Milford Opportunities Project

Low / Zero Transport Carbon Emission Feasibility Study

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Executive Summary

The Milford Opportunities Project is an initiative that seeks to create a self-funded, sustainable model for tourism that preserves the area's natural beauty and cultural heritage at Milford Sound Piopiotahi and along the Milford Road corridor. The project seeks to address the pressures placed on the area by increasing visitor demand and to maintain, enhance and sustain the Word Heritage Area of Piopiotahi.

The Milford Opportunities Masterplan was launched in July 2021 and establishes the key issues faced by Milford Sound Piopiotahi, as well as the concepts and solutions for addressing them.

As part of Stage three of this project, the feasibility of the Masterplan's recommendations are explored.

In support of Stage three of the Milford Opportunities Project, Stantec was commissioned by the Department of Conservation (DOC) in September 2023 to investigate zero and low carbon options for providing energy to the transportation system inclusive of a potential Te Anau – Milford bus service and existing tour boat operations, as well as supporting infrastructure at Milford Sound Piopiotahi and the Milford Corridor.

The objective of the feasibility study is to assess potential options to reduce or eliminate carbon emissions from bus and tour boat operations and identify options considered feasible for the specific requirements of Milford Sound.

Anthropomorphic climate change is a global challenge, and the transport sector is a significant contributor of carbon emissions, a key driver of global warming. In New Zealand, transport emissions account for 17 per cent of the country's gross emissions, caused by the dependence of most vehicles on carbon intensive fossil fuels.

New Zealand has responded to the threat of climate change by setting into a law a target for net zero greenhouse gas emissions by 2050.

This study supports these objectives by exploring options for the reduction or elimination of carbon emissions in long distance buses and in tour boat operations within Milford Sound Piopiotahi.

The study has considered a broad range of potential fuels and associated motive power systems that maybe applicable to the reduction or elimination of carbon intensive fuels used on buses and watercraft.

A wide range of assessment criteria were reviewed for each fuel option, with the following criteria identified as fundamental to feasibility:

- The fuel's carbon emissions both during production and at point of use.
- The availability of the fuel in domestic production or on the global market.
- The maturity of fuels and their associated motive power systems.

Fuel cost is also a key factor that will inform feasibility, however this initial screening focused on the high level attributes above, with fuel cost considered as part of the detailed appraisal of options.

The assessment identified four potential options that are feasible for long distance buses and tour boats:

Fuel/Energy Option	GHG Emissions	Fuel Availability	Maturity
Agricultural/Renewable Biodiesel	Marginal	Marginal	Good
Synthetic Diesel	Marginal	Marginal	Marginal
Hydrogen (Green production pathway)	Good	Marginal	Marginal
Electricity (Sustainable generation)	Good	Good	Good

Sustainably generated electricity used in Battery-electric systems produces no carbon emissions either during production or at point of use. Sustainable electrical energy is produced at scale in New Zealand and electricity may be supplied via electrical transmission. Battery-electric motive systems are in widespread use globally and domestically, with Battery-electric watercraft and buses in active service in New Zealand. On this basis, Battery-electric motive systems were assessed as potentially being the most feasible of the options considered.

Hydrogen was also assessed as being potentially feasible and produces no carbon emissions if hydrogen is produced through the use of sustainable electricity via electrolysis. Green hydrogen production is in its infancy, however there is potential for hydrogen production to scale up rapidly if demand emerges. Hydrogen may also be produced and stored locally. Hydrogen fuel cell vehicles are in limited production and use.

Biodiesel and synthetic diesel were also considered feasible, as they provide an avenue for reduced carbon emissions with minimal disruption or conversion required to existing fleet. While these fuels are not emission free, they do not increase net carbon emissions.

The four feasible options were further investigated in detail against the specific operating requirements and conditions of Milford Sound Piopiotahi.

A summary of the relative advantages and disadvantages of the options assessed in detail is provided below.

Motive System	Advantages	Disadvantages
Battery-electric	• Produces no carbon emissions or harmful emissions. • Low fuel and operational cost. • Available commercially. • Very mature – with Battery-electric systems in operation in New Zealand in both watercraft and bus applications.	• High infrastructure requirement. • Disposal cost and environmental impact of batteries. • Requires new fleet. • Limited to short term energy storage only.
Hydrogen Fuel Cell	• Produces no carbon emissions or harmful emissions. • Provides the potential for long-term energy storage.	• Moderate to high infrastructure requirement, dependent on if local hydrogen production is required. • Requires new fleet. • Disposal cost and environmental impact of fuel cells. • Limited commercial availability. • Limited operational maturity.
Synthetic Diesel	• Fully interchangeable with existing fuel. • Easy conversion/implementation. • No infrastructure requirement.	• Produces localised carbon and harmful emissions. • Very limited fuel production and high cost of fuel.
Biodiesel	• Interchangeable with existing fleet. • Easy conversion/implementation. • No infrastructure requirement.	• Produces localised carbon and harmful emissions. • Limited long term storage potential. • Potential for loss of habitat and biodiversity, depending on feedstock origin.

The key findings of the detailed assessment were:

- Battery-electric systems provide a zero-emission solution that has extremely low operating costs but requires a considerable investment in infrastructure, including the provision of enroute charging.
- Battery-electric buses do not have sufficient onboard energy storage to allow a return journey from Te Anau to Milford Sound and recharge facilities will be required at Milford Sound or between Milford Sound and the Cleddau Cirque.
- Battery technology is undergoing a rapid evolution, with advances in battery technology expected to provide increased energy density that may mitigate the requirement for enroute charging for buses in the future.
- Battery-electric buses will require between **3,894 and 19,468 kWh/day** for recharge depending on the number of buses in service, with a single bus requiring 559 kWh/day at Milford Sound.
- Battery-electric tour boats require recharge facilities located at births in Milford Sound and have an energy requirement of **50,500 kWh/day**.

- Hydrogen fuel cell systems offer advantages in terms of long-term energy storage and range, but this comes at the expense of a high fleet cost and potential investment in hydrogen production infrastructure and/or a high operating cost.
- Hydrogen fuel cell buses are estimated to require between **600 and 2,900 kg H_2** per day.
- Converting existing fleet (inclusive of bus and boat) to either battery-electric or hydrogen cell is prohibitively challenging and new specifically designed vehicles will be required to support either system.
- Synthetic fuels and biofuels may be used with existing fleet (bus and boat).
- Synthetic fuels may be implemented with minimal infrastructure and/or capital cost, but these fuels continue to produce localised emissions and are dependent on fuel that has limited production and high cost.
- Biodiesel fuels may also be implemented with minimal infrastructure and/or capital cost, but these fuels also produce localised emissions and fuel production may have broader environmental impacts to biodiversity and/or arable land food production.

Recommendation

Of the four technologies assessed in detail in this report, **the use of battery-electric motive power systems for both tour boats and buses is recommended** on the following grounds:

- Battery-electric systems allow for the complete elimination of carbon emissions.
- Electrical based motive power is considerably cheaper than the diesel equivalent.
- Battery-electric systems are mature and widely available.

Comparative to the use of hydrogen fuel cells, synthetic fuels and biofuels, battery-electric motive power systems have the following advantages:

- Battery-electric systems are considerably cheaper to operate than other options, as electricity is cheaper to produce than other fuel types.
- Battery-electric systems and vehicles are cheaper to produce than hydrogen cell vehicles and are more readily available on the open market.
- Battery-electric systems produce no carbon emissions, unlike synthetic fuels and biofuels.

The use of battery-electric systems is subject to the availability of sufficient electrical energy generation to support operations as Milford Sound Piopiotahi and requires charging and energy storage infrastructure.

Charging infrastructure, as well any upgrades required to electrical generation or transmission infrastructure will require considerable time to plan and implement and there are opportunities to reduce carbon emissions until such time as infrastructure is in place to allow conversion to battery-electric operations.

The following may be used as transitional options until such time as full conversion to electrical energy becomes feasible:

- Existing tour boats may introduce blended fuel regimes into current operations.
- Hybrid buses may be introduced for the hop on/hop off Te Anau – Milford service, in combination with blended fuel regimes.
- All vehicles (inclusive of bus and boat) may be transitioned to battery-electric vehicles as and when supporting infrastructure is in place.

Should the required infrastructure for battery-electric operations prove infeasible in the long term, it is recommended that:

- Existing tour boats introduce blended fuel regimes into current operations.
- Tour boats be replaced with hybrid vessels as they reach the end of their operational life.
- Tour boats transition to use of 100% biofuels or synthetic diesel as these fuels become available.
- Hybrid buses may be introduced for park and ride Te Anau – Milford service also transitioning to the use of 100% biofuels or synthetic diesel.

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Glossary

Term	Definition
Asset risk	The risk associated with the devaluation and disposal of assets at end of life.
Berth	A vessel's allotted place at a wharf or dock.
Boat	A small vessel. In the context of this study boat is used interchangeably with vessel or watercraft and refers specifically to the tour boat operations in Milford Sound Piopiotahi.
Carbon neutral	A fuel that produces localised carbon emissions but does not produce a net increase in global carbon.
Carbon intensive	A fuel that is dependent on fossilised carbon and releases emissions that increase the net volume of atmospheric carbon.
Conversion	The process of changing transport fleet and infrastructure from reliance on fossil fuels to an alternative.
Cryogenic	The cooling and maintenance of materials at very low temperature.
Depot	A place of the storage and servicing of buses when out of service.
Electrolysis	The process of converting ions of a compound in a liquid state into their reduced state by passing an electric current through a compound. In the context of this study, this refers to the separation of water into hydrogen and oxygen.
Electrolyser	The device used to separate water into hydrogen and oxygen.
Energy density	The amount of energy stored in a material by volume.
Operational life	The expected duration of operational service provided by a vehicle after which it may be sold or disposed of.
Feedstock	The raw material used to produce a refined fuel.
Fleet	All vehicles in operation to provide a given service and refers to both bus and tour boat operations.
Fuel	A material used to produce energy. In the context of this study, fuel may also refer to electrical energy.
Greenhouse gas emissions	A gas emission that absorbs infrared radiation emitted from the earths surface, predominately carbon dioxide.
Harmful emissions	A non-greenhouse gas emission that is harmful to human health or the environment, including nitrous oxide, sulfur oxide and fine particulates.
Kilowatt (kW)	A unit of electric power.
Megawatt hour (MWh)	A unit of measurement that describes the amount of energy produced by one Megawatt over the course of one hour.
Motive power	Converted energy used to impart motion.
Motive power system	A system of components, including energy storage and energy conversion used to generate motion from an energy source.
Node	Destinations enroute to Milford Sound Piopiotahi.
NOx	Oxides of nitrogen that are harmful to human health and the environment.
SOx	Sulfur oxides that are harmful to human health and the environment.
Stopping pattern	The location and timing of where buses stop.
Te Anau – Milford	The return journey for buses travelling from Te Anau - Milford Sound Piopiotahi and back.
Transition	The process of migrating from one motive power system to another.
Zero emission	A vehicle which produces no greenhouse gas or harmful emissions.

1 Introduction

1.1 Background

1.1.1 Milford Sound Piopiotahi

Milford Sound Piopiotahi is one of the world's most iconic destinations and attracts large volumes of visitors annually, which is projected to continue increasing. As it is located within the Fiordland National Park, holds UNESCO World Heritage status, and as the Milford Road corridor and the site itself are under stress, changes to visitor operations are required.

1.1.2 State Highway 94

State Highway 94 (SH94) is the main road used to access Milford Sound Piopiotahi. The road passes through mountain landscapes before entering the 1.2 km Homer Tunnel which emerges into rain-forest-carpeted canyons that descend to Milford Sound Piopiotahi.

SH94 is ranked third for personal risk of any Waka Kotahi New Zealand Transport Agency (NZTA) administered road in New Zealand and is considered challenging for international and inexperienced domestic drivers. The road is expensive to maintain, keep open in the winter, and is limited in its potential development due to terrain and natural hazards, particularly avalanches[1].

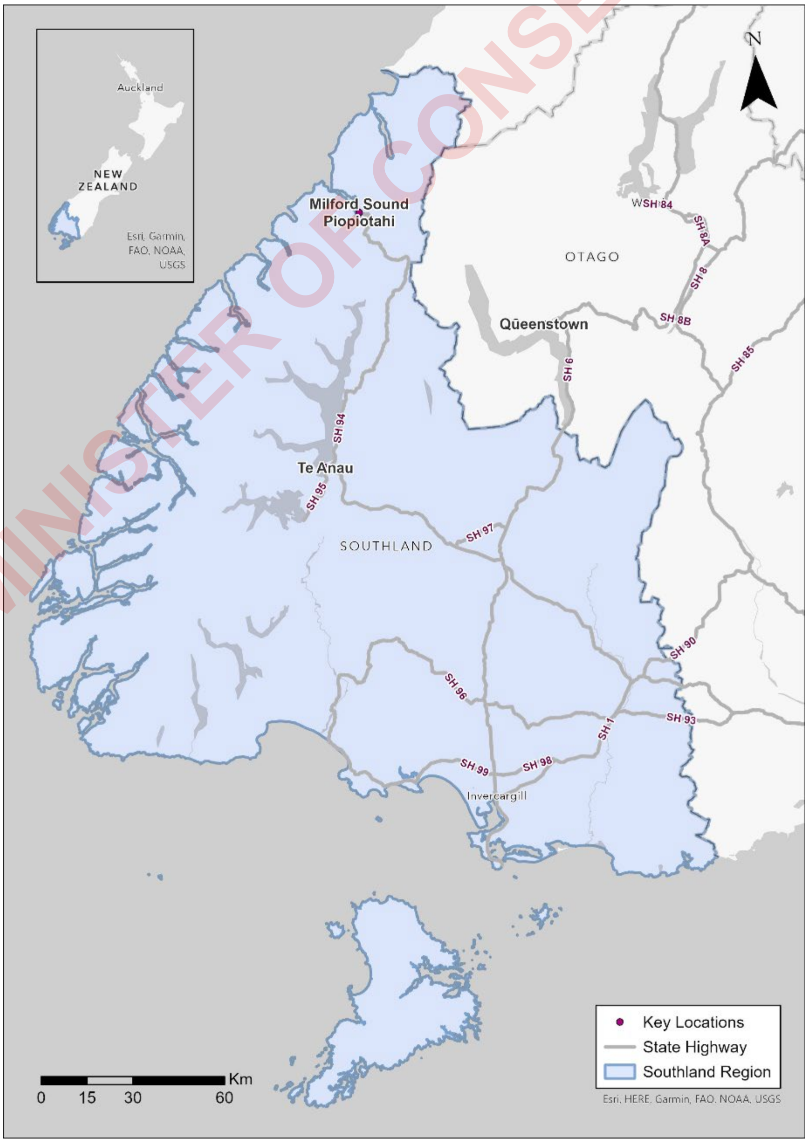

Figure 1-1: Milford Sound Piopiotahi

1.1.3 Tourism

Many tourism operators use SH94 to facilitate the bus trips that run from Queenstown to Milford Sound Piopiotahi and back in a day.

The long distance to Milford Sound Piopiotahi means that tourist operators will depart from Queenstown very early in the morning and arrive back late in the evening.

Subsequently, most tourists will visit Milford Sound Piopiotahi for a few hours around midday which creates congestion on the roads and at tourist facilities, particularly during the peak season in summer.

Some tourists arrive from the smaller tourism centre of Te Anau, which further exacerbates the high demand in the area.

Many tour boats operate around the peak-time demand to facilitate the movement of visitors around the area.

[1] 210503-MOP-Masterplan-FINAL.pdf (milfordopportunities.nz)

1.1.4 Milford Opportunities Project

The number of visitors to Milford Sound Piopiotahi more than doubled from around 437,000 to 883,000 in the six years between 2012 and 2018[2].

Much of this demand was derived from day trips from Queenstown, with visitors travelling to Milford either via bus or private motor vehicle. This is a journey of 290 km / 4 hours (one way).

As visitor numbers rose, this put more pressure on the natural environment as well the limited infrastructure along the Milford Road Corridor and wider Milford Sound Piopiotahi area.

Consequently, the Department of Conservation (DOC) and Southland District Council recognised that new thinking was required to safeguard the core character and values, World Heritage status, conservation values and the visitor experience.

The Milford Opportunities Project (MOP) was established in 2017 to investigate how the future of Milford Sound Piopiotahi, the road, the Te Anau basin, and wider region should be developed and managed.

Since its evolution, the MOP has been recognised as a government-funded initiative and is now overseen by the Ministers of Conservation, Tourism and Transport alongside Ngāi Tahu.

The initiative now seeks to look beyond the current constraints and explore ways to best implement a self-funded, sustainable tourism system for Milford Sound Piopiotahi.

1.2 Strategic Alignment

1.2.1 New Zealand Government Tourism Strategy

The focus of the New Zealand Aotearoa Government Tourism Strategy is:

> *"Te puāwai tonu o Aotearoa i te tupu tonu o te ao tāpoi New Zealand-Aotearoa through sustainable tourism growth".*

A main outcome emphasised in the strategy is to have regions and communities benefiting more from tourism.

As such, there is a desire to transform tourism in New Zealand from a model based on volume; a relatively short but intense peak tourist season, and intense concentration on a number of highly visited sites to a broader spatial and temporal spread and an increased focus on moving up the tourism value chain.

The strategy notes that visitors need the ability to get to where they want to visit in a safe, timely and cost-efficient manner. The journey should also be part of the visitor's experience, whether that be by walking, cycling, rail, road, sea, or air.

This is clearly demonstrated by the Milford Road, as it is considered to be one of the world's greatest road trips and a bucket list item for many international visitors to Aotearoa New Zealand.

1.2.2 Milford Opportunities Project Master Plan

The MOP Master Plan finalised in 2021 (by Stantec in collaboration with Boffa Miskell) includes outcomes around zero emissions tourism entailing a zero/low carbon bus fleet and hydroelectric power generation.

Specifically, these key outcomes include:

- The introduction of a managed access and transportation model to limit vehicle access and provide a better visitor experience on the road and encourage more even and widespread boat departures at Milford Sound Piopiotahi. Visitors will access by a park and ride bus service (some exceptions apply) at the Te Anau hub through a combination of express and hop on / off buses using zero carbon technology. Some limited priced and pre-booked parking would be retained at Milford Sound Piopiotahi, but at 60 percent less than current parking levels.
- Transitioning to a model that is largely public transport-based using zero carbon fuels has the potential to unlock a large range of benefits for Milford Sound Piopiotahi and New Zealand more widely.

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[2] Home - Milford Opportunities

The work delivered as part of this feasibility study forms part of the Masterplan and wider Milford Opportunities Project.

1.2.3 National Climate Change Goals

Transportation accounts for 17% of New Zealand's greenhouse gas emissions (GHG), 90% of which is attributed to road transport.

To reduce GHG emissions and meet New Zealand's domestic target under the Climate Change Response (Zero Carbon) Amendment Act[3], it is important that low / zero carbon emission options are explored in more detail within this study and more widely.

1.3 Purpose of this Study

1.3.1 Project Purpose

Stantec has been commissioned by the Department of Conservation (DOC) to investigate low / zero emission options for providing energy to the transportation system inclusive of a potential Te Anau – Milford bus service and existing tour boat operations, as well as supporting infrastructure at Milford Sound Piopiotahi and the Milford Corridor.

The objective of the feasibility study is to assess potential options to reduce or eliminate carbon emissions from bus and tour boat operations and identify options considered feasible for the specific requirements of Milford Sound.

[3] Climate Change Response (Zero Carbon) Amendment Act 2019 | Ministry for the Environment

2 Study Methodology

To provide a wholistic assessment of current and emerging technologies that support the transition to reduce or eliminate carbon emissions from bus and tour boat operations, this study has applied the following methodology as described in Figure 2-1 below.

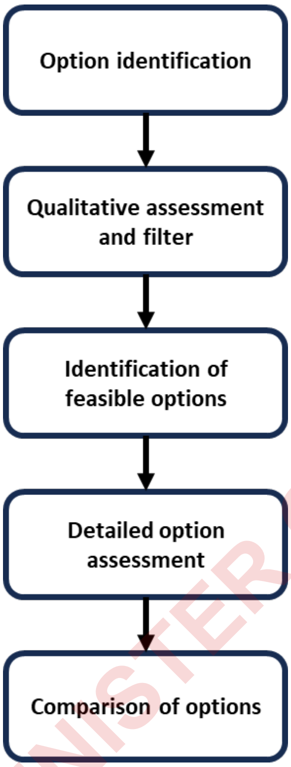

Figure 2-1: Study Methodology

This methodology allows for the identification and high-level appraisal of potential fuel or energy alternatives, with a short-list of feasible options assessed in greater detail to identify the potential advantages and disadvantages of each feasible option.

The specific characteristics of bus operations and tour boats in the context of Milford Sound Piopiotahi were identified and applied to each feasible option, then a general assessment of energy and infrastructure was undertaken. In addition, an overview of implementation considerations was also undertaken, including consideration of potential transition pathways to migrate the current operations to a low / zero carbon future was undertaken.

This study is limited to assessing the feasibility of reduced emission bus and tour boat services and excludes consideration of private transport, air travel and cruise ships which are out of scope of this investigation.

3 Study Area

3.1 Location

Milford Sound Piopiotahi is located in the remote southwest of the South Island of New Zealand and within the Fiordland National Park and Te Wahipounamu World Heritage Site.

Figure 3-1 shows the main route to Milford Sound Piopiotahi that is set out in the Master Plan. The Master Plan states there are opportunities to establish nodes and short stop experiences within this area between the Te Anau and Milford Sound Piopiotahi visitor hubs at the southern and northern end of the Milford Corridor.

On this basis, the study area shown below will be considered throughout this feasibility study.

Figure 3-1: Milford Sound Piopiotahi Study Area

3.2 Transport Access

Overland access to Milford Sound Piopiotahi is via SH94, a predominantly two-lane alpine highway that passes through Te Anau and terminates at Milford Sound Piopiotahi. It is also accessible by sea, with Milford Sound Piopiotahi maintaining berths for a fleet of commercial tour boat services and fishing vessels.

3.2.1 Long Distance Bus Access

The predominant form of access to Milford Sound Piopiotahi via overland transport is long distance bus services[4], although significant numbers of visitors also travel via privately owned transport.

[4] Almost 60% of visitors Milford Sound Piopiotahi do so by long-distance bus

Currently, most long-distance bus services focus on providing service from Queenstown to Milford Sound Piopiotahi, a round trip of approximately 600 km with a journey time of approximately 10 hours.

The Queenstown to Milford journey is at the limits of allowable drive time and provides limited opportunity for visiting key areas of interest along the Milford Corridor. The long journey time requires buses to depart very early from Queenstown which creates a heavy tidal flow of large volumes of buses travelling inbound in the morning and outbound in the afternoon.

The long journey time also means that most bus services from Queenstown arrive at Milford Sound Piopiotahi between 11am and 3pm, creating significant congestion during this period (see Figure 3-2 below).

Volumes of long-distance buses attending Milford Sound Piopiotahi vary according to seasonal demand, however during the peak summer season over 50 buses per day visit the area.

