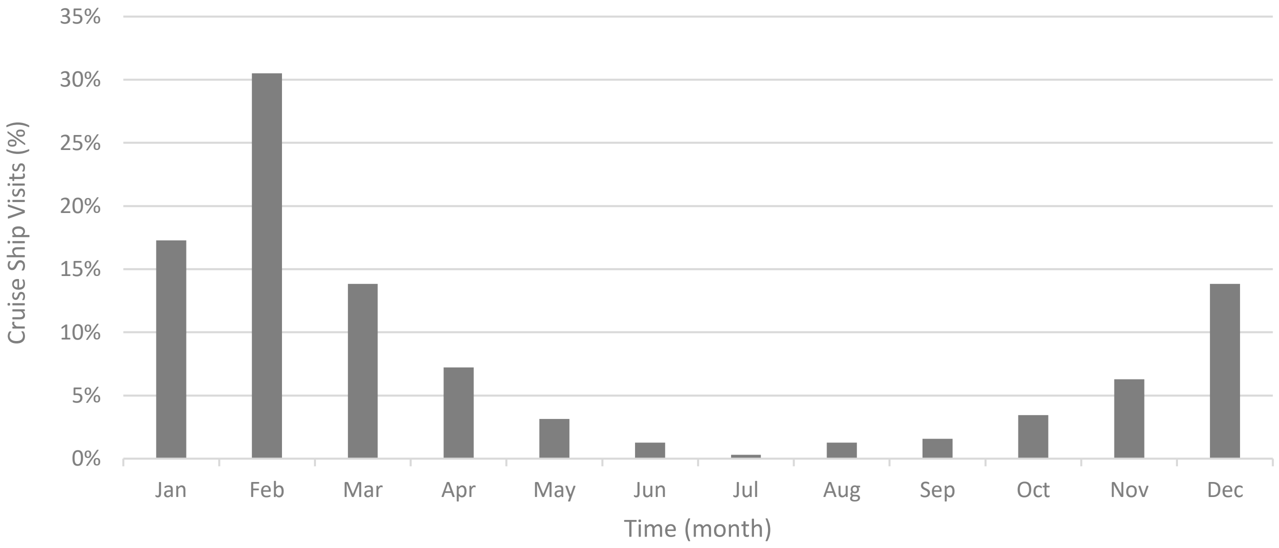


Graph 4: Shore Power Energy Potential, and Required Capacity in MVA (by Port)

Note: The labels indicate the capacity required to provide shore power to all vessels at berth, even if simultaneously.

Additionally, the number of cruise ship visits is very seasonal, peaking in the summer and reaching its lowest point in winter, sometimes even dropping to zero in July, as illustrated in Graph 5 for a typical port. In contrast, bulk and container ships maintain a more consistent operation throughout the year at all ports, making them better candidates for electrification in terms of infrastructure utilisation.

Percentage of Cruise Ship Visits Over Different Months of a Year



Graph 5: Percentage of Cruise Ship Visits Over Different Months of a Year

4.6 Shore Power Technology Providers

Within the shore power market, various technology providers play important roles in advancing sustainable maritime practices. Among these leaders are companies such as ABB Group, Siemens AG, Wärtsilä Corporation, and others, offering a diverse range of innovative solutions for shore power infrastructure.

- **ABB Group**: ABB offers a range of shore power solutions, including shore power converters, connection systems, and control and monitoring software.
- **Siemens AG**: Siemens provides shore power infrastructure solutions for ports and ships, including power conversion systems, switchgear, and automation technology.
- **Wärtsilä Corporation**: Wärtsilä offers shore power systems adapted to the needs of ports and ships, with a focus on energy efficiency and environmental sustainability.
- **Cavotec SA**: Cavotec specialises in supplying innovative shore power solutions, such as automated mooring systems and electrical power systems for vessels.
- **Schneider Electric SE**: Schneider Electric provides shore power equipment and solutions for ports and ships, including power distribution systems, transformers, and control systems.
- **Eaton Corporation**: Eaton offers a range of electrical power management solutions, including shore power systems for ports and vessels, designed to enhance energy efficiency and reduce emissions.
- **Phoenix Contact GmbH & Co. KG**: Phoenix Contact supplies electrical connection and automation solutions for shore power applications, including connectors, cables, and control systems.

4.7 Shore Power Findings

The future uptake of shore power is currently severely constrained by lack of:

- Regulatory levers
- Vessels able/willing to utilise it
- Network infrastructure
- Alignment between capital investment and benefits (fuel savings, electricity costs and emissions);
    - Vessel emissions at berth belong to shipping companies, and are only ‘Scope 3’ for ports and therefore optional for inclusion in the port’s emissions inventory. The Port Industry Association has identified this and is working on guidance to standardise emissions reporting across NZ ports.
    - Lack of clarity on capital expenditure (who pays?) for shore power infrastructure and capacity
    - Lack of clarity on return on investment (who benefits?) — likely a high price for shore power is needed, and unclear level of interest/willingness from shipping lines unless made mandatory.
    - It is possible that a best case is break-even (i.e. no return on investment)
- Lack of consensus by NZ ports around shore power infrastructure; shipping lines will not commit to costly retrofits unless they can be used at most or all ports

New electrical capacity for shore power could be around 2 – 3 MVA per port (30 – 35 MVA total in NZ), if only a single bulk carrier/container ship berth had shore power at each port, up to a range of 14 – 75 MVA per port (400 – 500 MVA total in NZ) for the capability to supply all simultaneously berthed vessels, including cruise ships. The larger number would be needed if shore power was to be made mandatory.

The overall impact to the NZ electricity grid and lines companies of electrical demand for shore power would need further port-specific analysis, but could be highest on summer days (due to cruise ships), and relatively steady otherwise due to bulk carriers and container vessels. Some seasonality might occur due to exports of refrigerated produce, meaning higher numbers of reefers (and higher shore power for container vessels) during harvest surges such as the kiwifruit harvest in Bay of Plenty.

