Electrification of non-road and heavy-duty vehicles

Prepared by: Narayan Gopinathan, UBC Sustainability Scholar, 2020
Prepared for: Cindy Onyejekwe and Sheryl Cumming, Metro Vancouver

August 2020

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organisations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

Acknowledgements

The author would like to thank the following individuals for their contribution, feedback, and support throughout this project.

Cindy Onyejekwe, Sheryl Cumming, Brendon James, Amy Thai, David McPhie, Chase LeCroy, Stacey Foreman, Eric Feeley, Clay Howey, and Victor Keller.

Cover Photo Credit: Wikimedia Commons

Contents

Executive Summary

To achieve deep decarbonization and stop climate change, a new mantra has emerged: Electrify everything. There are clear paths to doing so when it comes to certain types of energy use – for example, technology in small cars has developed rapidly. The next steps are the non-road equipment, such as construction equipment, and the heavy-duty trucks that move goods.

Though this technology is more nascent, there are promising developments in this area. There are electric excavators operating in Norway and there is electric airport equipment operating within Metro Vancouver. These options are likely to proliferate and become more viable over the coming years, and electrification of additional types of equipment is likely to become viable.

To enable the successful electrification of more types of equipment, charging infrastructure is necessary. As such, there are things that Metro Vancouver could do to support the adoption of electric equipment. The first would be to simply raise awareness of the options that are already available and becoming available. British Columbia already has programs to provide financial incentives for the electrification of special use vehicles, and that is another thing that fleet owners need to be made aware of. In addition, specialized equipment will require specialized charging infrastructure, and there may be a role that regional governments like Metro Vancouver can play in supporting the availability of this infrastructure.

This report assesses the extant options for electrification of different types of equipment in different parts of the world, and the institutional frameworks that enable regions to achieve success. The types of equipment investigated include ferries, buses, trucks, construction equipment, airport equipment, port equipment. The report also examines the possibility of solar photovoltaic charging infrastructure in Metro Vancouver.

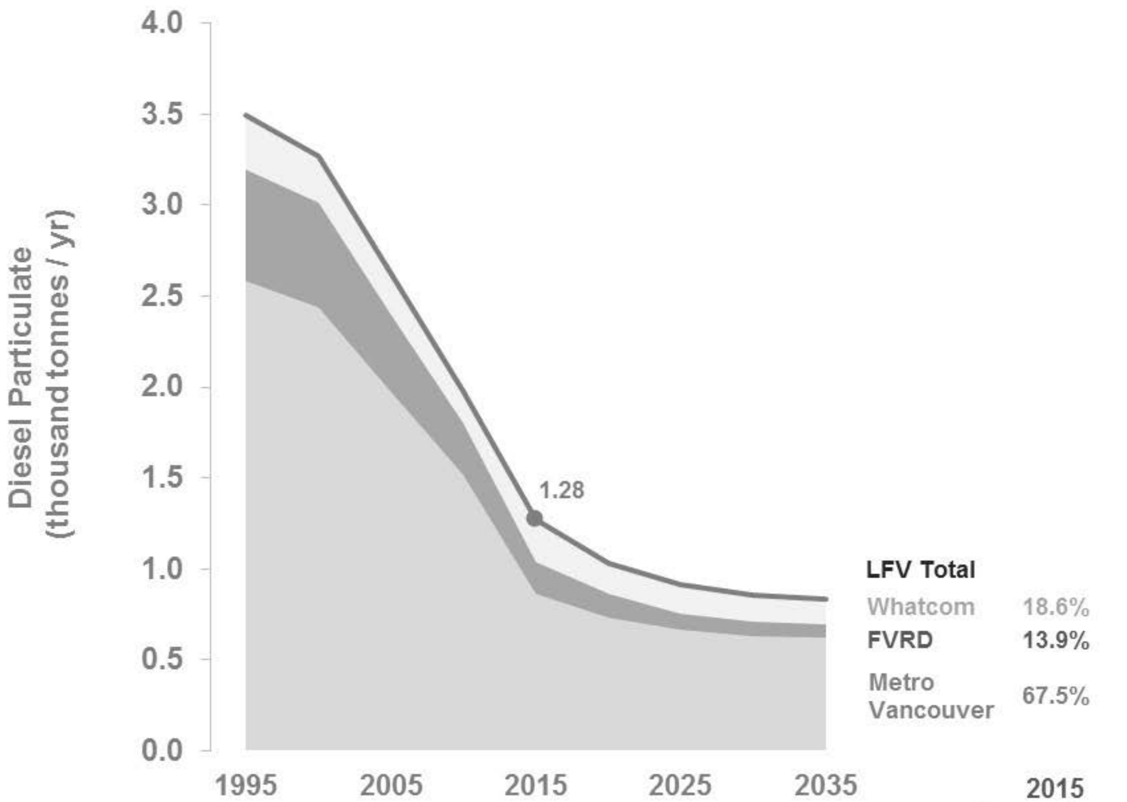
A charging station operated by BC Hydro.
Photo credit: Wikimedia Commons

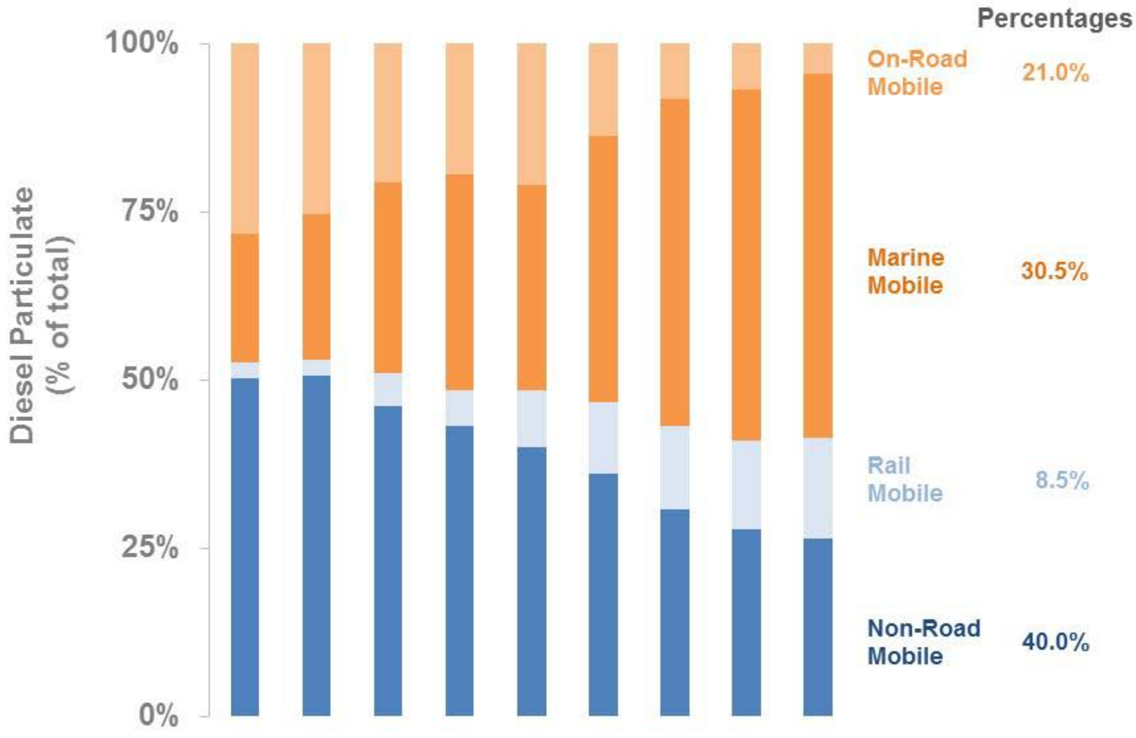
Introduction

The planet earth is in a climate emergency, and the keys to tackling climate change include eliminating greenhouse gas (GHG) emissions from electricity generation and electrifying almost all end uses of energy. British Columbia could take advantage of its low-carbon hydropower to drive forward electrification of other energy uses. In some applications, such as long-distance aircraft and marine vessels, the technology for full electrification is not yet available. In others, such as light-duty vehicles, it is available. And in others, such as certain categories of non-road engines, the technology is in its nascent stages of development. Electrification is, for most applications of energy use, the most viable way to eliminate greenhouse gas emissions and other contaminants that arise from the combustion of fuel. For this reason, Metro Vancouver is looking to identify ways to electrify the use of vehicles and equipment that operate in its region, which fall within its regulatory scope.

There is a specific reason to focus on equipment that burns diesel fuel. Diesel fuel combustion causes emissions of diesel particulate matter (DPM), which is toxic and carcinogenic. In Metro Vancouver, non-road mobile sources are the biggest source of DPM. This category includes construction equipment such as excavators and bulldozers, ground support equipment at the airport, among others. After non-road mobile sources, the next biggest source of DPM is marine mobile sources, such as ships and ferries. On-road mobile sources such as trucks and buses are next biggest source of DPM, followed by rail mobile sources. The graph on the right shows the sources of DPM emissions in the Lower Fraser Valley region, which includes sources within the Metro Vancouver and the Fraser Valley regions in British Columbia, Canada and Whatcom County in Washington, United States. Since Metro Vancouver is the most populated segment of this airshed, it is also its biggest source of emissions. The graph on the following page comes from the 2015 Lower Fraser Valley Air Emissions Inventory.

Metro Vancouver is not alone in trying to stop emissions of GHGs, DPM, or other emissions. Many cities around the world are engaging in the same struggle. The C40 network of cities was founded as a way for cities to share best practices and tips and work together through solutions to this challenge; and the Under 2 Coalition was developed as a way to do the same thing at a state and provincial level. Many cities are moving to electrify their urban bus fleets, open the streets to pedestrians and bicyclists, and promote the electrification of other engines.


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Diesel Particulate (thousand tonnes / yr)
1.28
1995
2005
2015
2025
2035
LFV Total
Whatcom 18.6%
FVRD 13.9%
Metro Vancouver 67.5%


2015 Percentages
100%
75%
50%
25%
0%
Diesel Particulate (% of total)
On-Road Mobile 21.0%
Marine Mobile 30.5%
Rail Mobile 8.5%
Non-Road Mobile 40.0%

Purpose

The purpose of this report is to assess the international status of electrification of non-road and heavy-duty equipment around the world, in phase 1, and to assess opportunities for electrification of these engines within Metro Vancouver, in Phase 2. These include all four mobile sources of diesel particulate emissions that were mentioned above: non-road mobile sources, marine sources, on-road mobile sources, and rail-based sources. There already exists a clear path to electrification of light duty vehicles, including regulations that enable this transition in British Columbia. However, electrification of the heavy-duty and non-road engines is in its nascent phase of development. This report examines what options are available and may become available in the near future.

Phase I – Jurisdictional Scan

1. Institutional Frameworks

The states, countries, and regions of the world that have had successfully reduced greenhouse gas emissions are the ones that have integrated sustainability and climate change mitigation into every aspect of policymaking. In many cases, elected governments have given regulatory power to autonomous institutions that enable climate and energy policies to be made, without the direct involvement of elected officials. In these cases, the legislature sets targets and delegates regulatory power to the autonomous regulatory agencies. An example is the California Air Resources Board (CARB) (Meckling and Nahm, 2017). In addition, the places that have succeeded are the ones that integrate climate change and sustainability into every aspect of policymaking.

Metro Vancouver, as a regional district, does not have the same options as a state or country, but it can holistically integrate sustainability into all aspects of policymaking, and is doing that. Almost uniquely in Canada for a local government, Metro Vancouver has the authority to manage air quality and regulate the discharge of air contaminants, which include greenhouse gases. This means that it could support the implementation of equipment electrification programs and reduce emissions with the goal of protecting human health and the global climate.

1.1 Institutional Framework in California

One of the most advanced regions of the world in the realm of climate and energy policy is the state of California. This state has developed many ways to electrify the end uses of energy. A major reason for that is its institutional history and culture.

For example, California has an Air Resources Board (CARB), which develops, sets, implements, and enforces regulations that relate to the climate change mitigation. The state legislature has given CARB the broad regulatory authority to enact regulations as it sees fit, including authorization of a market-based system of permits. The state also has an Energy Commission (CEC) and Public Utilities Commission (CPUC) which also implement and enforce the state's climate and energy policies.

The California Air Resources Board (CARB) is an institution unlike any other. It was created in 1967 to clean up the state's air. It has unique regulatory authority within the United States to regulate vehicle efficiency standards, which no other state has. It also operates the first comprehensive cap-and-trade program in North America, which was authorized by the state's Global Warming Solutions Act of 2006; and a low-carbon fuel standard (LCFS). A similar LCFS was implemented in British Columbia, modeled after the Californian standard. These regulations encourage the adoption of zero-emissions vehicles. To implement these regulations, CARB sets up markets for credits and issues credits that can be traded. The permits are auctioned and the money goes to fund projects to reduce emissions of GHG within California. CARB is a major reason that California has had such success combatting global warming. In addition to CARB, the other agencies of the state government, such as the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC), are also fully engaged with the ongoing effort to reduce emissions of greenhouse gases and DPM by electrifying all end uses of energy.

