Port of Vancouver Electrification Roadmap 2030

A strategy for advancing electrification opportunities across port activities

Vancouver Fraser Port Authority and BC Hydro

Final

Date: April 12, 2019

To: Dorota Kwasnik, Vancouver Fraser Port Authority

From: Cariad Garratt, Pinna Sustainability Inc.

Sustainability

EELO SOLUTIONS

EXECUTIVE SUMMARY

The Vancouver Fraser Port Authority (VFPA) and BC Hydro co-funded and collaborated on the preparation of this Electrification Roadmap 2030 for the Port of Vancouver. Port activities are predominantly fueled by fossil fuels, resulting in GHG emissions of over one million tonnes annually (based on the 2015 Port Emission Inventory). This Roadmap supports efforts to reduce the contributions to climate change from port activities by providing an assessment of the potential for each port activity to have viable electric options by the 2030 timeframe and identifying strategies for VFPA and BC Hydro to support electrification of these activities.

The approach undertaken involved first reviewing each activity to identify the Technology Readiness Level (TRL) of electric options in development or on the market. All activities with a TRL below six were removed from the remainder of the analysis, as these are unlikely to reach commercial deployment by 2030. Activities with technology that is at least TRL 6 represent approximately 531,000 tonnes of GHG emissions annually (referred to as Roadmap emissions), or half of the total 2015 PEI emissions. Next, each of the activities that remain were assessed for cost and operational barriers. These criteria in turn informed estimated timeframes for commercialization of equipment for the remaining activities, as shown in Table 1.

A scenario estimating uptake was developed to understand the potential electrical demand, GHG emission reductions and indicative capital costs that would be necessary to support the electrification scenario. The rates of uptake were estimated based on the estimated timeframes for commercialization outlined above. As a result, the scenario demonstrates:

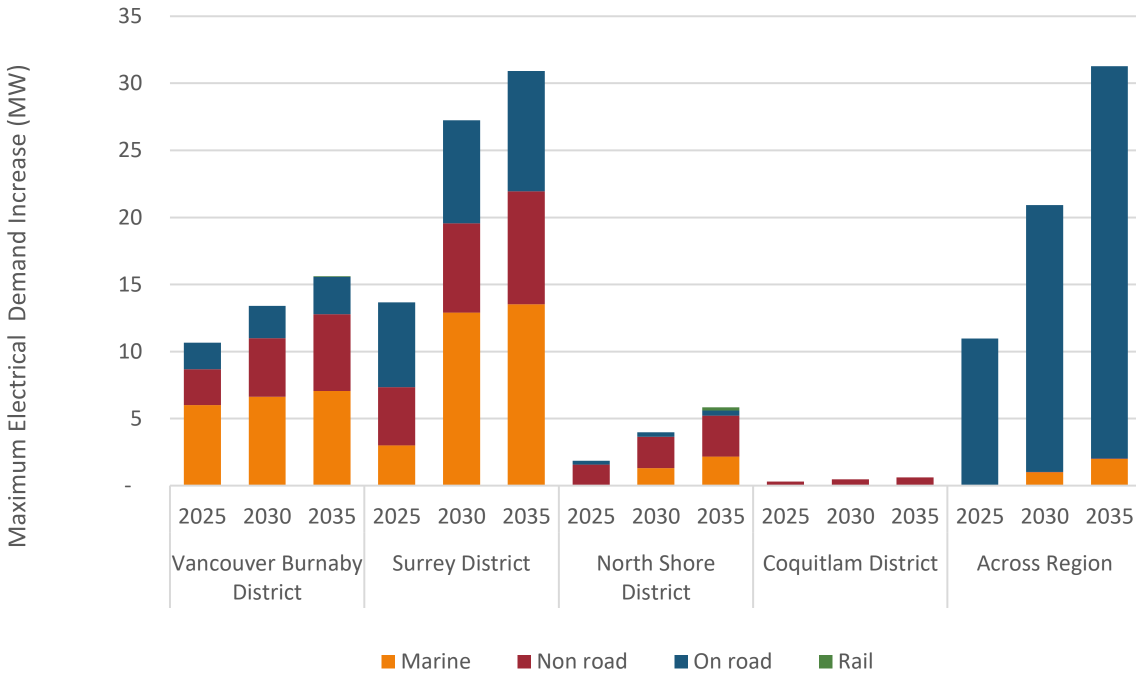
- An investment of $686M is needed for electrification of selected equipment by 2025, based on the assumed uptake levels in the scenario (equipment cost only, does not include charging infrastructure). An additional $440M is required to achieve the 2030 electrification transition.
- Annual GHG emissions would be reduced by 88,000 tCO_2e or 8% of total 2015 port emissions by 2025.
- By 2035, annual GHG emission would be reduced by 250,000 tCO_2e – approximately half of the Roadmap emissions or 25% of all port emissions in 2015.
- Maximum electrical demand would increase 37 MW by 2025 and 84 MW by 2035 across the region. This is shown by BC Hydro district in Figure 1.