It is worth noting that this analysis focused solely on electrical power demand; however, other factors could influence the conclusions and analyses. For instance, Cavotec, a leading engineering group specialising in automated docking and electrification systems for ports, suggests that cruise lines may be more motivated to adopt shore power than cargo shipping lines, as shore power is easier to accommodate with their existing onboard infrastructure or retrofitting capabilities and they are a more modern fleet. In contrast, bulk cargo ships may present greater challenges in adapting to plug-in systems due to less developed onboard infrastructure and an older fleet (less motivation to invest). This challenge may also apply to container ships, although Cavotec believes most newer container vessels have better compatibility (or retrofit potential) for shore power compared to older ones. Additionally, future vessels that already utilise sustainable fuels will have less motivation to connect to shore power, although this will depend on the relative price of those fuels compared to grid electricity.

5.0 PORTS EQUIPMENT/VEHICLES ELECTRIFICATION POWER DEMAND

Manufacturers of heavy equipment used at ports are increasingly offering battery-electric models. For ports, these can help reduce the diesel usage and emissions from port operations. They are also far less noisy than diesel-powered equipment, and produce no local emissions.

Battery-electric heavy equipment is commercially available for all use cases at ports, including tugs and pilot launches, although some categories are relatively new with only limited availability of electric models, as manufacturers have not yet scaled production. These electric models should have operating fuel costs that are about one-third that of diesel-powered equipment, plus substantially lower maintenance costs due to lack of a diesel engine. This can help justify the investment in their higher capital costs.

Note that third-party operators (e.g. log marshalling) at port facilities are excluded from the scope of this study. This would be some amount of extra potential for equipment electrification, not covered by the numbers in this report. This could be investigated in more detail as part of a port-specific study.

5.1 Cranes

In modern port operations, cranes play a vital role in the efficient handling of cargo, facilitating the loading and unloading of ships, as well as the movement and stacking of containers within the port yard. These powerful machines come in various types, each designed for specific tasks and operational requirements. Some main cranes include:

- Quay Cranes: These cranes operate along the quayside and are primarily responsible for loading and unloading cargo ships. This category includes ship-to-shore (STS) cranes, which are essential for efficiently transferring containers between ships and the terminal.
- Yard Cranes: These cranes operate within the container yard and are responsible for stacking, retrieving, and moving containers within the terminal. This category includes gantry cranes such as Rubber-Tired Gantry (RTG) cranes and Rail-Mounted Gantry (RMG) cranes.
- Mobile Harbour Cranes (MHCs): These versatile cranes can operate both along the quayside and within the container yard. They are used for a variety of cargo handling tasks, including loading and unloading ships, transferring cargo within the terminal, and handling non-containerised cargo.

Figure 2 illustrates the different types of port cranes mentioned above.

Different Types of Port Cranes: a) STS Cranes, b) RTG Cranes, c) RMG Cranes, d) MHCs

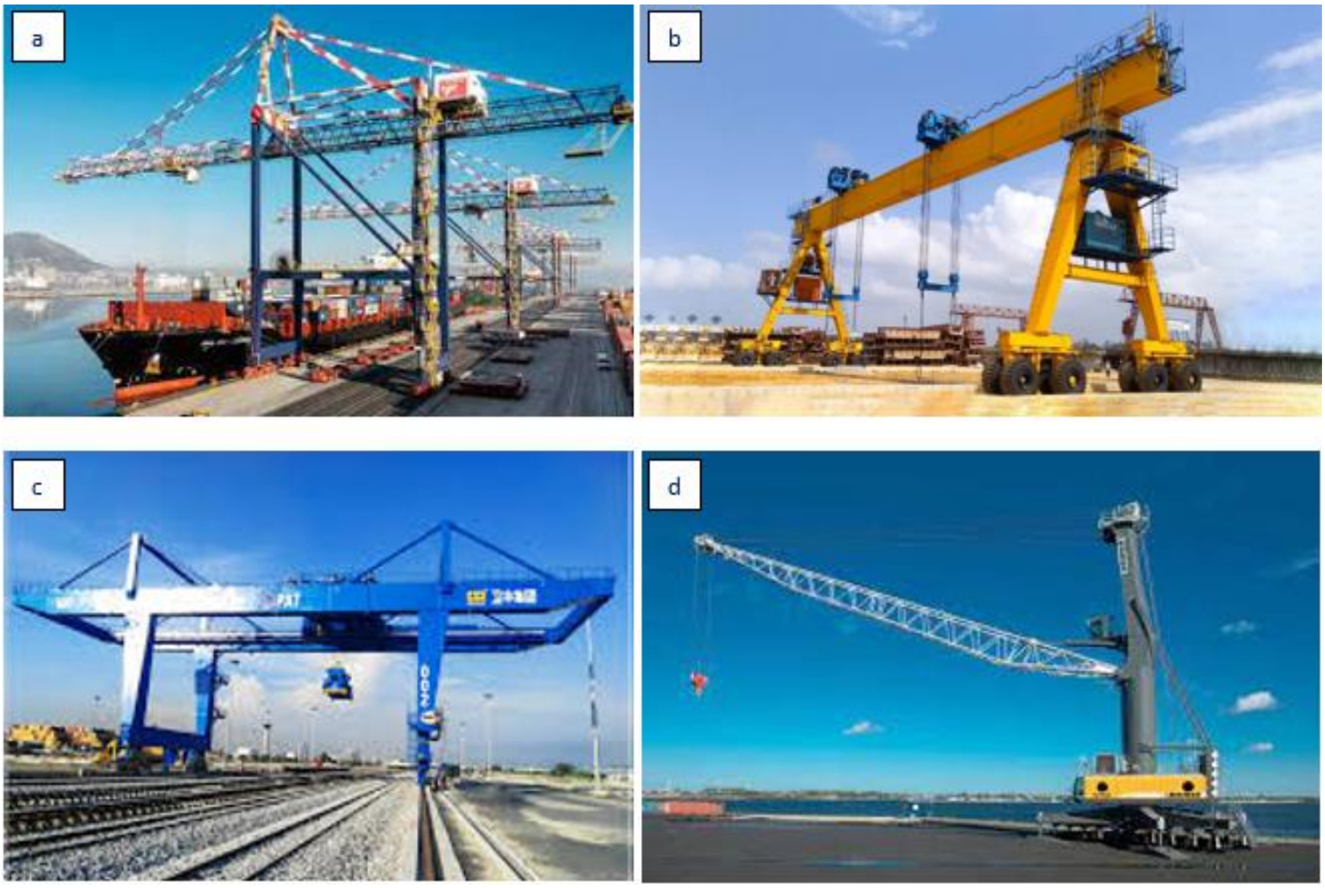


Figure 2: Different Types of Port Cranes: a) STS Cranes, b) RTG Cranes, c) RMG Cranes, d) MHCs