1.2 Institutional Framework in Norway

Norway is the world's capital of electric light duty vehicles. There are several factors that led to this status. Like British Columbia, Norway's electricity is overwhelmingly from hydropower. In addition, the country has long had heavy tax rates on vehicle registration, but in 1990, the country began allowing an exemption to the vehicle duty for electric vehicles (Henley and Ulven, 2020). In many places, EVs are allowed to have free parking, free tolls, free ferry rides, and drive in bus lanes. They are not required to pay VAT or road taxes (Henley and Ulven, 2020). The country has a 25% sales tax, but e-vehicle sales were exempted in 2001, and the e-vehicles were allowed to use bus lanes from 2001 (Nikel 2019). Norway's policies are supported by subsidies for electric vehicles which are financed through revenues from oil and gas production, which is an option not available to all countries (Harris, 2018). The same factors that lead Norway and other Scandinavian countries to lead in electrification of light duty vehicles also bring them to the forefront of electrification of heavy-duty and non-road equipment. These include marine engines on ferryboats, and construction equipment. These will be discussed in more detail in the next section.

2. Ferry and Marine Electrification

The electrification of ships and ferries is difficult because of the large size of these vehicles. However, this nascent technology is being developed in various parts of the world.

2.1 Europe – Scandinavia

Due to its geography, with abundant straits and fjords, water transportation is crucial in Scandinavia. In addition, the region enjoys abundant low-carbon hydropower and other forms of low-carbon electricity, and has enough wealth to invest in electrification. For those reasons, this region has led on the development of battery electric ferryboats as well. The world's first fully battery-electric car ferry was introduced in Norway in 2015. Called the Ampere, this boat crosses a route of 6 km across Norway's largest fjord, and charges for ten minutes at each end (Butler, 2019).

The MV Tycho Brahe and Aurora are a pair of ferries that are currently the world's largest entirely electric marine vessels, and started operation in 2017). They operate on a 4 km route between Helsingor, Denmark, and Helsingborg, Sweden, across the Oresund. Due to its short route length, this was a natural choice for the first all-electric ferry route. The Tycho Brahe was ready before its charging system, and had to postpone its launch for the charging system at the dock to be readied (Lambert, 2017). This leads to a lesson for electrification projects: charging infrastructure and electric equipment must be developed together.

The Tycho Brahe uses giant robotic arms to operate the charger. The batteries are located on the top of the ship, which has no impact on the ship's stability because the ship was originally built as a train ferry and is highly stable. The battery's location on the top of the ship improves safety in the case of a fire, collision, or waves overtopping the deck. The Tycho Brahe and Aurora use DC batteries which are connected in series, within modules. They have diesel generators as well, and can operate in three modes – electric, diesel, and hybrid. The diesel generators are used only during emergencies, or when the charging robots are undergoing maintenance. When it is in diesel mode, the drive train is still electric, but the diesel generator charges the battery. They were diesel electric ferries to start with, and were converted, a process which required significant investment in the ports. The charging system is entirely automated, with robot charging connectors. As soon as one of the ships arrives in port, the robot connects it to the charge port within 45 seconds. In theory the batteries are enough to do 3.5 crossings, but they charge at every docking to maintain battery health (Llewellyn, 2019).

Specifications of MV Tycho Brahe and Aurora

SPECIFICATION	VALUE
Distance of route	4 km
Ship length	238 m
Ship mass	8414 metric tons
Number of batteries	640
Capacity of each battery	6.5 kWh
Expected depth of discharge	40%
Module voltage	749
Expected lifetime of batteries	5 years
Expected crossings per year	17000
Expected lifetime crossings	85000

In 2020, another Danish ferry beat the record set by the Tycho Brahe. The Ellen travels between the Danish ports of Fynshav and Soby, on the island of Aero, and can sail 22 nautical miles between charges. It carries 30 vehicles and 200 passengers, and has a battery capacity of 4.3 MWh, which is equivalent to the amount that the average UK household consumes in a year. It has 840 lithium ion batteries from the Swiss firm Leclanché. It is part of an EU-backed project to electrify ferry routes, and is expected to reduce CO2 emissions by 2,000 tonnes a year. Its voyages last 70 minutes, and the ferry is recharged in 25 minutes using a mechanical arm, just like the Tycho Brahe. Its electricity comes from clean wind energy supplied by local turbines. However, the ferry is still having operational trouble, because the battery technology is complex. The weight of the batteries is a problem, and so the ship used a low-resistance design and lightweight materials. These enable operation costs to be only 25% of what a similar diesel boat would require. This is partly because of lower maintenance costs, as a diesel engine has 30,000 moving parts, while in an electric motor only the bearings need maintenance. The boat cost EUR21.3 million (C$32.3m), with the EU Horizon 2020 program funding EUR15m, or C$23.1m (Murray, 2020).

In addition, Norway is developing an electric autonomous container ship. The fertilizer company Yara will use this electric container ship, capable of holding 100 to 150 shipping containers, for short journeys within Norway. This ship will be used to replace the use of diesel trucks for this journey, and thus it will reduce DPM emissions. Yara estimates that it will replace 40,000 truck trips a year. It will be delivered in 2020, and be fully autonomous and operational by 2022. Roughly half of the project’s budget came from the Norwegian government (The Beam, 2018).

2.2 United States – Washington State

Washington State Ferries (WSF) is the world's second largest ferry operator. WSF has a plan for its upgrades through 2040 and it includes serious emissions reductions, and is moving towards electrification (Deign, 2019). On January 16, 2018, Washington Governor Jay Inslee issued Executive Order 18-01, which directs the state ferry system to "transition to a zero-carbon-emissions ferry fleet, including the accelerated adoption of both ferry electrification and operational improvements that will conserve energy and cut fuel use." The order specifically referenced the state's membership in the Under 2 Coalition and the Pacific Coast Collaborative, which British Columbia is also part of.

In April 2018, Governor Inslee approved US$600,000 (C$814,448) in funding to study conversion of WSF's three Jumbo Mark II Class vessels to plug-in electric-hybrid propulsion with charging connections at the terminals. These three vessels account for the highest fuel consumption and emissions in the fleet. Completing these conversions will reduce the carbon emissions from the current fleet by 25 percent. WSF plans to transition most of its fleet to hybrid electric and plug-in hybrid vessels by 2040 (Washington State Ferries, 2019). In 2019, this conversion took a major step forward. Washington State was awarded $112.7 million (C$153m) as part of a Volkswagen settlement with the US Federal government, because of Volkswagen's violations of the Clean Air Act. The Washington Department of Ecology allocated $35 million (C$47.5) of that money to WSF to convert the first of its three largest ferries (the Jumbo Mark II ferries) to hybrid diesel technology to reduce emissions. Each of these ferries can carry 202 cars and 1800 passengers, and operate on routes across Puget Sound from Seattle to Bainbridge Island and from Edmonds to Kingston, and together consume 14,000 gallons (52,996 L) of diesel a day (Giordano, 2019). The route from Seattle to Bainbridge, the first route to be electrified, is 8.6 miles (13.8 km) long. Although these are not going to be completely electrified as of yet, they are going to reduce CO2 emissions by 48,565 tonnes a year, equivalent to removing 10,000 cars from the road (Everman, 2019). Planning and design are happening in 2020, and the actual conversion will happen in 2021. On January 6, 2020, the plan got another funding boost with an additional $1.5m (C$2.0m) allocated to the project from the U.S. Dept of Transportation's Marine Administration (King 5, 2020). The cost of converting the first boat is estimated at US$40 million (C$54.3m), so the plan is mostly but not completely funded (Giordano, 2019).

Currently these ships each have 4 diesel generators which create electricity to power the motors, just like in a diesel-electric locomotive. The plan is to replace 2 of the generators with batteries. However, building the charging infrastructure is a major challenge. The hybrid system will operate even before the charging infrastructure is in place. During this stage, the diesel generator will charge the battery. This will realize efficiency savings, as only one diesel generator will be needed to power the ship, as opposed to four. When the charging infrastructure is installed at the ferry port, then savings will increase. The agency anticipates that shore charging can be completed in 20 minutes, which is the usual turnaround time for the ferries (Giordano, 2019).

2.3 British Columbia

The CleanBC Strategy, which is British Columbia's mid-century strategy for clean development, has a goal that all ferries operating in the BC Interior should be electric by 2040. The provincial government is taking major steps towards that goal, even during the COVID pandemic. On March 31, 2020, the BC Government announced that a ferry operating in the interior, across Arrow Lake, would be replaced with an electric cable ferry, and it entered into service the same week. The ferry is being built by Waterbridge Steel, a shipbuilder based in Nakusp, a town in the BC Interior along Arrow Lake (Chan, March 2020).

This is not the first cable ferry in BC. There are multiple cable ferries in the BC Interior. Some of them use energy directly from the flow of the river they cross. In addition, BC Ferries operates a cable ferry between Denman Island and Vancouver Island. The Denman Island connector is the world's longest cable ferry route, at 1.9 km. BC Ferries claims that the cable ferry has three times the fuel efficiency of a self-propelled ferry, however this cable ferry is not electric, and runs on diesel fuel (Haig-Brown, 2016).

Another ferry in the BC interior is planned to be electrified. The federal and provincial governments are spending $55 million to upgrade the Kootenay Lake Ferry between Balfour and Kootenay Bay, BC. The ferry will be able to carry 55 cars. The ferry will be operating by 2022, but will only be converted to full electric operation by 2030, after the shore power equipment is completed. Until then it will use diesel. The Canadian government is contributing $17,176,667; the BC government is funding $37,515,720 (Keating, 2019).

BC Ferries is also building a new class of hybrid electric ferries for its routes in the Salish Sea. The Island Class of ferries will be capable of moving to full electric propulsion in the future, but for the time being they use a diesel-electric hybrid system. BC Ferries is getting two of these boats in 2020, and two more in 2022. They are used on very short routes in the Salish Sea, and can carry 47 vehicles and 300 to 450 passengers. These ships are designed with full electrification in mind, but they are currently using hybrid technology, that lets them operate until sufficient shore charging infrastructure becomes available. These ferries have battery capacity of 800 kWh, and can be upgraded to 2000 kWh. Each boat costs $43.25m to $50m (BC Ferries, 2019).

An idea for marine electrification within the Metro Vancouver area is to use Island Class ferries for the Horseshoe Bay-Bowen Island Route. This route is only 3 nautical miles (5.6 km), making it shorter than the Powell River-Texada route, (which is 5.1 nmi (9.4 km) and will use Island class vessels). BC Ferries has their own independent authority to make decisions about deployment of vessels. The Queen of Capilano, which can carry 85 cars, is currently used on the route but has previously experienced frequent mechanical issues ("Queen of Capilano", 2006). The Queen of Capilano could be retired, and replaced with two Island class vessels. This is particularly important because marine mobile sources are the second biggest source of DPM emissions in the Metro Vancouver region, and are projected to become the biggest (Thai 2015).

3. Bus Electrification

Urban transit is a sweet spot for electrification. This has been known for many years, even before battery electrification was a viable option, even before climate change was a major concern. Rapid transit, light rail, streetcars, and trolleybuses have operated on electric power in urban areas for more than a century, because of the advantages of electric power. It does not generate local emissions, and if the electricity is from a clean source then it does not produce any emissions. Electrification enables higher frequency, capacity, and quality of service. Until recently, the only way to electrify urban transit was with overhead catenary wires, or with a third rail on a separated right of way. This requires a major capital investment.

Public transit buses are a major use of diesel fuel and a major source of emissions in many parts of the world. Fortunately, electrification of these buses is increasingly viable. Battery electric buses have become a viable option, and so it is possible and practical to electrify urban transit even without overhead wires. There are two types of electric buses, both of which operate in Metro Vancouver. Trolleybuses operate using trolley poles and electric catenary wires above the streets; and battery electric buses operate using lithium ion batteries.

The battery electric buses (BEBs) have four major advantages over combustion powered buses. First, BEBs emit nothing at the point of use, and even if the electricity is coming from coal, they typically emit less than combustion vehicles, and can emit almost nothing if the electricity is from clean sources. Second, electricity, as a fuel, is cheaper than diesel or natural gas. Third, these buses require less maintenance than combustion vehicles. Fourth, they provide a better experience for the rider, because the bus ride is quieter and cleaner (Roberts, 2018).

Since buses operate almost all day long, the fuel costs add up for diesel buses, and so do the health impacts of the DPM emitted. Urban air quality is a major reason that cities around the world are moving towards electric buses (e-buses). These buses have zero tailpipe emissions and typically lower lifecycle emissions, even if the power is dirty. This is especially important for urban transit buses since there are so many people boarding and disembarking every day. Another huge advantage for this application is that operating costs are often picked up by the local agency, but capital expenditure is often covered by the federal government, in both the US and Canada. Canadian Prime Minister Trudeau has made major capital investments in transit, but does not want the federal government of Canada to subsidize operating costs (Chan, May 2020). This means that Metro Vancouver should be able to get federal help buying new electric buses; and will reap the benefits of lower operating costs.

Beyond municipal policies, national level policies are typically needed to accelerate the transition to electric public transit, particularly in smaller cities. Several governments have set up funds for this. The UK has a Low Emission Bus Scheme which spent GBP 30m (C$50m) between 2016 and 2019. And in China, the national government provides financial support of up to 180,000 yuan (C$34,912) for the purchase of e-buses. In 2016, when the e-bus fleet was in its initial phases, new electric buses could subsidize receive a US$150,000 (C$203,612) subsidy in 2016 from the Chinese government, which covered half the cost. As such, national policy pushes like the one implemented by China are more successful than local ones (Xue and Zhou, 2018).

Another driver of the move to electrify buses is the lower operations and maintenance costs, which contribute to a lower total cost of ownership (TCO). In some places, such as China, they are also using this as an industrial policy – to build a domestic industry that can provide employment.