Finally, the Roadmap presents strategies for VFPA and BC Hydro to implement to support the transition to electric equipment, focusing on the first five years of implementation. Strategies include conducting feasibility studies, managing pilot projects, coordinating funding opportunities, reviewing and updating policies to address barriers, conducting infrastructure planning, deploying infrastructure in a timely manner to meet demand, and providing incentive programs. These strategies will need to be supported by investment from other government agencies, as well as through strong collaboration between port tenants and customers, equipment vendors, and technology developers and manufacturers.

Table 1. Estimated timing of commercialization of port activities

	Equipment / Activity	2020 – 2025	2025 – 2030	2030 – 2035
On-Road	Truck – Light – On Terminal	Early	Full	
	Truck - Heavy <200 km	Early	Full	
	Truck - Heavy 200-300 km	Early	Full	
	Truck - Heavy 301-400 km	Pre-commercial	Early	Full
	Truck - Heavy > 400 km	Pre-commercial	Early	Full
	Truck-Light	Early	Full	
	Truck-Medium	Early	Full	
	Vehicle – Passenger – On Road	Full		
	Vehicle – Passenger – On Terminal	Full		
Non-Road	Crane Other	Pre-commercial	Early	Full
	Dozer	Pre-commercial	Early	Full
	Excavator	Pre-commercial	Early	Full
	Forklifts <100 kW	Full		
	Forklifts 100+ kW	Early	Full	
	Off-Hwy Trucks	Pre-commercial	Early	Full
	Skid Steer Loader (small)	Full		
	RTG-cable reel retrofit	Early	Full	
	Rubber Tire Loaders	Pre-commercial	Early	Full
	Top/Side/Reach stackers	Pre-commercial	Early	Full
	Yard Trucks < 150 kW	Early	Full	
	Yard Trucks > 150 kW	Early	Full	
Rail	Terminal-owned switchers		Pre-commercial	Early
	Long-haul switchers			Pre-commercial
Marine	Shorepower-Container/Cruise	Full		
	Shorepower-Breakbulk		Early	
	Tug-Assist			Pre-commercial
	Tug-Tow			Pre-commercial
	Tug- Transit		Pre-commercial	Early
	Key	**Pre-commercial deployment**	**Early deployment (cost/operational barriers**	**Full deployment (other barriers)**

Figure 1. Estimated additional peak electrical demand by BC Hydro district for the Roadmap electrification scenario



CONTENTS

Executive Summary .... **i**

1 Study purpose and scope **1**

1.1 Purpose 1

1.2 Scope 1

1.3 Process and approach 2

2 Context **3**

2.1 Policy context 3

2.2 Emissions context 4

3 Potential timeframes for electrification **6**

3.1 Approach 6

3.2 Technology readiness level 7

3.3 Capital and lifetime fuel costs 9

3.4 Potential operational barriers 9

3.5 Results and estimated commercialization timeframes 10

4 Electrification scenario for Port of Vancouver **14**

4.1 Approach 14

4.2 Scenario assumptions 14

4.3 Scenario results 15

4.4 BC Hydro capacity considerations 18

4.5 Growth considerations 18

5 Strategies to support electrification **20**

5.1 General strategies to support electrification at the Port of Vancouver 21

5.2 Strategies to support on-road vehicle electrification 22

5.3 Strategies to support non-road equipment electrification 23

5.4 Strategies to support shorepower 25

6 Next steps **27**

Appendix A: Port Activities and Sectors **A-1**

Appendix B: Technical Readiness Levels **B-1**

Appendix C: Select equipment details **C-1**

Activity: Forklifts < 100 kW C-1

Activity: Forklifts 100 - 150 kW C-2

Activity: Rubber Tire Gantry Cranes C-3

Activity: Stackers (Top, Side, Reach) C-4

Activity: Yard Trucks C-5

Activity: Heavy Trucks (< 200 km) C-6

Activity: Heavy Trucks (200 – 400 km) C-7

Appendix D: BC Hydro District Maps **D-1**

Appendix E: Equipment Adoption Rates **E-1**

Appendix F: BC Hydro Capacity Considerations .... **F-**Error! Bookmark not defined.

1 STUDY PURPOSE AND SCOPE

1.1 PURPOSE

Vancouver Fraser Port Authority (VFPA) is continuing to strengthen its commitment to its corporate vision to be ***the world's most sustainable port*.** A key component of this sustainable vision is taking climate action by "being a leader among ports in energy conservation and alternative energy to minimize greenhouse gas emissions." Since the vast majority of energy use at the Port of Vancouver is fueled by diesel, and since BC Hydro provides a reliable source of low-carbon electricity to the port, electrification of suitable activities is a significant opportunity to make significant reductions in GHG emissions from port activities.