A crane can primarily be powered by two types of power supply: a diesel engine-driven generator located on top of the crane or electric power from the dock. While the majority of STS cranes in New Zealand ports are indeed electrically powered, mobile cranes typically rely on diesel fuel for operation.

The electrification of cranes can take different forms depending on various factors such as the location, power availability, environmental considerations, and operational requirements. Both grid and battery-powered solutions have their own advantages and limitations.

Stationary cranes are mostly already connected to the grid. Some mobile cranes could be hybrid models, using a diesel engine to move by plugging in to grid electricity when working at a specific wharf. On the other hand, mobile equipment are typically battery-powered, which offers greater flexibility in terms of deployment since they are not dependent on a fixed grid connection. However, adequate recharging infrastructure needs to be in place to support battery-powered cranes. This may involve installing charging stations or swapping out depleted batteries with fully charged ones.

Table 7 presents key specifications of various types of electric cranes utilised in port operations. Specifically, it outlines the crane type, technology provider in the market, power supply configuration, battery size, and charger capacity, where applicable.

Crane Type	Technology Provider in Market*	Power Supply	Battery Size (kWh)	Charger Capacity (kVA)	Charging Hours (h) 10-90%
STS	Konecranes	3-20 kV or 400 V	N/A	N/A	N/A
RTG - Reel Cable	Konecranes	Up to 12 kV	N/A	N/A	N/A
RTG - Battery	Konecranes	Unknown	222 (lasts for 4 h) 370 (lasts for 8 h)	111 185	1 2
RMG	Konecranes	6-20 kV	N/A	N/A	N/A
MHCs	Konecranes	400 V	250 (over 1 h)	Unknown	Unknown

Table 7: Specifications of Electric Cranes in Port Operations

* Only a technology provider has mentioned in the table for reference only

5.1.1 Findings

- The majority of quay cranes (STS) in New Zealand Ports are powered by grid electricity.
- Electrification of the remaining diesel cranes (600,000 L/y of diesel) could result in an electrical energy increase of 2.2 GWh/y, and net emissions reduction of 1,450 tonnes/y
- Peak electrical capacity requirements could be 100-200 kVA per crane, but average demand would be lower
- Hybrid mobile cranes can likely achieve most of the benefit of electric cranes, while retaining flexibility in terms of location etc

5.2 Forklifts, Stackers and Container Handlers

In the maritime industry, forklifts and stackers are types of equipment used for handling cargo in ports, terminals, warehouses, and onboard ships.

Forklifts are versatile machines equipped with forks or tines that are primarily used for lifting and transporting loads horizontally, including pallets, containers, and various types of goods. Stackers, on the other hand, are specialised machines designed specifically for vertical stacking and retrieval of loads. While some stackers may have forks similar to forklifts, their primary function is to stack goods vertically on shelves, racks, or other storage systems. Figure 3 shows a specific type of forklift and stacker used in the shipping industry.

A Type of Forklift (left side) and Stacker (right side) Used in Shipping Industry

Figure 3: A Type of Forklift (left side) and Stacker (right side) Used in Shipping Industry

In this study, it is assumed that empty container handlers and full container handlers are classified as types of forklifts and stackers, although they are distinct from traditional forklifts/stackers and are designed specifically for the handling of empty and full shipping containers, respectively. Figure 4 is a type of container handler in the shipping industry.

A Type of Container Handler

Figure 4: A Type of Container Handler

Some electric versions of forklifts, stackers and container handlers are already available in the market. Table 8 summarises the specifications of some examples of this electric equipment. Estimates, indicated in red, are provided for equipment where reliable data is unavailable.

Equipment Type	Technology Provider in Market*	Tonnage Handled	Battery Size (kWh)	Charger Capacity (kVA)	Charging Hours (h) 10-90%
Forklift	Carer Electric Forklift Solutions	Up to 22	268	Unknown	Unknown
Stacker	Global-CE	Up to 45	423	300	1.4
Empty Container Handler	SANY Australia	Up to 9	329 (lasts for 10h)	330	1
Full Container Handler	Taylor	41	900	180	5

Table 8: Specifications of Electric Forklifts, Stackers, and Container Handlers in Port Operations

* Only a technology provider has mentioned in the table for reference only

5.2.1 Findings

Electric forklift and stackers require substantial recharging loads. Ports could consider machines with swappable batteries, or a stationary battery for the chargers, or an increased number of machines to allow for charging to be spread across shifts.

5.3 Straddle Carriers

A Straddle Carrier typically refers to a specialised vehicle designed for handling ISO standard containers within port terminals and intermodal yards. These carriers are stationary and not intended for road use. They are utilised for stacking and transporting containers by lifting and carrying them while positioned across the load, attaching to the container's top lifting points using a container spreader. Figure 5 provides an example of straddle carriers in shipping industry.

Straddle Carrier in Shipping Industry

Figure 5: Straddle Carrier in Shipping Industry

Table 9 presents the specifications of an example of electric straddle carriers in port operations.