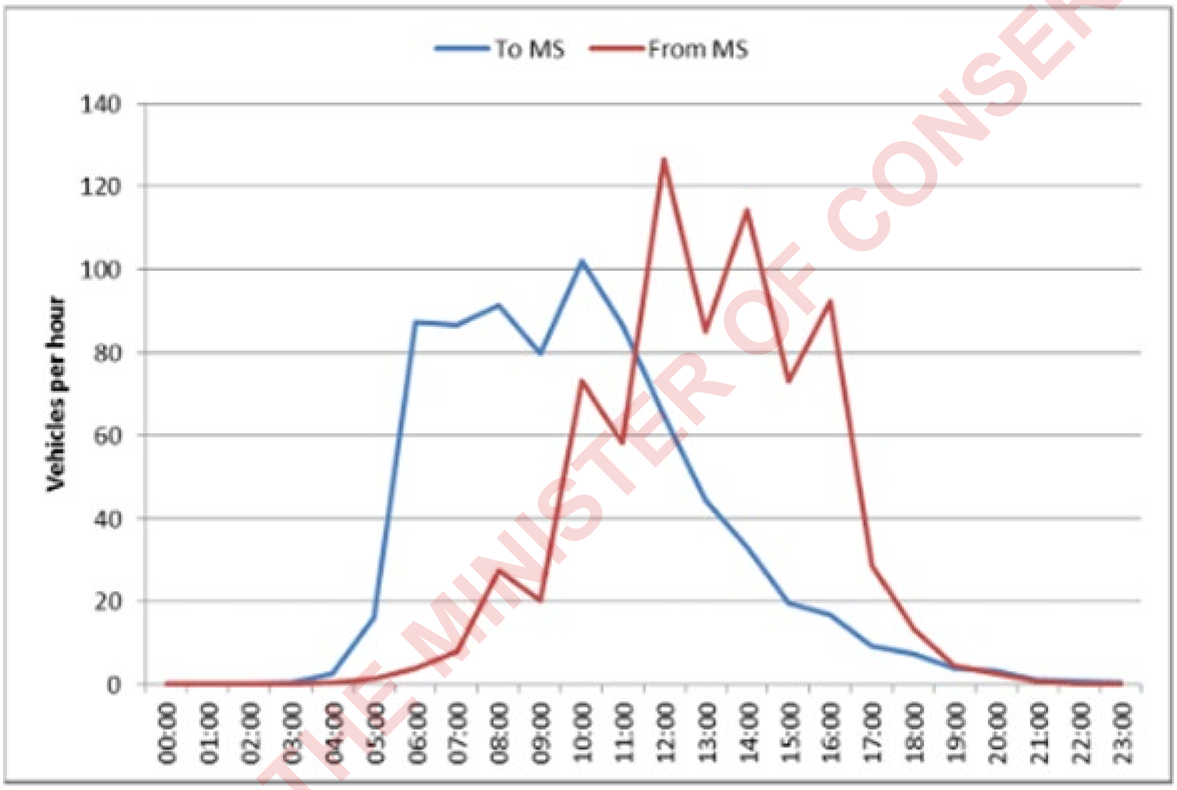

Figure 3-2: Vehicle Arrival Flow into Milford Sound Piopiotahi[5]

3.2.2 Tour Boat Services

Milford Sound Piopiotahi is home to a small fleet of commercial tour boats, which provide a range of tours around key attractions within Milford Sound Piopiotahi, as shown in Figure 3-3.

[5] 210331-Transport-and-Access-Report.pdf (milfordopportunities.nz)

Figure 3-3: Tour Boat Operations within Milford Sound Piopiotahi

In addition, some tourist vessels also provide overnight stays at moorings within the Milford Sound Piopiotahi.

Tour boats are commercial operations with vessels owned and operated by six different operators, as shown in Table 3-1 below.

Table 3-1: Milford Sound Piopiotahi Tour Boat Fleet[6]

Operator	Vessel Name
Southern Discoveries (SD)	Lady Stirling
Southern Discoveries (SD)	Spirit
Southern Discoveries (SD)	Pride
Southern Discoveries (SD)	Lady Bown
Fiordland Discoveries (FD)	Jewel
Real NZ (RNZ)	Sinbad
Real NZ (RNZ)	Mariner
Real NZ (RNZ)	Haven
Real NZ (RNZ)	Sovereign
Real NZ (RNZ)	Te Namu
Real NZ (RNZ)	Monarch
Cruise Milford (CM)	Adventurer
Cruise Milford (CM)	Explorer
Pure Milford (PM)	Gem
Pure Milford (PM)	Maiden
Mitre Peak Cruises (MP)	MP1
Mitre Peak Cruises (MP)	MP2

[6] Sourced from Milford Sound Summer Schedule 1 October 2023 – 30 April 2024

All tour boats in operation are berthed at Milford Sound Piopiotahi, with vessels rotating through the available berths according to the seasonal operating schedule.

An example of the summer (2023 / 24) tour boat operating schedule is provided in Figure 3-4.

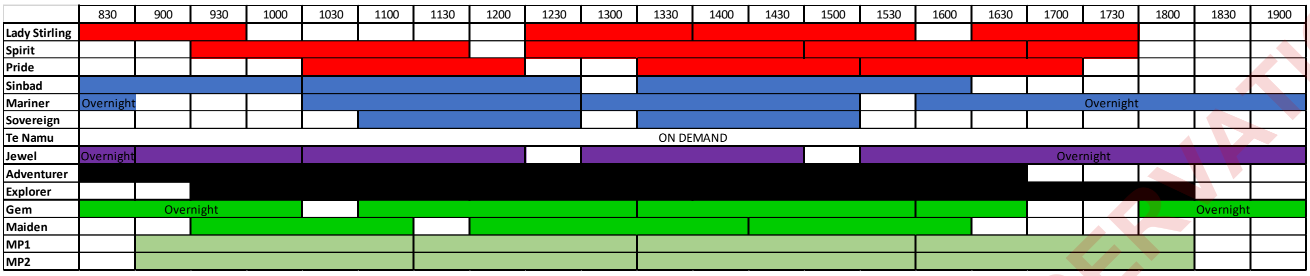

Figure 3-4: Tour Boat Operating Schedule (23/24 Summer)

4 Options Assessed

4.1 Introduction

Motive power systems have utilised a wide variety of different fuel and energy in various applications historically, however, with the advent of internal combustion and the widespread exploitation of abundant fossil fuels, fossilised hydrocarbons have become the dominant fuel for transportation globally since the early 20th century.

Fossil fuels, notably petroleum and its derivatives, provide an easily transportable fuel that has a high energy density at low cost. As the exploitation and refinement of fossil fuels is well established, the cost associated with a production and distribution system have long been recovered and fossil fuels are readily available and inexpensive relative to other fuels/energy.

With the large-scale global adoption of internal combustion motive systems, there is a considerable economy of scale in the provision and maintenance of internal combustion systems.

These advantages come at a considerable cost to the environment, with fossil fuel use responsible for the release of fossilised carbon into the atmosphere. This is a major contributor to global warming and produces other pollutants harmful to human health and the environment.

To provide a wholistic appraisal of all potential fuel and energy options, a range of alternatives have been assessed, inclusive of fossil fuels. This is to provide a summary of all potential options that may prove viable in addressing the specific challenges faced by transportation to and within Milford Sound Piopiotahi.

4.2 Carbon Positive Options

Carbon positive fuels are fuels that liberate fossilised carbon into the atmosphere, usually via combustion, thus increasing the net volume of global carbon.

Carbon positive fuels are formed naturally in the earth's crust from the remains of dead plants and animals that are exposed to heat and pressure over millions of years. The result is the formation of hydrocarbons, an organic compound formed from hydrogen and carbon. Carbon positive fuels occur in diverse range of forms including gas (natural gas) liquids (oil) and solids (coal). Fossil fuels may be refined into a number of products for end use, most notably petroleum and diesel, which is widely used in transportation applications including private and commercial motor vehicles, buses and buses and watercraft.

A fuel may be considered carbon positive even if it produces no carbon emissions at point of use[7], as the production mechanism may be either reliant on fossil fuels for energy, or as a by-product of the production process.

Table 4-1 below shows the carbon positive fuel options considered as part of this study. It should be noted that clean diesel is the current fuel in use for both bus services and tour boat operations, as well as in use as the fuel source for auxiliary power generation at Milford Sound Piopiotahi.

[7] Sometimes referred to as tail pipe emissions.

Table 4-1: Summary of Carbon Positive Options Assessed

Fuel Type	Transport Mode	Carbon Positive Options
Solid Coal	Boat	Coal is a solid form of rock mostly made up of carbon with a variable of other elements such as sulphur, hydrogen, and nitrogen. It is considered as a fossil fuel and has historically been used as a major power source of energy. Through the gasification of the solid rock a liquid fuel source can be extracted and used as a source of energy.
Coal Dust	Boat	Coal dust is a coal combustion product that is composed of the particulates that are driven out of coal-fired boilers. In the past, the product was simply entrained in flue gases. It can be used a lightweight aggregate (LWA) which offers the opportunity to recycle waste streams.
SynGas (Non-renewable pathways)	Boat	SynGas is a synthetic gas mixture primarily made up of hydrogen and carbon monoxide. It is highly combustible and often used as a form of diesel fuel. Syngas may be produced from a variety of mechanisms; however non-renewable pathways are dependent on the use of fossil fuels and are therefore carbon positive.
Heavy Fuel Oil (HFO)	Boat	Heavy fuel oil, often referred to as “refinery residual”, is a fraction petroleum product and is a blend of various oils. It is most widely used for large ocean-going commercial vessels.
Low Sulphur Fuel Oil (LSFO)	Boat	LSFO is a fuel mainly used for large ocean-going commercial vessels. It is low in sulphur with content below 1%, has a lower viscosity and density than conventional HFO.
Very Low Sulphur Fuel Oil (VLSFO)	Boat	VLSFO is a fuel type with sulphur content not exceeding 0.50% sulphur.
Ultra Low Sulphur Fuel Oil (ULSFO)	Boat	ULSFO is a fuel type with sulphur content not exceeding 0.10% sulphur.
Diesel	Both	Diesel fuel, also called diesel oil, is any liquid fuel specifically designed for a diesel engine. The most common type is a specific fractional distillate of petroleum fuel oil. It is often used to fuel heavy trucks, but diesel exhaust, especially in older engines, produces significant quantities of harmful emissions.
Clean Diesel (Do Minimum)	Both	Clean Diesel is diesel fuel with significantly reduced sulphur content. The diesel that is commercially available in New Zealand is considered to be clean diesel. In the context of this study, clean diesel is used as comparator to all other options.
Petrol / Gasoline	Both	Petrol / gasoline is a mixture of volatile, flammable liquid hydrocarbons derived from petroleum and used as fuel for internal-combustion engines. Gasoline is primarily used as an automobile fuel due to its high energy of combustion and capacity to readily mix with air in a carburettor.
Marine Diesel Oil (MDO)	Boat	MDO is a blend of gasoil and heavy fuel oil. It is widely used by medium to medium / high speed marine diesel engines. It is favoured particularly in the shipping industry due to its lower price compared to refined fuels. However, MDO has a high level of sulphur so many countries and organisation have established regulations and laws on MDO use.
Hydrogen (Non-green production pathway)	Both	Hydrogen may be combusted or chemically reacted to produce energy. It is one of the cleanest fuel sources at point of use and can be considered as a zero-carbon emission fuel as only water is produced as a by-product. Non-green production

Fuel Type	Transport Mode	Carbon Positive Options
		pathways for hydrogen are a by-product of hydrocarbon extraction and refinement. While the use of hydrogen is carbon free, extraction of non-green hydrogen produces significant GHG emissions.
Blended Diesel	Both	Blended diesel, or E-diesel, is a blend of ethanol with diesel fuel. Standard diesel fuel is typically blended with up to 15% (by volume) of ethanol using an additive package that helps maintain blend stability and other properties.
Liquified Natural Gas (LNG)	Both	LNG is liquified methane gas, extracted and purified from fossil fuel reservoirs via hydrocarbon extraction processes.
Compressed Natural Gas (CNG)	Both	CNG is liquified methane gas, extracted and purified from fossil fuel reservoirs via hydrocarbon extraction processes.

4.3 Carbon Neutral Options

A carbon neutral fuel produces no net increase in global carbon emissions and are produced through the capture and recycling of atmospheric carbon. Carbon fuels may be broadly categorised into two categories:

- **Biofuels** – which are produced by organic processes, often utilising biomass or organic waste products.
- **Synthetics** – which are produced chemically by hydrogenating carbon dioxide.

Carbon neutral fuels are compatible with internal combustion engines and are combusted to produce energy, resulting in localised carbon emissions at point of use. The combustion process can also produce quantities of harmful emissions or particulates depending on the specific biofuel used.

Table 4-2 below shows the carbon neutral options that were assessed.

Table 4-2: Summary of Carbon Neutral Options Assessed

Fuel Type	Transport Mode	Carbon Neutral Options
Pulverised Flammable Powder (Excluding coal dust)	Boat	Carbon based powders are extremely combustible when mixed with air and may be used in internal combustion.
Wood – Solid Fuel	Boat	Solid wood fuel is a biomass sourced from wood, charcoal, chips, sheets, or sawdust. It is considered to be one of the oldest heating sources, although is now the largest use of energy derived from a solid fuel biomass.
Wood – Pelletised Wood	Boat	Wood pellets are the most common type of pellet fuel and generally made from compacted sawdust and related industrial wastes from the milling of lumber, manufacture of wood products and furniture and construction. It can emit large quantities of poisonous carbon monoxide during storage. When handled, wood pellets give off fine dust which can cause serious dust explosions.
Agricultural Bioethanol	Both	Agricultural bioethanol is derived from plants cultivated expressly for its production. These plants are usually rich in cellulose and include sugar cane, sugar beets or some grains e.g., corn. It emits less CO_2 than fossil fuels, combustion does not generate smell or waste and CO_2 can be captured and used in industrial application.
By-product Bioethanol	Both	By-product bioethanol comes from agricultural / urban waste, mainly the decomposition of biomass coming from wood. It can also be obtained from plant species not intended for food, such as algae. It emits less CO_2 than fossil fuels and

Fuel Type	Transport Mode	Carbon Neutral Options
		combustion does not generate smell or waste and the CO_2 can be captured and used in industrial application.
Agricultural Biodiesel	Both	This is a form of diesel fuel derived from plants and animals, consisting of long-chain fatty acid esters. In transport, biodiesel is typically used as a diesel substitute and can also be used in residential and industrial space heating. It is a drop-in biofuel, meaning it is compatible with existing diesel engines and distribution infrastructure. It is usually blended with petro-diesel since most engines cannot run on pure biodiesel without modification.
Renewable Biodiesel	Both	This is a diesel equivalent fuel derived from agricultural materials that have the potential to provide a clean-burning alternative to petroleum.
Synthetic Diesel	Both	Produced from the direct capture of atmospheric carbon and the chemical hydrogenation of carbon dioxide and hydrogen.
Hydrogen Production (Biomass / waste)	Both	Biomass-derived liquid reforming is one of the pathways to produce hydrogen. Renewable liquid fuels, such as ethanol, are reacted with high-temperature steam to produce hydrogen near the point of end use. Bio-mass derived liquids can be transported more easily than their biomass feedstocks, allowing for semi-central production or possibly distributed hydrogen production at fuelling stations.
Biomethane	Both	Biogas is produced through reforming and fermentation of waste material to produce hydrogen. It utilises naturally occurring biological methane.
Methanol (Green production pathways)	Both	Green methanol is produced from low carbon sources, such as biomass or via carbon capture. It can be used in transport fuel and as feedstock, it can be blended with traditional gasoline or diesel fuel and has a lower sulphur content. However, it is expensive, flammable and requires double the fuel tank size compared to its oil equivalent.
Ethanol	Both	This is a renewable, domestically produced alcohol fuel made form plant material such as corn, sugar cane or grasses. The most common blend is E10 (10% ethanol, 90% gasoline). It is also available as E85 (or flex fuel) which is a high-level blend containing 51-83% ethanol depending on geography and season.
Butanol	Both	Butanol is produced from the same feedstocks as ethanol, including corn grains and other biomass. Biobutanol is an alternative to conventional transportation fuels and the benefits include higher energy content, lower Reid vapour pressure, increased energy securing, fewer emissions and more transport options.

4.4 Carbon Free Options

Carbon free fuel or energy does not use carbon to produce energy, and therefore, produces no carbon emissions. Carbon free fuels/energy use renewable electrical power generation to provide motive power, however, there are different approaches to how this energy may be stored and transported. These approaches include:

- **Hydrogen based systems,** including ammonia store electrical energy chemically, allow for long term storage, but the conversion of electricity is inefficient.
- **Electrical systems** store electricity in batteries or other energy storage mediums, which provide highly efficient energy conversion at point of use, however, they have very poor long term energy retention.

Table 4-3 below shows the carbon free options that were assessed.

Table 4-3: Summary of Carbon Free Options Assessed

Fuel Type	Transport Mode	Carbon Free Options
Hydrogen (Green production pathway)	Both	The green production pathway uses 100% renewable energy to split water into hydrogen and oxygen. The oxygen output is also a key benefit in this process, with oxygen production being eight times the mass of hydrogen produced.
Ammonia (Green production pathway)	Both	Green ammonia can be produced by using renewable energy to create hydrogen through electrolysis, and then running it through a Haber-Bosch process powered by green energy as well. Other fully green methods under development, include "reverse fuel cell" technology that converts renewable energy, water, and air into ammonia without needing a separate hydrogen electrolysis process.
Electricity (Sustainable generation)	Both	Electrofuels are a type of drop-in replacement fuel. They are manufactured using captured CO_2 or CO, together with hydrogen obtained from sustainable electricity sources such as wind, solar and nuclear power. The process uses CO_2 in manufacturing and releases around the same amount of CO_2 into the air when the fuel is burned, for an overall low carbon footprint.

5 Qualitative Options Assessment

5.1 Long-list Options

A long-list of potential fuel types was developed and qualitatively assessed across 16 criteria that considered the potential emissions reduction and environmental impacts of fuel or energy options, as well practical and operational factors that influence their viability within the context of Milford Sound Piopiotahi.

A 'Traffic Light Assessment' approach was used to assess the fuel options against the selected criteria i.e., red to highlight negative impacts of the fuel type, orange as moderate, and green as low.

The criteria descriptions along with the results from the long list options assessment can be found in Fuel Option Qualitative Assessment Appendix A.

5.2 Short-list Options

To identify the most feasible option(s) that would align with providing a low / zero carbon fuel alternative, the following points were considered when refining the long-list of options:

- The potential for the reduction or elimination of carbon emissions was considered fundamental to the project objectives. Therefore, any option that produced positive carbon emissions was therefore ruled out as viable options.
- The potential availability of the fuel or energy must be available and have the production potential to meet demand for Milford Sound Piopiotahi operations to be considered practically feasible. Therefore, any option dependent on a fuel that was not in production and readily available at least on the global market was also eliminated as unfeasible.
- The relative maturity and commercial availability of motive power systems supported by the fuel was identified as a key consideration. Motive power systems compatible with both bus and watercraft must be available and mature for them to be considered applicable as replacement for existing bus and boat motive systems within Milford Sound Piopiotahi.

Subsequently, all fuel options were ranked against the following three criteria to determine the potential fuel options:

- GHG Emissions
- Fuel Availability
- Maturity

Table 5-1 provides the results from the qualitative options assessment.

Table 5-1: Long-list Fuel / Energy Options

Fuel/Energy Option	GHG Emissions	Fuel Availability	Maturity
Solid Coal	[red]	[green]	[orange]
Coal Dust	[red]	[green]	[red]
SynGas (Non-renewable pathways)	[red]	[red]	[green]
Heavy Fuel Oil (HFO)	[red]	[green]	[green]
Low Sulphur Fuel Oil (LSFO)	[red]	[green]	[green]
Very Low Sulphur Fuel Oil (VLSFO)	[red]	[green]	[green]
Ultra Low Sulphur Fuel Oil (ULSFO)	[red]	[green]	[green]
Diesel	[red]	[green]	[green]
Clean Diesel (Do Minimum)	[red]	[green]	[green]
Petrol / Gasoline	[red]	[green]	[green]
Marine Diesel Oil (MDO)	[red]	[green]	[green]
Hydrogen (Non-green production pathway)	[red]	[green]	[green]
Blended Diesel	[red]	[green]	[green]
Liquified Natural Gas (LNG)	[red]	[green]	[green]
Compressed Natural Gas (CNG)	[red]	[green]	[green]
Pulverised Flammable Powder (Excluding coal dust)	[orange]	[red]	[red]
Wood – Solid Fuel	[orange]	[green]	[red]
Wood – Pelletised Wood	[orange]	[green]	[red]
Agricultural/renewable Biodiesel	[orange]	[orange]	[green]
Synthetic Diesel	[orange]	[orange]	[orange]
Hydrogen Production (Biomass / waste)	[orange]	[red]	[orange]
Biomethane	[orange]	[red]	[orange]
Methanol (Green production pathways)	[orange]	[orange]	[red]
Butanol	[orange]	[red]	[red]
Hydrogen (Green production pathway)	[green]	[orange]	[orange]
Ammonia (Green production pathway)	[green]	[green]	[red]
Electricity (Sustainable generation)	[green]	[green]	[green]

KEY	GHG Emissions	Fuel Availability	Maturity
[green]	Produces no global GHG emissions during production or use	Fuel is produced at scale and readily available on the open market.	Technology is in large scale use and readily available on the commercial market
[orange]	Provides no net increase to global GHG emissions during production or use	Fuel is in limited commercial production	Technology is in limited use (small scale trials) and has limited market availability.
[red]	Produces positive GHG emissions during production or use	Fuel is not currently available or produced at scale.	Technology is at prototype only and is not available on the commercial market.

Based on this assessment, the following options were identified as the most feasible for low / zero carbon solutions for bus and boat operations to and within Milford Sound Piopiotahi:

- **A range of carbon neutral drop-in fuels** - These provide opportunities to reduce carbon emissions but produce localised carbon and harmful emissions. Carbon-neutral fuels are produced domestically at a relatively small scale, but production can be scaled up if demand eventuates. Furthermore, the use of biofuels and synthetic fuels is mature, with these fuels emulating fossil fuels and may be used in place of fossil fuel diesel in conventional internal combustion engines. Carbon-neutral fuels offer advantages in terms of ease of conversion.
- **Green Hydrogen** - Hydrogen provides an emissions free fuel that may be easily produced with water as the feedstock. Current commercial production is low, but hydrogen may be produced on a relatively small scale. The use of hydrogen in transport applications has been trialed extensively and is in commercial production.
- **Electricity** - Electricity is clean, readily available and produced predominately through renewables. Electrical motive systems are in widespread production and use and battery electric motive systems are readily available on the market.

Overall, the assessment highlighted that electricity is the best performing option against the three assessment criteria. This is because electric fuel emits zero emissions which aligns with the study objectives. In addition, this option is well established globally compared to hydrogen and low / neutral carbon drop in fuels, and therefore, more readily available and affordable.

6 Detailed Options Assessment

While the qualitative assessment provided a high-level appraisal of factors that influence of a fuel's potential feasibility, a detailed assessment was also required to determine the specific requirements, opportunities, and limitations of each option relative to the specific operating requirements and conditions of Milford Sound Piopiotahi.

The detailed assessment also considered key concepts from the Milford Opportunities Project Masterplan, which seek to control access to Milford Sound Piopiotahi coupled with the introduction of park and ride bus service from Te Anau - Milford Sound Piopiotahi using low / zero-emission vehicles.

The detailed assessment considers the following:

- The composition and design of alternative motive powers systems for both bus and tour boat services.
- An assessment of the fuel/energy requirements for each option.
- An assessment of the potential infrastructure required to support the use of the fuels.
- Consideration of potential implications to current operations imposed by the use of an alternative motive power system.
- Consideration of the maintenance requirements of alternative systems.
- Consideration of the potential operational life span and end of life disposal of systems.

6.1 Overland Route Profile

SH94 provides the only overland access to Milford Sound Piopiotahi. The route from Te Anau to Milford Sound Piopiotahi is approximately 120 kms (one way) and is predominantly two-lanes.

SH 94 is an alpine highway, climbing from sea level at its lowest point to over 900 m at the route's apex.

The route includes the 1.2 km Homer tunnel which connects the valley of the Hollyford River to the Cleddau Valley. The tunnel is limited to one way operation, with access controlled by traffic signals. The alpine section of SH94 is avalanche prone in winter and spring, particularly near the entrances to the tunnel portals.

The route elevation profiles for the Te Anau - Milford Sound Piopiotahi and return are shown in Figure 6-1 and Figure 6-2 respectively.