3.1 China

China is the global leader in electrification of buses. Of the world's battery electric buses, 99% of them are operating in China. By the end of 2018, 18% of China's bus fleet was already electrified (Eckhouse, 2019). The country achieved this milestone with a top-down approach. There were national mandates, subsidies for manufacturers, and policy competitions among its cities. The first city to complete electrification of its bus fleet was Shenzhen, which turned its entire fleet of 16,359 buses electric. This is more than the total number of buses operating in New York, LA, Toronto, New Jersey, and Toronto, combined (Xue and Zhou, 2018). This success happened because multiple different levels of government worked together to achieve this. The Chinese government subsidized the purchase of electric buses with a subsidy of $150,000 (C$203,612) for each bus, which is half of the purchase price. The mayor's office in Shenzhen also played a key role in directing this transition. To reduce costs, some of the buses were leased instead of bought (Sisson, 2018, and Poon, 2018). Shenzhen also has a big advantage in being flat and having a mild climate. Other Chinese cities with steep hills or harsh winters have more difficulty electrifying their bus fleets (Keegan, 2018).

In Shenzhen, in addition to the purchase subsidy, there is an operational subsidy that comes from the local government. The city has built 40,000 charging piles, and the Shenzhen Bus Company has 180 depots with their own charging facilities. One of them can charge 20 buses at once. This investment in charging stations has been a key driver of the success. The bus company also has to rent charging stations from the municipal government and private sector (Keegan, 2018).

A major reason that the Chinese made such a push to electrify their bus fleets is serious concern about air quality. Shenzhen is one of the only cities in China to dramatically reduce its air pollution, and its government attributes its success to the electrification of buses. Another rationale for this push was the desire to reduce dependence on imported oil. China does not have domestic reserves of oil; but they do have domestic reserves of lithium and coal, which power the BEBs. In addition, the Chinese have an advantage in building the new transit systems from scratch; while European and American operators have to fit BEBs into existing systems, which can add complexity. For these reasons, 98% of electric buses operate in China, according to the International Energy Agency's 2020 electric vehicle outlook.

One reason for China's advantage in electrification of battery electric buses is that they dominate the world production of lithium ion batteries. This is partly due to geology. China has domestic reserves of lithium, and in 2018 its annual production of lithium was 8,000 tonnes, which are the world's third largest; and the same year its lithium reserves were one million tonnes (Rapier, 2019). China does not have domestic reserves of oil, so by switching to battery electric buses, China has reduced its reliance on imported oil; and increased its reliance on domestic resources.

China's electric bus fleet is so massive that it is drastically reducing demand for oil. By the end of 2019, a cumulative 270,000 barrels per day of oil demand were displaced by the growing uses of electric buses, primarily in China (Nightingale, 2019). These buses are so large, and drive so much, that the replacement of just two diesel buses with electric versions reduces oil consumption by a barrel per day. However, the greenhouse gas benefit of this transition has been blunted by the fact that the country's electricity is more than 60% coal, and the electricity emits more than .6 kg CO_2e per kWh (Li, et al., 2017).

3.2 California

In 2018, the California Air Resources Board (CARB) approved a regulation that sets a goal for would require all public transit buses used in the state to be zero-emissions buses (ZEB) by 2040, and incorporates a gradual transition to that end state over the coming years (CARB, 2018). Agencies will follow a phased schedule from 2023 to 2029, after which point all new transit buses bought will have to be zero-emissions. This is known as the Innovative Clean Transit Regulation (ICT).

Before the ICT Regulation was issued, more than 50 transit agencies in California had already committed to making ZEB purchases, and 16 agencies had committed to making a full transition to ZEBs. The buses are not required to be electric. Hydrogen powered buses and other ZEB options are available. This is happening because a broad range of California state agencies are working together. The state Department of General Services is streamlining ZEB purchases; and the California Public Utilities Commission (CPUC) has approved investments in charging infrastructure by the state's investor owned utilities.

3.3 Metro Vancouver

The Metro Vancouver region has one transportation authority, TransLink. The Metro Vancouver Regional District does not have authority over TransLink operations, but the service areas overlap.

TransLink does have a plan to move to 100% electric operations by 2050, and to power their operations with 100% renewable energy. The agency's low-carbon transition plan recommends replacing transit buses at the end of their useful life with battery electric buses. These would start with purchases in 2021; and all new purchases after 2030 will be electric. They have three strategies for electrification – cautious, progressive, and aggressive. The Aggressive strategy represents the fastest possible way to electrify their operations without early retirement of buses, and would achieve 50% electrification by 2030 and full electrification by 2040 (TransLink, 2020). MV has an opportunity to work with the federal, provincial, and local governments, to push TransLink to implement aggressive electrification.

To achieve full electrification, TransLink in conjunction with municipalities will need to make major infrastructure upgrades. These include strengthening streets because the electric buses are heavier; procuring mobile power generation capacity for bus charging in case of a power outage; and investing in charging equipment.

One potential point of concern of the TransLink 2050 plan is the axle weight of BEBs. A depot-charged 40-foot BEB has a rear axle weight 1200 to 1800 kg more than an equivalent diesel bus. This means that certain roads may need to be strengthened to handle the frequent use by heavier buses. In-route charged electric buses have smaller batteries than depot-charged buses, so they will have a rear axle weight 300 to 750 kg more than a diesel bus (TransLink, 2020).

The modeling indicated that expanding the trolleybus network is the costliest option for electrification, and that utilizing battery electric buses is the most cost-effective. The modeling did not consider the slope of the routes, which might pose a problem because battery electric buses struggle on steep hills, just like diesel buses do (Levy 2019). For that reason, BEBs are a good option for the flat routes, but trolleybus network expansion may be a viable option for the routes that contain steep hills. Specific routes that could be targeted for trolleybus expansion could include 33 to UBC and 95 to SFU, which both have hills on their routes. Portions of these routes already have trolley wires, which could present an opportunity. However, the staff at TransLink and their consultants, MJ Bradley and Associates, are confident that battery electric buses are the best option, for all routes of TransLink that don't already have catenary wires. They found that the cost of adding new catenary wires is too high to be viable.

3.4 Potential issues with electrification of buses and solutions

With most categories of the heavy equipment that is discussed in this report, the biggest barrier to electrification is the availability of electric models. The electric options are still being developed. For transit buses, that problem is not there; as there are many models of electric buses available on the market. However, there are still other barriers to electrification of transit buses. There are four major barriers to electrification of public transit buses.

High upfront costs. This applies not only to the bus itself, but the charging infrastructure as well. Many cities don't have the cash to pay for the high upfront costs of these, even with additional support from their national government. There is an opportunity for leasing to sidestep this issue. Leasing a bus can be more affordable than buying one for cash-strapped governments and agencies, and can enable operating savings to be realized immediately.

Scalability: Most e-buses on the road in North America and Europe were bought using national and regional grants. This is not scalable, until costs of BEBs decrease.

Flexibility: Due to the need to stay within range of a charging station, the e-buses are not as flexible as traditional buses, which have a longer range and can fill up at a gas station. Some agencies are waiting until the battery cost comes down even more, as they don't want to spend money on a technology and watch it become cheaper. To address lack of flexibility, agencies may need to have extra buses available for contingencies.

Charging: The charging infrastructure may not be available, and it is not completely standardized. There may also be issues with the grid stability if large amounts of power are taken at once to charge battery buses. Apart from the charging station, grid reinforcements are often needed to support charging. The possibility of power outages during extreme weather events is a concern, as is the space for installing charging stations at a depot or terminus. For electricity supply and grid issues, it is crucial to involve utilities and grid operators from the beginning.

3.5 Financial and operational models for e-bus deployment

To improve feasibility of e-bus deployment, one option for cities looking to deploy electric buses is battery leasing. This means that the agency pays for the bus; but leases the batteries. This option was introduced by Proterra, an electric bus manufacturer based in California. This brings the capital cost of a bus down to the cost of a diesel bus; and payments for the battery are in fixed service payments for the lifetime of an asset. Another option is an operating lease – essentially leasing the whole bus. Another option is for agencies to work together to make bulk orders of buses that lets them achieve economies of scale and get better deals.

There are multiple charging configurations for electric buses, and they confer different advantages and disadvantages. They include:

- Traditional plug-in charging is the most common. Using a 'slow charger' (15-22 kW), an e-bus can charge in 10h. Higher power rates can charge faster, but they only go up to 120 kW.
- Pantograph charging uses roof-mounted equipment to charge the bus. These can be located at bus terminals. Power output is 100 to 300 kW, allowing for rapid top-up of the battery.
- Inductive Wireless charging uses coils under the road surface that transfer energy to matching coils in the bus. Such systems are commercially available, and can go up to 200 kW.

To determine what charging option is best, operators need to consider the range, topography, usage patterns. They have to ensure there is excess battery capacity available as a buffer, in case of traffic jams. Overnight depot charging is most common, followed by the combination of depot charging and fast charging top-ups.

It may take 10 years before the upfront cost of e-buses reaches cost parity with diesel buses, and Bloomberg New Energy Finance (BNEF) expects this to happen in 2030 (Bloomberg New Energy Finance, 2018). However, increasing demand for e-buses can bring down the cost faster.

3.6 Electrification of School buses

Distinct from the buses that do public transit, the school buses are another ideal use case for electrification. They offer large public health benefits, because children are more susceptible to the adverse effects of DPM than adults are (C. Shahan, 2020). America's largest fleet of electric school buses is used by the Twin Rivers School District, in Sacramento. These buses were financed with a grant from the California Energy Commission, which spent US$90m (C$119.7m) to put 200 electric school buses on the road across the state (Luery, 2020). In Virginia, Dominion Energy is helping sixteen school districts buy fifty electric school buses. Electric school buses cost US$340,000 to US$400,000 (C$461,416 to C$542,894), while a diesel bus costs US$200,000 (C$271,447); but the utility is covering the difference for these districts (Rosen, 2020). These buses, built by Thomas, can travel 134 miles on a charge of their 220 kWh battery packs. Fuel costs for these buses are 19 ¢/mi, while they are 85 ¢/mi for the diesel buses (C$0.26 and C$1.15 respectively).

	ELECTRIC SCHOOL BUS	DIESEL SCHOOL BUS
Upfront purchase Cost	C$461,416-542,894	C$271,447
Operating cost per mile	C$0.26	C$1.15
Battery capacity	220 kWh	N/A
Range (miles)	134 mi	N/A

School buses typically travel 12,000 miles per year, as opposed to 50,000 miles a year for public transit buses. This can make it harder to justify the higher upfront cost of an electric bus. But, this can be turned into an advantage. Since they sit idle for much of the day, they have more time to charge, and can charge when the grid is at its cleanest because of abundant sunshine and solar energy. In addition, they can potentially be used for vehicle-to-grid integration. This means that the batteries in the bus could be used to store energy for the power grid, and store renewable energy and displace the use of fossil fuels. This works because the schools typically close for summer, and the buses sit idle, and that is the same season when electricity usage peaks; so the buses can soak up solar energy on sunny summer days, and discharge it to the grid after sunset. This reduces amount of generating capacity needed on the power grid (Muller, 2020).

If electrification of school buses is not financially feasible, another option to protect health and reduce DPM exposure is to retrofit and replace older school buses. The Oregon Department of Environmental Quality has a program to do this. They will primarily replace these with cleaner diesel vehicles, as the cost of electrification would be higher. The program is technology neutral, and are primarily focused on getting the oldest diesel engines, which do not have emission controls, off the road. Complete electrification is not mandated by this policy.

4. Truck electrification

Though electrification of heavy trucks is much more technically difficult than electrification of other vehicles, heavy-duty vehicle electric trucks are being developed, though they are still in their nascent stages.

At least six heavy truck manufacturers are planning to develop battery electric heavy trucks by 2021, with two others planning for hydrogen trucks. One truck manufacturer, Freightliner, is testing its electric prototype eCascadia and preparing for mass production to begin in 2021. Volvo Trucks is also testing a fleet of 23 battery-electric heavy-duty trucks at the ports of Los Angeles and Long Beach. In addition, Tesla is manufacturing an electric semi, which will cost US$1.26 per mile to operate, as compared to US$1.36/mi for a diesel truck (C$1.05/km and C$1.16/km respectively) (Carpenter, 2020). The diesel operating cost would likely be more in Canada, because of the exchange rate and the carbon tax. The Freightliner eCascadia, a full-sized Class 8 semi-truck, will have a 250-mile (402 km) range, and can charge 80% of its 550 kWh battery in 90 min. The Freightliner EM2 106, a medium duty truck, will have a 230-mile (370 km) range and can charge 80% of its 325 kWh battery in 60 minutes (Freightliner). The Tesla Semi will come in two models, with a 300 and 500 mi (483 to 805 km) range, and Tesla is taking reservations now (Tesla).

In addition, Volvo is developing autonomous electric trucks that can pull trailers without fuel. These sleek machines do not maintain the full profile of the truck tractors, but are smaller than cars. They can pull trailers at low speeds around areas that are delineated, and currently operate in the port of Gothenburg in Sweden (Karlsson).

Garbage trucks are another category of heavy duty on-road vehicles, and they are a ripe target for electrification because their frequent stops and starts give them an opportunity to recover the energy, which diesel vehicles cannot do. Last year, Recology bought the first electric garbage truck, which is a rear loader and is operating in Seattle. This is a Class 8 truck made by BYD, and the garbage truck body is made by Viper. It has a 295 kWh battery pack. It only has a range of 56 miles (90 km), and 600 pickups. Recharging the truck takes 9 hours at a 33 kW AC outlet. It can also be charged at higher rates, and takes 2.5 hours to charge at 120 kW, or 1.5 hours to charge at 240 kW (Gitlin, 2020). These garbage trucks belong to Recology. Seattle officials have targeted the transition of the entire fleet of garbage trucks for the city to run on renewable sources by this year, 2020. Seattle already has dozens of garbage trucks powered by renewable natural gas, which comes from the decaying trash in the landfills; and also has 80 Recology trucks which are powered by renewable biodiesel from vegetable oil (Nickelsburg, 2020).