Equipment Type	Technology Provider in Market*	Tonnage Handled	Battery Size (kWh)	Charger Capacity (kVA)	Charging Hours (min) 10-90%
Straddle Carrier	Kalmar	40/50/60	High Energy (lasts for 4 h)	Unknown	45
			High Power (lasts for 0.75 h)	Unknown	5

Table 9: Specifications of Electric Straddle Carriers in Port Operations

5.3.1 Findings

The larger ports in NZ have over 50 straddles on site. Their operating hours during busy periods can be about 22 hours per day. There are unlikely to be any issues with charging requirements for a small number (2-3) of electric straddles. However, if thay are all replaced with battery electric models, they may all need to be charged during shift breaks (i.e. all at the same time), which would require very high charging loads (estimated as 5-10 MVA). Large stationary batteries could help manage this impact on the local electrical infrastructure.

Therefore, for the larger ports, to avoid impractically high charging loads they could consider straddles with swappable batteries, or a stationary battery for the chargers, or an increased number of machines to allow for charging to be spread across shifts.

5.4 Tugboats

Tugboats play a crucial role in maritime operations by assisting larger vessels in manoeuvring safely within ports, harbours, and other confined waterways. Their primary responsibilities include guiding ships during docking and undocking procedures, providing additional propulsion and steering power when needed, towing non-propelled vessels such as barges, assisting in salvage and rescue operations during emergencies, and serving as fireboats equipped for firefighting duties. Figure 6 provides an example of a tugboat.

A Tugboat

Figure 6: A Tugboat

Electrification offers a sustainable alternative by replacing fossil fuel combustion with cleaner electricity. Furthermore, it aligns with international efforts to reduce greenhouse gas emissions and combat climate change. Table 10 presents the specifications of an example of available electric straddle carriers in port operations in the market.

Tugboat	Technology Provider in Market*	Battery Size (kWh)	Charger Capacity (kVA)	Charging Hours (h)
RSD-E Tug 2513	Damen	2,800	1,500	2

Table 10: Specifications of Electric Tugboat in Port Operations

* Only a technology provider has mentioned in the table for reference only

5.4.1 Findings

- Port of Auckland has already replaced one of its tugboats with an electric version and looking to replace the other two in 2027 and 2029. This tugboat is performing “better than expected” in terms of fuel/cost savings.
- Port Marlborough says they have enough electrical supply capacity for hybrid tugboats, but not for full electric tugboats as per Auckland, as the charging load is too high. Different charging patterns could be investigated, to mitigate capacity issues as part of further work.
- Port Marlborough: Pilot boats and tugboats at this port travel long distances due to the longer port boundary (Marlborough Sounds), resulting in significant fuel usage and range requirements, making battery electric power a less viable option than at other ports.
- South Port notes that they operate as a tidal port, meaning they cannot facilitate shipping movements at any given time like non-tidal ports. Consequently, this results in scheduled downtime for specific operations, such as tugboats and pilot boats, likely enabling a more gradual and adaptable charging process with lower charger power requirements. Typically, there are 2 to 3 (max 4) vessel movements per tide window, which lasts approximately 6 hours. Larger vessels are only accommodated during high tide.

5.5 Pilot Boats

A pilot boat is a vessel specifically designed to transport maritime pilots between land and inbound or outbound ships that they are guiding through ports or narrow waterways. Figure 7 shows an example pilot boat.

A Pilot Boat

Figure 7: A Pilot Boat

Like other fuel-powered equipment, electrification of pilot boats offers operational benefits such as lower fuel costs, quieter operation, reduced vibration, and lower maintenance costs, contributing to enhanced crew comfort and productivity.

For example, Table 11 provides details of a commercially available electric pilot boat, including its battery size. This vessel is quoted as being suitable for journeys of 5 nm, which can be accomplished on battery power alone. The vessel has backup generators for contingency.

Pilot Boat	Technology Provider in Market*	Battery Size (kWh)	Charger Capacity (kVA)	Charging Hours (h)
RAlly 1600-E	Robert Allan Ltd	815	Unknown	Unknown

Table 11: Specifications of Electric Pilot Boat in Port Operations

Smaller vessels may also be suitable for different pilot boat duties at other ports.

5.6 Other Light and Heavy Vehicles

In the shipping industry, light vehicles such as passenger cars and utility vehicles (utes) serve critical roles in various operations, including transportation of personnel, goods, and equipment within port facilities and logistics hubs. In addition to light vehicles, the shipping industry relies heavily on a range of heavy vehicles, including tractors, excavators, trucks, and other specialised machinery, which are essential for cargo handling, dredging and maintenance activities within port facilities.

Traditionally powered by internal combustion engines, these vehicles contribute to carbon emissions and environmental concerns. However, there is a growing momentum towards electrification within the shipping industry, driven by the imperative for sustainability, efficiency and operating costs.

Centreport states they it is unable to use straddles due to earthquakes, so use terminal tractors (trucks) with battery swapping (one battery per shift)

5.6.1 Findings

While detailed analysis of the exact number and duty for light and heavy vehicles at each port is beyond the scope of this study, the required charging capacity and operational flexibility of electrical equivalent vehicles is not expected to be a major issue in terms of electrical capacity.