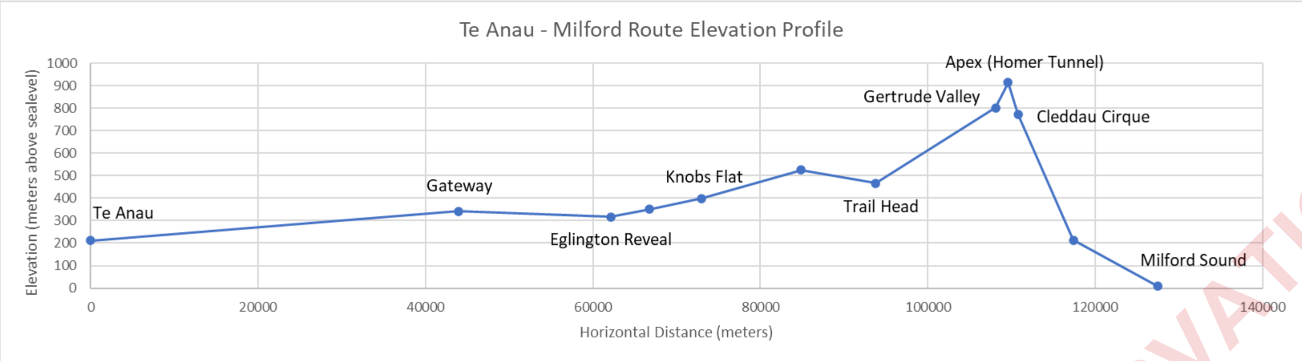

Figure 6-1: Te Anau - Milford Sound Piopiotahi Inbound Route Elevation Profile

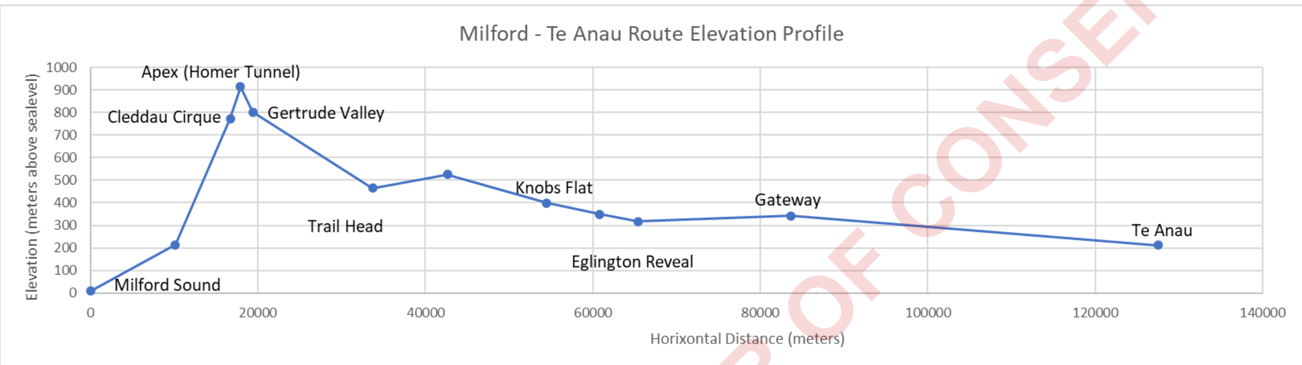

Figure 6-2: Milford Sound Piopiotahi - Te Anau Outbound Route Elevation Profile

As Figure 6-1 and Figure 6-2 illustrate, the maximum elevation change for vehicles occurs on the return journey as SH94 climbs from sea level to the eastern portal of the Homer tunnel via the Cleddau Cirque. This leg requires a climb of over 900m vertical meters.

For the inbound journey from Te Anau - Milford Sound Piopiotahi, the route elevation profile and climb is less steep, with the largest elevation change occurring between the Trail Head and the eastern portal to the Homer Tunnel via Gertrude Valley.

6.1.1 Route Weight Restrictions

Weight restrictions are an important design consideration where new forms of motive power are considered for use. Some components of different motive power systems, such as batteries, are very heavy and vehicle design must consider route weight restrictions during design.

Roads in New Zealand have legislation that governs the maximum dimensions and mass of vehicles. These rules are defined in the Land Transport Rule: Vehicle Dimensions and Mass 2016[8].

Bridges may be posted with specific weight restrictions that take precedence of the limits stated in the legislation.

There are six bridges on SH94 between Te Anau and Milford Sound Piopiotahi, however none have posted weight restrictions.

Generally, vehicle weights are limited to no more than 39,000 kg, however different axle configurations may be used to enable heavier vehicle designs.

6.2 Demand Profile

The number of visitors to Milford Sound Piopiotahi varies from year to year, with the COVID-19 pandemic and associated border closures and disruption to global movements significantly curtailing visitor access during the 2020 – 2022 period.

[8] Land Transport Rule - Vehicle Dimensions and Mass 2016 | NZ Transport Agency (nzta.govt.nz)

Prior to the COVID-19 pandemic, visitor numbers to Milford Sound Piopiotahi peaked at 946,000 in the 2018 / 2019 season, the majority of these visitors travelling overland via SH94 by bus or private motor vehicle.

In order to assess the energy requirements associated with a return bus service connecting Te Anau – Milford Sound Piopiotahi, the following demand scenarios were applied:

Table 6-1: Demand Scenarios

Daily Passenger Volume	Number of Buses Required[9]
1,200	25
2,000	41
4,000	82
6,000	122

These demand scenarios will be further refined subject to the completion of further transport modelling which is being undertaken as part of separate project.

6.2.1 Operations

For the purposes of assessing the park and ride bus service from Te Anau - Milford, buses are assumed to depart from a depot located proximate to Te Anau. Buses are assumed to make three stops at key activity nodes on the inbound journey and a further three stops on the return journey, attending those destinations along the corridor not attended by the inbound journey.

In practice, the operational timetable may provide multiple stopping patterns throughout the day to ensure regular attendance at all nodes along the corridor. This provides visitors with the opportunity to access bus services at any location and in any direction of travel throughout the day.

It is noted that overland transport to Milford Sound Piopiotahi currently has a heavy tidal pattern, with an influx of vehicles towards Milford Sound Piopiotahi during the morning and reverse outbound flow in the evening. This pattern works well with the one-way access control at the Homer Tunnel. The introduction of park and ride bus connections with a hop on / hop off stopping pattern throughout the day may change this tidal flow and result in greater delay for vehicles moving through the tunnel.

The operational schedule for tour boats serving these customers is shown in Figure 3-4 previously, and for the purposes of assessing energy requirements for these watercrafts, this operational profile is assumed to be maintained. Depending on the number and arrival pattern of visitors to Milford Sound Piopiotahi due to the introduction of a bus connection between Te Anau and Milford Sound Piopiotahi, additional sailings may be required in the morning or evening to meet visitor demand.

[9] Coach requirement assumes a passenger capacity of 49 passengers per vehicle and excludes additional spare vehicles required for operational redundancy.

7 Battery-electric Motive Power Feasibility

7.1 Introduction

Electricity has been adapted for use in a huge and diverse range of application, ranging from commercial and industrial applications to being the standard energy for domestic appliances.

Electricity may be generated through wide variety to mechanisms, including power generation through hydrocarbon combustion (such as coal or oil) or generated through renewable mechanisms such as hydro-electric, geothermal, photo-voltaic or wind turbine power generation.

Electricity produced by renewables produce no carbon emissions. In New Zealand, 82% of the national grid generated electricity is via renewable sources, predominately hydro-electric. This high percentage is largely attributed to all the South Island's electric consumption being derived from renewables.

The remaining 18% is supplied by coal and natural gas-based power generation. However, with the current proportion of renewable power generation, carbon emissions per unit of power generated are low and carbon intensive power generation is scheduled to be completely phased out by 2050.

As a result, electricity is a viable 'fuel' for eliminating carbon emissions in several sectors.

Evolution in battery technology in recent decades has made battery electric systems increasingly more viable for transportation, with batteries in particular evolving to provide improved energy retention, capacity and performance with reduced weight and size.

Long-term storage of electrical energy remains the largest challenge to widespread adoption, with most energy storage mediums allowing energy retention for hours or days only. While this is typically acceptable for day-to-day transport operations, long term storage is a factor where power generation is limited, or if there is limited access to grid generated electricity.

The storage of electrical energy in transport systems may be accommodated in a number of ways, including:

- **Batteries** – capable of storing a relatively large amount of electrical energy but are limited in the rate and output of energy that they can achieve for charging or discharging. Batteries may be comprised of a variety of different chemistries, however, lithium-Ion batteries are currently the most ubiquitous form in use in transport applications.
- **Super capacitors** – can charge or discharge rapidly, allowing for rapid acceleration, however they have low storage capacity which limits their effective range unless supplemented by regular enroute charging.
- **Fly Wheels** – store energy kinetically by accelerating and maintaining a rotor (the fly wheel) to a very high speed but are difficult to maintain and can fail catastrophically.

Of these storage systems, batteries are the preferred storage medium for transport in both bus and watercraft.

Electric motive systems are highly efficient, with between 70% and 90% of electrical energy converted into motive power. By way of comparison, diesel based internal combustion is around 45% efficient.

7.2 Composition of Battery-Electric Motive Power System

Battery-electric systems, irrespective of the mode to which they are applied, contain the similar basic components to function effectively:

- **Batteries** – to provide a storage medium for energy.
- **Battery Management System** – to regulate the state, performance, and charge of batteries.
- **Battery Coolant Systems** – that regulate the battery temperature to maintain optimal performance and mitigate the change of battery overheat.
- **Electric engine** – to convert electrical energy into motive power.

In addition, some systems also include regenerative energy capture, where energy used to break the vehicle is recaptured, converted and stored as electrical energy. Regenerative breaking is a feature of land based electrical motive systems including buses but is of limited effectiveness for watercraft due to water-resistance.

A diagram of a conceptual battery-electric system is illustrated in Figure 7-1 below.

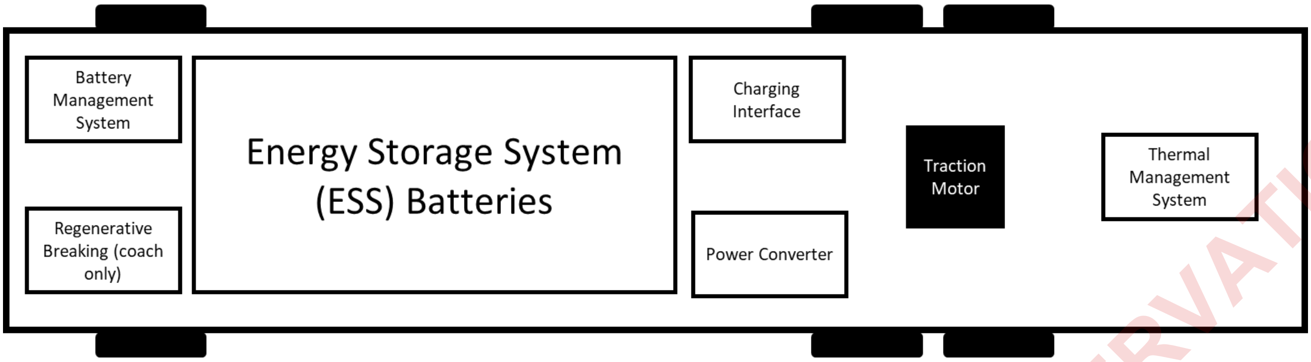

Figure 7-1: Components of a Battery-electric Motive System

7.3 Battery-electric Buses

A battery-electric bus is a long distance, high-capacity passenger vehicle that is driven by an electric motor, with energy stored on-board in batteries.

Battery-electric buses first entered service in the early 20th century, however, the constraints imposed by the weight and capacity of the battery systems of the day limited their application. The widespread exploitation of fossil fuels that occurred during the same period, coupled with the low cost and high energy density fossil fuel(s) resulted in diesel based internal combustion becoming the standard motive system for long distance bus travel.

Improvements in battery technology, particularly over the last decade, have reduced the weight and increased the storage capacity of batteries. Battery-electric buses are now in service in significant numbers, with may metropolitan operators converting their entire fleet in battery-electric systems.

These improvements to batteries have also extended the range of batteries, making battery-electric systems more viable for long distance travel. Improvements in battery charging also means regenerative energy capture is more effective, resulting in further increases in range.

7.3.1 Design Trade-offs

Battery weight is a key factor in vehicle design as this contributes to the vehicle weight.

Vehicle weight is a key consideration in the achievable range of a motive power system, as heavier vehicles require more energy to create motive power. Larger capacity battery systems, while allowing larger volumes of electricity to be stored, also significantly increase weight which can result in an iterative cycle to right-size the appropriate battery weight and capacity to match the specific range requirements of the bus. Increasing battery capacity also potentially decreases the number of passengers that may be carried. The total weight of a battery-electric bus cannot exceed the weight restrictions imposed by the vehicle dimensions and mass legislation.

The provision of enroute recharging may be used to reduce the requirement for additional batteries, by providing opportunities for buses to 'top up' their energy reserves on route. Charging stations situated at strategic locations along a route, such as mid-way up a climb, allow vehicles to restore battery charge, mitigating the requirement for additional or larger batteries and the associated increase in weight.

The conversion of existing diesel buses to battery-electric systems is likely to be prohibitively challenging and costly.

7.4 Battery-electric Boats

A battery-electric boat is a water going craft driven by electric motors with energy stored in onboard batteries (see example in Figure 7-2 right).

As was the case with many transport applications, electricity was first used as a motive power system for vessels in the late 19th century, with the first battery electric vessel used in 1880. The invention of internal combustion and the development and exploitation of fossil fuels quickly resulted in the decline of battery-electric watercraft, with first gasoline and then diesel becoming the prevalent fuel from the 1920's onwards.

Battery-electric motive power systems for boats and ships are once again a focus of significant research and investment, driven by their potential to provide zero-emission energy, as well as the price of electricity, which is significantly lower than many fossil fuels.

Figure 7-2: East by West Battery-electric Boat Operating in Wellington

The design characteristics and operating environment of watercraft introduces some distinct challenges, comparative to landbound systems. Watercraft must contend with fluid dynamics and water resistance, which mitigates significant regenerative energy capture. Operating speed is also a crucial consideration, with fast operating speeds (20 knots or higher) requiring exponentially more energy than slow operating speeds (5 knots or less) due to drag.

Watercraft must also contend with highly variable operating conditions, with swell, current and wind all impacting range, performance, and efficiency.

Unlike land-based systems, there are often few opportunities for enroute recharging.

7.4.1 Design Trade-offs

The design of battery-electric watercraft is considerably more complex than the bus equivalent.

As is the case with battery-electric buses, battery weight is key consideration and point of trade off in the design of battery-electric watercraft, however vessels must also consider distribution of this weight and how it impacts displacement, which also impacts the handling and performance.

The higher the weight, the more water is displaced, resulting in increased drag and an increased energy requirement to provide motive power. As batteries weigh significantly more than their equivalent diesel fuel tank, weight reduction is required to reduce displacement and provide energy efficiency and range. Similar to the design of buses, there is an iterative design process to right size batteries to the vessel, seeking to strike the right balance between energy storage and weight.

To combat weight increases imposed by battery-electric systems, watercraft may use lighter materials such as aluminum or carbon composites, which also impact the handling maintenance of the vessel over its lifetime.

Hull form is also key element of the design process, with the requirement to manage weight often resulting in decreased draft.

Electric engines also introduce new design challenges. Electric engines provide the ability to accurately control the release of energy and have the potential to provide extremely high torque. With the use of lighter hull materials comes decreased rigidity and strength and vessel design needs to ensure electric engines are structurally supported.

Battery-electric watercraft are very different from the diesel based boats currently in service. The complexities imposed in particular by the management of battery weight mean that conversion of existing watercraft to battery-electric motive power is likely to be prohibitively challenging and the use of battery-electric systems will require the introduction of new vessels.

7.5 Energy Consumption

7.5.1 Battery Electric Bus Energy Consumption

The energy consumption of battery-electric buses is not uniform. Many different factors impact energy consumption, including:

- Individual driving behavior.
- Temperature.
- Road and weather conditions
- Route profile.

Of these variables, the route profile is the most significant in determining overall energy consumption.

As battery-electric buses include the ability to capture and regenerate electricity, the energy consumption of the vehicle changes at is ascends and descends significant grades. Energy expenditure for ascending grades is significantly higher than that required for level operation, while on the decline buses have the ability 'top up' their batteries on the move with energy recovered from the braking system.

The energy consumption profile for the Te Anau - Milford Sound Piopiotahi and return journeys are illustrated in Figure 7-3 and Figure 7-4.

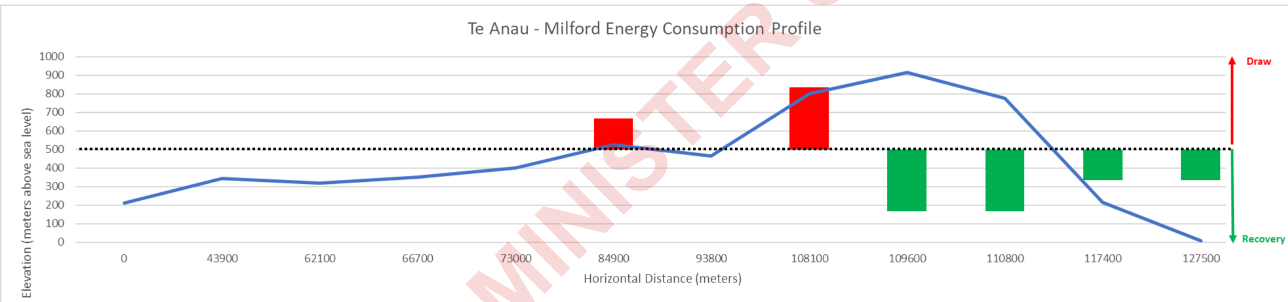

Figure 7-3: Te Anau - Milford (Inbound) Energy Consumption Profile

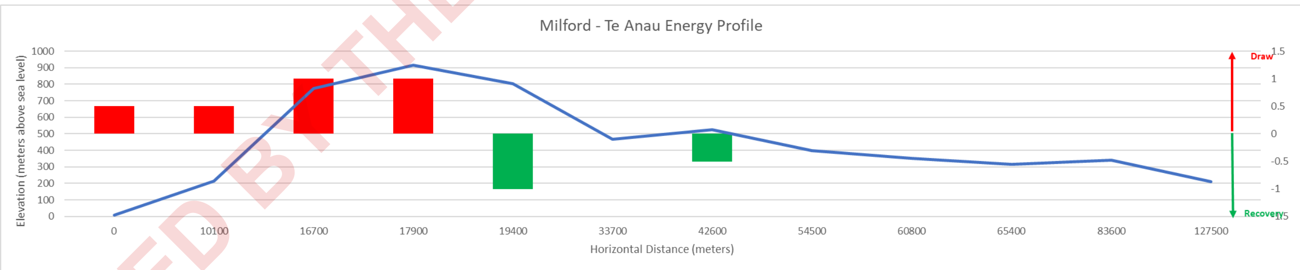

Figure 7-4: Milford - Te Anau (Outbound) Energy Consumption Profile

As these profiles show, power consumption for the inbound journey peaks on the climb from Trail Head to the apex of the route at the entry portal to the Homer tunnel beyond this point, buses recover energy on the downgrade from Cleddau Cirque to Milford Sound Piopiotahi.

The inverse is true for the return journey. The most significant energy consumption for the journey occurs on the outbound leg on climb from sea level at Milford Sound Piopiotahi to the apex of the route at close to 940 m above sea level.

For the purposes of assessing the potential energy requirement for battery-electric buses for the return journey from Te – Anau to Milford, the following reference vehicle was used to model potential energy requirements:

- Battery Capacity: 400 kWh[10]
- Passenger capacity: 49 passengers
- Average operating speed: 80 km/h
- Peak operating speed: 100 km/h
- Base energy consumption rate: 1.5 kW/km

As outlined in 7.3.1 above, there many potential design tradeoffs to consider in choosing an appropriate battery capacity and bus design. The reference vehicle was chosen as it is equivalent to long distance battery-electric buses currently in service in New Zealand.

The daily energy consumption of the design vehicle was assessed against the demand scenarios as shown in Table 7-1.

Table 7-1: Battery-Electric Bus Energy Consumption Assessment

Daily Passenger Volume	Number of Buses Required	Energy Requirement at Milford
	Single Vehicle	559 kWh per day[11]
1,200	25	3,894 kWh per day
2,000	41	6,489 kWh per day
4,000	82	12,979 kWh per day
6,000	122	19,468 kWh per day

The energy assessment indicated for a single bus, the energy requirement for a return journey from Te Anau – Milford required 559 kWh[12], which exceeds the available capacity of the 400 kWh battery. This means the Te-Anau to Milford and return journey exceeds the energy storage capacity of the batteries and in order for battery-electric buses to be feasible, vehicles must have opportunity to recharge enroute[13].

Table 7-1 provides a summary of the energy required to support bus operations under different demand scenarios.

In practice, the assessment indicates that battery-electric buses have sufficient energy to reach Milford Sound Piopiotahi however they will require recharge in order to have sufficient energy for the return journey. Recharging will be required at Milford Sound Piopiotahi or enroute[14] between Milford Sound Piopiotahi and the Cleddau Cirque.

Operations typically require an operating margin of around 15%[15] of the total battery capacity. In addition, battery performance also declines in cold weather and significant energy margins would be appropriate given the variability of seasonal climate and condition of the route, particularly if vehicles are required to use chains.

In practical terms, for a 400 kWh battery-electric bus, approximately 60 kW are reserved for battery management, onboard systems, cooling etc. A further 60 kW are reserved as operating margin, with the remaining 280 kW representing the practical energy and range for the vehicle.

This assessment concludes that given the operational profile and expected energy consumption of battery-electric vehicles, recharge will be required either at Milford Sound Piopiotahi, or enroute between Milford Sound and the Cleddau Cirque.

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[11] A 400 kWh battery has been referenced, as this battery size is currently in use in long distance bus services in New Zealand
[12] Including energy allowances for onboard systems and battery management.
[13] Battery capacity and range have improved significantly over the past decade and it is likely that battery capacity will continue to improve in the future. The assessment of energy consumption and the conclusion that enroute charging will be required is based on the limitations evident with current technology and advancements in battery capacity may negate this requirement in the future.
[14] Enroute recharging will require sufficient space to allow multiple vehicles to recharge simultaneously and must have access to sufficient power generation or transmission.
[15] The 15% operating margin is typically imposed by operators to provide a safety margin and ensure battery capacity is maintained. While the operating margin may be reduced, this margin should reflect the route profile and the risk profile of a vehicle running out of motive power during operation.

7.5.2 Battery-Electric Tour Boat Energy Consumption

There are a large range of variables that have the potential to affect the energy consumption of watercraft, with boat design arguably the most significant in terms of its impact energy efficiency.

The current fleet of tour boats serving Milford Sound Piopiotahi are not of uniform design, with a variety of different vessels currently service.

To provide a high-level appraisal of the potential energy requirements of converting tour boat operations to battery-electric motive systems, the current tour boat fleet has been used as the basis for estimating energy requirements.

For the purpose of the assessment, each boat in current service has been categorised by size, with battery capacity scaled according to the size of the vessel, as shown in Table 7-2.

Table 7-2: Tour Boat Battery Capacity Assumptions

Vessel	Category	Assumed Battery Capacity (kWh)
Lady Stirling	Small	200
Spirit	Medium	500
Pride	Large	800
Jewel	Medium	500
Sinbad	Small	200
Mariner	Medium	500
Haven	Medium	500
Sovereign	Large	800
Te Namu	Small	200
Adventure	Medium	500
Explorer	Medium	500
Gem	Small	200
Maiden	Medium	500
MP1	Medium	500
MP2	Medium	500

The following observations informed the assessment of the potential energy consumption of tour boats:

- Vessels are assumed to have no regenerative energy capture.
- Tour operations within Milford are a mix of low and high-speed operations.
- There are no opportunities to charge watercraft while in service. All recharge must therefore occur when the vessel is berthed at Milford Sound Piopiotahi.