Beyond these new vehicles being developed, more are developed on a regular basis. There is a comprehensive database maintained by Calstart, a Californian non-governmental organization, which is regularly updated and contains information on the zero-emissions options available for all of the on-road heavy duty equipment that are available in different regions of the world, including North America, Latin America, Europe, China, and India. This database is the Zero Emissions Technology Inventory (ZETI), and is available online.

4.1 California

On June 25, 2020, the California Air Resources Board (CARB) developed a revolutionary regulation that will require increasing percentages of heavy trucks sold and registered in the state to be zero-emissions vehicles. This regulation is the first of its kind in the world, and will force heavy truck companies to innovate and develop more zero emissions options. This rule was designed to reduce diesel particulate matter in air pollution hotspots, also known as 'diesel death zones', which are often surrounded by warehouses and freeways carrying heavy diesel-powered trucks. People living in the communities in these areas suffer from high rates of heart disease, asthma, and cancer, due to the high rates of pollution caused by the diesel trucks. This rule is revolutionary in part because there are no commercially available heavy-duty electric options on the market today (Profita, 2020).

The new regulation, known as the Advanced Clean Trucks (ACT) regulation, will require increasing percentages of heavy trucks to use zero-emissions technology. It affects trucks of classes 2B to 8. This means that they apply to all trucks which weigh more than 8500 pounds or 3856 kg. To be more specific, this regulation will start being enforced in the year 2024, and will require increasing percentages of trucks to be electric between 2024 and 2035. By the year 2035, zero-emissions vehicles will need to account for 55% of sales of trucks and chassis of class 2b to 3, 75% of sales of class 4-8 straight trucks, and 40% of sales of truck tractors (California Air Resources Board, 2020). These do not necessarily have to be electric trucks. Other options include hydrogen and fuel cell vehicles.

Recent studies indicated that the benefits this regulation will save billions of dollars in fuel and health costs, due to reduced air pollution. Two different studies have quantified the benefits of the regulation in greenhouse gas emission and dollars, and obtained almost identical results. CARB's own internal model estimated the cost savings of this rule between now and 2040 to be US$6.0 billion (C$8.0 billion). An independent model known as the California Energy Policy Simulator (EPS) estimated the cost savings at US$7.3 billion (C$9.7 billion). The results depend on the prices of large lithium ion batteries. CARB conservatively assumes that the prices of lithium ion batteries will decline more slowly than the prices for smaller batteries. EPS assumes that the costs per kilowatt-hour will be the same for large and small batteries, because large batteries can achieve economies of scale that counteract the other difficulties in making large batteries. These studies find that the ACT regulation will reduce cumulative GHG emission by 17.3 to 17.6 million tonnes of CO2e. In addition to the cost savings, the rule will deliver public health benefits worth a cumulative total of 8.9 billion US dollars, or 11.8 billion Canadian dollars, due to the severe health impacts of DPM. All of these figures are in 2018 dollars (Fine, et al., 2020).

The state of California is not the only one adopting standards for emissions from heavy trucks. A group of fifteen American states signed a memorandum of understanding that by the year 2050, all heavy-duty trucks sold in their states would be zero-emissions vehicles. This memorandum of understanding is not legally binding, and apart from California, the commitments are not enshrined into law. However, they do send an important signal to where the market is headed and indicate a firm intent to phase out fossil fuels.

In addition to the ACT Rule, to enable the adoption of low-emissions vehicles such as electric trucks, CARB maintains an incentive program for these vehicles, which comes in the form of a voucher incentive applied at the time of purchase. This program is known as the Hybrid and Zero-Emissions Truck and Bus Voucher Incentive Project (HVIP). CARB maintains a comprehensive list of trucks, buses, and other equipment that are eligible for incentives under HVIP. The goal is to reduce emissions of DPM and greenhouse gases from trucks, buses, and other heavy equipment. There is a similar program operated in British Columbia, known as the Special Use Vehicle Incentive Program (SUVI).

4.2 British Columbia

British Columbia has an incentive program to support the purchase of clean energy vehicles, (CEVs). The CEV for BC incentive program is an incentive program that makes clean energy vehicles, such as electric cars, affordable for ordinary British Columbians. This program maintains vehicle point of sale incentives, and it also includes incentives for charging infrastructure for Level 2 chargers and DC Fast Chargers. It has enabled investment in hydrogen fueling stations. It has also included incentives for transitioning fleets to clean energy vehicles, and funded research, public outreach, and training. Program applicants must be individuals, businesses, non-profits, or public entities, including municipal and regional governments and First Nations; but provincial, crown, and federal government agencies are excluded. The incentives apply to standard light-duty vehicles with a manufacturer’s suggested retail price of C$55,000 or below.

The Specialty Use Vehicle Incentive Program is a program that applies incentives to the electrification of specialty use vehicles in British Columbia. Electric and hydrogen fuel cell vehicles can both be eligible for these incentives, which can be up to C$50,000, or 35% of the vehicle's manufacturer's suggested retail price (MSRP). The SUVI program is available to individuals, and to public and private vehicle fleets in British Columbia. Individuals may only access incentives for electric motorcycles and low-speed vehicles; while fleets may access all vehicle categories but are limited to five rebates per fleet. This incentive program covers emissions from vehicles other than on-road light duty vehicles. Among others, these include non-road applications that currently use non-road diesel engines. The SUVI program includes incentives for purchase of zero emissions options – including electric and hydrogen fuel cell powered options – for medium and heavy duty on-road vehicles, non-road specialty equipment such as forklifts, and airport and port specialty vehicles.

The SUVI rebates support hydrogen and electric vehicles in a variety of applications, including motorcycles, low-speed vehicles, and specialty use vehicles. These include non-road applications such as lawnmowers, as well as medium and heavy duty on-road vehicles. It specifically targets vehicles that are not eligible for the other existing ZEV incentives that are maintained by British Columbia, such as the CEV for BC incentive program.

4.3 Oregon

On June 30, 2019, the Oregon legislature passed a bill, House Bill 2007 (HB2007), to meaningfully reduce DPM emissions in the Portland area. It phases out the oldest diesel engines in Multnomah, Clackamas, and Washington Counties, which comprise the Metro Portland region. It stops the purchase of diesel vehicles that were made before 2010, and requires all diesel engines made before that date to be phased out by 2029. By 2023, the all diesel-powered medium- and heavy-duty trucks must run on engines that were made in 1997 or newer. By 2029, all diesel-powered medium duty trucks must run on engines that were made in or after 2010. Among heavy duty trucks, they will have to be made in or after 2007 if they are privately owned, and in or after 2010 if they are publicly owned. Trucks may comply by switching to a cleaner fuel, such as electricity or natural gas, or by using retrofit technology to capture emissions. As such, this bill is technology-neutral and does not require electrification, but electrification is one way to comply with its requirements.

The bill does not set standards for construction equipment or other non-road diesel engines, but it requires that 80% of state funded construction projects in this region meet Tier 4 standards. This approach – requiring higher standards for construction equipment on publicly funded construction projects – could be implemented in Metro Vancouver as part of the non-road diesel engine emissions regulatory program, which will be discussed in the recommendations.

These regulations have both metaphorical carrots and sticks. The regulations in HB2007 are the sticks, as they are the mandates for getting rid of the older diesel engines. The carrots, or incentives, are the grant money that the state or local governments can provide to the equipment owner to fund the retrofit. Typically, the authorities will only provide partial funding. The owner typically has to pay the upfront cost and they can receive a partial reimbursement after verifying that the equipment was completely upgraded or replaced, and that the older equipment was destroyed. The biggest source of funding for these programs in the US is the Volkswagen settlement, which is not available in Canada. However, the authorities in Oregon are looking for additional sources of funding.

4.4 Heavy Duty Truck Charging Infrastructure

The West Coast Clean Transit Corridor Initiative (WCCTCI) is a collaboration between agencies, utilities, and fleet owners in California, Oregon, and Washington, to create a network of heavy-duty truck chargers up and down the Interstate 5 (I-5) corridor. Utilities and public agencies in the states of California, Oregon, and Washington are building the network for heavy duty trucks and other vehicles along the I-5 corridor and the other neighboring freeway corridors. Charging stations will be installed at 50-mile intervals in order to enable trucks to drive in the area of the network without any gaps in the range of the electric trucks.

Due to Metro Vancouver's location at the north end of the I-5 corridor, it may be possible for utilities, provincial authorities, or other entities within the Metro Vancouver region to participate in this network. This possibility is discussed in more detail in phase 2 of the report.

One key finding is that when installing heavy duty truck charging infrastructure, there are major economies of scale. Installing multiple chargers at one site is much more cost-effective than installing them independently, because the wiring can be used for multiple chargers. For example, if the chargers each have a 50 kW capacity, then installation of an individual charger costs US$45,506 (C$61,849); while installing 6 to 50 chargers at one site costs only US$17,692 (C$24,046) each – a reduction in per-unit cost of 61%. A similar percent reduction can be achieved with different capacity chargers. For that reason, charging infrastructure must be sited carefully and locations must be selected to ensure maximum utilization. It is also possible to build a site with multiple chargers, but only build a few chargers at the beginning, and adding more chargers over time as demand increases. This strategy could lower the upfront cost of construction. The following table gives costs of charger installation for heavy duty electric truck chargers, as measured by the power output and the number of chargers that are installed at each site. The following table is from page 45 of the Background Research Technical Memorandum for the WCCTCI, and all figures are in USD.

Table 11: Installation Costs per DC Fast Charger, by Power Level and Chargers per Site

	50 kW				150 kW				350 kW			
	1 charger per site	2 chargers per site	3-5 chargers per site	6-50 chargers per site	1 charger per site	2 chargers per site	3-5 chargers per site	6-20 chargers per site	1 charger per site	2 chargers per site	3-5 chargers per site	6-10 chargers per site
Labor	$19,200	$15,200	$11,200	$7,200	$20,160	$15,960	$11,760	$7,560	$27,840	$22,040	$16,240	$10,440
Materials	$26,000	$20,800	$15,600	$10,400	$27,300	$21,840	$16,380	$10,920	$37,700	$30,160	$22,620	$15,080
Permit	$200	$150	$100	$50	$210	$158	$105	$53	$290	$218	$145	$73
Taxes	$106	$100	$64	$42	$111	$89	$67	$45	$154	$123	$92	$62
Total	$45,506	$36,235	$26,964	$17,692	$47,781	$38,047	$28,312	$18,577	$65,984	$52,541	$39,097	$25,654

Source: International Council on Clean Transportation (2019b)

5. Reduction in emissions from construction equipment

Construction equipment is a major source of emissions from non-road diesel engines, and is one of the largest sources of non-road diesel emissions in Metro Vancouver, as in many other cities around the world. The ultimate solution is to transition to zero-emissions technology, but there are some other solutions as well, which can reduce emissions.

5.1 Regulation of emissions from construction equipment

In London, England, 7% of NOx, 14% of PM2.5, and 8% of PM10 emissions come from construction equipment (Fidler, 2019). For this reason, London has a Low Emission Zone for non-road mobile machinery. This requires that all engines with a power rating between 37 KW and 560 KW meet and emissions standard based on the stage. The standards that need to be met vary based on the area, with the most polluted areas having a higher standard than the rest of the city (London City Hall).

Similar issues are present in the state of Oregon. In Oregon, the state has a Clean Diesel Initiative that serves to reduce DPM by “working with fleet owners and operators to offer ways they can take advantage of the benefits of diesel engines, while reducing their impact. Fleets get help choosing the right mix of strategies for their business and in some cases, the fuel savings pays for the strategy, especially when combined with tax credits (and grants when available). Strategies for reducing diesel exhaust are categorized under three primary approaches: burning less fuel, burning cleaner fuel and burning fuel cleaner.” Although electrification is alluded to, as a cleaner fuel that diesel engines could “burn”, this is not an electrification program, but a program to reduce toxic emissions from diesel engines that operate.

The City of Portland, Oregon, along with other government jurisdictions in its metropolitan region, has a program, known as the Clean Air Construction Program, to reduce emissions from construction equipment on publicly funded construction projects. The equipment is required to meet progressively higher thresholds for engine emissions, and is required to shut down if the vehicle idles for more than five minutes. This program is described in more detail in Phase 2 of this report, which details potential recommendations and strategies that Metro Vancouver can follow to reduce diesel emissions.

The Clean Air Construction Program was developed by a working group made of representatives from each public agency in the collaborative. The urban and metropolitan authorities convened this group due to state inaction on the problem of DPM from non-road diesel engines. In Oregon, local authorities do not have the authority to regulate air quality, so their only option was to pursue diesel emissions requirements on public construction sites as a contract requirement.

They conducted research into the diesel emissions requirements in other parts of the US, and used that research, combined with other information from local subject matter experts, and developed proposed requirements (named the Clean Air Construction Standard). The proposed Clean Air Construction Standard was published and subjected to a public comment period as well as stakeholder outreach efforts, both among clean air advocates as well as contractors. They took that feedback, finalized changes, and implemented the Clean Air Standard. Metro Vancouver was one of the cities that they looked at, but that was mainly from standpoint of implementation. They looked at the software that Metro Vancouver uses to monitor and enforce compliance with the clean air regulations.

Portland does not have estimates for how much this will reduce emissions. Non-road vehicles are not required to be registered with the state in Oregon, unlike road vehicles, and so they do not have the necessary baseline data to run a model to estimate this. They will track data as the program is implemented, as the program requires equipment to be registered with the metropolitan authorities if it is going to be used on public construction sites.