5.7 Stationary Combustion Equipment (Generator Set)

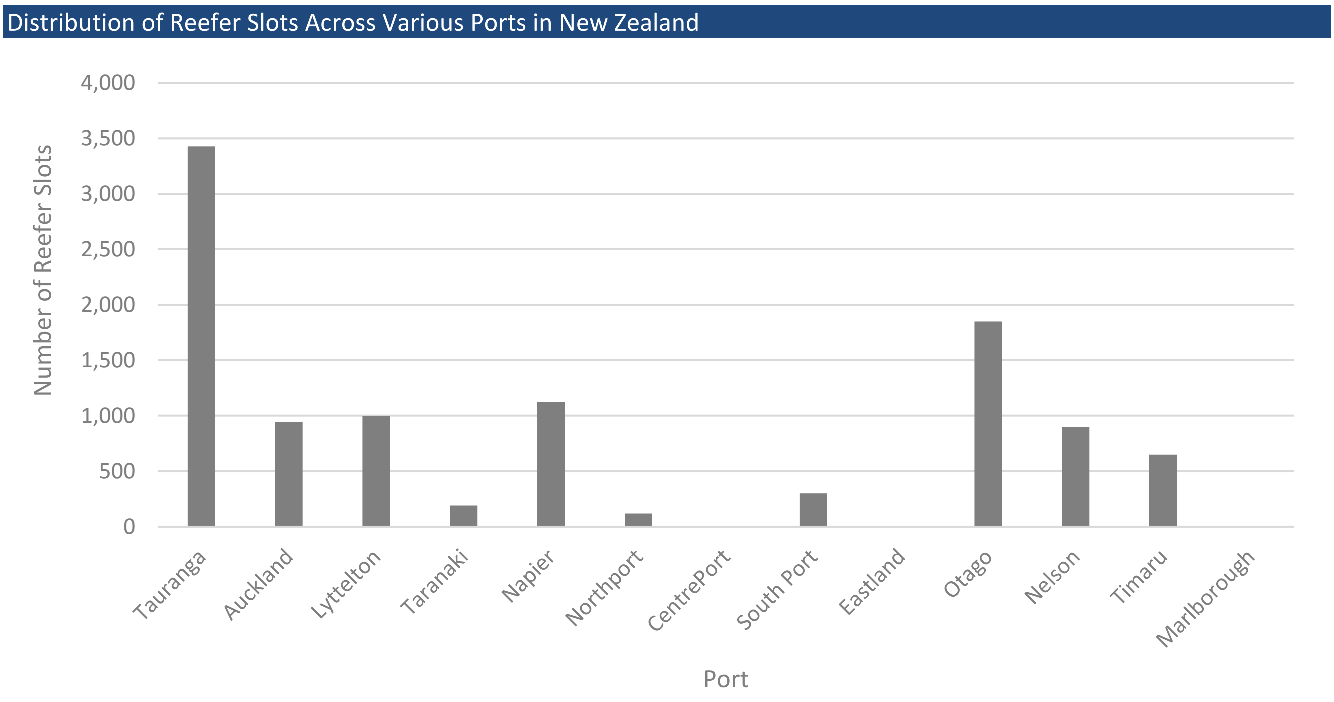
Generator sets, or Gensets, are diesel generators commonly used to provide mobile power to various applications, including refrigerated containers (reefers) at ports.

Reefers require a constant electrical power source to drive their refrigeration systems, for preserving perishable goods during transportation. They are used to transport a wide range of temperature-sensitive goods, including fruits, vegetables, seafood, dairy products, meat products, pharmaceuticals, and chemicals.

Most reefers are plugged in to mains electricity where possible, as this is a far lower-cost way of providing them with electricity. At most ports, mains power is around $0.15 per kWh, while gensets provide electricity at around $0.50 – $0.60 per kWh, often with additional genset hireage of +$0.40 per kWh added to this.

Ports only have a certain number of ‘reefer slots’ available. In rare instances where the number of reefers exceeds the number of mains-powered reefer slots, gensets are used to provide power to the extra reefers. Due to the continuous nature of the demand, the value of the refrigerated cargo, and the rare instances when it is needed, mobile batteries or on-site renewables are not a good fit for providing this reefer power. It appears that gensets are mostly a good solution for this issue.

Graph 6 illustrates the distribution of reefer slots across various ports in New Zealand based on the values provided in Table 1.



Graph 6: Distribution of Reefer Slots Across Various Ports in New Zealand

A small number of ports still have substantial genset diesel use. These ports are a good candidate for investigating electrical infrastructure upgrades to provide additional mains power for reefers. This could be the scope of a more detailed, port-specific study.

6.0 SUMMARY OF ELECTRIFICATION IMPACT

6.1 Mobile Equipment

Current diesel use for port mobile equipment is around 20M litres per year. If fully electrified across all ports in NZ, this would add around 60 GWh/y of electricity consumption.

The proportion of diesel use that can be reduced by electrifying the different types of mobile equipment can be seen in Graph 1. Note that genset diesel use is mostly attributable to a handful of ports.

The key issues for electrification of port mobile equipment are:

- Integration of recharging with port operations; limited battery-electric vehicle range/duty, limited driver schedules/breaks for recharging, etc
- Insufficient electrical capacity at port and in local network (region) to recharge any significant numbers of battery-electric mobile equipment

Partial electrification (of some heavy vehicles) at each port may not require infrastructure upgrades.

Stationary batteries for charging battery-electric heavy equipment could help reduce the scale of network upgrades.

Expansion of mains power infrastructure for additional reefer slots could be an economic proposition at the few ports that still have substantial genset diesel use.

6.2 Shore Power

Shore power, if required for all vessel types and at all ports, would add around 450 – 500 GWh/y of electricity consumption.

About 68% of this represents bulk ships, 16% is cruise ships, and 16% is container vessels. Anecdotally, cruise ships could be the most likely to adopt shore power if offered at economic rates, followed by container vessels, and bulk ships would be the least likely to adopt shore power without regulation.

The shore power capacity requirement for cruise ships is far larger than that required for bulk vessels, or container vessels.

7.0 FUTURE FUELS

7.1 Global Context

Currently, all ocean-going vessels rely on fossil fuels such as heavy fuel oil (HFO), light fuel oil (LFO), marine gas oil (MGO), or marine diesel. All three fuels produce carbon emissions from combustion, equivalent to about 3.2 tonnes CO_2 per tonne of fuel. These fuels are globally available, with many operators choosing refuelling location(s) based on fuel price – known as 'bunker arbitrage'.

Importantly, ocean-going international trade vessels sit outside the boundary for countries' national greenhouse gas emissions (GHG) reporting. The International Maritime Organisation (IMO) has set the following targets to address this gap:

- 40% reduction in specific emissions (per tonne-km) of shipping by 2030, compared to a 2008 baseline
- 20-30% absolute reduction in shipping emissions by 2030, compared to 2008
- 5-10% of all energy use for international shipping to be zero or low carbon, by 2030
- Net-zero GHG for the international shipping industry by 2050

Achieving these targets will require investment, support and accountability from a vast array different stakeholders in the shipping industry. Many large shipping operators such as Maersk have set their own targets for emissions reductions, of similar ambition. Some key manufacturers of the large marine engines used in these vessels, like Wärtsilä and MAN Energy Solutions, have also announced support and the development of new dual-fuel engines (and retrofit options) suitable for burning both existing fossil fuels and future low-carbon fuels including methanol, ammonia and hydrogen.