Based on these observations, it is assumed each vessel in operation will require complete recharge once per day.

To calculate the expected peak energy consumption per day for tour boat operations, all vessels were assumed to be in service with operational running hours estimated from the current peak operating schedule described in Figure 3-4 previously.

Total daily energy consumption for the tour boat fleet is therefore **50,500 kWh per day** and this power must be available and transmittable to the current berths where recharging will occur.

Increases in the number of visitors per day and changes to the arrival and departure patterns of these visitors could result in:

- The introduction of additional tour boats or the replacement of smaller vessels with larger vessels capable of carrying more passengers.
- Changes to daily operational schedule of tours, with the existing fleet undertaking more sailings throughout the day.

Both these factors would result in increases in the daily power requirement beyond that estimated above.

7.6 Infrastructure Requirement

Like any fuel system, battery-electric motive power systems require infrastructure to generate, distribute and store energy. The following section the specific infrastructure requirements battery-electric buses, at Milford Sound Piopiotahi, Te Anau and enroute.

7.6.1 Power Supply

Battery-electric motive systems use electricity as the base energy source and this power must be generated from renewable, carbon-free sources.

Options for power supply essentially fall into two categories:

- Power may be supplied from the national grid, the nationwide system of electric power generation and transmission.
- Power may be supplied from small scale, localised power generation (micro-grid power generation) at or near point of use.

Utilisation of the national grid provides consistency of supply, as natural fluctuations in power generation are managed at national level. The price of grid generated electricity is determined by the electricity wholesale spot market, with the spot price of electricity fluctuating every half hour according to demand. The price of electricity may vary considerably across an average day, with prices higher during periods of peak demand and generally lower throughout the night when demand decreases. Use of the national grid requires electrical transmission infrastructure transmit energy from point of supply to point of use.

Alternatively, power generation may be undertaken using small scale, localised power generation from a variety of mechanisms, including small-scale hydro-electric systems, photovoltaic systems, wind turbines etc. Micro-grid power generation reduces the requirement for electrical transmission for remote locations, as the distances between power generation and point of use are minimised, however power generation capacity may be limited and variable.

Te Anau is connected to the national grid, which provides opportunities for grid supplied power for bus depots located there.

There is no national grid transmission to Milford Sound Piopiotahi or along SH 94. Power supply for facilities located enroute and at Milford Sound Piopiotahi (most notably all power required by tour boat services) would need to be generated locally, or via extensions to national grid transmission infrastructure to provide connection to Milford Sound Piopiotahi. As further discussed in the Recommendations Report delivered as part of this project scope, extending the national grid with a 33 kV cable should be sufficient to meet the energy demand of battery-electric buses and boats.

7.6.2 Options for Battery-electric Recharge

There are two strategies for the recharge of battery electric systems as summarised in Table 7-3:

Table 7-3: Comparison of Recharge Options

Recharge Approach	Advantages	Disadvantages
Slow (trickle) charging	• Power cost may be reduced with use of overnight and/or smart charging. • Lower infrastructure cost. • Plug-in.	• Recharge of high-capacity batteries in hours. • Limits recharge to overnight or scheduled periods when the vehicle is taken out of service to charge. • Maximises space requirements, particularly for large fleets.

Recharge Approach	Advantages	Disadvantages
Fast Charging	• Allows for recharge of high-capacity batteries in minutes. • Provides maximum operational flexibility and opportunity charging	• Requires large volumes of energy and/or energy storage. • Requires specialised on-board infrastructure (such as a pantograph) which increases the capital cost per vehicle (required for all buses and may also be required to maintain operational flexibility for tour boats. • Recharge stations must have access to a consistent power supply with sufficient power generation capacity and/or storage. • Recharge stations require specialised infrastructure and a larger footprint. • High power cost. • High infrastructure cost.

The mix of modes and operations evident in this study suggest that a mix of fast and slow recharge systems will be required for operational flexibility, however it is likely that the appropriate charging solution for tour boats in Milford Sound Piopiotahi will be determined by the available power capacity.

7.6.3 Bus Depot Facilities

As shown in Figure 7-5 right, coaches are stored at depot's when not service. Depot's include facilities for vehicle maintenance, facilities for staff and often include on-site fuel storage refueling infrastructure to enable vehicles to refuel when out of service. Depots are usually located on or near the start of operational routes, to minimise out of service operation[16].

The use of battery-electric buses requires changes to the layout and infrastructure of depots to permit vehicles to recharge when out-of-service.

Given buses from Te Anau – Milford will not be in service during the night, a slow charge system will allow buses to charge overnight using base load, which reduces the cost of power. Slow charge depot facilities may require battery storage at the depot and vehicle charging may be accommodated through a variety of means including:

Figure 7-5: Example of a Coach Depot

- Induction.
- Pantograph.
- Overhead, pedestal, or wall mounted direct connection.

As slow charging requires vehicles to be parked for between 6-8 hours during charging, sufficient depot space will be required to accommodate the simultaneous charge of vehicles.

In addition, there may be civil and electrical works required to upgrade electrical transmission, for example, when installing new power transmission cables.

[16] Referred to as dead running

7.6.4 Bus Enroute Recharging

As 7.5.1 concluded, battery-electric buses making the journey from Te Anau - Milford and return will require facilities to recharge batteries enroute in order to be considered viable.

As buses will be in service, a fast-charging strategy will likely be required to minimise vehicle downtime while vehicles are in service. Fast charging also supports large vehicle fleets, while minimising the infrastructure footprint, as multiple vehicles will be recharged through a single charge station over the day.

Figure 7-6 shows an example of a fast-charging point.

Figure 7-6: Fast Charging Point for Electric Buses

Enroute fast charge stations provide an effective range extension for battery-electric buses, meaning buses may be designed with fewer batteries, reducing the overall capital cost of the fleet. In addition, fast charging enables opportunity charging which allows buses to recharge with minimal downtime for around 10-20 minutes.

Fast charging stations may be provided with a range of power ratings and typically use direct current to transmit electricity to the bus via a physical connection (either plug in or pantograph).

Charging stations require large quantities of energy and must be connected to either the national grid or to a microgrid with sufficient power generation capacity to meet peak demand. Batteries may also be required to maintain consistency of power supply.

The optimal location for a fast charge station on the Te Anau route will be influenced by a number of factors, including the power requirements for tour boat operations within Milford and the available options for power generation and transmission. Buses will require recharge either at Milford Sound Piopiotahi, or enroute between Milford Sound Piopiotahi and the Cleddau Cirque[17].

It is also important to note that the requirement for enroute charging will be negated should both bus and boat operations in Milford convert to Battery-electric systems. If tour boats are converted to Battery-electric, they will require recharge within Milford Sound Piopiotahi that could also be used to by buses, providing the additional power capacity required to make the return journey to Te Anau and mitigating the need for a sperate enroute charging facility elsewhere on the route.

7.6.5 Tour Boat Harbour/Berth Charging

All Battery-electric watercraft must recharge while berthed, as there is no opportunity for enroute recharging. Figure 7-7 shows an example of a battery-electric charge point used for tour boats.

Figure 7-7: Example of a Battery-electric Recharge Point used for Tour Boats

A mix of fast and slow charging strategies may be applicable for tour boats, depending on the operational schedule and the specific power consumption of each vessel.

Under the current schedule, the larger vessels (Pride and Sovereign) are only in use during the day, with relatively short (30 minutes or less) intervals between sailings. If battery charge is sufficient to last the day, these vessels may be charged overnight, however fast charging would provide maximum operational flexibility and allow additional sailings to be provided if demand warranted.

Medium sized vessels are in use throughout the day, with minimal downtime between sailings and most do not provide overnight trips. Once again, depending on the specific energy consumption of the vessels, overnight charging may be sufficient, but fast charging provides maximum operational flexibility.

Smaller vessels, such as the water taxi service commonly used by Milford Track walkers, have a range of operating patterns, providing on-demand, day trips and overnight tours. Fast charging would maximise the utility and flexibility of these smaller vessels.

[17] The specific location and feasibility of locations for enroute charging is beyond the scope of this study, however it is noted the topography and conditions of SH94 mean that physical space is limited, particularly where multiple buses may require simultaneous recharge under peak demand.

The availability of fast charging infrastructure for tour boats may also provide opportunities to reduce the battery requirements for vessels by providing the option for rapid recharge between sailings, reducing the onboard energy storage requirement for tour boats.

Fast charge facilities allow for the rapid recharge of onboard batteries, with 800 kWh batteries capable of being recharged in less than twenty minutes. In practice, batteries are unlikely to be fully depleted and fast charging provides the operational flexibility to 'top up' batteries between sailings.

Charging infrastructure is dependent on access to sufficient power generation and transmission infrastructure, with fast charging requiring higher volumes of power during the day. Batteries may also be needed to provided onshore.

7.6.5.1 Other Considerations for Enroute Charging

Charging infrastructure requires sufficient electrical energy generation and/or transmission to meet the expected energy requirements of the fleet of vehicles in operation. Milford Sound Piopiotahi is not connected to the national grid and the appropriate location and configuration of charging infrastructure is therefore dependent on the generation capacity at Milford Sound or enroute.

Ideally, a combined battery-electric solution for buses and boats would provide recharge facilities for buses at Milford Sound Piopiotahi, where sufficient space is available for infrastructure, however this is predicated on the availability of sufficient electrical energy via generation or transmission.

In the absence sufficient energy for charging for buses at Milford Sound Piopiotahi, charging will be required enroute on the return journey between Milford Sound and the Cleddau Cirque.

The specific location for enroute charging will be informed by many factors including:

- The volume and operating profile of buses expected to recharge, including an assessment of the space requirement for simultaneous charging for multiple buses.
- Space requirements for vehicle access and storage.
- Space requirements for battery storage and charging infrastructure.
- Ease of providing electrical transmission from point of generation to the recharge point.

In addition, parts of the SH94 are prone to avalanche. Recharging facilities should be located in areas free from avalanche risk to mitigate damage to fleet, infrastructure and potential loss of life.

Milford Sound Piopiotahi is an area of natural beauty and is globally significant conservation area. Charging infrastructure, including any power generation or transmission infrastructure required to support it, should minimise the impact to the environment. Parts of the Te Anau to Milford route also includes the habitat of the indigenous alpine parrot – the Kea. Recharging infrastructure to be designed to minimise the risk of damage from and to Kea.

7.7 Operations

Electric motive systems perform differently to conventional internal combustion engines and there is a period of familiarisation required by drivers to accustom themselves to the different handling characteristics of battery-electric vehicles.

Electric motors allow for fine control in the release of power and provide a very smooth torque curve which results in the Battery-electric vehicles feeling highly response to small changes in power control.

Range anxiety is also a factor with new motive systems, with drivers unfamiliar with operational range of new energy storage systems.

Battery-electric vehicles are heavier than their diesel equivalents. This affects bus handling to a degree; however, the increased weight and distribution of this weight is most apparent in watercraft, which handle distinctly differently due to different displacement and hull form.

Recharge time is a key determinant in operations. Fast charging provides operational flexibility and allows for high vehicle utilisation, while slow charging provides better charging economy. Depending on the specific charging strategy and infrastructure adopted, operating schedules may need to be adjusted to accommodate charging requirements.

7.8 Maintenance

All vehicles require regular servicing. The skills, equipment and regimes required to maintain diesel internal combustion engines is very different from that required to maintain electrical systems and electric motors.

With a change in technology comes a change in the skills and equipment needed to appropriately maintain and repair vehicles and maintenance staff will require training and certification as the fleet put into service. Alternatively, operators may choose to contract maintenance to specialist outside parties, however, this introduces the risk that vehicles may be out of service for extended periods.

Any new infrastructure will also require maintenance, including depot facilities, enroute charging stations and/or charging stations at Milford Sound Piopiotahi commercial berths.

In general, battery-electric systems have a long operational life and require less maintenance than internal combustion-based systems. This is due to the absence of moving parts and vibration associated with electric systems.

7.9 Battery Lifespan and Disposal

Batteries lose the ability to carry charge over time in a process known as voltage decay and when batteries degrade to 70 - 80% of the original capacity, they are defined as at end-of-life, at least in their capacity as energy carries for transport.

Lithium-ion batteries are the most common battery chemistry for use in transport applications and require replacement every 7-10 years.

This means battery-electric buses and watercraft will need to factor for the rolling replacement of batteries at regular intervals and the end-of-life batteries will require disposal.

There is a potential secondary market for used batteries, which could be repurposed to provide auxiliary energy storage for land-based facilities for example, however as most battery-electric motive systems have only entered service comparatively recently, resale value of end-of-life batteries has yet to be established.

Alternatively, batteries may be refurbished, however, this requires the disassembly of battery modules at specialist factories.

End-of-life batteries may also be recycled to reclaim valuable metals, however, this process is energy intensive.

7.10 Other Environmental Impacts

Battery-electric vehicles use less raw materials over their operational life, due to the reduced material requirements associated with fuel storage and transportation. Fossil fuels must be physically transported from point of supply to point of use and require dedicated storage infrastructure. In contrast, electricity may be efficiently transported over long distances with appropriate electrical transmission infrastructure.

However, it should be noted that battery-electric vehicles have a larger manufacturing impact, with studies indicating battery-electric buses have an embodied carbon up to 50% higher than an equivalent diesel bus. This is largely due to the manufacturing process of batteries, which requires metals such as Lithium, whose extraction process is both carbon intensive and environmentally destructive.

End-of-life batteries are also a potential environmental risk, as they contain elements and compounds that are toxic.

7.11 Key Points

The assessment of the feasibility of battery-electric systems for bus and boat revealed the following:

- The conversion of existing bus and boat fleet to battery-electric systems is prohibitively challenging.
- New specifically designed vehicles will be required for both bus and boat fleet in order to make battery-electric systems feasible.
- Milford Sound Piopiotahi is not connected to the national grid and existing power generation is limited.
- The use of battery-electric buses will require between 3,894 kWh and 19,468 kWh per day, depending on the number of buses in service.

- Battery-electric buses will require recharge either at Milford Sound Piopiotahi, or at enroute between Milford and Cleddau Cirque.
- Buses will require the use of fast recharge facilities
- The use of battery-electric tour boats will require 50,500 kWh per day with all vessels in service.
- Recharge facilities must be provided at births within Milford Sound Piopiotahi for watercraft.
- Tour boats will require a mix of fast and slow recharge facilities.
- Battery replacement and disposal will be required every 7-10 years.
- End of life batteries may have secondary applications in non-transport uses, such as energy storage for fixed infrastructure, etc.
- Significant new infrastructure, including depot facilities, charging infrastructure and associated battery storage will be required to support the use of battery-electric systems for both bus and boat.

8 Hydrogen Fuel Cell Feasibility

8.1 Introduction

Hydrogen is the lightest chemical element and is colorless, odorless, tasteless and highly combustible. Hydrogen is highly abundant, however most hydrogen is in the form of molecules such as water or organic compounds.

The volatility of hydrogen, coupled with its availability, have made hydrogen a viable alternative to fossil fuels as an energy carrier.

Pure hydrogen occurs naturally deep within the earth's crust, however for the commercial production of hydrogen there a number of different production pathways as summarised in Table 8-1.

Table 8-1: Hydrogen Production Pathways

Hydrogen Production Pathway	Description
Green	Hydrogen produced via the electrolysis of water, with energy provided by renewable power generation
Turquoise	Hydrogen produced from the thermal splitting of methane.
Blue	Produced from hydrocarbon reformation with carbon sequestering and storage
Gray	Produced through the steam reformation of natural gas
Brown or black	Produced from the gasification of brown or black coal
Red, pink or purple	Uses nuclear power to thermochemically split water or contributes to steam to natural gas reforming.
Yellow	Hydrogen produced mixed fossil fuel and renewable power sources
Gold or white	Naturally occurring hydrogen release via mining.

Of these production pathways, only green hydrogen production may be considered as carbon free.

As pure hydrogen does not occur naturally and requires energy to produce, hydrogen may be considered an energy carrier i.e., it stores energy invested in production which may then converted into a usable form. In the case of green production pathways, electrical energy is converted into hydrogen, stored and then converted into a usable form.

Hydrogen is key feedstock of a number of alternative fuels, including ammonia and synthetic fuels.

Hydrogen may be converted into usable energy via two mechanisms:

- **Combustion** – where hydrogen is combusted inside a modified internal combustion engine or gas turbine to produce motive power. The combustion process is carbon free, however it does produce NOx.
- **Electrochemical** – where hydrogen is chemically reacted with an oxidant in a fuel cell to produce electricity. The only emission produced is water vapor.

Of the two mechanisms, electrochemical production via a fuel cell is the preferred method of energy generation for transport.

In terms of energy efficiency, hydrogen has between 20% and 30% conversion loss during production and a further 20% - 30% conversion loss at point of use. This may be compared with diesel combustion which has conversion energy loss of approximately 50% from liquid fuel to motive power.

Pure hydrogen's natural state is as a gas and hydrogen storage therefore requires the use of high-pressure containment vessels, or hydrogen may be cooled to -253°C and cryogenically stored as a liquid.

As green hydrogen is produced from electricity, the primary difference between electrical motive-power systems and hydrogen motive-power systems is the characteristics of the energy storage:

- Battery storage allows for highly efficient energy conversion but may not be stored long term.

- Hydrogen storage allows for the long-term storage of electrical energy (in the form of chemical energy) but comes at the expense of energy efficiency with between 40% and 60% of potential energy lost due to conversion, which is broadly similar to the 50% energy lost when converting diesel to motive power.
- The diagram in Figure 8-1 shows how hydrogen is produced from electricity through electrolysis.

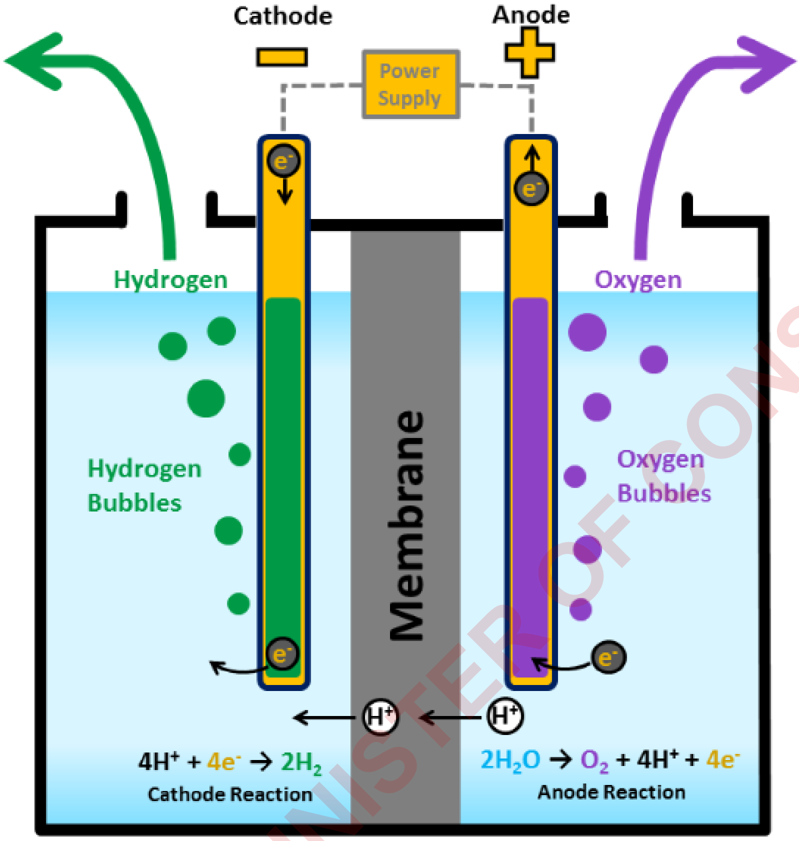

Figure 8-1: Diagram of Hydrogen Production from Electricity

8.2 Composition of Hydrogen Motive Power System

Hydrogen may be used to produce energy via combustion, or via electrochemical conversion in a fuel cell.

While hydrogen may be combusted to produce energy in a modified internal combustion engine or gas turbine, practical examples of hydrogen combustion in transport are extremely limited, with most transport applications utilising hydrogen fuel cells to produce energy electrochemically.

The assessment of hydrogen motive power systems therefore focuses on the use of Hydrogen fuel cells as these systems are commercially available and relatively mature.

A hydrogen based motive power system (irrespective of mode) has the following key components:

- A hydrogen fuel storage system (either as a pressurised gas[18] or cryogenically cooled liquid).
- A fuel cell for the conversion of chemical energy into electricity.
- An electric motor.

In addition, most hydrogen motive power systems include an auxiliary battery system to store excess electrical energy and regenerative energy capture, if applicable to the mode.

A simplified diagram of the basic components of a hydrogen fuel system is shown in Figure 8-2.

[18] 350 or 700 Bar

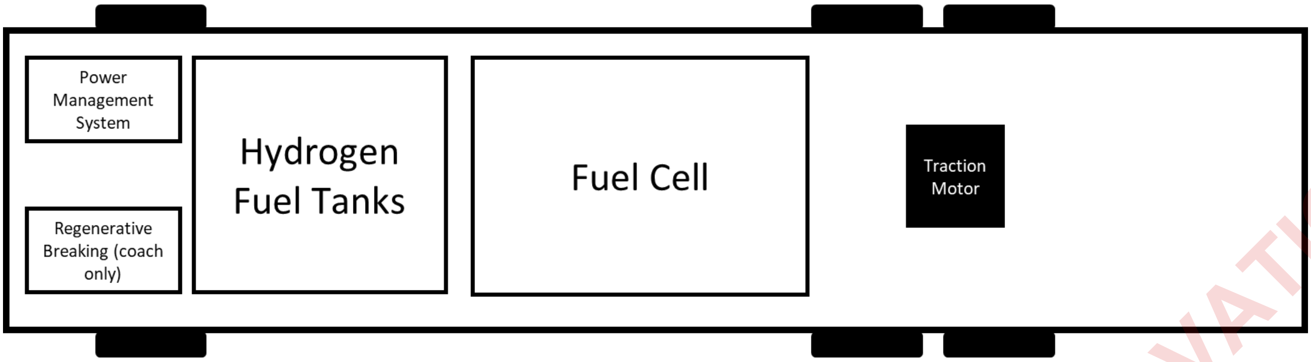

Figure 8-2: Components of a hydrogen fuel cell motive system

8.2.1 Fuel Cell

A fuel cell is an electrochemical cell that converts chemical energy (in this case hydrogen) and an oxidizing agent (oxygen) to produce electricity through a pair of redox reactions.

The are many designs and fuels that may be used to produce electro-chemical energy, however, hydrogen fuel cells are the predominate form of commercially produced and available fuel cells for transport applications.

A diagram of a fuel cell is shown in Figure 8-3.