The biggest barrier to developing this program is the resources, specifically the staff and money to build the program. In addition, there is a lack of baseline data for sources of emissions. For this reason, the regulations in Portland apply only to larger worksites, and the threshold is determined by the dollar value of the contract. This approach was taken because there was a need to prioritize program resources, as applying it to all construction contracts would be too large of an administrative task.

5.2 Electrification of Construction Equipment

The simplest type of construction equipment to electrify is the tower crane, because it stays in one place. Tower cranes used in construction began a transition to electric power in the 1970s, because of the greater efficiency. They can be easily connected to the grid because they stay stationary at their base, and on average consume 244 kW of power, at 208V and 800 amps (Aggreko).

Since there are many tall buildings under construction in the Metro Vancouver region, and this is likely to continue through the coming decades, the cranes that build high-rise buildings are a major type of equipment that are used in the region. Tower cranes can be electric or diesel powered. The electric versions would be directly connected to the grid, and would not need batteries. This is viable because tower cranes stay in one place while they are operating, unlike other construction equipment. It should be possible to prohibit the operation of diesel-powered tower cranes, since electrification is widely available.

The other types of construction equipment are much more difficult to electrify, because they would require batteries. In early 2019, Caterpillar unveiled an electric excavator, with a giant 300 kWh battery pack. This was built in Norway for a construction company, which plans to use eight of these. This is the first time that an excavator of this size – 26 tonnes – has been converted to electric operation. The battery pack weighs 3.4 tons, with 300 kWh of capacity, which enables 5-7 hours of use before needing to recharge (Lambert, January 2019). It can charge in 1 hour if current of 63 amps is available. It can also be used while plugged into a charger; in which case it can run around the clock. It was built by Caterpillar and Pon, and is called the 323F excavator, and is sold as part of the company's Z line of earthmoving equipment. Pon is also planning to offer a conversion service, to convert existing excavators to electric operation (Hanley, 2018). In addition, a different Norwegian company, NASTA, is developing its own zero-emissions excavator, which will use battery and fuel cell technology. The first prototype is being built on an existing Hitachi excavator.

Volvo announced last year that it will stop development of new diesel equipment for small applications, to transition entirely to electric versions. It announced the development of four new compact excavators and wheel loaders, which will be available for customers to buy shortly.

SPECS FOR ECR25 ELECTRIC EXCAVATOR	
Weight	2730 kg
Length	3.876 m
Digging depth	2.761 m
Run time on a charge	8 hours
Charging time	6 hours

SPECS FOR L25 ELECTRIC FRONT LOADER	
Weight	5000 kg
Carrying Capacity	3300 kg
Maximum lift height	2.5 m
Charge time (standard European outlet)	12 hours
Charge time (proprietary Volvo outlet)	2 hours

In addition to Volvo, Hidromek is also launching electric construction equipment. These include excavators, wheel loaders, and soil compactors.   There are also electric compact excavators made by Mecalac, which use lithium iron phosphate batteries, and can operate for 8 hours on a charge.   Bobcat has electric options for small equipment. It unveiled the prototype for the electric E10e mini-excavator in 2016. It can run for a full eight-hour day on a charge, and takes 2.5 hours to charge. JCB also launched an electric excavator in 2018. The 19C-1 E-Tec is a 2-ton excavator that can work all day on a six-hour charge. The excavator has an electric motor and three lithium-ion batteries which can store 15 kWh of energy. This will deliver the same speed and power output as the diesel counterpart, the 19C-1. Wacker Neuson has a lineup of existing battery electric machines, including wheel loaders, the battery powered rammers, and a dual-power excavator. Electric mobile cranes are also available (Champkin). One option is the Spierings City Boy, which is a plug-in hybrid, and can operate in diesel, hybrid, or electric mode (Spierings).

The trend towards electrification is a global one, as the entire world faces problems with emissions from diesel engines. Since construction sites are often in urban areas, the DPM from construction vehicles harms many people who are near them. In addition, the lower cost of electric power compared to diesel fuel, and the lower cost of maintaining electric vehicles, means that the electric propulsion could lower the vehicle's operating cost. In addition to the aforementioned companies, Komatsu and Caterpillar are releasing electric construction equipment. The options for charging the vehicles include DC fast charging. Overnight charging is a good option for equipment that operates during the day. For equipment that operates around the clock, tethered charging-to connect the vehicle to the grid – may be necessary. Another option for round-the-clock work is in-field battery swapping.

6. Light Duty vehicle fleet electrification

Light duty vehicles are not the main focus of this report, as the pathways to electrify these engines already exist, and British Columbian legislation already exists that will end sales of light-duty combustion vehicles by 2040. The provincial legislation requires 10% of the light duty vehicles sold in the province to be ZEVs by 2025, 30% by 2030, and 100% by 2040 ("Zero-Emission Vehicles Act," 2019). However, there is still more that needs to be done to enable this transition, and there is more that Metro Vancouver can learn from other places around the world.

To electrify the fleets of vehicles that operate in the Metro Vancouver region, be they heavy duty trucks or light duty vehicles, public agencies in the Metro Vancouver region such as the provincial and local authorities, as well as utilities like BC Hydro, must take an active role in developing charging infrastructure. Though Metro Vancouver does not have direct authority over this matter, it can play a coordinating role. Electric vehicles cannot operate if they do not have a place to charge. During the first phase of the push to electrify light duty vehicles, electric vehicle adoption was primarily limited to people who had their own homes with garages where they could install their own charging equipment. Moving forward, that will not be enough.

Now that British Columbia allows Transportation Network Companies like Lyft to operate in Vancouver, there has been concern that these new fleets of vehicles could increase congestion and emissions. However, this concern is ameliorated by the new announcement that Lyft has made that it will complete electrification of its vehicle fleet by the year 2030. The sustainability policy manager of Lyft has been emphatic that his company will not be able to achieve this goal alone. They will do it in conjunction with partners at the state/provincial, regional, and municipal government levels. This is particularly important because of the charging infrastructure. Rideshare vehicles make many trips in a day, and so if they only charge at night their batteries will deplete. For rideshare vehicles, time is money, so they cannot afford to spend hours charging in the middle of the day. For that reason, electric rideshare vehicles require DC fast charging in urban areas to be available to them. This is where local and regional governments must play a role. To this end, public authorities in the Metro Vancouver region can engage stakeholders who have the authority to expand the use of charging infrastructure, particularly the high-power charging equipment such as EC fast chargers. Charging stations for both light duty and heavy-duty equipment are needed throughout the Metro Vancouver region.

It is crucial for Metro Vancouver to work with municipalities, utilities, and other entities to ensure charging infrastructure is built in the region for electric vehicles across the spectrum of sizes and uses. This is especially crucial for heavy duty vehicles, because heavy duty vehicle electrification suffers from a chicken-and-egg problem: vehicle owners will not want to electrify if there is no charging infrastructure; and the private sector will not provide enough charging infrastructure if there are no electric vehicles that would use it. Eventually, the private sector may come up with their own solutions – just as ChargePoint, Petro-Canada, and other companies are building electric vehicle service equipment for light duty vehicles – but the health effects of DPM and climate change warrant public investment and coordination to speed this transition. Heavy duty vehicles and equipment is large and expensive, and the market for electric heavy-duty equipment small, so the transition will be slow in this realm. For this reason, it is crucial for governments like Metro Vancouver to act.

7. Airport Equipment Electrification

One key category of non-road equipment that is ripe for electrification is the ground support equipment (GSE) that operates at airports such as Vancouver International Airport (YVR). Other airports large and small have moved forward on this. At JFK airport in New York, JetBlue is converting its fleet of baggage tractors and belt loaders, which are the largest portion of its GSE, to be electric.

Six of the most common pieces of airport GSE have electric versions available. These are the pushbacks, belt loaders, container loaders, luggage tugs, lavatory trucks, and water trucks. British Airways uses electric robotic aircraft tugs, known as Mototok. These can move aircraft of any size, apart from the biggest double-decker planes. They are remotely controlled so they do not need crew in them. There are also other manufacturers of electric aircraft tugs, such as Eagle, JetPorter, and Lektro.

In Vancouver International Airport, 53% of the GSE that is operated by licensed ground handling companies is electric, as of late 2019. This does not include the equipment owned and operated by airlines with their own ground handling division, such as Air Canada, which have their own targets for greenhouse gas reduction and governed by the ground handling licence at YVR. In addition, the airport operates several electric buses that bring passengers from the terminal to remote stands where they can board and disembark the planes. These buses are entirely electric, and they use both overnight and opportunity charging.

In 2015, the Vancouver Airport Authority required all licenced ground handling companies to steadily increase the proportion of GSE that is electric, up to the point of 50% electric GSE by the year 2020. This goal was achieved in advance of the target, as 53% of GSE operated by contractors was electric in 2019. The primary target of electrification was the smaller ground support equipment, such as the baggage tugs. Even prior to 2015, there were regulations prohibiting the use of diesel-powered baggage tugs, because they operate in a partially enclosed space where DPM would cause unacceptable health problems. Before electrification, many of these machines used gasoline or propane. The earlier electric versions of this equipment use lead-acid batteries, but the newer vehicles use lithium-ion batteries. The airport has installed 50 common use charging points around the airport, and plans to increase that number to 94 by the end of the year 2020. These charging points have two charging points in each station, and are manufactured by PosiCharge, which has cornered the market for charging electric industrial equipment such as airport GSE.

They did this by requiring their licensed ground handling companies to electrify ten percent of their fleet each year between 2015 and 2020, with financial penalties for noncompliance. The companies had flexibility to choose which equipment to target for electrification. Prior to this program's implementation in 2015, there was no requirement that the ground handlers have electric equipment.

VANCOUVER AIRPORT GSE ELECTRIFICATION STATISTICS	
Percent of Airport GSE that is electric	53%
Total reduction of GHG emissions (between 2015 and 2019)	2000 tonnes
Reduction in fossil powered GSE	17%
Reduction in diesel powered GSE	42%
Increase in electric GSE	50%
Increase in overall GSE	9%

The market is not yet mature enough for electrification of the heavier GSE. For more niche types of equipment, since the market is small, there are fewer available options. For some types of airport equipment, such as snowplows, the electrification would require either battery swapping or a doubling of the fleet; because during snow emergencies, the entire snowplow fleet must be operating around the clock, leaving no time to charge. Given the immaturity of the market, the airport has developed a contract with its ground fleet operators that continues the 50% standard for the 5-year period from 2020 to 2025 but has introduced the requirement that all smaller pieces of equipment introduced into GSE fleets must be electric.

Lessons from the airport for other sites depend on the type of site. While many may be specific to airports, others may be applicable to other types. Even in other settings, Metro Vancouver could steadily increase targets for electrification of specific classes of non-road engines – or all non-road engines – and give the operators the flexibility to choose what types to target.

8. Port equipment electrification

Many types of equipment at container ports can and should be electrified. These include the gantry cranes that lift containers onto and off of the ships. The ports of Savannah and Long Beach, in Georgia and California, respectively, have completed this transition, and reduce fuel usage by 95% compared to diesel cranes. The Long Beach Container Terminal has achieved an 88% reduction in DPM emissions compared to a 2005 baseline. In Long Beach, the cranes are automated, and do not need light to operate, so the terminal can keep the lights off and save 10 million kWh/y.

In addition, the drayage trucks in Los Angeles and Long Beach, which move the containers from the ships to the rail yards, are being electrified as well. In 2008, the Port of Long Beach adopted a Clean Trucks Program (CTP), which phased out the oldest and most polluting diesel trucks over time. In 2012, the CTP was fully implemented, and the oldest trucks were completely banned, which reduced port truck emissions by 90%. In 2016, the South Coast Air Quality Management District (SCAQMD) gave a grant of $23.6million to trial electric trucks for this purpose, which were used to make zero-emissions battery electric trucks and plug-in hybrid trucks; this money was raised through California’s cap and trade program.

A recent report by researchers at UCLA found that electrification of all drayage trucks would be financially viable this decade for the ports of L.A. and Long Beach. One major reason is that there are incentives given by the local authorities, and there is also a state low-carbon fuel standard (LCFS), which can enable operators of vehicles with low carbon fuels to claim credits.

Just like California, British Columbia also has a low-carbon fuel standard, which means that electrification of all drayage trucks at the Vancouver Fraser Port Authority could be also viable in Metro Vancouver as well, if the governments give the right incentives.

9. Forklift and warehouse equipment electrification

Another category of equipment that is ripe for electrification is the equipment that operates in and around warehouses, such as forklifts and motorized carts for carrying equipment. Many electric options are already available, and in many cases, this equipment is already electric. Since these types of equipment often operate indoors, there is a strong necessity to avoid emissions of particulates or toxic air contaminants. However, some of this equipment runs on fossil fuels such as propane, gasoline, or diesel.

Especially due to the abundant low-carbon electricity available in British Columbia, electrification is the best option for this type of equipment in the Metro Vancouver region. Metro Vancouver can provide an incentive to transition to zero emission equipment through emissions standards-based fees under the non-road diesel engine regulation. Indoor equipment likely operates on electricity already to protect indoor air quality. This is further discussed in more detail in Phase 2 of this report.

10. Solar photovoltaic charging

There is a possibility of using solar power for charging of the electric vehicles. Some argue that British Columbia's hydropower grid is already tapped out and cannot support additional electric load from widespread electrification, unless additional low-carbon electric generating capacity is built. Professor Roland Clift argues that additional electric load in British Columbia comes from coal-fired generation in Alberta, so the British Columbia should not move to electrify end uses of energy until it adds more low-carbon power.