Although global production of methanol, ammonia and hydrogen is currently almost entirely fossil fuel based, they have the potential to be manufactured from green electricity with very low associated carbon emissions – perhaps with a reduction of 80-100% in comparison to existing shipping fuels.

7.1.1 Bunkering

A key issue in terms of New Zealand's limited influence in this area is that most international shipping/cruise vessels that visit NZ Ports do not refuel ('bunker') here, due to the high cost and low availability of fuel. It appears that most international vessels carry more than enough fuel for the return trip to/from New Zealand.

Prior to the Marsden Point refinery ceasing operations in 2022, the refinery produced around 12 PJ/y of fuel oil which was used in NZ for international shipping and cruises. It appears that the loss of this local supply of fuel oil has not triggered a need to import an equivalent amount, inferring that most of the international shipping operators who did refuel here are simply refuelling overseas ('bunkering') instead. There is now only about 4.0 PJ/y of fuel oil used in NZ for international shipping, which is imported from refineries overseas, as seen in Figure 8.

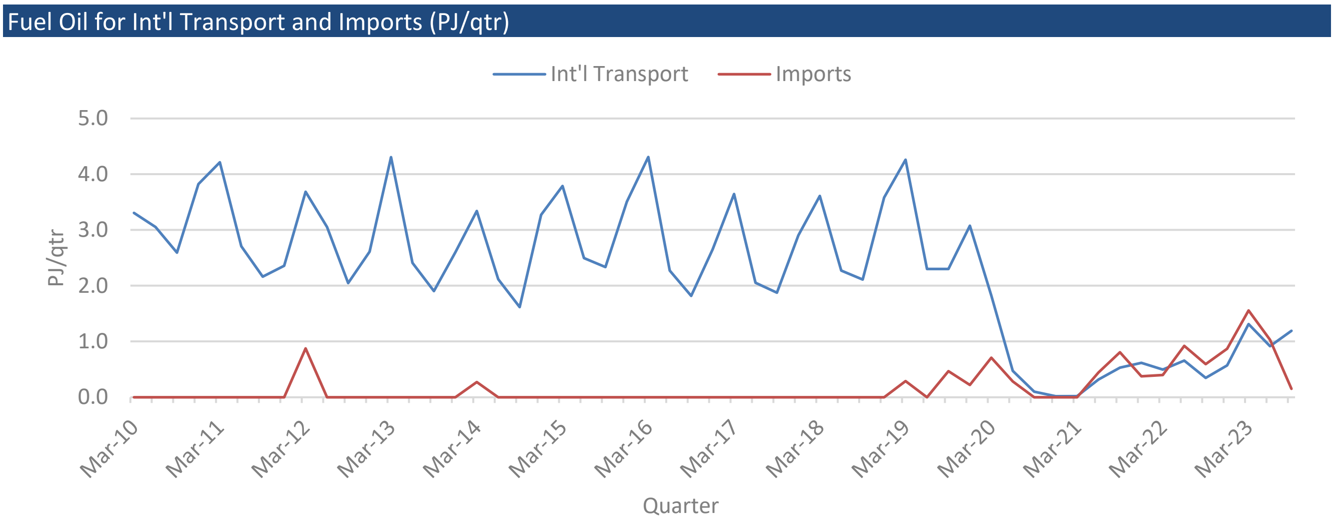


Figure 8: Fuel Oil for Int'l Transport and Imports (PJ/qtr)

Most NZ Ports do not offer refuelling for international shipping vessels. For those that do, this is typically carried out by a separate fuel company operating on Port land/wharf space.

Due to the lower energy density of future fuels, there is a conceivable scenario where future vessels may need to refuel in New Zealand. Note that this is only a possibility, and if shipping lines can not access future fuels at a low enough cost, they will likely make other compromises on vessel design or cargo capacity to enable them to maximise their profits. The opportunity to supply future fuels to international shipping operators visiting New Zealand may be present in future, especially if New Zealand scales up manufacture of green hydrogen/methanol/ammonia for export. However, geographical and shipping route constraints may constrain the size of this opportunity.

7.1.2 Future Fuels Comparison

Currently, the IMO regulates shipping fuel emissions at the point of combustion ('tank-to-wake') and without regard to the source of fuel, i.e. regardless whether the fuel is biodiesel of fossil diesel. However, they have issued preliminary guidance for a life-cycle basis for fuel emissions comparison, which they term 'well-to-wake' and takes into consideration the source, production, refining, distribution, and use of the fuel. These are fuel and case specific.

Some preliminary comparison of future fuel options in terms of safety has already been investigated by industry organisations, such as *Together in Safety*. They concluded that the preferred future fuels from a safety perspective, are (in order); methanol, LNG, H_2 then ammonia.

There are existing regulations in place for both Methanol and LNG for use as a marine fuel, but not for ammonia or H_2.

7.1.3 Other options

It is notable that battery electric vessels are not under consideration at all for international shipping. This is likely due to three factors compromising the shipping economics:

- Low energy density of batteries, meaning (30x) larger 'fuel' volume needed so less available for cargo
- High cost of batteries impacting shipbuilding costs
- Extremely high power requirements (tens/hundreds of MW) that would be needed for recharging batteries for large ocean-going vessels; this is not considered feasible, nor are there any plans to investigate this in our research.

Battery electric vessels will likely find application in near-shore routes such as ferries or short cargo routes, where battery storage and charging requirements (hence electricity costs) are at a more manageable scale.

Plug-in hybrid vessels, capable of short range battery-electric only propulsion, may also be suitable for certain ferry or short cargo routes within New Zealand.