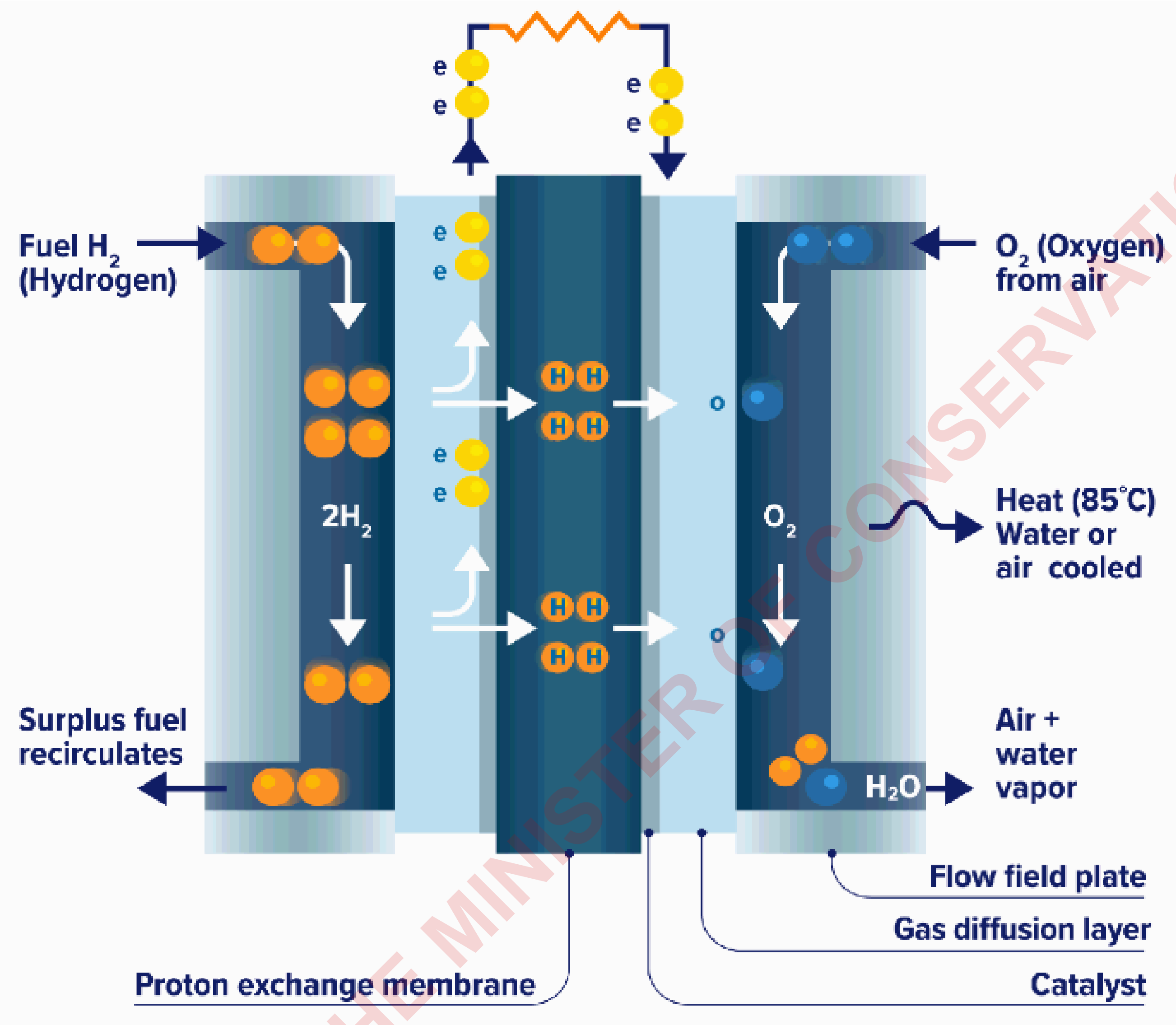

Figure 8-3: Hydrogen Fuel Cell

A fuel cell operates continuously as long as flows of hydrogen are maintained.

Hydrogen fuel cells are manufactured using a range of rare metals and rare earths, most notably platinum. Hydrogen fuel cells also have an operational life span similar to batteries of around 7-10 years, after which they must be refurbished or replaced.

8.3 Hydrogen Fuel Cell Bus

A hydrogen fuel cell bus is a bus designed for long distance travel that uses a hydrogen fuel cell as its power source for electrically driven wheels, typically augmented by a battery and a regenerative energy capture system.

Figure 8-4 below shows an example of a hydrogen fuel cell bus operated by Auckland Transport in New Zealand. This bus has a range of around 400 km[19], although more recent international developments have extended this up to 1,000km[20].

[19] Auckland Transport begins 2-year trial of hydrogen bus - Green Car Congress
[20] Irizar i6S Efficient Hydrogen coach unveiled with 1,000km range - routeone (route-one.net)

Figure 8-4: Example of a Hydrogen Fuel Cell Bus

Hydrogen fuel cell buses first entered widespread trails in the late 1990s and as of 2020 have entered commercial production with 5,648 fuel cell buses in use globally.

Hydrogen buses are zero-emission vehicles and they produce no carbon or harmful emissions at point of use.

Hydrogen fuel cell buses utilises either gaseous hydrogen, stored in pressurised storage vessels, or as a cryogenically cooled liquid, with liquid hydrogen providing a higher energy density per volume. In practical terms, cryogenic cooling allows for greater volume of energy to be stored, which translates to additional range.

The conversion of existing internal combustion based buses to hydrogen fuel cells will likely be prohibitively challenging.

Comparative to electrical motive systems, fuel cell buses are lighter, provide greater range and longer run time and allow for rapid refueling. Hydrogen fuel cells also perform better in cold temperatures.

8.4 Hydrogen Fuel Cell Watercraft

Hydrogen powered watercraft utilise a fuel cell to convert hydrogen into electrical energy, which is then converted into motive power via an electric motor.

The application of hydrogen fuel cells for watercraft has been slower than other modes, with relatively few examples of hydrogen cell based motive-power systems in active use evident globally.

There were no examples of hydrogen cell based water craft of comparable size and use to tour boats currently in service in Milford Sound Piopiotahi identified[21].

As is the case with battery-electric watercraft, weight, the distribution of this weight and the displacement of the vessel are of critical importance. Relative to battery-electric systems, fuel cell systems require less weight. This mean's fewer trade-offs in the design of vessels to manage weight, potentially providing economies relative to battery-electric systems.

Fuel cell watercraft will also require on-board storage for hydrogen fuel.

[21] As there are no working examples of equivalent hydrogen cell based watercraft in use, it is not possible to estimate fuel consumption.

Conversion of existing fleet to hydrogen fuel cell is likely to be prohibitively challenging, due to the complexity of designing around new engine systems and weight management. The use of hydrogen for tour boats will therefore require the introduction of new vessels specifically designed for this motive power system.

8.5 Energy Consumption

For the purposes of assessing the potential energy requirement for hydrogen fuel-cell buses for the return journey from Te Anau to Milford, the following reference vehicle was used to model potential energy requirements:

- Passenger capacity: 49 passengers
- Average operating speed: 80 km/h
- Peak operating speed: 100 km/h
- Base energy consumption rate: 10 kg/100km[22]

Storage capacity was not considered as a constraining factor – on the assumption that onboard fuel capacity could be right-sized to meet range requirements.

The estimated hydrogen requirement for hydrogen fuel cell buses against the demand scenarios is shown in Table 8-2.

Table 8-2: Estimated Hydrogen Consumption

Daily Passenger Volume	Number of Buses Required	Fuel requirement (kg Hydrogen)
1,200	25	600 kg per day
2,000	41	984 kg per day
4,000	82	1,968 kg per day
6,000	122	2,928 kg per day

It is not possible to provide an equivalent estimation of hydrogen fuel consumption for tour boat operations, as there is no applicable fuel consumption rate to benchmark against for the range of vessels in service.

8.6 Infrastructure Requirement

The use of hydrogen requires infrastructure to produce, store and distribute hydrogen. As hydrogen has very different properties to conventional fossil fuels (specifically diesel), hydrogen specific fuel storage and transmission infrastructure is required at point of use.

[22] Refences for hydrogen buses in operation internationally provides a large range of fuel consumption rates varying between 5 – 16 kg/100km. However, the most recent sources show consumption rates in the range between 8-10 kg/100 km. It is to be noted that many of these referenced buses are for short distance travel, whereas long distance traveling is expected to have a lowered fuel consumption. However, for this level of study, a consumption rate of 10 kg/100km is deemed appropriate. References include "Caponi, Ferrario, Del Sotto, Bocci, Hydrogen Refueling Stations and Fuel Cell Buses Four Year Operational Analysis Under Real-World Conditions, *International Journal of Hydrogen Energy,* 2022" and "Hensher, Wei, Balbontin, Comparative Assessment of Zero Emission Electric and Hydrogen Buses in Australia, Institute of Transport and Logistics Studies (ITLS) The University of Sydney Business School, 2021".

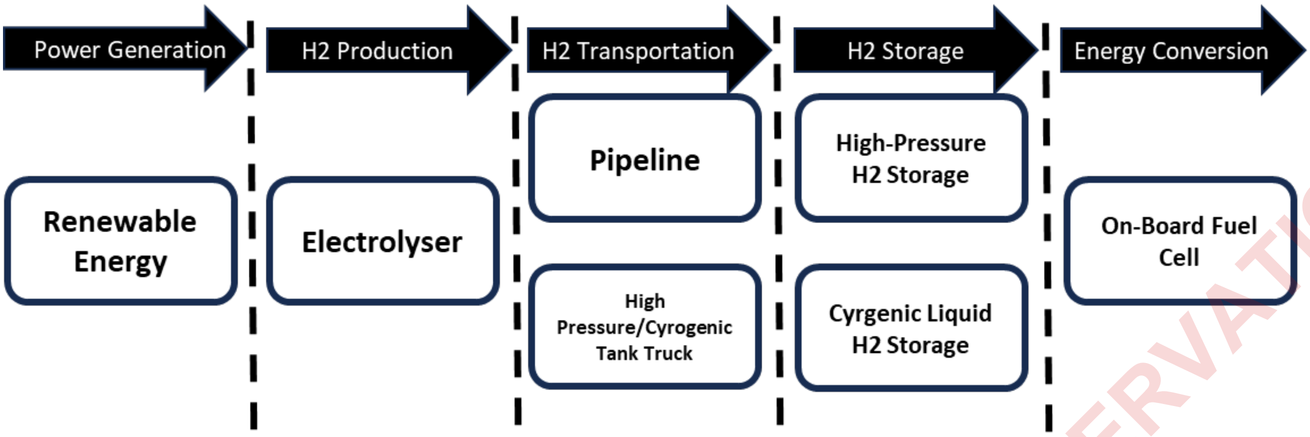

Figure 8-5: Hydrogen Infrastructure

8.6.1 Hydrogen Supply

The availability of commercial quantities of green hydrogen is a critical factor when considering the viability of hydrogen motive systems.

Green hydrogen production at scale is in its infancy in New Zealand, however there is potential for the rapid upscale of hydrogen projects through such initiatives as the Southern Green Hydrogen Project[23].

While hydrogen is readily available on both the domestic and international markets, green hydrogen is in relatively short supply. Many countries internationally are investing in green hydrogen for domestic use, hydrogen on the international market is almost entirely[24] produced by carbon intensive means.

Hydrogen production is heavily dependent on the cost of electricity, with electricity estimated to comprise around half the production costs for a hydrogen plant in 2022, increasing to around 80% of total cost as capital costs are reduced overtime.

New Zealand electricity prices are informed by trading on the spot market, with considerable variance in costs depending on grid power generation capacity and demand, however New Zealand's prices averaged $133 NZD/MWh between 2018 – 2023. Electricity prices are forecast to fall as new and cheaper renewable generation is brought online to service electrification, but hydrogen production and other major sources of demand for power will likely put upward pressure on electricity as more demand emerges. To reach a production price of $2NZD per kilogram of hydrogen in 2050, these estimates found an electricity price of $55NZD/MWh would be needed.

Hydrogen use in the transport sector is limited in New Zealand and as a result there is minimal hydrogen specific fuel storage and transmission infrastructure at a national level. While interest in the potential for hydrogen in many sectors of the New Zealand economy, large scale demand has yet to emerge and as a result, production and transmission infrastructure has not been heavily invested in. This creates a chicken and egg scenario, where the upfront cost of establishing production and transmission infrastructure dissuades demand of the fuel, preventing the economies of scale that would improve its commercial viability.

Hydrogen may also be produced at a relatively small scale, with small scale eletrolysers coupled with localised power generation to create hydrogen at or near the point of use. Currently, electrolysers produce one kilogram of hydrogen using around 55 kWh of electricity, which contains the energy equivalent of 33.33 kWh of energy.

Small scale, localised hydrogen production is dependent on the availability of water and power, with power supply required to ensure the ongoing production of hydrogen to meet demand.

Hydrogen produced in localised plants may be stored onsite for use or delivered directly to point of use.

The volume of hydrogen produced will be dependent on the available power. Due to the inefficiencies associated with the transformation of energy, small scale hydrogen production provides a less efficient use of energy than the direct use of

[23] A proposal to use New Zealand renewable electricity to produce hydrogen in the form of ammonia.
[24] 96% of global hydrogen production was via carbon intensive pathways in 2021.

electrical energy but does provide the opportunity to store energy for extended periods. This is of particular importance where power generation capacity or demand fluctuate.

8.6.2 Depot Facilities

Hydrogen storage will be required at the depot, to provide onsite reserves of fuel and allow for bus refueling when out of service.

Hydrogen storage may be undertaken with pressurised storage vessels or via cryogenic cooling in liquid storage, with specialized refueling infrastructure required to allow buses to refuel.

The footprint of hydrogen storage infrastructure is comparable to that of diesel, however on the assumption that there is no local supply of hydrogen available, storage facilities must allow for the regular attendance of delivery vehicles to maintain hydrogen supplies.

8.6.3 Harbor/Berth

Hydrogen storage will be required at Milford Sound Piopiotahi to permit tour boats to refuel between sailings.

Hydrogen storage may be undertaken with pressurised storage vessels or via cryogenic cooling in liquid storage, with specialised refueling infrastructure required to allow watercraft to refuel.

The footprint of hydrogen storage infrastructure is comparable to that of diesel, however on the assumption that there is no local supply of hydrogen available, storage facilities must allow for the regular attendance of delivery vehicles to maintain hydrogen supplies.

Hydrogen storage at Milford Sound Piopiotahi could also be used to provide additional supplementary storage and refueling capacity for buses prior to them commencing their return journey to Te Anau.

8.7 Operations

The performance of hydrogen fuel-cell boats and buses is similar to battery-electric vehicles. This is because both motive systems are reliant on electric motors for the conversion of energy into motive force.

Hydrogen does provide advantages in terms of extended vehicle range and from a driver perspective, reduction in range anxiety associated with Battery-electric systems.

Hydrogen may also be refueled rapidly and is roughly equivalent to the time required to refuel using diesel. This means the use of hydrogen imposes minimal operational disruption as refueling may be undertaken within the existing operational schedule of both buses and boat operations.

8.8 Maintenance

Hydrogen fuel cell vehicles and associated infrastructure will require the introduction of new maintenance regimes and the retraining of maintenance staff. In addition, hydrogen is highly volatile and requires specific safety measures to mitigate the risk of explosion.

Hydrogen is extremely flammable, even mixed with small volumes of air and the safe storage, handling and use of hydrogen requires specific safety protocols, including:

- Inerting and purging gas lines and chambers.
- Ignition source management.
- Leak and flame detection.
- Ventilation and explosive venting.
- Cryogenic handling and BLEVE[25] mitigation.
- Hydrogen Safety.

[25] Boiling liquid expanding vapour explosion.

Because of the reduction in vibrations and moving parts associated with the use of hydrogen fuel cell motive power systems, maintenance requirements will likely be less than the equivalent internal combustion-based system and vehicle operational life spans longer.

8.9 Fuel Cell lifespan and disposal

Hydrogen fuel cells (as well as any battery systems in use for regenerative energy capture) have a lifespan typically much less than the vehicle they power, and fuel cells and batteries will likely require replacement over the course of the vehicles use.

Hydrogen fuel cells require refurbishment or replacement every 7-10 years. While refurbishment is possible, this requires the disassembly and reconstruction of the fuel cell in a specialised factory.

8.10 Other Environmental Impacts

Whilst hydrogen fuel cells provide zero carbon emissions at the point of use, there are carbon emissions associated the production of fuel cells and associate infrastructure.

Fuel cells are dependent on a number of rare materials, most notably platinum, which have produced significant carbon emissions (as well as other harmful environmental impacts) during the extraction process.

As discussed above, hydrogen fuel cells also have a limited operational life and will eventually require disposal.

8.11 Key Points

The assessment of the feasibility of hydrogen fuel cell systems for bus and boat revealed the following:

- Only hydrogen produced via green pathways may be considered zero emission.
- The conversion of existing bus and boat fleet to hydrogen fuel cell systems is prohibitively challenging.
- New specifically designed vehicles will be required for both bus and boat fleet in order to make hydrogen fuel cell systems feasible.
- Large scale commercial production of green hydrogen production is limited, although hydrogen may be produced locally through the use of electrolysers if sufficient electrical energy is available.
- Hydrogen fuel cell buses are estimated to require between 600 and 2,900 kg H_2 per day.
- Hydrogen fuel cells will require replacement and disposal every 7-10 years.
- Significant new infrastructure, including depot facilities and hydrogen storage will be required to support the use of hydrogen for both bus and boat.

9 Synthetic and Biofuel Feasibility

9.1 Introduction

Synthetic fuels and biofuels include a range of fuels designed to chemically emulate fossil fuels; however their formation is based on the capture of atmospheric carbon either chemically, or via carbon sequestration through organic processes like photosynthesis.

The primary distinctions between these different fuel types are:

- **Synthetic fuels** – are produced through the reaction of fats and waste oils with hydrogen using the Fischer-Tropsch process.
- **Biofuels** – are produced from biomass.

Comparable to other fuel/energy systems discussed previously in this study, synthetic and biofuels seek to develop a fuel that is essentially 'drop in' i.e., it may be used in place of standard fossil fuel diesel with minimal change required to fleet or fuel storage and distribution systems.

The trade-off is that synthetic and biofuels are not zero-carbon and are still reliant on the capture and combustion of carbon with the attendant release of localised carbon emissions and other harmful combustion by-products.

9.2 Composition of Synthetic/Biofuel Power System

There are a range different fuels and systems required for energy conversion dependent on the specific fuel in use. For the purposes of this appraisal however, synthetic diesel or biodiesel equivalent to standard fossil fuel diesel are considered most applicable to both bus and boat operations to and within Milford Sound Piopiotahi.

As such, the basic composition of a synthetic/biofuel power system is identical to a standard fossil fuel based motive power system. Each vehicle must contain onboard liquid fuel storage, an internal combustion engine and drivetrain to convert chemical energy into motive power.

9.3 Synthetic Diesel Supply

Synthetic diesel is reliant on two primary feedstocks – carbon, in the form of waste fats and oils, and hydrogen.

In this sense, synthetic diesel production in New Zealand is limited by the availability of commercial quantities of green hydrogen, which has yet to become established at scale.

Synthetic fuels are available on the international market, however caution must be exercised as the definition of synthetic fuels includes synthetic fuels generated from fossil fuel feedstocks, such as coal or natural gas. Global production of green synthetic diesel (or other fuels) is limited.

Figure 9-1 below demonstrates how green synthetic fuels are produced.

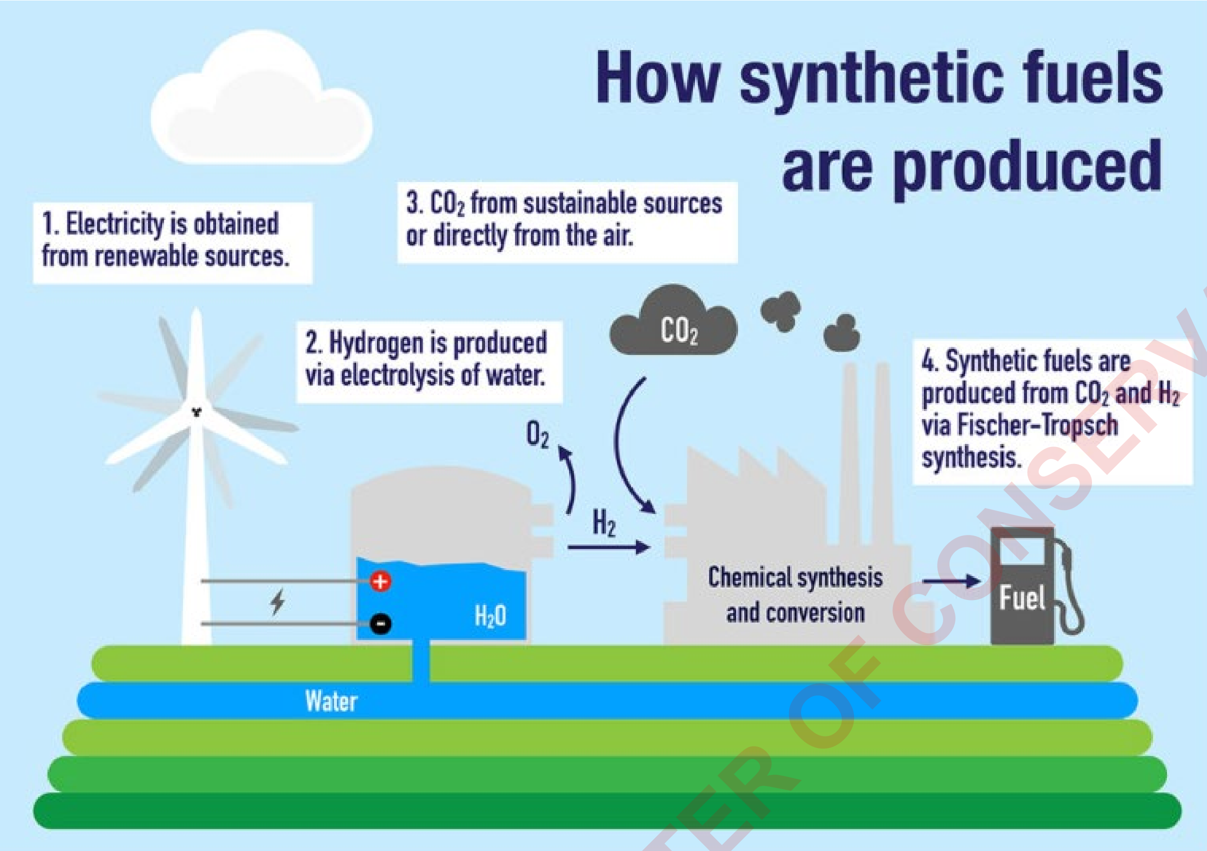

Figure 9-1: Diagram of Synthetic Fuel Production

9.4 Biodiesel Supply

Biodiesel is available on the global market, with over 81 million tonnes of oil equivalent produced in 2017. The US is the largest producer and consumer of biodiesel, followed by Europe, South America and South East Asia.

The nearest major producer biofuels is Indonesia, however the feedstock for this production is palm oil and oil palm plantations are a major source of native rainforest deforestation and reduction in biodiversity.

Figure 9-2: Image of Biodiesel

Biodiesel is not currently produced in commercial quantities domestically, although it has been produced historically. Current reliance on tallow as a feedstock made the domestic production of biodiesel economically unviable, however there is potential to utilise wood waste/slash as an alternative feedstock which would make the commercial, domestic production of biodiesel a more feasible proposition.

9.5 Infrastructure Requirement

As synthetic diesel and/or biodiesel are interchangeable with conventional fossil fuel, minimal new infrastructure will be required, as existing storage facilities may also be used to store synthetic and/or biofuels.

9.6 Depot Facilities

Bus depots will need to be proximate to a refueling station or provide onsite fuel storage and refueling within the depot.

9.7 Harbor/Berth

Vessels will require sufficient fuel storage proximate berths to allow vessels to be refueled. Existing infrastructure may be used.

9.8 Operations

A primary point of difference between synthetic biofuels (in this case synthetic diesel) and biodiesel is the extent to which they are interchangeable with conventional fossil fuels.

Synthetic fuels are completely interchangeable with conventional diesel and synthetic diesel maybe used in place of fossil fuel diesel with no change required to existing fleet or storage infrastructure.

Biodiesel fuels are not as interchangeable with conventional diesel and engines must be modified to permit their exclusive use. Alternatively, biodiesels may be mixed with standard biodiesel in a 'blend', with proportions of biodiesel scaled up overtime.

Synthetic and biodiesel degrades over time, with degraded fuels forming contaminants and increased fuel acidity. This means synthetic and biofuels have a decreased 'shelf life' relative to conventional diesel and operational regimes will need to ensure that fuel reserves are managed and used.

Both fuels also exhibit different performance at lower temperatures than fossil fuel diesel, which may be a factor for winter operations.