One possibility is the addition of solar microgrids. One such microgrid was built on the campus of the British Columbia Institute of Technology (BCIT). This microgrid was built for experimental purposes, and has the ability to operate independently of the power grid. However, to build such a complex microgrid requires additional investment, and would not be cost-effective for general purposes in the Metro Vancouver region, which has access to the BC Hydro grid and low electricity prices. For the time being, it makes more sense to rely on grid electricity because of the low prices.

However, in the long term, as British Columbia moves to electrify all transportation in its province, it will need to increase electric generating capacity without increasing emissions of greenhouse gases. This means that it will need to invest in renewable power sources such as solar and wind energy. A recent study found that the electrification of the road vehicle fleet in British Columbia would require electrical generating capacity to increase by 60%, relative to a scenario with no electrification. However, the availability of low-cost renewable energy options, such as solar and wind, mean that the levelized cost of electricity would likely increase by only 9%. This study found that to reduce costs and emissions, and optimize the entire system, utilities should have some control over charging. This way, they can implement smart charging, and charge vehicular batteries when the cost of electricity is the lowest and renewable energy is most abundant.

This study incorporated the additional hydropower generation developed at Site C, but did not incorporate any potential changes in electric demand due to changing economic conditions, as it used the base case projections for demand that were produced by BC Hydro. Despite their findings that low-cost options like solar and wind energy will be useful for adding electric generating capacity, the authors of this study do not anticipate that solar photovoltaic generation is a good fit for Metro Vancouver, given the climatic conditions.

Phase 2 – Summary and recommendations

There are many options for electrification of many different types of equipment. Some of these are not available on the market as of yet but others are already available. Many more technologies are in the nascent phases of development. Metro Vancouver has an opportunity to be proactive in supporting the adoption of advanced technologies to enable serious reductions in emissions of greenhouse gases and particulate matter.

In the realm of construction equipment, zero emissions options are being developed, and may be ready for mass deployment in the coming years.

In the realm of airport and port equipment, many electric options are already available and already in use at Vancouver International Airport and at the many port facilities throughout Metro Vancouver.

In the realm of marine equipment, BC Ferries is developing plug-in hybrid electric vessels, known as the Island Class vessels, that will operate on short routes in the Salish Sea. These are designed for complete electrification, and will transition to full electric operation in the near future, as soon as the necessary charging infrastructure becomes available, which should be within the next five to ten years.

In the realm of heavy duty on-road vehicles, electrification is becoming increasingly viable. TransLink already has a plan to electrify all the public transit buses that operate in Metro Vancouver, as do other bus operators around the world. Heavy duty trucks are becoming increasingly viable targets for electrification as well, and the market is likely to develop rapidly due to the new Advanced Clean Trucks regulations that has been promulgated by the California Air Resources Board. Utilities and agencies within the Metro Vancouver region could support market buy-in by investing in charging equipment, potentially in coordination with the West Coast Clean Transit Corridor Initiative. This is discussed in more detail in the recommendations section below.

In the realm of warehouse equipment, many electric options are available, and the regional district has an opportunity to ensure that electrification is completed. It can do this by developing standards and mandates to require electrification of this equipment.

Metro Vancouver has an opportunity to proactively work to realize the benefits of these opportunities. To support the rollout and adoption of these advanced technologies, Metro Vancouver must work with all involved stakeholders. Electrification of different types of equipment will require different types of charging infrastructure, and Metro Vancouver may have a role to play in ensuring that all parts of the regional district have access to the charging infrastructure that they will need. In addition, it may have a role to play in simply increasing awareness of the options that are available and the programs that the British Columbian government has to support electrification.

Recommendations and Next Steps

Metro Vancouver can and must be proactive in the effort to electrify, or otherwise eliminate emissions from, all types of equipment that operate in the region. In order to do that, there are several angles of attack.

One crucial strategy is simply to raise awareness of the options that are available and the incentives that are offered by the province of British Columbia. There may be equipment operators who don't know about these options and incentives, and so raising awareness is the first step. Another is to update existing bylaws to strengthen regulation of non-road diesel engines. There are extant regulations that require registration and limit the use of unregistered non-road diesel engines that do not meet at least Tier 2 standards. These regulations could be updated to require higher standards.

In addition, it may be possible to lobby and work with other stakeholders and fleet operators to electrify operations. For example, BC Ferries is developing its partly electrified Island Class of ferries and is planning to use them on short routes in the Salish Sea. The route between Bowen Island and Horseshoe Bay, in Metro Vancouver, might be a good fit for this due to its short length.

Metro Vancouver can work with all involved stakeholders to develop the charging infrastructure necessary for electrification of other types of equipment. This could potentially include encouraging stakeholders to coordinate with the West Coast Clean Transit Corridor Initiative; and adding heavy truck charging equipment in the Metro Vancouver region. One potential location for a truck charging station would be at the Pacific Highway Border Crossing, and there may be others throughout the region.

It is necessary for Metro Vancouver to proactively support rollout of charging infrastructure in the region, for both heavy and light duty vehicles. The introduction of transportation network companies presents an opportunity for deep electrification of the light duty fleet in Metro Vancouver. To realize this opportunity, Metro Vancouver must proactively invest in DC fast charging infrastructure, along with others forms of light duty charging infrastructure.

Though the technology is not fully mature as of 2020, there are increasing options for electrification of many types of non-road and heavy-duty equipment. Within the coming years, as more options become available, the path will be even clearer for electrification of non-road and heavy equipment, and the elimination of greenhouse gas and diesel particulate emissions.

Recommendation 1 – Update existing bylaws

One thing that Metro Vancouver could do would be to amend its existing bylaws to reduce the emissions of DPM. There is an existing bylaw, Non-Road Diesel Engine Emission Regulation Bylaw No. 1161, 2012, which regulates the emissions of DPM from non-road diesel engines. This bylaw does not apply to machines used in farm operations or personal recreation vehicles. This registration requires registration and labelling requirements for Tier 0 and Tier 1 non-road diesel engines. This requirement can be partially waived if the engine meets the standard of a Tier 2 engine or better.

In order to reduce emissions of greenhouse gases, NO_x, and DPM from non-road diesel engines, the MVRD can update this bylaw to strengthen it. One possibility might be to remove the exemptions for personal recreation vehicles and farm equipment. Another possibility would be to expand its requirements to require registration of all non-road diesel engines, up to and including Tier 4. In addition, at the time and place of registration – whether online or in person – Metro Vancouver should provide the registrants with information about the zero-emissions options that are available and the SUVI incentives from the province of BC that incentivize the purchase of zero-emissions technologies.

This regulation limits the operation of non-road diesel engine that do not meet at least Tier 2 standards for DPM emissions, effective January 31, 2020. This requirement can be progressively updated to similarly limit the operation of non-road diesel engines that do not meet Tier 3 and 4 standards for DPM emissions, for the coming years. This progressive restriction of lower tiers of diesel engines would be similar to the regulation that Portland is implementing for public construction contracts.

Recommendation 2 – Develop a Clean Air Construction Program

One example of a municipal bylaw that could be emulated by Metro Vancouver is the Clean Air Construction Program, found in the metropolitan region of Portland, Oregon. The City of Portland, along with its neighboring municipal, county, and metropolitan authorities, has developed municipal bylaws that require publicly funded construction projects to implement regulations that reduce the emissions of greenhouse gases, nitrous oxides, and DPM. These agencies are the City of Portland, Multnomah County, Port of Portland, Washington County, and Metro (which is a regional governing body analogous to Metro Vancouver).

To do this, they are implementing a standard set of idle reduction and diesel equipment requirements on job sites; and implementing a regional program to verify compliance with these requirements. In developing this program, the staff of the city government looked at the DPM reduction programs that were in place in several other jurisdictions including Metro Vancouver. The staff of Portland's government consulted with Metro Vancouver in developing the process and the software to monitor compliance.

The Portland Clean Air Construction Program is a program to reduce diesel emissions construction projects. It is a collaboration among public agencies in the Metro Portland area. The City of Portland, Port of Portland, Metro, Multnomah County, and Washington County are all collaborating to implement this project. They are implementing a standard set of idle reduction and diesel reduction policies, and implementing a regional program to verify compliance with the requirements. These requirements are not applied to every single construction site, but only the big ones. There are thresholds for the dollar value of the contracts beyond which the requirements apply. For the City of Portland, the diesel reduction requirements apply to all contracts with dollar value above one million US dollars; for the other governments in the region the requirements apply to contracts with dollar value above five hundred thousand US dollars. Contracts that fall below these thresholds are exempt from the requirements. This threshold approach was chosen for a variety of reasons, including alignment with other contract threshold-based contractor requirements and implementation feasibility given available staff and funding resources.

All contractors that work on these projects must reduce idling, by requiring all diesel equipment to shut down after five minutes of inactivity. There are exceptions in cases where the safety of contractors may be compromised by shutdown, if the equipment meets the most stringent EPA guidelines or has been retrofitted with a diesel particulate filter, or if the equipment is such that frequent shutdowns would damage the engine.

Different tiers of engines will be prohibited from worksites on a phased basis. On January 1, 2022, Tier 0 engines will be restricted from operating on these worksites. Each year thereafter, the next tier of engine will be restricted until Tier 3 engines are restricted on January 1, 2024. Through this date, the engines that have restrictions are prohibited unless they are retrofitted with emission control devices.

Unfortunately, they were unable to estimate the reduction in emissions that will take place as a result of the regulations. The state of Oregon does not require registration of non-road engines, so Portland does not have access to the baseline data that would enable them to construct a model of the emissions and the quantify by which emissions would decrease. However, since this municipal bylaw does require the registration of vehicles, Metro Portland will be tracking this data moving forward.

A recommendation of this report is for Metro Vancouver to develop a program to reduce diesel emissions from public construction projects, similar to the one that Metro Portland has developed. It should be possible for Metro Vancouver to design a set of policies to reduce the emissions from non-road diesel engines that is similar to this one.

This is not an engine electrification program, but it is a concrete action that can be taken by a Metropolitan government to reduce the emissions of DPM. Given the fact that electric and zero-emissions options for construction vehicles are still in the very nascent phases of development, the authorities in Metro Portland decided that this was their best option for reducing emissions of DPM. This is a program that Metro Vancouver could emulate, for the same reason.

Recommendation 3: Set standards for electrification of non-road engines

In order to achieve its goals related to the electrification of ground support equipment, the Vancouver Airport Authority set increasing standards for electrification of the ground support equipment that was registered by ground handling contractors at the Airport. Existing bylaws require the registration of almost all non-road diesel engines in Metro Vancouver, and these bylaws could be expanded in scope to require registration of all non-road diesel engines. In doing that, Metro Vancouver could pursue the same strategy that the Vancouver Airport Authority did for its own fleet of ground support equipment. It can set increasing standards for the electrification of non-road engines that are registered with the regional district.

This would be similar to the strategy that the province of British Columbia is using to electrify light duty vehicles. An increasing percentage of the vehicles sold in each year would have to be zero-emissions vehicles. As of right now, it may not be possible to set a standard for 100% electrification, as not all categories of equipment have commercially available zero-emissions options. However, it would be possible to set a standard that a certain percentage of non-road equipment has to be electric, with increasing targets as time moves forward.

This would give the operators a requirement to electrify and to reduce emissions, but it would also give them the flexibility necessary to avoid hampering their operations. The pieces of equipment that can be electrified more cost-effectively will be electrified first. As more options become available, Metro Vancouver can increase the percentage of equipment that is required to electrify, and the emissions will further decrease.

Recommendation 4: Build charging infrastructure

In order to realize the potential for electrification in the region of Metro Vancouver, sufficient charging infrastructure must be available.

One opportunity in this realm is to work with BC Hydro and the West Coast Clean Transit Corridor Initiative to build heavy duty charging infrastructure in Metro Vancouver. This Initiative aims to build a network of heavy-duty truck charging stations along the entirety of Interstate 5 (I-5). I-5 is the only road that stretches from the Mexican border to the Canadian border, and connects BC to BC, that is Baja California to British Columbia. Its northern end is at the Peace Arch Border Crossing; however, heavy commercial traffic is not allowed to use that crossing, so for the purposes of commercial vehicles, the northern end of I-5 is at the nearby Pacific Highway Border Crossing. At this location, heavy trucks have to stop to be inspected. If they are powered by diesel, they must either idle while they wait, or turn off the engines and turn them on again, which is harmful because particulate matter emissions are highest during the first minute of a diesel engine’s operation. For this reason, cross-border truck traffic is an important target for electrification. In order to enable that, a heavy-duty charging station could be built at the Pacific Highway Port of Entry. This would let the heavy trucks charge while their goods are being inspected at the border. To enable the development of heavy-duty charging stations, it would be necessary to work with the local electric utility, in this case BC Hydro, because the high-power requirements would require upgrades to the local electric service infrastructure. This would likely be in the interest of BC Hydro to complete, for the same reason that it is in the interest of the utilities that are currently developing the WCCTCI. Metro Vancouver can play a role in coordinating these activities, and with siting and permitting development of charging infrastructure within its regional district.

The West Coast Clean Transit Corridor Initiative is funded by utilities that operate in California, Oregon, and Washington. The initiative was developed after Southern California Edison convened utilities to develop a network of heavy-duty charging infrastructure along this corridor. Its presence on the border of Metro Vancouver provides a straightforward way for Metro Vancouver to tap into this network, and develop a network of charging infrastructure within Metro Vancouver that can connect to the network.