Other fuel efficiency options are also under investigation by the shipping industry, including:

- Harnessing wind energy via kites or lift surfaces mounted to the vessel
- Vessel hydrodynamics improvements

7.1.4 Survey of NZ Ports

NZ Port staff discussions about future fuels during the course of this study led to the following key points:

- Larger vessels typically all refuel overseas, especially since Marsden Pt refinery closure
- There are no indications yet of any future demand for low-carbon future fuels, nor for LNG
- The drivers of change would be purely related to carbon emissions, or reducing reliance on oil, with expectations of a significant price premium for low-carbon future fuels
- No shipping lines are considering battery electric vessels, but short routes (ie Wellington-Picton), near-shore fishing trips or recreational boating could be achieved with battery/hybrid vessels in future
- Shipping lines are likely to be the main stakeholders in selecting fuel types, bunkering locations needed etc. Ports have very limited influence here
- Hydrogen has not been talked about with regard to powering vessels that visit/operate in NZ waters. It has been looked at by a few ports as a fuel for mobile equipment, but battery electric equipment is widely considered better
- Ammonia is unfamiliar and concerning to most NZ Ports, who lack experience dealing with the related specific hazards, and are often close to residential areas. NZ Ports are aware of discussions internationally, relating to its potential use as a bunkering fuel. Could be likely as a fuel for vessels shipping bulk ammonia as a product already.
  - Methanol is considered more likely as a vessel fuel and easier to integrate into NZ Ports. Port Taranaki already has experience with methanol storage and ship loading capacity, with export methanol made from natural gas at Methanex Taranaki.

7.2 Low-carbon Fuels

7.2.1 Green Methanol

Methanol is currently manufactured and shipped as a commodity product around the world, in large chemical plants that use fossil fuels as a feedstock and energy source. Global supply chains, fuel handling and regulations are already established.

Green methanol is produced by combining green hydrogen with a (renewable) source of carbon dioxide, and requires a substantial energy input for the chemical process. The methanol can be combusted in modified but relatively conventional engines. The use of green methanol would provide a 'well-to-wake' efficiency of about 10-15%, from renewable electricity to delivered mechanical power from a marine engine.

Manufacturing methanol requires a source of carbon. In conventional methanol manufacture, this carbon is from natural gas or coal. For low-emissions green methanol, this carbon must be sourced from either biomass, or via direct air capture (DAC). It must be noted that DAC does not yet exist at scale in industry.

Methanol is comparable to existing fuels in terms of handling and hazards, but has additional fire prevention measures due to a low flash point of 60 °C. It has around half the volumetric energy density of conventional fuels, so would require about twice the onboard volume for fuel storage.

The regulations allowing methanol to be used as a fuel are already in place, and trials of green methanol as a bunkering fuel have been carried out in 2023 at the ports of Rotterdam and Singapore. It is likely that this will be restricted to key trade routes, at least initially, due to the limited number of ships able to use this fuel, the limited availability of this fuel and the limited facilities with green methanol bunkering.

Engine manufacturers including Wärtsilä, MAN Energy Systems and HD Hyundai have already developed or are developing dual-fuel engines capable of burning methanol, with some models in service since 2016. Some recent new orders by shipping lines, correct at the time of writing, include:

Maersk

- 24x container vessels on order, all with dual-fuel engines capable of burning conventional fuels and methanol

HD Hyundai Heavy Industries

- 16x vessels on order, all with dual-fuel engines capable of burning conventional fuels and methanol

Other shipping lines are already operating vessels capable of burning methanol, in their engines, for example the methanol producer Methanex who operates a number of methanol plants globally including a plant in Taranaki. Their methanol tanker vessel Taranaki Sun is powered by methanol and has visited Port Taranaki.

Some ~110 of the current global orderbook of 2,200 vessels are for methanol-powered engines, with a further 130 of the vessels on order due to use conventional liquid fuels but to be 'methanol ready' for a later retrofit.

7.2.2 Green Ammonia

Ammonia is currently manufactured as a fertiliser, in large chemical plants that use fossil fuels as a feedstock and energy source. Global supply chains, fuel handling and regulations are already established for bulk shipping, but not for its use as a fuel.

Green ammonia is produced by combining green hydrogen with nitrogen from air, and requires a substantial energy input from renewable electricity to make hydrogen using electrolysis, and then to synthesise ammonia. The ammonia can be combusted in modified but relatively conventional engines. The use of green ammonia would provide a 'well-to-wake' efficiency of about 24-30%, from renewable electricity to delivered mechanical power from a marine engine.

Ammonia combustion produces no carbon emissions as there is no carbon content in the fuel. However, there are Nitrous Oxide (NOx) emissions, which require mitigation via emissions control systems.

Ammonia is toxic and its use as a fuel brings new hazards to shipping staff and operators. It is acutely toxic to marine life. It has about one-third of the volumetric energy density of conventional fuels, so would require about 3x the onboard volume for fuel storage.

Despite these challenges, ammonia has been identified as one candidate for fuelling international shipping routes.

There are no regulations allowing ammonia to be used as a marine fuel as yet, but work is underway by the IMO, and there are announcements from multiple Ports of an intention to allow ammonia to be stored and dispensed as a bunkering fuel from around 2026. It is likely that this will initially be restricted to key trade routes, due to the limited number of ships that will be able to use this fuel and the limited number of bunkering facilities.

Engine manufacturers are already developing engines capable of burning ammonia. Some demonstrator examples have recently been built, including:

Fortescue *Green Pioneer*

- Offshore platform supply vessel, retrofitted in 2023
- Engines are capable of burning either conventional fuels or ammonia
- Fortescue is a global Oil & Gas, Mining and Minerals company based in Australia

Yara *Eyde*

- Is the first container vessel ordered with dual-fuel engines capable of burning either conventional fuels or ammonia
- Delivery expected in 2026, for a fertiliser shipping route between Norway and Germany
- Yara is a fertiliser manufacturer based in Norway

None of the current global orderbook of 2,200 vessels are for ammonia-powered engines, but 191 of the vessels on order are due to use conventional liquid fuels but to be ‘ammonia ready’ for a later retrofit.