9.9 Maintenance

Broadly, the maintenance requirements for the use of synthetic diesel or biodiesel are similar to that required for conventional diesel use. There are some distinct differences however, with synthetic and biodiesel prone to biological contamination[26], which can result in the formation of sludge, which clogs filters and piping. Management of diesel bus requires the frequent draining of storage tanks, which also reduces the potential for long term storage.

Fuel system componentry – especially hoses and gaskets – are prone to deposit formation and a loss of integrity with some fuels and may require replacement or conversion.

The operating lifespan of a synthetic or biofuel diesel vessel or bus will be broadly comparable to a conventional diesel motive power system.

9.10 Other Environmental Impacts

As is the case with hydrogen, synthetic and biofuels require energy to produce and refine feedstocks into usable fuels and the source of this energy must be from renewables to consider these fuels as carbon neutral.

In addition, the depending on the means of production of feedstocks, biofuels may also contribute carbon and NOx emissions due to use of nitrogen fertilizer and other through the use of machinery dependent on fossil fuels for harvesting and transport.

Land use is also a major factor when considering the potential for wider environmental impacts. The use of arable land for the production of crops specifically for fuel production results in decreased food production and potential impacts to the economics of the food supply chain.

Alternatively, land may be converted from wild habitats resulting in decreased biodiversity and establishment of crop monocultures. Loss of natural habitual can change hydrology, increase erosion and impact water quality. Land clearing from wild conditions also results in carbon emissions as existing vegetation is burned off or allowed to decay.

[26] Sometimes referred to as diesel bug

Many of these impacts may be mitigated by advancements in biofuel production which allow waste streams to be used in place of dedicated crops.

9.11 Key Points

The assessment of the feasibility of synthetic fuel and biofuel systems for bus and boat revealed the following:

- Synthetic fuels and biofuels may be used as a substitute 'drop-in' fuel in existing fleet.
- Synthetic fuels and biofuels may also be used in blended fuels.
- Synthetic fuels and biofuels may be used in existing fleet (both bus and boat).
- Synthetic fuels and biofuels are carbon neutral fuels and may be used to reduce, but not eliminate global carbon emissions.
- Synthetic fuel production is limited and dependent on green hydrogen as a feedstock.
- Biofuels are commercially available but global biofuel production is dependent on the use of arable land, with the attendant risk of decreased biodiversity associated with monoculture and habitat loss.
- The use of synthetic fuels and biofuels will not require new infrastructure.

10 Hybrid Vehicles

A hybrid vehicle combines a system for the conversion of chemical energy (such as an internal combustion engine or a hydrogen fuel cell) with an energy storage system and a regenerative energy capture system. The result is a vehicle that combines characteristics of both systems, providing improved fuel consumption efficiency and reduced emissions.

Hydrogen fuel cell vehicles may be considered hybrids, in that that typically combine battery storage and energy recovery as part of the overall motive power system.

Hybrid systems may also be applied to conventional internal combustion systems, through the addition of onboard storage and energy recovery (where applicable). Hybrid systems, when applied to standard fossil fuel based internal combustion, reduce fuel consumption, and thereby reduce carbon emissions, but these motive systems are still fundamentally reliant on carbon-intensive fuels. Similarly, hybrid systems may be combined with the use of blended fuels or drop in bio or synthetic fuels.

Hybrid systems allow reduced fuel consumption and provide an extension to vehicle range; however, this comes at the expense of increased weight and complexity of onboard systems.

As is the case with battery electric vehicles, the battery components of hybrid systems will require replacement during the operational life of the vehicle.

Hybrid systems in isolation provide a limited reduction in carbon emissions, but combined with carbon neutral fuels provide additional range and reduced fuel consumption, resulting in decreased operational costs.

Conversion of existing watercraft to hybrid systems is likely to be prohibitively challenging, due to the complexities of managing weight. Similarly, conversion of existing diesel buses to hybrids is technically feasible, but the cost of doing so should be balanced against the cost of purchasing a new hybrid vehicle and the expected operational life of the bus fleet.

Fundamentally, as standard internal combustion based hybrid systems retain their reliance on carbon based fuels, hybrid systems do not provide a pathway for the elimination of the carbon, but do provide opportunities to reduce carbon emissions relative to the continued use of diesel based internal combustion.

Within the context of Milford Sound Piopiotahi, hybrid systems do not provide a long term solution for the elimination of carbon emissions, but may provide an option in the short term to reduce both emissions and operational cost, until such time as an alternative carbon-free solution is in place.

Key Points

- Hybrid systems combine electrical energy storage and recovery with an internal combustion engine.
- Hybrid systems reduce fuel consumption and thereby reduce carbon emissions, but are still dependent on energy derived from the combustion of carbon based fuels.
- Hybrid systems do not provide a long term pathway for the elimination of carbon emissions but may be used to reduce carbon emissions until such time as a carbon-free alternative is in place.

11 Options Comparision

11.1 Cost

Cost is an important consideration in determining the viability and feasibility of an option.

Costs associated with the conversion current tour boat operations in Milford Sound Piopiotahi and the introduction of a new hop on/hop off bus service may be categorised as:

- **Capital cost** – the total expenditure required to bring a project to a commercially operable status – including the conversion or replacement of fleet, depot or berth infrastructure and energy production and storage infrastructure. Capital costs are 'one off' expenses incurred for the purchase of infrastructure, plant, and land. Capital cost may be 'paid off' when the operational revenue recovers the cost of investment.
- **Operating cost** – are costs incurred during the normal operation of the transport service and include driver wages, fuel costs, maintenance etc. Operating costs are continual costs that are incurred throughout the lifetime of the transport service, although costs may fluctuate overtime.

The costs associated with introduction and/or conversion of a transport service may be considered capital costs.

A detailed cost appraisal will be required to assess the potential cost of all options, however, a comparison of key component costs (both capital and operational) is provided below.

This cost comparison focuses predominantly on buses, as it is not possible to obtain cost information relating to watercraft, as these vessels require a much more complex development cycle, and it is not possible to provide an accurate estimate of fleet capital cost.

11.1.1 Fleet Capital Cost Comparison

A comparison of the estimate fleet cost for the hop on/hop off Te Anau - Milford bus service is provided in Table 11-1.

Total fleet cost estimations have been provided for each of the demand scenarios assessed in this study.

Table 11-1: Bus Fleet Cost Comparison

Motive System	Capital Cost per Bus	Fleet Cost 1,200 daily visitors	Fleet Cost 2,000 daily visitors	Fleet Cost 4,000 daily visitors	Fleet Cost 6,000 daily visitors
Diesel/Synthetic Diesel	$500,000	$12,244,898	$20,408,163	$40,816,327	$61,224,489
Battery-electric	$750,000	$18,367,347	$30,612,245	$61,224,490	$91,836,734
Hydrogen Fuel Cell	$1,000,000	$22,448,796	$40,816,327	$81,632,653	$122,448,980
Biofuels	$550,000	$13,469,388	$22,448,980	$44,897,959	$67,346,939
Hybrid System	$750,000	$18,367,347	$30,612,245	$61,224,490	$91,836,734

As Table 11-1 illustrates, the per bus and total cost of hydrogen fuel cells is significantly higher than other options, followed by Battery-electric systems.

Synthetic diesel is assumed to be completely compatible with standard diesel buses with the capital cost of a synthetic diesel fleet assumed to be the same as a conventional diesel fleet.

In contrast, a standard internal-combustion bus will require some optimisation to efficiently run biofuels which is reflected in the increased capital cost per vehicle.

11.1.2 Fuel Cost Comparison

A general comparison of fuel costs is provided in Table 11-2. These costs are reflective of current costs and are indicative only – some fuels are not in widespread production domestically or widely represented on the international market.

Table 11-2: Fuel Cost Comparison

Fuel	Cost Rate (NZD)	Cost Per Km NZ$	Cost per Return Journey[27] NZ$	GHG Emissions per litre
Diesel	$2.5 per litre	$2.02	$485	2.69 kg CO_2 per litre
Electricity	$0.97 per km[28]	$0.97	$233	0
Green Hydrogen	$8.42 per kilogram[29]	$0.84	$202	0
Synthetic Diesel	$16 per litre	$3.84	$922	0.128 kg CO_2 per litre[30]
Biofuels	$3.18 per litre	$1.84	$442	0.128 kg CO_2 per litre[30]

As Table 11-2 indicates, synthetic diesel is significantly more expensive than diesel, reflective of the low rates of production of these fuels.

In contrast, electricity and green hydrogen provides the lowest fuel cost. Electricity has further opportunities to reduce the energy cost by using smart recharging to align fleet recharge with periods of low-cost electricity.

11.2 Infrastructure Comparison

Given the complexity and variables associated with infrastructure it is not possible to provide a specific estimate of the capital cost of infrastructure for each motive power system.

Table 11-3 provides a summary of the potential infrastructure requirement for both bus and boats.

Table 11-3: Infrastructure Comparison

Motive System	New Depot Infrastructure Requirement	New Berth Infrastructure Requirement	New Energy Transmission/Generation Infrastructure Requirement
Diesel	None	None	None
Battery Electric	High	High	High
Hydrogen Fuel Cell	Moderate	Moderate	Moderate/high[31]
Synthetic Diesel/Biofuels	None	None	None

As Table 11-3 illustrates, Battery-electric systems have a high infrastructure requirement, associated with the potential for electrical transmission and storage at depots and berths, as well as the potential for additional transmission or power generation infrastructure necessary to provide sufficient power supply. The specific infrastructure requirement will be informed by many variables; however, it is important to note that if both bus and watercraft at Milford are using Battery-electric systems, enroute charging infrastructure will not be required for buses.

Hydrogen fuel cell vehicles will require new storage and fuel transfer infrastructure at the depot/berth and will also require fuel storage or transmission infrastructure, as well as the potential for local hydrogen production with associated power generation.

In contrast, synthetic diesel and biodiesel fuels are assumed to be compatible with existing fuel storage and transmission infrastructure.

[27] Assumes a round trip journey from Te Anau to Milford and return of 240km.
[28] The cost of electricity varies according to power generation capacity and demand – meaning the cost per km of vehicle charging in peak will be higher than one charging off peak..
[29] Source: Perez, RJE, Analysis of the levelized cost of green hydrogen production for very heavy vehicles in New Zealand, Victoria University of Wellington, 2020
[30] Net global carbon emissions. Carbon emissions at point of use are similar to conventional diesel.
[31] Hydrogen production at Milford Sound Piopiotahi with associated renewable power has a high infrastructure requirement.

11.3 Comparison of Advantages and Disadvantages

A summary of the general advantages and disadvantages of each fuel is provided in Table 11-4.

Table 11-4: Fuel Comparison Advantages and Disadvantages

Motive System	Advantages	Disadvantages
Battery Electric	• Produces no carbon emissions or harmful emissions. • Low fuel and operational cost. • Available commercially. • Very mature – with Battery-electric systems in operation in New Zealand in both watercraft and bus applications.	• High infrastructure requirement. • Disposal cost and environmental impact of batteries. • High cost of conversion. • Limited to short term energy storage only.
Hydrogen Fuel Cell	• Produces no carbon emissions or harmful emissions. • Provides the potential for long-term energy storage.	• Moderate to high infrastructure requirement, dependent on if local hydrogen production is required. • Disposal cost and environmental impact of fuel cells. • Limited commercial availability. • Limited operational maturity.
Synthetic Diesel	• Fully interchangeable with existing fuel. • Easy conversion/implementation. • No infrastructure requirement.	• Produces localised carbon and harmful emissions. • Very limited fuel production and high cost of fuel.
Biodiesel	• Interchangeable with existing fleet. • Easy conversion/implementation. • No infrastructure requirement.	• Produces localised carbon and harmful emissions. • Limited long term storage potential. • Potential for loss of habitat and biodiversity, depending on feedstock origin.

Key Points

- Synthetic and biodiesel based vehicles have the lowest capital cost per vehicle of the alternatives considered.
- Battery-electric vehicles and hybrid vehicles are similarly priced in terms of capital cost.
- Hydrogen fuel cell vehicles have the highest capital cost per vehicle.
- Electricity is the cheapest fuel of the alternatives considered and provides a reduction in cost when compared to diesel.
- Synthetic diesel is significantly more expensive when compared to diesel, however this cost may reduce if production is scaled up.
- Battery-electric and hydrogen systems have a significant infrastructure requirement and associated capital cost.

11.4 Conclusion

The four alternative motive power systems considered in detail in this report were:

- Battery-electric
- Hydrogen Fuel Cell
- Synthetic Diesel
- Biodiesel

While all four motive systems are potentially feasible for the both the Te Anau – Milford bus and tour boat operations within Milford, there were distinct tradeoffs evident with different technology:

- Battery-electric systems provide a zero-emission solution that has extremely low operating costs. However, this will require a considerable investment in infrastructure as a recharging station will be required to facilitate a Te Anau – Milford return journey.
- Hydrogen fuel cell systems offer advantages in terms of long-term energy storage, but this comes at the expense of a high fleet cost and potential investment in hydrogen production infrastructure and/or a high operating cost.
- Synthetic fuels may be implemented with minimal infrastructure and/or capital cost, but these fuels continue to produce localised emissions and are dependent on fuel that has limited production and high cost.
- Biodiesel fuels may also be implemented with minimal infrastructure and/or capital cost, but these fuels also produce localised emissions and fuel production may have broader environmental impacts to biodiversity and/or arable land food production.

With regard to these motive systems application to bus and tour boat operations, a combined approach whereby both bus and boat operations share the same motive power system provides maximum efficiency in terms of infrastructure provision and cost.

11.5 Recommendation

Of the four technologies assessed in detail in this report, **the use of battery-electric motive power systems for both tour boats and buses is recommended** on the following grounds:

- Battery-electric systems allow for the complete elimination of carbon emissions.
- Electrical based motive power is considerably cheaper than the diesel equivalent.
- Battery-electric systems are mature and widely available.

Comparative to the use of hydrogen fuel cells, synthetic fuels and biofuels, battery-electric motive power systems have the following advantages:

- Battery-electric systems are considerably cheaper to operate than most other options, as electricity is cheaper to produce than other fuel types.
- Battery-electric systems and vehicles are cheaper to produce than hydrogen cell vehicles and are more readily available on the open market.
- Battery-electric systems produce no carbon emissions, unlike synthetic fuels and biofuels.

The use of battery-electric systems is subject to the availability of sufficient electrical energy generation to support operations as Milford Sound Piopiotahi and requires charging and energy storage infrastructure.

The following may be used as transitional options until such time as full conversion to electrical energy becomes feasible:

- Existing tour boats introduce blended fuel regimes into current operations.
- Tour boats be replaced with hybrid vessels as they reach the end of their operational life.
- Tour boats transition to use of 100% biofuels or synthetic diesel as these fuels become available.
- Hybrid buses may be introduced for the hop on/hop off Te Anau – Milford service also transitioning to the use of 100% biofuels or synthetic diesel.

12 Considerations for Implementation

The transition from the current reliance on diesel to an alternative fuel and motive system is complex, with many different factors that must be considered. This is particularly relevant where there are existing commercial operators in place that may be required to change their commercial operations and/or invest in new infrastructure.

The construction of infrastructure (particularly in an area of environmental importance) has a long lead and construction time and consideration must be given to how carbon reduction or elimination policies are implemented to ensure access is maintained to Milford Sound Piopiotahi and commercial operations remain viable without disruption.

Depending on what technology is ultimately selected, some infrastructure (such as power generation or transmission infrastructure) may serve multiple purposes and require capital investment and maintenance beyond the capabilities of an individual operator to provide and the mix of infrastructure ownership and procurement must be considered carefully prior to implementation.

In addition, many of the technologies considered in this study continue to evolve. Batteries in particular have benefited considerably from innovations in battery chemistry over the last decade that has significantly improved energy storage efficiency. If such innovations continue, improved battery storage may negate the requirement for recharge infrastructure for buses in the future.

12.1 Timing

New Zealand has set a target for net-zero carbon emissions by 2050, with 2035 a key milestone for the reduction of carbon emissions.

To achieve these objectives, carbon intensive fuels must ultimately be phased out, however the rapidity at which this transition occurs may be informed by a number of factors.

Vehicle (boat and bus) asset life is a key consideration, as vehicles purchased recently may reasonably expect a service life of 20 years or more. A rapid transition to alternative motive systems would accelerate the elimination of carbon emissions but would require the bulk retirement of existing fleet and the introduction of new fleet within a short time-period, which provides opportunities for bulk purchase, but imposes significant disruption and upfront cost to implementation. The financing of a rapid transition would also impose challenges to existing operators who would likely require significant capital to support the accelerated design and implementation of new fleet. It also means there is a significant risk of stranded assets, as retired fleet are disposed of on-mass.

Alternatively, a rolling transition into new motive power systems could be undertaken in alignment with the operational life of the fleet, with assets replaced at end-of-life. This approach allows for management of implementation costs and spreads the capital requirement over many years, depending on the remaining lifespan of the current fleet. The staged roll-out of fleet also provides opportunities to capitalise on any reduction in prices as carbon-free technology becomes more ubiquitous.

This comes at the expense of extending the use of carbon intensive fleet and the potential requirement to operate and maintain diverse motive systems and fuels concurrently.

12.2 Transition Strategies

While this study has investigated a range of motive power systems in isolation, in reality, given the mix of fleet across both bus and watercraft and the potential lead time for infrastructure, there are a number of strategies evident to migrate the current fossil fuel dependent operations to a zero-carbon future.

12.2.1 Minimise Disruption

Given the profile and demand for access to Milford Sound Piopiotahi, maintaining efficient operations during conversion to new motive power systems is paramount. The current mix of tour boats in service have a range of service lives and the introduction of new bus service, in combination to changes to access to the Milford area will be complex to implement.

One strategy for transition focuses on minimising disruption to operations by utilising a range of different motive-systems, commencing with the introduction of blended biofuels in current tour boat operations and long-distance bus services, with the proportion of biofuels increased according to fuel availability and efficiency.

As funding becomes available, supporting infrastructure for battery-electric motive systems (both watercraft and buses) can commence, while vessels reaching their end of life can be transitioned into battery-electric as soon as supporting infrastructure is in place. Similarly, buses for the new hop on/hop off Te Anau – Milford service may be introduced first utilising blended diesel, allowing the desired bus service to be established without the lead time associated with infrastructure implementation. As infrastructure is put in place, internal combustion-based buses may be retired or resold and replaced with a zero-carbon motive system.

Hybrid systems for buses or boats may also be introduced in the short or medium term, depending on the expected lead time for supporting infrastructure. Ultimately, the fleets operational lifespan should be considered in regard to the expected lead time for infrastructure to ensure any transition is cost effective and minimises the risk of stranded assets when full transition to battery-electric systems is achieved.

This approach allows operators to maintain access and services within Milford Sound Piopiotahi, while providing a short-term opportunity to reduce carbon emissions. The phase out of fleet may be timed to coincide with infrastructure completion.

12.2.2 Maximise Environmental Outcomes

Alternatively, the rapid investment in infrastructure early for either a Battery-electric or hydrogen fuel cell based system provides the ability to rapidly transition both bus and boat operations into zero-emission motive systems.

This provides maximum impact in terms of reducing carbon emissions, as a complete conversion rapidly eliminates all carbon-emissions associated with a more gradual transition dependent on the use of carbon-neutral or fossil fuel based fuels. In addition, rapid transition provides significant whole of life benefits, as the maintenance and fuel costs may be reduced across the life of the service. It also eliminates the complexity of maintaining and operating different technologies concurrently across bus and boat operations.

This approach comes at a considerable upfront cost, with investment required initially to ensure infrastructure is in place to support the preferred technology. It also means that carbon emissions will continue to be produced at current levels until all infrastructure is completed and the new fleet is in operation. Any delays in infrastructure implementation will result in the continued emission of carbon at current levels.

12.2.3 Recommended Transition Approach

The lead time required for the design and construction of infrastructure required to support battery-electric services is likely to be significant, especially given the areas remote location. Given this, the rapid transition to battery-electric motive power for both bus and boat is unlikely to be feasible in the short term.

On the assumption that the planning and construction of infrastructure will take a minimum of 5-10 years, it is recommended that short term opportunities for carbon reduction be explored, with full transition to battery electric systems occurring as and when infrastructure becomes available.

For buses, hybrid systems coupled with the use of reduced carbon fuels may be viable, particularly if long lead times are expected for infrastructure completion.

For tour boats, the use of reduced carbon fuels is recommended in the short to medium term given the complexity of boat design and the range of operators and vessels in service. This also allows operators to commence the design process for new battery-electric vessels well in advance of the infrastructure being in place while maintain operations in Milford Sound Piopiotahi.

This is illustrated in Figure 12-1.

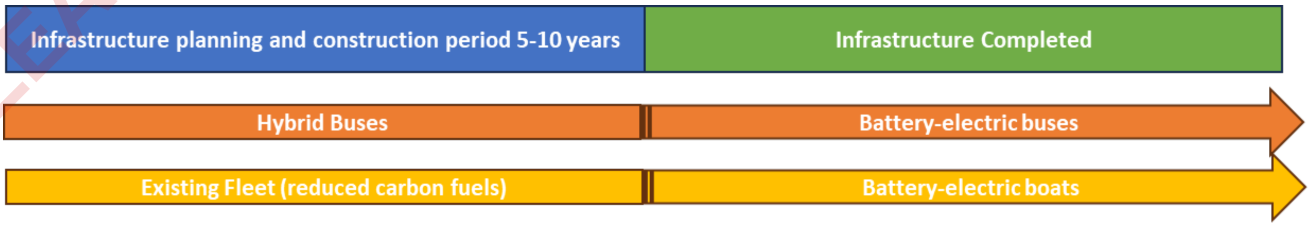

Figure 12-1: Recommended Transition Approach

Appendices

Appendix A Fuel Option Qualitative Assessment

Criteria	Criteria Description
Greenhouse Gas Emissions (GHG)	The fuel/energy contribution to the net balance of global greenhouse gases.
Harmful emissions	The production of nitrous oxides (NOx), sulfur oxides (SOx), fine particulates and other non-GHG gases at point of use that may be hazardous to human health.
Environmental contamination	The potential for the fuel/energy to damage the environment through storage, spills, contamination etc.
Disposal	The ease of disposal of end-of-life systems, such as batteries.
Safety	The relative safety for the storage, handling and use of the fuel or energy and the scale of safety protocols necessary to mitigate risk.
New infrastructure requirements	The potential scale of infrastructure required to support the use of the fuel/energy within Milford Sound Piopiotahi
Storage	The ease of storage of the fuel/energy
Energy efficiency	The efficiency in which energy is converted into motive power.
Operation impact	The potential for the fuel/energy system to impose changes to the operations of long-distance buses and tour boat operations.
Maintenance	The ease of maintenance over the vehicle's lifetime
Acceptance	Global and domestic support for the fuel/energy
Fuel Availability	The supply of the fuel/energy either domestically produced or on available on the international market.
Fuel Cost	The likely range of costs of alternatives relative to the price of diesel.
Disruption	The potential for disruption to access to Milford Sound Piopiotahi as a result of conversion to the fuel/energy.
Upgrade / Retrofit	The potential to retrofit or upgrade the existing bus and boat fleet to allow fuel/energy use.
Maturity	The commercial availability of the technology and its level of adoption and use.