In addition, the region must proactively build out charging infrastructure for light duty vehicles as well. The pending arrival of transportation network companies (TNC) like Uber and Lyft, along with Lyft's commitment to electrify its vehicle fleet by 2030, presents an opportunity and a challenge for Metro Vancouver. The opportunity will be realized if Metro Vancouver and its member jurisdictions proactively invest in the DC fast charging infrastructure necessary for these fleet vehicles to charge. Lyft will not succeed in electrification if it does not have partners in the cities where it works, and achieving this electrification is in the interest of all stakeholders, for the benefit of air quality and climate change mitigation.

Metro Vancouver's statutory authority may be limited in this regard, as it has no authority over roadside infrastructure. TransLink and municipal and provincial authorities may have to take the lead on the provision of charging infrastructure, along with utilities like BC Hydro and private companies. However, Metro Vancouver may be able to play a coordinating role to ensure the charging network has enough capacity to complete electrification of the region's vehicle fleet.

Conclusion

As a result of the climate crisis and the COVID crisis, emissions of greenhouse gases and particulate matter have gotten increased attention. Though Metro Vancouver is blessed with good air quality and a temperate climate, and is quite resilient to climate shocks, this region must do more to reduce its emissions of greenhouse gases and particulate matter. There are many opportunities that can be taken in Metro Vancouver and around the world to electrify and otherwise reduce emissions from non-road engines and heavy-duty vehicles.

In certain classes of heavy equipment, zero-emissions options are not commercially available as of summer of 2020. In other classes, they are available and commercially viable. Metro Vancouver can set standards and implement programs to ensure that this equipment is electrified to the extent possible. In addition, they can set standards to reduce emissions from non-road diesel engines, even in the categories for which zero-emissions options are not available, in order to reduce emissions of diesel DPM. It can also support the rollout of electric non-road and heavy-duty vehicles by investing in charging infrastructure, potentially in coordination with other actors across the border in the United States.

This decade must be one of bold and decisive climate action, and Metro Vancouver is no exception. Metro Vancouver, along with other places around the world, has an opportunity to electrify its economy and reduce emissions.

References

"Innovative Clean Transit Regulation." California Air Resources Board, California Air Resources Board, 14 Dec. 2018, https://ww2.arb.ca.gov/sites/default/files/2019-10/ictfro-Clean-Final_0.pdf

"2018 Detailed Electricity Statistics." China Energy Portal, 2019, chinaenergyportal.org/en/2018-detailed-electricity-statistics-update-of-dec-2019/#.

Adair, Mike. "Home." Electric School Buses, 24 May 2020, www.blue-bird.com/buses/electric-school-buses.

Aggreko. "A Quick Guide to Tower Cranes." Aggreko, 11 Feb. 2019, www.aggreko.com/en-us/news/2019/nam-articles/construction/a-quick-guide-to-tower-cranes.

Baker, Rick. Eastern Research Group, Inc., 2020, pp. 1–26, OREGON 2017 NON-ROAD DIESEL ENGINE INVENTORY STUDY FINDINGS.

"BC Ferries Schedule." BC Ferries Schedules: Bowen Island – Vancouver (Snug Cove-Horseshoe Bay), www.bcferries.com/m/schedules/mainland/biva-current.php.

"BC SUVI List of Eligible Vehicles." Plug In BC, 2 July 2020, pluginbc.ca/suvi/bc-suvi-list-of-eligible-vehicles-jul-02-2020/.

Bloomberg New Energy Finance, 2018, Electric Buses in Cities, data.bloomberglp.com/professional/sites/24/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf.

Brinkman, Sarah. "Seaports Need a Lot of Energy, But Electrification Can Reduce Pollution and Costs." Alliance to Save Energy, 24 Apr. 2019, www.ase.org/blog/seaports-need-lot-energy-electrification-can-reduce-pollution-and-costs.

"British Columbia Ferry Services Inc." BC Ferries' Island Class Vessels | BC Ferries- British Columbia Ferry Services Inc., 2019, www.bcferries.com/about/projects/island-class.html.

"British Columbia Ferry Services Inc." New Cable Ferry for Buckley Bay-Denman Island Service | BC Ferries- British Columbia Ferry Services Inc., 2015, www.bcferries.com/about/projects/cable-ferry.html.

Butler, Jeff. "Norway Leads an Electric Ferry Revolution." Plugboats, 4 Feb. 2020, plugboats.com/norway-leads-an-electric-ferry-revolution/.

C40 Cities, 2019, pp. 2–3, HOW CITIES ARE DRIVING THE FUTURE WE WANT: City Progress towards Meeting Green and Healthy Streets Declaration Commitments.

California Air Resources Board. Advanced Clean Trucks Fact Sheet, California Air Resources Board, 2020.

California Air Resources Board. California Climate Investments, ww2.arb.ca.gov/our-work/programs/california-climate-investments.

California Air Resources Board. California Transitioning to All-Electric Public Bus Fleet by 2040, California Air Resources Board, 14 Dec. 2018, ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040.

California Climate Investments, 2020, ww2.arb.ca.gov/our-work/programs/california-climate-investments.

CALSTART (2020): Drive to Zero's Zero-emission Technology Inventory (ZETI) Tool Version 5.5. https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

"Carbon Reduction." YVR, Vancouver International Airport, www.yvr.ca/en/about-yvr/environment/carbon-reduction.

Carpenter, Susan. "Big Rigs Begin to Trade Diesel for Electric Motors." The New York Times, The New York Times, 19 Mar. 2020, www.nytimes.com/2020/03/19/business/electric-semi-trucks-big-rigs.html.

"CEV for BC." Clean Energy Vehicles for British Columbia | New Car Dealers of BC, 2020, www.cevforbc.ca/.

Chaichan, Miqdam T, et al. International Journal of Scientific & Engineering Research, vol. 7, no. 3, Mar. 2016, uotechnology.edu.iq/paper/PDF/power/No.%2022.pdf.

Champkin, Julian. "Are Cranes Electric?" Http://Www.cranestodaymagazine.com, www.cranestodaymagazine.com/features/are-cranes-electric-6989009/.

Chan, Kenneth. "BC Government Launches New Electric Cable Ferry into Service." Daily Hive, Vancouver Urbanized, 31 Mar. 2020, dailyhive.com/vancouver/arrow-park-cable-ferry-vessel-electric.

Chan, Kenneth. "Trudeau Says Emergency Public Transit Funding Is Not a Federal Responsibility: Urbanized." Trudeau Says Emergency Public Transit Funding Is Not Federal Responsibility, Daily Hive, 8 May 2020, dailyhive.com/vancouver/trudeau-federal-government-transit-funding.

Cheng, Tiffany. “Volvo CE Unveils Electric Compact Excavator and Wheel Loader at Bauma.” Volvo Construction Equipment, 10 Apr. 2019, www.volvoce.com/global/en/news-and-events/press-releases/2019/volvo-ce-unveils-electric-compact-excavator-and-wheel-loader-at-bauma/.

“Clean Trucks.” Port of Long Beach, Port of Long Beach, 2019, www.polb.com/environment/clean-trucks/#program-details.

Deign, Jason. “World's Second-Largest Ferry Operator Switching From Diesel to Batteries.” World's Second-Largest Ferry Operator Switching From Diesel to Batteries | Greentech Media, Greentech Media, 29 Nov. 2019, www.greentechmedia.com/articles/read/worlds-second-largest-ferry-operator-switching-from-diesel-to-batteries.

Dennis, Keith, et al. “Environmentally Beneficial Electrification: The Dawn of ‘Emissions Efficiency.’” The Electricity Journal, vol. 29, no. 6, 2016, pp. 52–58., doi:10.1016/j.tej.2016.07.007.

Eckhouse, Brian. “The U.S. Has a Fleet of 300 Electric Buses. China Has 421,000.” Bloomberg.com, Bloomberg, 15 May 2019, www.bloomberg.com/news/articles/2019-05-15/in-shift-to-electric-bus-it-s-china-ahead-of-u-s-421-000-to-300?sref=RR4MPTfe.

“ECR25 Electric: Electric Machines: Overview.” ECR25 Electric | Electric Machines | Overview | Volvo Construction Equipment, 2019, www.volvoce.com/united-states/en-us/products/electric-machines/ecr25-electric/#overview.

Electric Aircraft and Helicopter Tugs, www.mototok.com/tugs.

“Electric Airport Ground Support Equipment.” San Joaquin Air Pollution Control District, www.valleyair.org/transportation/Internet%20GSE%20handout.pdf.

Electric Ground Support Equipment at Airports , Dec. 2017, afdc.energy.gov/files/u/publication/egse_airports.pdf.

“Electric Snow Plow Vehicles.” Electric Vehicles, 2020, www.alke.com/electric-snow-plow-vehicles.

Emobility- It's Time to Launch Our Electric Construction Machines I Volvo CE, 2019, www.volvoce.com/global/en/our-offer/emobility/.

Everman, Hannah. “Plan to Convert State's Largest Ferries to Electric Moves Forward.” king5.Com, 23 Oct. 2019, www.king5.com/article/news/local/washington-state-ferries-converting-to-electric-power/281-191657ee-4b04-4ffa-9b79-dd864cd1a82d.

Fidler, Eddie. “Do Electric Construction Vehicles Make Sense for the Industry?” Do Electric Construction Vehicles Make Sense? | ARC Advisory, 26 June 2019, www.arcweb.com/blog/do-electric-construction-vehicles-make-sense-industry.

Fine, Jamie, et al. “Report: California's Clean Truck Rule Will Save the Economy Billions, Eliminate Vast Amounts of Pollution.” Energy Exchange, Environmental Defense Fund, 22 June 2020, blogs.edf.org/energyexchange/2020/06/17/report-californias-clean-truck-rule-will-save-the-economy-billions-eliminate-vast-amounts-of-pollution/.

Foreman, Stacey. “Clean Air Construction Overview and Requirements.” Portland.gov, City of Portland, 2020, www.portland.gov/omf/brfs/procurement/clean-air-construction/clean-air-construction-overview-and-requirements#toc-idle-reduction-requirements.

Freightliner. “e-Mobility.” *Freightliner Trucks*, freightliner.com/e-mobility/.

Gallucci, Maria. “Amid Trump's Rollbacks, 15 States Rev up Plans for Electric Trucks and Vans.” Grist, Grist, 24 July 2020, grist.org/energy/daimler-electric-truck-amazon-van-trump-fuel-economy/.

Giordano, Lizz. “Washington State Ferries Plans for an Electric-Hybrid Fleet.” Seattle Weekly, Seattle Weekly, 5 Nov. 2019, www.seattleweekly.com/news/washington-state-ferries-plans-for-an-electric-hybrid-fleet/.

Gitlin, Jonathan M. “Seattle Makes History with Electric Garbage Truck.” Ars Technica, 22 May 2019, arstechnica.com/cars/2019/05/seattle-makes-history-with-electric-garbage-truck/.

Gopinathan, Narayan, et al. “Mid-Century Strategies: Pathways to a Low-Carbon Future?” Climate Policy, vol. 19, no. 9, 2019, pp. 1088–1101., doi:10.1080/14693062.2019.1627178.

Haig-Brown, Alan. “British Columbia's New Cable Ferry Always on Its Moorings.” Professional Mariner, 30 Nov. 2016, www.professionalmariner.com/December-January-2017/British-Columbias-new-cable-ferry-always-on-its-moorings/.

Hanley, Steve. “Scandinavia Is Home To Heavy-Duty Electric Construction Equipment & Truck Development.” CleanTechnica, 30 Jan. 2018, cleantechnica.com/2018/01/30/scandinavia-home-heavy-duty-electric-construction-equipment-truck-development/.

Harris, Chris. “How Oil-Rich Norway Is Leading the World on Electric Cars.” Euronews, 13 Apr. 2018, www.euronews.com/2018/04/11/how-oil-rich-norway-is-leading-the-world-on-electric-cars.

“HB 2007: Diesel Clean-Up Bill.” Oregon Environmental Council, 25 Oct. 2019, oeconline.org/diesel/.

Henley, Jon, and Elisabeth Ulven. “Norway and the A-Ha Moment That Made Electric Cars the Answer.” The Guardian, Guardian News and Media, 19 Apr. 2020, www.theguardian.com/environment/2020/apr/19/norway-and-the-a-ha-moment-that-made-electric-cars-the-answer.

Henley, Steve. “Scandinavia Is Home To Heavy-Duty Electric Construction Equipment & Truck Development.” CleanTechnica, 30 Jan. 2018, cleantechnica.com/2018/01/30/scandinavia-home-heavy-duty-electric-construction-equipment-truck-development/.

“Hidromek Exhibits New Electric Excavator at Bauma 2019.” Highway, 9 Dec. 2019, www.oemoffhighway.com/trends/equipment-launches/press-release/21045014/hidromek-hidromek-exhibits-new-electric-excavator-at-bauma-2019.

“How Shipping Is Tackling Emissions Article | Vancouver Fraser Port Authority | BBC StoryWorks.” BBC News, Port of Vancouver, 2019, www.bbc.com/storyworks/vancouver-fraser-port-authority/how-shipping-is-tackling-emissions?obOrigUrl=true.

“Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) and Low NOx Engine Incentives in 2009 to Accelerate the Purchase of Cleaner, More Efficient Trucks and Buses in California.” California HVIP, 2020, www.californiahvip.org/.

“Hyundai Construction Equipment (HCE) to Develop ‘Hydrogen Fuel Excavators’ with Hyundai Motors.” FuelCellsWorks, 17 Mar. 2020, fuelcellsworks.com/news/hyundai-construction-equipment-hce-to-develop-hydrogen-fuel-excavators-with-hyundai-motors/.