7.2.3 Biofuel/Biogas/Synthetic Diesel

These fuels are mostly equivalent to conventional fuels, if processed in a suitable manner, but are produced from biological sources. Currently, due to the higher energy input and feedstock supply/processing issues involved in manufacturing these fuels, they are currently about 3x the cost of their fossil fuel equivalents.

Research in this area does not support a significant decrease in cost for these biofuels. However, future increases to the price of conventional fossil fuels could make the cost barrier less of an issue.

The global supply of low-cost biomass sources is not expected to be sufficient to produce low cost biofuels for marine shipping.

7.2.4 LNG

LNG is already used as a marine vessel fuel, but mostly for LNG tankers due to the presence of ‘boil-off’ natural gas from the near-cryogenic LNG carried as cargo.

The use of LNG as a fuel could provide emissions reductions of around 20% versus fuel oil, when considering the combustion of the fuel alone (‘tank-to-wake’). If the upstream fuel production processes are taken into account (‘well-to-wake’), the savings versus fuel oil could be negated, or for popular dual-fuel LNG engine types could even be more emissions-intensive than fuel oil.

There is limited potential for New Zealand to provide LNG as a marine fuel, due to an absence of liquefaction facilities required to convert natural gas to LNG. It appears that these liquefaction facilities are most economic when built for bulk export of LNG, rather than for marine refuelling only.

Some ~860 of the current global orderbook of 2,200 vessels are for LNG-powered engines, with a further 95 of the vessels on order due to use conventional liquid fuels but to be ‘LNG ready’ for a later retrofit. Part of the reason for this high number is the expansion of the LNG tanker fleet, with around 100 vessels on order, which have LNG engines. The other ~760 are container ships, cruise ships and bulk carriers.

7.2.5 Green Hydrogen

Hydrogen is of interest to the shipping industry as a marine fuel. It is not currently shipped in any notable volume.

Conceptually, it is similar to LNG in that the most practical way to move green hydrogen could be in a pressurised, liquified state at cryogenic temperatures. This would require new regulations and bunkering equipment, in addition to the fuel supply chain.

Suggestions from engine manufacturers and industry research indicate that the low energy density and availability of hydrogen may make short-sea routes more likely, and/or for future green hydrogen tanker (bulk carrier) routes where using boil-off gas as engine fuel is possible. It appears that the use of green hydrogen as a widespread fuel for international ocean-going shipping routes is unlikely.

Some ~16 of the current global orderbook of 2,200 vessels are for hydrogen-powered engines, with a further 9 of the vessels on order due to use conventional fuels but to be ‘hydrogen ready’ for a later retrofit.

7.3 Summary of Future Fuel Findings

Battery electric or plug-in hybrid vessels may find some application in near-shore routes such as ferries or short cargo routes. These will need multi-MW scale charging infrastructure.

Hydrogen and ammonia, while subjects of some interest globally, could be relatively niche fuels due to high price and difficulty storing and handling them. Regulations are not yet established for their use as fuels.

Methanol appears to be the preferred marine future fuel in terms of global technological and regulatory maturity, new vessel orderbook (for container ships), and ability of global ports to bunker and refuel vessels.

The global vessel orderbook shows considerable diversity, including a move away from conventional fuels, a big commitment to LNG as a fuel, and a sizeable proportion of dual-fuel capable (future fuel ready) vessels. This is shown in Figure 9 below, with data as of June 2023. Importantly though, the dual-fuel vessels will run on conventional fuels for the foreseeable future, hence are shown in black below.

Global Vessel Orderbook by Engine Fuel Type (Total; 2,200)

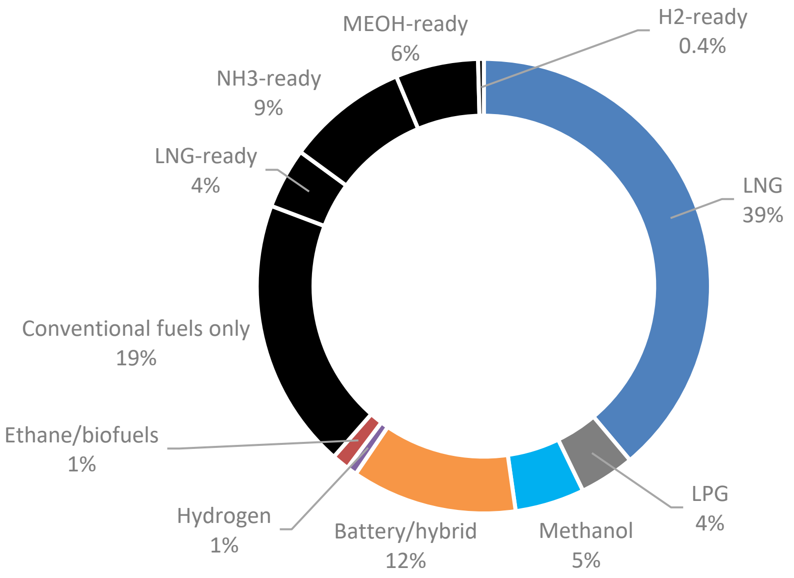


Figure 9: Global Vessel Orderbook by Engine Fuel Type (Total; 2,200)

NZ ports do not currently refuel international vessels. It is possible that this could change in future, with widespread adoption of methanol as a future fuel, due to the energy density of methanol being about 45% that of conventional marine fuels, and existing manufacturing capacity and storage/shiploading experience in NZ (at Methanex Taranaki). A similar possibility exists for future vessels powered by ammonia or hydrogen.

It appears that almost all new/retrofitted/ordered vessels capable of burning methanol have ‘dual fuel’ engines, which can also burn conventional fuels. Despite industry-wide targets on emissions reductions, shipping operators are still likely to have some freedom in choosing fuel types based on operating cost and regulatory requirements in different jurisdictions.

The supply of green methanol is currently in its infancy. Globally, roughly 0.5M tonnes/y of green methanol are manufactured today, compared to 100M-110M tonnes/y of conventional (fossil fuel) methanol. Announced projects could increase the supply of green methanol to about 5.5M tonnes/y by 2027. Current global shipping fuel use would require 540M+ tonnes/y of green methanol.

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