Fuel Type	Engine Type	Bus Compatibility	Boat Compatibility	GHG Emissions (Global)	Harmful Emissions (Local)	Environmental Impacts (Local)	Disposal Impact	Safety	New Infrastructure Requirement	Storage Potential	Energy Efficiency	Operation	Maintenance	Global / National acceptance	Fuel availability	Fuel Cost	Disruption	Upgrade / Retrofit Potential	Maturity
Solid Coal	External combustion/boiler		X																
Coal Dust	IC/HEV		X																
SynGas (non renewabe pathways)	IC/HEV		X																
Heavy Fuel Oil (HFO)	IC/HEV		X																
Low Sulfur Fuel Oil (LSFO)	IC/HEV		X																
Very Low Sulfur Fuel Oil (VLSFO)	IC/HEV		X																
Ultra Low Sulfur Fuel Oil (ULSFO)	IC/HEV		X																
Diesel	IC/HEV	X	X																
Clean Diesel	IC/HEV	X	X																
Petrol/Gasoline	IC/HEV	X	X																
Marine Diesel Oil (MDO)	IC/HEV		X																
Hydrogen (non-green production pathway)	Gas Turbine/Fuel Cell/ Internal Combustion	X	X																
Blended Diesel	Internal combustion	X	X																
Liquified Natural Gas (LNG)	Gas Turbine/Internal Combustion	X	X																
Compressed Natural Gas (CNG)	Gas Turbine/Internal Combustion	X	X																
Pulverised Flammable Powder (excluding coal dust)	Internal Combustion		X																
Wood - Solid Fuel	External combustion/boiler/ Wood gas generator		X																
Wood - Pelletised Wood	IC/HEV		X																
Agricultural Bioethanol	IC/HEV	X	X																
By-product Bioethanol	IC/HEV	X	X																

Fuel Type	Engine Type	Bus Compatibility	Boat Compatibility	GHG Emissions (Global)	Harmful Emissions (Local)	Environmental Impacts (Local)	Disposal Impact	Safety	New Infrastructure Requirement	Storage Potential	Energy Efficiency	Operation	Maintenance	Global / National acceptance	Fuel availability	Fuel Cost	Disruption	Upgrade / Retrofit Potential	Maturity
Agricultural Biodiesel	IC/HEV	X	X																
By-product/ Renewable Biodiesel	IC/HEV	X	X																
Synthetic Diesel	IC/HEV	X	X																
Hydrogen Production (biomass/waste)	IC/HEV/FCEV	X	X																
Biomethane	Gas Turbine/Internal Combustion	X	X																
Methanol (green production pathways)	Internal Combustion/Fuel Cell	X	X																
Ethanol	IC/HEV	X	X																
Butanol	IC/HEV	X	X																
Hydrogen (green production pathway)	Gas Turbine/Fuel Cell/Internal Combustion	X	X																
Ammonia (Green production pathway)	IC/HEV	X	X																
Electricity (sustainable generation)	Battery	X	X																

Fuel Type	GHG Emissions (Global)	Harmful Emissions (Local)	Environmental Impacts (Local)	Disposal Impact	Safety	New Infrastructure Requirement	Storage Potential	Energy Efficiency	Operation	Maintenance	Global / National Acceptance	Fuel Availability	Fuel Cost	Disruption	Upgrade or Retrofit Potential	Maturity
Solid Coal	Coal is a fossil fuel and produces significant GHG emission on conversion to energy. High energy requirement for extraction and transportation	Coal contains other contaminants including NO_X, SO_X, particulates, and black carbon.	Solid coal produces localised particulate pollutants that are toxic and harmful to the environment.	Battery disposal may be required with HEV system. Ash and other waste products will require disposal.	Imposes new safety protocols for the handling and storage of coal.	Solid coal requires bulk storage and transportation facilities.	Solid coal may be stored on-site but requires significant space.	Very inefficient, with low relative energy efficiency.	Imposes significant labour and range limitations.	Utilises redundant technologies with specialist maintenance requirements. Very high maintenance required to maintain boilers and coal power energy production.	Both national and global policies seek to discontinue the production and use of coal.	Readily available domestically from Greymouth.	Coal is mined domestically and does not require import. Coal prices vary according to quality but are significantly cheaper than other fuel sources.	Very significant disruption during transition.	No upgrade or retrofit possible.	Largely historical as motive power.
Coal Dust	Coal is a fossil fuel and produces significant GHG emission on conversion to energy. High energy requirement for extraction and transportation	Coal contains other contaminants including NO_X, SO_X, particulates, and black carbon.	If inappropriately stored, coal dust could potentially produce localised contamination and pollutants.	Battery disposal may be required with HEV system. Ash and other waste products will require disposal.	Powdered coal is highly volatile with high risk of explosion. Powdered coal is also toxic. Handling and use would require strict safety protocols.	Will require specific bulk storage and transportation facilities.	Pulverised coal may be stored on-site but requires significant space.	Moderately efficient in terms of energy potential.	Imposes significant labour and range limitations.	Will require specialised maintenance requirements and protocols.	Both national and global policies seek to discontinue the production and use of coal.	Readily available domestically from Greymouth.	Coal is mined domestically and does not require import. Coal prices vary according to quality but are significantly cheaper than other fuel sources.	Very significant disruption during transition.	No upgrade or retrofit possible.	Not commercially available motive power system available for the class of boats in use.
SynGas (non-renewable pathways)	SynGas is produced via multiple pathways, including gasification of coal. All pathways (excluding biogas) liberate significant volumes of fossilised carbon.	SynGas production produces significant volumes of harmful contaminants (as per coal). Energy conversion of SynGas as motive power is relatively clean.	The storage, maintenance and transfer of syngas imposes the risk of contamination via accident or spill.	Battery disposal may be required with HEV system.	Syngas requires equivalent handling and safety to natural gas.	Will require specialised, pressurised containment vessels, equivalent to natural gas.	May be stored on site in pressurised storage vessels.	Moderately efficient in terms of energy potential and use.		Requires maintenance of slightly different fuel management but essentially uses standard IC engine.	Syngas is a modern fuel type that is becoming increasingly established in the global market.	Not widely available domestically, start up in Auckland uses plastic recycling for syngas generation. NZ previously utilized syngas production during the oil crisis to produce syngas from the natural gas reserves and could do so again.	Scalable depending on production potential and supply.	Low disruption during transition with potential for SynGas to be used for other domestic purposes on site.	Possible to upgrade or retrofit existing IC power systems like LPG conversion.	Syngas production is mature, Syngas use relies on existing technologies and is mature.

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Heavy Fuel Oil (HFO)	HFO is a by-product of petroleum refinement. Produces high volumes of GHG during production and use.	HFO contains large volumes of impurities and produces extreme levels of hazardous biproducts, in excess of standard diesel.	The storage, maintenance and transfer of fuel oil imposes risk of contamination via accident or spill. High viscosity, coupled with impurities mean any contamination would result in extremely serious environmental impacts.	Battery disposal may be required with HEV system.	Low volatility and widespread use mean safety protocols well established.	Requires liquid fuel bunkers	May be stored on site in liquid containment vessels.	Moderately efficient in terms of energy potential.	Only examples of use are for heavy marine applications - no examples of application in smaller vessels.	Standard IC power system and fuel system would impose very little change to maintenance requirements.	HFO already faces restrictions in some areas of natural importance (Antarctica). Global and national policies seek to discontinue use.	Widely available globally.	Very low cost of production means market price is very low relative to other fuels. Approximately 50% cheaper than diesel.	N/a due to lack of application for size of vessel.	No upgrade or retrofit possible.	Very mature in terms of large vessel use, no examples of application in smaller vessels.
Low Sulphur Fuel Oil (LSFO)	HFO is a by-product of petroleum refinement. Produces high volumes of GHG during production and use.	Reduced Sulphur emissions comparative to HFO.	The storage, maintenance and transfer of fuel oil imposes risk of contamination via accident or spill. High viscosity, coupled with impurities mean any contamination would result in extremely serious environmental impacts.	Battery disposal may be required with HEV system.	Low volatility and widespread use mean safety protocols well established.	Requires liquid fuel bunkers	May be stored on site in liquid containment vessels.	Moderately efficient in terms of energy potential.	Only examples of use are for heavy marine applications - no examples of application in smaller vessels.	Standard IC power system and fuel system would impose very little change to maintenance requirements.	Global or national policies on the use of LSFO seek to discontinue use.	Widely available globally.	Very low cost of production means market price is very low relative to other fuels. Approximately 50% cheaper than diesel.	N/a due to lack of application for size of vessel.	No upgrade or retrofit possible.	Very mature in terms of large vessel use, no examples of application in smaller vessels.
Very Low Sulphur Fuel Oil (VLSFO)	HFO is a by-product of petroleum refinement. Produces high volumes of GHG during production and use.	Reduced Sulphur emissions comparative to HFO.	The storage, maintenance and transfer of fuel oil imposes risk of contamination via accident or spill. High viscosity, coupled with impurities mean any contamination would result in extremely serious environmental impacts.	Battery disposal may be required with HEV system.	Low volatility and widespread use mean safety protocols well established.	Requires liquid fuel bunkers	May be stored on site in liquid containment vessels.	Moderately efficient in terms of energy potential.	Only examples of use are for heavy marine applications - no examples of application in smaller vessels.	Standard IC power system and fuel system would impose very little change to maintenance requirements.	Global or national policies on the use of VLSFO seek to discontinue use.	Widely available globally.	Very low cost of production means market price is very low relative to other fuels. Approximately 50% cheaper than diesel.	N/a due to lack of application for size of vessel.	No upgrade or retrofit possible.	Very mature in terms of large vessel use, no examples of application in smaller vessels.

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Ultra Low Sulphur Fuel Oil (ULSFO)	HFO is a by-product of petroleum refinement. Produces high volumes of GHG during production and use.	Reduced Sulphur emissions comparative to HFO.	The storage, maintenance and transfer of fuel oil imposes risk of contamination via accident or spill. High viscosity, coupled with impurities mean any contamination would result in extremely serious environmental impacts.	Battery disposal may be required with HEV system.	Low volatility and widespread use mean safety protocols well established.	Requires liquid fuel bunkers	May be stored on site in liquid containment vessels.	Moderately efficient in terms of energy potential.	Only examples of use are for heavy marine applications - no examples of application in smaller vessels.	Standard IC power system and fuel system would impose very little change to maintenance requirements.	Global or national policies on the use of ULSFO seek to discontinue use.	Widely available globally.	Very low cost of production means market price is very low relative to other fuels. Approximately 50 percent cheaper than diesel.	N/a due to lack of application for size of vessel.	No upgrade or retrofit possible.	Very mature in terms of large vessel use, no examples of application in smaller vessels.
Diesel	Diesel production and use produces high volumes of GHG emissions.	Standard diesel combustion produces fine particulates, NOx and SOx.	The storage, maintenance and transfer of diesel imposes risk of contamination via accident or spill. There are recent examples of diesel contamination in the Milford area.	Battery disposal may be required with HEV system.	Diesel is a compression-based fuel and therefore very safe to handle and store. Safety protocols are well established, with Diesel used routinely across the country with very low risk.	Diesel is already in use in Milford and storage and transmission infrastructure is in place.	Liquid storage already on site, which may be scaled up if needed.	Diesel (and clean diesel) are the current benchmark in terms of efficiency and use.	Diesel (or clean diesel) is currently in use for both bus and boat and represents the benchmark for operations.	Standard IC power system and existing fuel system mean no change is required to current maintenance regimes.	Widely accepted and in use nationally and globally.	Widely available globally.	Low fuel cost, due to high use and supply.	Currently in use.	No upgrade required.	Very mature in terms of bus and boat use, with diesel the standard fuel type for these vessels and vehicles.
Clean Diesel	Diesel production and use produces high volumes of GHG emissions.	Clean diesel produces lower volumes of harmful pollutants, in particular SO_x. Clean diesel still produces localised harmful emissions at point of combustion.	The storage, maintenance and transfer of diesel imposes risk of contamination via accident or spill. There are recent examples of diesel contamination in the Milford area.	Battery disposal may be required with HEV system.	Diesel is a compression-based fuel and therefore very safe to handle and store. Safety protocols are well established, with Diesel used routinely across the country with very low risk.	Diesel is already in use in Milford and storage and transmission infrastructure is in place.	Liquid storage already on site, which may be scaled up if needed.	Diesel (and clean diesel) is the current benchmark in terms of efficiency and use.	Diesel (or clean diesel) is currently in use for both bus and boat and represents the benchmark for operations.	Standard IC power system and existing fuel system mean no change is required to current maintenance regimes.	Widely accepted and in use nationally and globally.	Widely available globally.	Low fuel cost, due to high use and supply.	Currently in use.	No upgrade required.	Very mature in terms of bus and boat use, with diesel the standard fuel type for these vessels and vehicles.

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Petrol/Gasoline	Petrol/Gasoline production produces high volumes of GHG emissions during production and use.	Petrol / Gasoline combustion produces Carbone monoxide, NO_x, particulates etc. Petrol/Gasoline (comparative to diesel) produces less harmful emissions.	The storage, maintenance and transfer of diesel imposes risk of contamination via accident or spill.	Battery disposal may be required with HEV system.	While petrol/Gasoline is more volitive than diesel, safety protocols are well established, with petrol used routinely across the country with very low risk.	Petrol/gasoline may use existing storage and transmission infrastructure.	Liquid storage already on site, which may be scaled up if needed.	Petrol/gasoline is broadly equivalent to diesel in terms of energy efficiency.	Petrol/gasoline is broadly like diesel in terms of operations. Higher volatility means petrol/gasoline is less efficient in terms of high commercial applications.	Standard IC power system and existing fuel system mean no change is required to current maintenance regimes.	Widely accepted and in use nationally and globally.	Widely available globally.	Low fuel cost, due to high use and supply.	Very minor disruption required for conversion.	Existing systems may be upgraded to utilise different fuels.	Very mature, with petrol/gasoline in widespread use (although largely for non-commercial uses)
Marine Diesel Oil (MDO)	MDO produces high volumes of GHG's both during production and at point of use.	Very high sulphur content results in high volumes of harmful emissions.	The storage, maintenance and transfer of fuel oil imposes risk of contamination via accident or spill. High viscosity, coupled with impurities mean any contamination would result in extremely serious environmental impacts.	Battery disposal may be required with HEV system.	Low volatility and widespread use mean safety protocols well established.	Requires liquid fuel bunkers.	May be stored on site in liquid containment vessels.	Moderately efficient in terms of energy potential.		Standard IC power system and fuel system would impose very little change to maintenance requirements.		Widely available globally.	Very low cost of production means market price is very low relative to other fuels. Approximately 50 percent cheaper than diesel.			Very mature fuel all be it, not used for land transport.
Hydrogen (non-green production pathway)	Hydrogen production via steam reformation or oxidation of fossil fuel reserves produces considerable volumes of CO2 (higher than standard petroleum refinement).	No harmful emissions at point of use, although this excludes harmful emissions produced during production.	Hydrogen produces very little point of use of pollution and any issues with storage or transmission of liquid or gaseous hydrogen would result in the evaporation and escape of gaseous hydrogen with no long-lasting contamination	Hydrogen fuel cells require disposal or recycle at end of life. Fuel cells contain a range of toxic and valuable metals and materials, with recycling preferred to recover gold, silver, platinum, palladium, rhodium, iridium, and ruthenium. Fuel cells have a typical life	Hydrogen is extremely volatile when mixed with the correct ratio of air and due to the small size of the hydrogen molecule, is difficult to store and transport without leakage. New safety protocols will be required.	Will require new cryogenic liquid storage or gaseous storage, transmission systems and, logistics (including potential deliver by road or boat)	Hydrogen may be stored as a liquid if cryogenically cooled, or as a gas. Due to size of hydrogen molecule, there is a high risk of leakage.	Hydrogen has much lower volumetric energy density than diesel (as a point of comparison) with its energy density around one quarter of the hydrocarbon alternative. This means larger onboard fuel storage will be required for buses and boats.	Hydrogen fuel cells may operate at altitude and in cold temperatures and provide an operational range of around 450km (depending on size of fuel tank). Refuelling takes less than 10 minutes. Fuel cell vehicles are highly reliable. Acceleration and handling is broadly equivalent to	Hydrogen fuel cells have no moving parts, reducing maintenance requirements considerably. Maintenance regimes will need to change significantly to accommodate electricity-based drive train. Regular inspection of storage tanks is required.	Globally and nationally hydrogen is supported as an alternative to fossil fuels.	Biomass/waste stream hydrogen production not evident domestically.	Hydrogen is considered a low cost fuel. Large scale production would be expected to lower cost.	Significant disruption due to shift in storage, transmission, and operations.	Potential for retrofit of existing diesel buses and boats.	Hydrogen production via steam reformation very mature with most hydrogen on the global market provided from this source.

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				span of up to 250km and will require replacement depending on the work pattern of the boat or bus. In addition, onboard batteries will also require disposal at end of life.					a diesel vehicle.							
Blended Diesel	Blended diesel consists of a mix of fossil fuel and biological fuel types, with proportions of biological fuel ranging from 5% to 20%. Relative to the use of unblended diesel, blended diesel produces less emissions, however it still fundamentally dependent on a component of fossil fuels which produce GHG emissions during production and at point of use.	Blended diesel is similar to clean diesel in that it produces harmful particulates, NOx and SOx. Relative volumes of these emissions are dependent on the proportion of fossil fuel in use.	The storage, maintenance and transfer of diesel imposes risk of contamination via accident or spill.	Battery disposal may be required with HEV system.	Diesel is a compression-based fuel and therefore very safe to handle and store. Safety protocols are well established, with Diesel used routinely across the country with very low risk. The blended component of carbon neutral fuels does not significantly change the risk profile and the fuel uses the same safety protocols as conventional diesel.	Blended diesel uses the same infrastructure as standard diesel, with this infrastructure already in place in Milford.	Liquid storage already on site, which may be scaled up if needed.	Blended diesel provides similar energy efficiency to Diesel.	Blended diesel is equivalent to standard diesel in terms of operation and may be used in both bus and boat.	Blended diesel is more prone to 'diesel bug' or biological contamination of the fuel. The use of blended diesel imposes higher maintenance requirements for fuel storage, transmission and onboard fuel tanks.	Blended diesel is increasingly viewed as a transition pathway to the substitution of biofuels.	While fossil diesel is readily available, NZ produces very little biofuels, with biofuels comprising 0.1% of total liquid fuel sales (comparative to 4% globally). NZ lacks a mandate for biofuel targets and has not set standards for biofuels.	Due to the lack of domestic production, Biofuels are significantly more expensive (relative to standard diesel) domestically. International ly, biofuels cost on average 20% more than their fossil fuel equivalent.	Blended fuels require no transition or disruption to implement.	Biofuels may be progressively introduced into standard IC power plants with no modification	Biofuel use is mature, as is production. Blended mixes are in use in a number of jurisdictions globally.

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Liquified Natural Gas (LNG)	LNG is produced via the exploitation of fossil methane reservoirs via fracking. Methane is an extremely significant GHG and methane leaks during production and transport are a significant contributor to global heating.	Very low sulphur content and harmful emissions	Methane is clean burning and does not produce significant environmental hazards.	Battery disposal may be required with HEV system.	Safety protocols are established; however, LNG has some specific safety related factors - such as rapid gas expansion or rapid phase transition explosion when LNG comes into contact with water.	Requires cryogenically cooled storage tanks. Transmission would be required via truck or sea.	LNG is condensed into a liquid for transportation and requires cryogenic storage.	Energy density is approximately 60% of Diesel. Comparative to CNG, LNG provides higher power to weight ratio.	Feasible as both bus and boat operating system. Storage requirements means LNG tanks have a specified hold time before the pressure build is relieved, which may impact operational schedules.	Reduced maintenance relative to diesel. Storage tanks will require regular inspection and pressure management is major concern.	LNG was largely confined to local use (near point of production) due to challenges of cryogenic storage and transportation. These have been largely resolved, with the fuel now widely available internationally.	Bi-Product of fracking and hydrocarbon extraction. - LNG has become increasingly available in the 21st century. Several commercial production plants located in Australia, with many more globally. Natural gas is produced domestically via Taranaki onshore and offshore extraction.	Very low cost - wholesale price is 1/5 of diesel.	Duel fuel conversion allows for simple transition to use LNG if required. Will require storage and distribution infrastructure upgrades at Milford.	Dual fuel conversion possible with standard Diesel powerplants.	Use of LNG in large vehicles (trucks) mature in Chine and USA. Use in marine systems also commercially in operation, 175 sea-going LNG-powered ships in service in 2021, with a further 200 on order.
Compressed Natural Gas (CNG)	CNG is produced via the exploitation of fossil methane reservoirs via fracking. Methane is an extremely significant GHG and methane leaks during production and transport are a significant contributor to global heating.	Very low sulphur content and harmful emissions	Methane is clean burning and does not produce significant environmental hazards.	Battery disposal may be required with HEV system.	CNG is widely used with well-established safety protocols and handling regimes.	Will require pressurised storage on site, with transmission via truck or sea.	CNG is stored at ambient temperature and high pressure. Relative to LNG, it is cheaper to store, but requires larger area for storage.	Energy density is approximately 60 percent of Diesel. Has reduced power output at high rev's/use.	Feasible as both bus and boat operating system. CNG has reduced power to weight ratio during high power/torque (may be an issue with incline climbing) and increased space for gas storage due to lower energy density and requirement to store fuel as gas.	Reduced maintenance relative to diesel. High pressure storage tanks will require periodic inspection and certification.	CNG has been widely adopted globally as an alternative to diesel/petroleum, with widespread adoption during periods of instability of oil supply. Acceptance of use is declining due to recognition of the climate impacts of extraction.	Bi-Product of fracking and hydrocarbon extraction. - LNG has become increasingly available in the 21st century. Several commercial production plants located in Australia, with many more globally. Natural gas is produced domestically via Taranaki onshore and offshore extraction.	Very low cost - wholesale price is 1/5 of diesel.	Duel fuel conversion allows for simple transition to use LNG if required. Will require storage and distribution infrastructure upgrades at Milford.	Dual fuel conversion possible with standard Diesel powerplants.	Use of CNG is well established with large scale commercial operation in buses (including NZ during the 1970's and 80's).