Ibekwe, David. “British Airways' New Electric Robot Has Slashed Pushback Delays by 54% at One of the World's Busiest Airports- We Used It to Move a 130-Ton Airplane.” Business Insider, 17 July 2018, www.businessinsider.in/british-airways-new-electric-robot-has-slashed-pushback-delays-by-54-at-one-of-the-worlds-busiest-airports-we-used-it-to-move-a-130-ton-airplane/articleshow/65024292.cms.

International Energy Agency, 2020, pp. 63–64, 2020 EV Outlook.

Jensen, Sara. “Electrified Construction Equipment.” Highway, 19 July 2019, www.oemoffhighway.com/trends/electrification/article/21061499/electrified-construction-equipment.

"JetBlue Introduces the Largest Electric Ground Service Equipment (EGSE) Fleet at New York's JFK International Airport, Cutting Four Million Pounds of Greenhouse Gas Emissions per Year." Business Wire, 26 Sept. 2019, www.businesswire.com/news/home/20190926005676/en/JetBlue-Introduces-Largest-Electric-Ground-Service-Equipment.

Johansen, Ole Henrik. "Verdens Første Av Sitt Slag- Og Den Er Bygget i Norge." Tek.no, 27 Jan. 2019, www.tek.no/nyheter/sniktitt/i/8mjbgW/caterpillar-323f-z-line-zero-emission.

Jolly, Jasper. "Jumbo Jet Sunset: Coronavirus Hastens the End of the Boeing 747." The Guardian, Guardian News and Media, 9 May 2020, www.theguardian.com/business/2020/may/09/boeing-747-coronavirus-hastens-end-jumbo-jet-sunset.

Jones, Kendall. "Electric Dreams: Will Heavy Construction Equipment Go All-Electric?" ConstructConnect, Construction Project Management Software, 22 Feb. 2019, www.constructconnect.com/blog/electric-dreams-will-heavy-construction-equipment-go-electric.

Karlsson, Mikael. "Vera." Volvo Trucks, 12 Sept. 2018, www.volvotrucks.com/en-en/about-us/automation/vera.html.

Keating, Bob. "New Ferry Announced for Free Kootenay Lake Route | CBC News." CBCnews, CBC/Radio Canada, 30 Apr. 2019, www.cbc.ca/news/canada/british-columbia/longest-free-ferry-crossing-to-get-major-upgrade-1.5115756.

Keegan, Matthew. "Shenzhen's Silent Revolution: World's First Fully Electric Bus Fleet Quietens Chinese Megacity." The Guardian, Guardian News and Media, 12 Dec. 2018, www.theguardian.com/cities/2018/dec/12/silence-shenzhen-world-first-electric-bus-fleet.

Keller, Victor, et al. "Electrification of Road Transportation with Utility Controlled Charging: A Case Study for British Columbia with a 93% Renewable Electricity Target." Applied Energy, vol. 253, 2019, p. 113536., doi:10.1016/j.apenergy.2019.113536.

KING 5 Staff. "Washington State Ferries Get $1.5 Million to Convert Vessel to Hybrid-Electric Power." king5.Com, King 5, 7 Jan. 2020, www.king5.com/article/tech/science/environment/washington-state-ferries-get-15-million-to-convert-vessel-to-hybrid-electric-power/281-868ce791-1b76-4256-8430-6dcbbcaf0dba.

Kitowski, Jack. "CALSTART to Administer $40 Million CARB Program Offering Attractive Discounts on Advanced Zero-Emission Off-Road Freight Equipment: August 5, 2019." CALSTART, 25 June 2020, calstart.org/coreannouncement/.

Lambert, Fred. "Caterpillar Unveils an All-Electric 26-Ton Excavator with a Giant 300 KWh Battery Pack." Electrek, 29 Jan. 2019, electrek.co/2019/01/29/caterpillar-electric-excavator-giant-battery-pack/.

Lambert, Fred. "Construction Equipment Is Going Electric, Volvo CE Now Favors Electric over Diesel for Smaller Machines." Electrek, 17 Jan. 2019, electrek.co/2019/01/17/construction-equipment-electric-volvo-ce/.

Lambert, Fred. "Two Massive Ferries Are about to Become the Biggest All-Electric Ships in the World." Electrek, 24 Aug. 2017, electrek.co/2017/08/24/all-electric-ferries-abb/.

"Lektro." JBT LEKTRO Inc, www.lektro.com/.

Levy, Alon. "Battery-Electric Buses Yield Mixed Results for Cities." CityLab, Bloomberg, 17 Jan. 2019, www.citylab.com/transportation/2019/01/electric-bus-battery-recharge-new-flyer-byd-proterra-beb/577954/.

Li, Xin, et al. "China's Electricity Emission Intensity in 2020 – an Analysis at Provincial Level." Energy Procedia, Elsevier, 2017, www.sciencedirect.com/science/article/abs/pii/S1876610217361714.

Llewellyn, Robert. "100% Electric Ferry Crossing | Fully Charged 4k'." YouTube, 13 May 2019, www.youtube.com/watch?v=rE_M1n-ClOA&feature=emb_rel_pause.

London City Hall. "Non-Road Mobile Machinery (NRMM)." London City Hall, 30 June 2020, www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/nrmm.

Luery, Mike. "California Invests Millions in Electric School Buses." KCRA, KCRA, 19 Dec. 2019, www.kcra.com/article/twin-rivers-school-district-electric-buses/30275955#.

Lyft, Inc. "Leading the Transition to Zero Emissions: Our Commitment to 100% Electric Vehicles by 2030." Lyft, Lyft, 17 June 2020, www.lyft.com/blog/posts/leading-the-transition-to-zero-emissions.

"Maps and Data- Vehicle Weight Classes & Categories." Alternative Fuels Data Center: Maps and Data- Vehicle Weight Classes, afdc.energy.gov/data/10380.

Meckling, Jonas, and Jonas Nahm. “The Power of Process: State Capacity and Climate Policy.” Governance, vol. 31, no. 4, 2018, pp. 741–757., doi:10.1111/gove.12338.

Mele, Jim. “California Awards $23.6 Million for Clean Drayage Trucks.” Fleet Owner, 4 May 2016, www.fleetowner.com/running-green/article/21693467/california-awards-236-million-for-clean-drayage-trucks.

Miller, Marshall R. California Energy Commission, 2016, pp. 4–37, California Off-Road Transportation Electrification Demand Forecast.

Muller, Joann. “Fleets of Electric School Buses Are Being Tested to Store Power for the Grid.” Axios, 10 Jan. 2020, www.axios.com/electric-school-buses-vehicle-to-grid-power-19f7b6b1-662b-4501-a96e-dcf3fd57a886.html.

Murray, Adrienne. “Plug-in and Sail: Meet the Electric Ferry Pioneers.” BBC News, BBC, 14 Jan. 2020, www.bbc.com/news/business-50233206.

Nickelsburg, Monica. “Seattle Rolls out Electric Garbage Trucks in Pioneering Transition Away from Fossil Fuels.” GeekWire, 30 May 2019, www.geekwire.com/2019/seattle-rolls-nations-first-fully-electric-garbage-trucks-transition-fossil-fuel-free-.

Nightingale, Alaric. “Forget Tesla, It's China's E-Buses That Are Denting Oil Demand.” Bloomberg.com, Bloomberg, 19 Mar. 2019, www.bloomberg.com/news/articles/2019-03-19/forget-tesla-it-s-china-s-e-buses-that-are-denting-oil-demand?sref=RR4MPTfe.

Nikel, David. “Electric Cars: Why Little Norway Leads The World In EV Usage.” Forbes, Forbes Magazine, 19 June 2019, www.forbes.com/sites/davidnikel/2019/06/18/electric-cars-why-little-norway-leads-the-world-in-ev-usage/#1186183213e3.

Poon, Linda. “In China, Shenzhen Electrified Its Entire Bus Fleet.” Bloomberg.com, Bloomberg, 8 May 2018, www.citylab.com/transportation/2018/05/how-china-charged-into-the-electric-bus-revolution/559571/.

Profita, Cassandra. “California's Landmark Electric Truck Rule Targets 'Diesel Death Zone'.” NPR, 26 June 2020, www.npr.org/2020/06/26/883634480/californias-landmark-electric-truck-rule-targets-diesel-death-zone?

“Queen of Capilano.” M.V. Queen of Capilano- BC Ferries, 30 Oct. 2006, www.westcoastferries.ca/ferries/bcferries/queenofcapilano.html#:~:text=An%20Intermediate%2Dclass%20ferry%2C%20the,youngest%20ferries%20in%20the%20fleet.

Randall, Chris. “Southern California Edison Sets Fleet Electrification Targets.” Electrive.com, 23 July 2020, www.electrive.com/2020/07/23/southern-california-edison-sets-fleet-electrification-targets/.

Rapier, Robert. “Why China Is Dominating Lithium-Ion Battery Production.” Forbes, Forbes Magazine, 4 Aug. 2019, www.forbes.com/sites/rrapier/2019/08/04/why-china-is-dominating-lithium-ion-battery-production/#4819aa5e3786.

Richmond, Craig. Vancouver International Airport, 2020, ENVIRONMENTAL MANAGEMENT PLAN YVR, www.yvr.ca/-/media/yvr/documents/environment/2020/yvr-environmental-management-plan.pdf.

Roberts, David. “The Key to Tackling Climate Change: Electrify Everything.” Vox, Vox, 19 Sept. 2016, www.vox.com/2016/9/19/12938086/electrify-everything.

Rosen, Ellen. “Making Yellow School Buses a Little More Green.” The New York Times, The New York Times, 22 Jan. 2020, www.nytimes.com/2020/01/22/business/energy-environment/electric-school-buses.html.

Rubenstone, Jeff. “Construction Equipment Goes Electric, But Hurdles Remain.” Engineering NewsRecord RSS, Engineering News-Record, 11 June 2020, www.enr.com/articles/47007-construction-equipment-goes-electric-but-hurdles-remain.

Shahan, Cynthia. “Largest Electric School Bus Program In United States Launching In Virginia.” CleanTechnica, 26 June 2020, cleantechnica.com/2020/01/12/largest-electric-school-bus-program-in-united-states-launching-in-virginia/.

Shahan, Zachary. “Zero-Emission Locomotive ‘999’ Restored For Use In California.” CleanTechnica, 19 June 2020, cleantechnica.com/2020/06/19/zero-emission-locomotive-999-restored-for-use-in-california/.

Sisson, Patrick. “Electric Bus Adoption Has Lots of Roadblocks: New Reports Offer Solutions.” Curbed, Curbed, 21 May 2019, www.curbed.com/2019/5/21/18634181/transportation-electric-vehicle-bus-mass-transit.

Sisson, Patrick. “How a Chinese City Turned All Its 16,000 Buses Electric.” Curbed, Curbed, 4 May 2018, www.curbed.com/2018/5/4/17320838/china-bus-shenzhen-electric-bus-transportation.

“Specialty-Use Vehicle Incentive Program.” Plug In BC, pluginbc.ca/suvi/.

Spierings City Boy, Spierings, www.spieringscranes.com/en/kranen/sk487-at3/.

Tesla. “Semi: Tesla.” Tesla Semi, www.tesla.com/semi.

Thai, Amy. Metro Vancouver, 2018, pp. 11, 2015 Lower Fraser Valley Air Emissions Inventory and Forecast.

The Beam. “The World's First Electric Autonomous Container Ship To Set Sail In Norway.” CleanTechnica, 22 Aug. 2018, cleantechnica.com/2018/08/23/the-worlds-first-electric-autonomous-container-ship-to-set-sail-in-norway/.

“TOWER CRANES.” JK Crane :: Tower Cranes, 2020, www.jkcrane.com/equipment/tower-cranes.

“TransLink Low Carbon Transition Plan.” TransLink, TransLink, 2020, www.translink.ca/-/media/Documents/about_translink/corporate_overview/policies/translink_low_carbon_fleet_transition_plan_20200224.pdf .

TransLink, 2020, pp. 21–41, Low Carbon Fleet Transition Plan.

“Washington State Ferries Get $1.5 Million to Convert Vessel to Hybrid-Electric Power.” king5.Com, 7 Jan. 2020, www.king5.com/article/tech/science/environment/washington-state-ferries-get-15-million-to-convert-vessel-to-hybrid-electric-power/281-868ce791-1b76-4256-8430-6dcbbcaf0dba.

Washington State Ferries, 2019, pp. 98, WSF 2040 Long Range Plan.

West Coast Clean Transit Corridor Initiative, 2020, pp. 45. Interstate 5 Corridor Background Research Technical Memorandum.

West Coast Clean Transit Corridor Initiative, 2020, pp. 40, West Coast Clean Transit Corridor Initiative Final Report.

West Coast Clean Transit Corridor Initiative, June 2020, www.westcoastcleantransit.com/.

Vancouver Airport Authority, 2020, pp. 1–8, Reducing Environmental Impact of Ground Support Equipment at YVR.

Xue, Lulu, and Weimin Zhou. “How Did Shenzhen, China Build World's Largest Electric Bus Fleet?” World Resources Institute, 22 Mar. 2019, www.wri.org/blog/2018/04/how-did-shenzhen-china-build-world-s-largest-electric-bus-fleet.

“Zero-Emission Technology Inventory.” Global Commercial Drive To Zero Program, 2020, globaldrivetozero.org/tools/zero-emission-technology-inventory/.

“Zero-Emission Vehicles Act.” Ministry of Energy and Mines, Province of British Columbia, 9 Mar. 2020, www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/zero-emission-vehicles-act