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Pulverised Flammable Powder (excluding coal dust)	Assuming powders are derived from biological sources (i.e., wood etc.) PFP is considered carbon neutral.	Imperfect combustion results in significant combustion emissions, include particulates, carbon, NOx, SOx etc.	Varies dependent on the type of fuel powder used. Assuming organic base powders, fairly low risk of local contamination.	Battery disposal may be required with HEV system. Ash and other waste products will require disposal.	PFP's introduce new safety protocols regarding safe handling and storage, with imperfect combustion also introducing the risk of flash explosion in the powerplant	Will require new storage silos, transmission infrastructure etc.	Powders may be stored in silo's and will last indefinitely.	Experiments with PFP's indicate low energy efficiency with combustion process, resulting in low energy conversion, high rates of combustion bi products and unburnt fuel.	Low energy efficiency, coupled with totally new fuel supply systems will likely significantly impact operations.	Inefficiency in combustion process will require significant upkeep to maintain power plants.	No national support or opposition to the use of PFP's, reflecting the infancy of the technology.	Precursor fuels (wood biomass, agricultural products etc) are readily available, however there is market production of PFP's for fuel.	Due to absence of supply - fuel cost likely to be very high.	Conversion to PFP's will require significant new infrastructure, conversion or replacement of existing fleet and establishment of new logistical supply chain.	No evidence of upgrade or refit potential.	No examples of use of PFP in any prototype or commercial transport system (bus or boat).
Wood - Solid Fuel	Solid wood burning liberates stored carbon, however as this carbon is liberated from biomass, it does not increase net atmospheric carbon. As such, it is carbon neutral.	Inefficient combustion processes results in the production of significant harmful emissions - including carbon particulates, embers, ash, etc.	Dead wood stored in volume releases carbon monoxide. Wood combustion produces localised emissions - smoke and can interact with fog in certain climatic conditions to produce smog.	Ash and combustion biproducts will require disposal	Solid fuel will require different handling and storage protocols. Management of carbon monoxide and risk of dust explosion associated with this fuel.	Will require bulk storage, as well as new logistics chain to move high quantity of bulk fuel products.	May be stored on site, however because fuel is bulky, space requirements for storage significantly higher than other fuel types.	Wood combustion (via external combustion and boiler) is extremely inefficient relative to other fuel types, including coal using the same system.	Low energy efficiency, coupled with high labour requirement will significantly impact operations. Size of power plan and storage likely to reduce seating capacity. Not feasible for buses.	Will impose significant maintenance requirements for a niche power plant.	Solid wood combustion is not opposed or supported, largely due to its lack of moder application in transport.	New Zealand has a ready supply of forestry and wood products.	Wood is extremely cheap; however, this is offset by high handling and transport costs.	Conversion to soldi fuel and external combustion will impose significant disruption. New logistics will be required.	No potential for upgrade or retrofit.	Post-mature - this technology is largely historical as motive power.
Wood - Pelletised Wood	Wood pellets utilise forestry waste material and are therefore carbon neutral.	Minimal NOx and SOx, however pellet combustion produces particulates.	Pellets may release localised carbon monoxide.	Battery disposal may be required with HEV system. Ash and other waste products require disposal.	Pelletised wood will require different handling and storage protocols.	Will require storage silos and new transmission equipment or logistic chains.	May be stored in volume in silos. Bulkier than other liquid or gas-based fuels, means more space/storage will be required. May be stored for extended periods.	Wood pellets have a similar energy density to coal.	No evidence of practical application of wood pellets, however the nature of the fuel, coupled with the lower energy density suggests operational range and use would be significantly less than diesel.	Use of entirely new hopper and feed system, coupled with inefficient combustion would significantly increase maintenance requirements.	Wood pellets are supported nationally and internationally as an easy and accessible form of biofuel.	Ready supply domestically of wood pellets with several production plants established. Hi availability of forestry waste products means supply will continue.	High availability of domestic supply coupled with monetisation of forestry waste streams means fuel price is very low.	Significant disruption due to shift in storage, transmission, and operations.	No ability to retrofit or upgrade existing engines - this fuel would require a complete rebuild with custom vehicles.	No evidence of pelletised wood used in transport motive power systems

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Agricultural Bioethanol	Agricultural bioethanol is produced from crop biomass, as such production is carbon neutral. Emissions at point of combustion are 20 percent lower than diesel.	Combustion of ethanol produces heat, water vapor and carbon dioxide.	Local emissions and risk of contamination are minimal. Production mechanism introduces opportunity cost in terms of land required for precursor crops, as well as loss of biodiversity due to monoculture.	Battery disposal may be required with HEV system.	Ethanol is highly volatile (relative to diesel) and will require safety and handling protocols more equivalent to Petrol/Gasoline.	Will require liquid storage and transmission infrastructure but will likely be able to use existing infrastructure used for diesel.	May be stored on site in liquid containment vessels.	Bioethanol has an energy density approximately 75% of diesel - meaning more fuel will be required for equivalent range. Bioethanol volatility means it is better used for hi-octane fuel types.	Difference in energy density means onboard fuel tanks will need to be larger to maintain the same range.	Special/different lubrication may be required; however, maintenance practices are very similar to standard diesel.	Bioethanol is increasingly supported globally as an alternative to fossil fuels with large scale production occurring in the US, China, Indonesia etc. Domestically, biofuels are supported, but no mandate in place to encourage production and supply.	Bioethanol currently produced at small scale by utilization of milk whey waste products. Local production is very limited, however globally bioethanol is readily available on the international market.	Current fuel price is between 1.5 to 1.8 times the cost of conventional diesel - reflective of lack of domestic supply. If the fuel was more widely used, supply increases would likely result in price decrease	Assuming suitable supply can be located, minimal disruption would be expected from transitioning to this fuel.	Diesel engines can be converted to bioethanol operation with relatively ease.	Bioethanol use as fuel is very mature, with ethanol first considered for use in internal combustion in the early 20th century.
By-product Bioethanol	By-product bioethanol uses organic waste that is fermented to form alcohol. As it is utilizing waste streams from other renewable industries, the fuel is considered carbon neutral	Combustion of ethanol produces heat, water vapor and carbon dioxide.	Local emissions and risk of contamination are minimal.	Battery disposal may be required with HEV system.	Ethanol is highly volatile (relative to diesel) and will require safety and handling protocols more equivalent to Petrol/Gasoline.	Will require liquid storage and transmission infrastructure but will likely be able to use existing infrastructure used for diesel.	May be stored on site in liquid containment vessels.	Bioethanol has an energy density approximately 75% of diesel - meaning more fuel will be required for equivalent range. Bioethanol volatility means it is better used for hi-octane fuel types.	Difference in energy density means onboard fuel tanks will need to be larger to maintain the same range.	Special/different lubrication may be required; however, maintenance practices are very similar to standard diesel.	Bioethanol is increasingly supported globally as an alternative to fossil fuels with large scale production occurring in the US, China, Indonesia etc. Domestically, biofuels are supported, but no mandate is placed to encourage production and supply.	Bioethanol currently produced at small scale by utilization of milk whey waste products. Local production is very limited, however globally bioethanol is readily available on the international market.	Current fuel price is between 1.5 to 1.8 times the cost of conventional diesel - reflective of lack of domestic supply. If the fuel was more widely used, supply increases would likely result in price decrease	Assuming suitable supply can be located, minimal disruption would be expected from transitioning to this fuel.	Diesel engines can be converted to bioethanol operation with relatively ease.	Bioethanol use as fuel is very mature, with ethanol first considered for use in internal combustion in the early 20th century.

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Agricultural Biodiesel	Biodiesel utilizes carbon sequestered from biological processes and is therefore considered carbon neutral.	Biodiesel produces up to 30 percent higher concentrations of NOx emissions, depending on the feedstock used to produced.	The storage, maintenance and transfer of biodiesel imposes risk of contamination via accident or spill. Relative impact of such a spill would be less than the diesel equivalent as biodiesel is fully biodegradable.	Battery disposal may be required with HEV system.	Equivalent to standard diesel.	May use existing infrastructure.	May be stored in liquid containment vessels and may use existing storage vessels.	Slightly less energy efficient than standard diesel, diesel is about 90 percent of the energy density of standard diesel.	Reduced energy density may result in slightly reduced range. Not likely to impact boat operations due to the comparative short distance of use. It may impact buses, requiring them to top up or carry more fuel onboard.	Maintenance regimes equivalent to standard diesel. Lubricity is improved over conventional diesel. Introduces higher risk for diesel bug biological contamination of supply.	Biodiesel is increasingly supported globally as an alternative to fossil fuels with large scale production occurring in the US, China, Indonesia etc. Domestically, biofuels are supported, but no mandate is placed to encourage production and supply.	Ready supply of feedstocks domestically, however only small-scale production is evident domestically. High cost of infrastructure to establish biofuels, however it is available on the international market.	Current fuel price is between 1.5 to 1.8 times the cost of conventional diesel - reflective of lack of domestic supply. If the fuel was more widely used, supply increases would likely result in price decrease	Biodiesel (B100) can be designed to be a drop-in fuel, meaning no change is required to current operations.	B100 drop in fuels may be used in existing engines.	Biodiesel use and production is mature, however market demand is small.
By-product/ Renewable Biodiesel	Biodiesel utilizes carbon sequestered from biological processes and is therefore considered carbon neutral.	Biodiesel produces up to 30 percent higher concentrations of NOx emissions, depending on the feedstock used to produced.	The storage, maintenance and transfer of biodiesel imposes risk of contamination via accident or spill. Relative impact of such a spill would be less than the diesel equivalent as biodiesel is fully biodegradable.	Battery disposal may be required with HEV system.	Equivalent to standard diesel.	may use existing infrastructure.	May be stored in liquid containment vessels and may use existing storage vessels.	Slightly less energy efficient than standard diesel, diesel is about 90% of the energy density of standard diesel.	Reduced energy density may result in slightly reduced range. Not likely to impact boat operations due to the comparative short distance of use. It may impact buses, requiring them to top up or carry more fuel onboard.	Maintenance regimes equivalent to standard diesel. Lubricity is improved over conventional diesel. Introduces higher risk for diesel bug biological contamination of supply.	Biodiesel is increasingly supported globally as an alternative to fossil fuels with large scale production occurring in the US, China, Indonesia etc. Domestically, biofuels are supported, but no mandate is placed to encourage production and supply.	Ready supply of feedstocks domestically, however only small-scale production is evident domestically. High cost of infrastructure to establish biofuels, however it is available on the international market.	Current fuel price is between 1.5 to 1.8 times the cost of conventional diesel - reflective of lack of domestic supply. If the fuel was more widely used, supply increases would likely result in price decrease	Biodiesel (B100) can be designed to be a drop-in fuel, meaning no change is required to current operations.	B100 drop in fuels may be used in existing engines.	Biodiesel use and production is mature, however market demand is small.

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Synthetic Diesel	Utilizes atmospheric carbon dioxide that is hydrogenated to produce synthetic fuel.	Produces significant quantities of NOx and methane.	The storage of synthetic diesel imposes a risk of contamination or spill.	Battery disposal may be required with HEV system.	Equivalent to standard diesel.	may use existing infrastructure.	May be stored in liquid containment vessels and may use existing storage vessels.	Slightly less energy efficient than standard diesel, diesel is about 90% of the energy density of standard diesel.	Reduced energy density may result in slightly reduced range. Not likely to impact boat operations due to the comparative short distance of use. It may impact buses, requiring them to top up or carry more fuel onboard.	Maintenance regimes equivalent to standard diesel. Lubricity is improved over conventional diesel. Introduces higher risk for diesel bug biological contamination of supply.	Synthetic biofuels are supported domestically and globally, as a potential pathway for the reduction of carbon emissions.	Synthetic diesel is dependent on hydrogen and limited supply chains for hydrogen production have limited the availability domestically.	Synthetic fuel is likely to be significantly more costly than diesel, although costs will reduce as production scales to meet demand.	Synthetic diesel is designed to be equivalent to diesel, allowing minimal change to operations	Synthetic diesel may be used as a drop in fuel in existing engines.	Scaled production is dependent on immature technologies.
Hydrogen Production (biomass/waste)	Biomass hydrogen production utilizes sequestered carbon from biological waste material that is reformed to produce carbon emissions and pure hydrogen during production. This results in no net increase in carbon - carbon neutral.	When combusted can produce small quantities of NO_X, as well as H_20. When used in a fuel cell, only H_20 is produced.	Hydrogen produces very little point of use of pollution and any issues with storage or transmission of liquid or gaseous hydrogen would result in the evaporation and escape of gaseous hydrogen with no long-lasting contamination.	Assuming use of fuel cells, fuel cells will require disposal or recycle at end of life. Fuel cells contain a range of toxic and valuable metals and materials, with recycling preferred to recover gold, silver, platinum, palladium, rhodium, iridium, and ruthenium. Fuel cells have a typical life span of up to 250km and will require replacement depending on the work pattern of the boat or bus. In addition, onboard batteries will also	Hydrogen is extremely volatile when mixed with the correct ratio of air and due to the small size of the hydrogen molecule, is difficult to store and transport without leakage. New safety protocols will be required.	Will require new cryogenic liquid storage or gaseous storage, transmission systems and, logistics (including potential deliver by road or boat)	Hydrogen may be stored as a liquid if cryogenically cooled, or as a gas. Due to size of hydrogen molecule, there is a high risk of leakage.	Hydrogen has much lower volumetric energy density than diesel (as a point of comparison) with its energy density approximately 1/4 of the hydrocarbon alternative. This means larger onboard fuel storage will be required for buses and boats.	Hydrogen fuel cells may operate at altitude and in cold temperatures and provide an operational range of around 450km (depending on size of fuel tank). Refuelling takes less than 10 minutes. Fuel cell vehicles are highly reliable. Acceleration and handling is broadly equivalent to a diesel vehicle.	Hydrogen fuel cells have no moving parts, reducing maintenance requirements considerably. Maintenance regimes will need to change significantly to accommodate electricity-based drive train. Regular inspection of storage tanks is required.	Globally and nationally hydrogen is supported as an alternative to fossil fuels.	Biomass/waste stream hydrogen production not evident domestically.	Hydrogen is approximately 2-3 times more expensive than diesel/petrol with cost largely driven by lack of supply/demand. Large scale production would be expected to lower cost.	Significant disruption due to shift in storage, transmission, and operations.	Potential for retrofit of existing diesel buses and boats.	Hydrogen fuel cells have been in use for several decades, however large-scale production and transmission is still in its infancy in NZ.

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				require disposal at end of life.												
Biomethane	Biomass hydrogen production utilizes sequestered carbon from biological waste material that is reformed to produce carbon emissions and pure hydrogen during production. This results in no net increase in carbon - carbon neutral.	CO_2 is made as a produce when biomethane is used as an energy source.	Production facilities has minimal impact on the environment. No additional raw materials are needed for production, therefore, does not negatively impact the environment as much as other fuel production.		Risk of toxic hydrogen sulphides when methane used as energy source. Leaks of unburned methane presents an additional risk as methane is a potent GHG. Can be explosive when mixed with air							No evidence of large-scale generation or capture of biomethane domestically, and little evidence of significant commercial availability on the international market.	More expensive than methanol			Becoming more widely used internationally.
Methanol (green production pathways)	Methanol is synthesized from a mix of hydrogen, carbon dioxide and carbon monoxide and produces 95 percent less carbon emissions than a diesel equivalent.	Methanol reduces NOx emissions by 80 percent and eliminates SOx and particulates.	Methanol can be hazardous and an environmental contaminant if leaks or mishap occurs. Methanol can kill wildlife, including fish and stunt plant growth, particularly with long term exposure.	Assuming use of fuel cells, fuel cells will require disposal or recycle at end of life. Fuel cells contain a range of toxic and valuable metals and materials, with recycling preferred to recover gold, silver, platinum, palladium, rhodium, iridium and ruthenium. Fuel cells have a typical life span of up to 250km and will require replacement depending on the work pattern of the boat or bus. In	Methanol is highly volatile and hazardous. New safety protocols will be required.	Will require liquid storage and transmission infrastructure but will likely be able to use existing infrastructure used for diesel.	May be stored in liquid containment vessels and may use existing storage vessels.	Methanol has a lower volumetric energy density than diesel (approximately 50% less) - meaning larger fuel storage will be required.	Difficulty for spark ignition in low temperature operation (assuming combustion). Fuel cells equivalent to hydrogen (above).	Higher maintenance and wear associated with water and acid combustion products when used in IC. Much lower maintenance if used in fuel cell	Global support for use of Methanol in shipping industry. Also supports of methanol/ petrol blend.	Only one domestic supplier, but available on the international market	Approximate to diesel	Minimal disruption if existing IC power systems are tuned to run on methanol/ethanol. Fuel cell conversion will require bigger change to fleet (bus and boat).	Readily usable in existing IC systems with minor modifications only.	Currently in widespread use in marine shipping. Methanol/blend buses undergoing trial in India.

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				addition, onboard batteries will also require disposal at end of life. If combustin g, should be low for disposal impact.												
Ethanol	Ethanol is produced from high sugar yield crops. As such it does not liberate fossil carbon and is considered carbon neutral. Land use choices used to generate ethanol may result in carbon emissions - i.e., conversion of carbon sinks (forestry, wetlands etc.) into crop land will result in net increases to carbon emissions.	Ethanol combustion and evaporative emissions include NOX, CO, CO2. Relative to diesel, ethanol produces lower volumes of harmful emissions	Ethanol can be hazardous and an environmental contaminant if leaks or mishap occurs. Ethanol can kill wildlife, including fish.	Battery disposal may be required with HEV system.	Ethanol is highly volatile (relative to diesel) and will require safety and handling protocols more equivalent to Petrol/Gas oline.	Will require liquid storage and transmissio n infrastructur e but will likely be able to use existing infrastructur e used for diesel.	May be stored in liquid containment vessels and may use existing storage vessels.	E100 (pure ethanol) has 60 percent of the energy in diesel.	Lower energy density means range reduction relative to diesel. Difficulty for spark ignition in low temperature.	Special lubricants required, but maintenance practices very similar to conventional fuel operations.	Used extensivel y in petrol fuel blends, mixed support for ethanol as a fuel, largely related to land and cultivation practices required to generate feed stock. Ethanol production in NZ is via whey - a byproduct of the dairy industry.	20 million litres produced annually - 60% going to export market. No use in transport industry currently.	Slightly cheaper than diesel, however savings are offset by increased volume requirement.	Minimal disruption if existing IC power systems are tuned to run on methanol/et hanol.	Existing IC systems may be upgraded and tuned to use ethanol.	Currently used predominate ly in fuel blends. Ethanol as a fuel date back to the first developmen t of the iC engine.

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Butanol	Produced through similar mechanisms to methanol/ethanol.	Similar to Ethanol.	Similar to ethanol	Battery disposal may be required with HEV system.	Butanol is highly volatile (relative to diesel) and will require safety and handling protocols more equivalent to Petrol/Gasoline.	Will require liquid storage and transmission infrastructure but will likely be able to use existing infrastructure used for diesel.	May be stored in liquid containment vessels and may use existing storage vessels.	Butanol contains a higher energy density than Ethanol - providing approximately 80% of the energy density of Diesel.	Butanol may be used as fuel blend or potentially as a drop in alternative fuel. Due to the relatively high energy density, operational range should be proximate to standard diesel. Also suffers from park ignition issues at low temperatures.	Special lubricants required, but maintenance practices very similar to conventional fuel operations.	Not widely utilized, butanol is undergoing development in America. If fuel trials are successful, it is likely to be supported as a low carbon alternative to fossil fuels.	No large-scale production of Butanol evident.	Difficult to estimate given absence of large-scale production, however production pathways are similar to ethanol - potentially equivalent price.	Minimal disruption of IC engines may be tuned to run effectively on 100% Butanol.	Drop in fuel with no engine modification required.	No production vehicle of any type currently uses Butanol exclusively, although blended butanol vehicles are being trialed.
Hydrogen (green production pathway)	Green hydrogen is produced from the electrolysis of water. If power inputs are based on renewables, this may be considered carbon free. Utilization of Hydrogen in either combustion or fuel cells produces water only - entirely carbon free.	Only by-products of hydrogen are water - no harmful emissions produced.	Hydrogen produces very little point of use of pollution and any issues with storage or transmission of liquid or gaseous hydrogen would result in the evaporation and escape of gaseous hydrogen with no long-lasting contamination.	Assuming use of fuel cells, fuel cells will require disposal or recycle at end of life. Fuel cells contain a range of toxic and valuable metals and materials, with recycling preferred to recover gold, silver, platinum, palladium, rhodium, iridium and ruthenium. Fuel cells have a typical life span of up to 250km and will require replacement depending on the work pattern of the boat or bus. In addition, onboard batteries will also require	Hydrogen is extremely volatile when mixed with the correct ratio of air and due to the small size of the hydrogen molecule, is difficult to store and transport without leakage. New safety protocols will be required.	Will require new cryogenic liquid storage or gaseous storage, transmission systems and, logistics (including potential deliver by road or boat)	Hydrogen may be stored as a liquid if cryogenically cooled, or as a gas. Due to size of hydrogen molecule, there is a high risk of leakage.	Hydrogen has much lower volumetric energy density than diesel (as a point of comparison) with its energy density approximately 1/4 of the hydrocarbon alternative. This means larger onboard fuel storage will be required for buses and boats.	Hydrogen fuel cells may operate at altitude and in cold temperatures and provide an operational range of around 450km (depending on size of fuel tank). Refuelling takes less than 10 minutes. Fuel cell vehicles are highly reliable. Acceleration and handling is broadly equivalent to a diesel vehicle.	Hydrogen fuel cells have no moving parts, reducing maintenance requirements considerably. Maintenance regimes will need to change significantly to accommodate electricity-based drive train. Regular inspection of storage tanks is required.	Globally and nationally hydrogen is supported as an alternative to fossil fuels.	Currently only small-scale production available domestically, however woodside energy and meridian are developing a proposal for the largest global production of green hydrogen (in the form of ammonia).	Hydrogen is approximately 2-3 times more expensive than diesel/petrol with cost largely driven by lack of supply/demand. Large scale production would be expected to lower cost.	Significant disruption due to shift in storage, transmission, and operations.	Potential for retrofit of existing diesel buses and boats.	Hydrogen fuel cells have been in use for several decades, however large-scale production and transmission is still in its infancy in NZ.

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				disposal at end of life.												
Ammonia (Green production pathway)	Green ammonia is produced using similar pathways to hydrogen - indeed ammonia is produced as a means of efficiently storing hydrogen, with the hydrogen liberated at point of use.	Ammonia combustion or use in fuel cells produces very high volumes of NOX.	Ammonia can be highly toxic and an environmental contaminant if leaks or mishap occurs. Ammonia can kill wildlife as well deposit significant concentrations of NOx in soils or waterways.	Battery disposal may be required with HEV system.	Ammonia has low volatility, mitigating risk of flash explosion. Ammonia is toxic to humans in high concentrations and will require the development of new safety protocols.	Ammonia may be stored in liquid storage tanks,	Ammonia is far more efficient (relative to hydrogen) for storage and may be stored in bulk as a liquid at modest pressures (10-15 bar) or refrigerated. Ammonia may also be stored and 'cracked' on site to produce hydrogen.	Ammonia provides much higher energy density than hydrogen (70% higher than liquid hydrogen and 300% higher than gaseous hydrogen). Ammonia is proximate to fossil fuels in terms of energy efficiency.	Hydrogen energy potential suggests proximate range and performance relative to diesel - noting the direct use of ammonia is in its infancy.	Ammonia storage will require regular inspection and certification. Maintenance requirements will depend on motive power system (IC or Fuel cell) - however undoubtedly will require significant change to maintenance regime.	Ammonia is widely produced for other uses. The use of ammonia as an alternative to carbon intensive fuels is supported, however the high emission of NOX is a point of concern for use.	Ammonia is in large scale production globally and domestically. There is the potential for further expansion of ammonia production linked o the Meridian energy proposal - with ammonia used as a storage medium for hydrogen.	Potentially very cheap - green ammonia may be produced at around 60% of the cost of fossil fuels.	Will require significant change to storage, transmission, and logistics.	Difficult to assess, given the maturity of this fuel type - high ignition temperature of ammonia suggesting significant modifications may be required for use in combustion engines.	Ammonia use as fuel is in it's infancy, with no evidence of dedicated motive power systems developed for commercial use.
Electricity (sustainable generation)	In so far as electricity is generated from renewables, electricity is a zero-carbon energy source.	Electricity produces zero emissions.	Storage systems (capacitors, batteries etc.) have no risk of local fuel leak or contamination.	Batteries have limited lifespans - may be refurbished or recycled, but ultimately will require disposal.	Electricity is widely used as an energy source throughout the world, with safety protocols well established.	Existing electrical generation is already in the area, however the ability to expand capacity to make electrical motive power viable at Milford is limited. Transmission infrastructure to allow grid connection may be required to make this viable, coupled with battery storage systems.	Electrical storage potential is limited, with long term storage not feasible. This means access to consistent reliable supply of electricity is necessary to make this energy source viable.	Electricity is extremely efficient, with a 90 percent conversion rate of electrical energy to motive power. Electricity is the most efficient form of energy for use in motive power systems.	Electricity (coupled with battery electric systems) is likely to be highly effective for boat operations, given the small duration and distance of sailings, as well as access to potential recharge. Range potential for buses requires confirmation - with grade, temperature and distance suggesting Milford may be approaching the limits of range for current battery electric systems.	Use of electric motive power will require a significant change in maintenance regimes, however electric power systems have few moving parts and have a much-reduced maintenance requirements and longer operational life span relative to IC engines. Batteries will require replacement as they age - resulting in voltage decay.	Electricity is in widespread use and is highly supported as a carbon zero motive power option.	Electricity is produced domestically and there is evident excess capacity and the ability to scale power generation up using renewable systems. Electricity production at Milford is limited however and ultimately increased generation or transmission may be required to make this viable for boats.	Electricity is extremely cheap relative to other fuel types.	Main point of disruption will be the infrastructure response necessary to secure sufficient on-site power at Milford.	Potential for existing fleet to refitted to provide electric motive power.	Electricity for use in motive power is widely available and in use worldwide, including buses, boats etc.

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