This Roadmap was undertaken as a joint effort between VFPA and BC Hydro to assess the opportunities for electrification of port-related activities by 2030, and to identify strategies to support the transition towards electrification across the Port of Vancouver.

For the purposes of this report, "electrification" may include equipment that is connected to the grid (e.g. shorepower for ships, cable-reel rubber tire gantry cranes (RTGs)), uses batteries to store electricity, uses hydrogen from fuel cells, or a combination of these. This assumes that any hydrogen required is sourced from and produced by electricity from the BC grid.

1.2 SCOPE

The types and geographic extent of port activities included in the electrification assessment are defined by the activities incorporated in the 2015 Port Emissions Inventory (PEI),[1] which included the following categories of activity: marine, non-road, on-road, on-road terminal, rail and administration.[2] Collectively, these activities resulted in almost 1.1 million tonnes of CO_2e emissions and over 4.2 million MWh of energy use, in 2015. The Administration category represents fuel and electricity used in buildings and lighting on port lands (approximately 1% of the overall GHG emissions) is excluded from this analysis.

VFPA is a non-shareholder, financially self-sufficient entity, established by the Government of Canada in January 2008, pursuant to the *Canada Marine Act* (RSC 1998.c.10) ("CMA"), and is subject to the provisions of the CMA, the Regulations and Letters Patent issued pursuant thereto. VFPA is accountable to the federal Minister of Transport. Outside of VFPA corporate operations (which accounted for less than 1% of GHG emissions at the Port of Vancouver in 2015), VFPA does not directly own or operate terminals, equipment, vessels, trucks or rail. However, both VFPA and BC Hydro can support the electrification of port-related activities through supportive actions, such as feasibility studies, pilot

[1] https://www.portvancouver.com/wp-content/uploads/2017/12/2015PortEmissionsInventory.pdf

[2] See Appendix A: Port Activities and Sectors for more details.

projects, and funding or partnership opportunities that accelerate electrification of equipment, vessels and vehicles.

The Roadmap will serve as a guide to support electrification activities across the Port of Vancouver, with an outlook to 2030. More detailed guidance is included for the first five years (2020 to 2025) of the Roadmap.

1.3 Process and Approach

A Port Electrification Roadmap Team (POwER Team) was established with representatives of both VFPA and BC Hydro to guide the development of the Roadmap. Pinna Sustainability was retained, with the support of EELO Solutions, to facilitate the process and conduct analysis under the guidance of the POwER Team.

The following key steps were taken to develop the Port Electrification Roadmap 2030, with POwER Team meetings held six times during the process:

1. Review the current port activity, emission and policy **context** (Section 2).
2. Review each activity for **technology readiness** to convert to electrification within the 2030 timeframe (Section 3).
3. Define additional **economic and operational criteria** to better understand the potential for uptake of this equipment by 2030 (Section 3).
4. Based on these criteria, identify activities that have **potential for electrification by the 2030 timeframe** (Section 3).
5. **Quantify** potential electrical demand, estimated capital investment costs and resulting GHG emissions reductions from electrification of select activities by the following timeframes: 2025, 2030, beyond 2030 (Section 4).
6. Identify **strategies** to support the electrification of equipment, considering the technical, economic and social barriers that need to be addressed (Section 5).

2 CONTEXT

2.1 POLICY CONTEXT

Climate change is increasingly being recognized across the globe as one of the most prescient issues facing the planet in the 21st Century. The Paris Agreement (2015) represents a global commitment to respond to climate change and to limit global temperature increase this century to well below 2 degrees Celsius above pre-industrial levels, and to attempt to limit the temperature to 1.5 degrees Celsius.[3] At a global scale, this means that anthropogenic CO_2 emissions need to decline by about 45% from 2010 levels by 2030, and reach net zero around 2050 (based on modeled pathways).[4]

Canada made a commitment to reduce emissions by 30% by 2030, relative to 2005, across all activities and sectors across the country,[5] and established the Pan-Canadian Framework for Clean Growth and Climate Change to guide efforts toward this target.[6]

BC made a commitment to reduce emissions by 40% by 2030 and 80% by 2050, relative to 2007,[7] and set out the path to meeting these targets in the CleanBC plan (2018).[8]

As noted in the purpose section (1.1), VFPA has established a vision to be the most sustainable port in the world, and intends to demonstrate leadership among ports in minimizing greenhouse gas emissions. Other major ports and certain private sector companies in the marine industry are also taking leadership roles in addressing climate change. Early directions in these initiatives include significant emphasis on electrification and conversion to alternative fuels (natural gas, biofuels).

Although it is not yet clear precisely what role port activities must play in reaching the international, national and provincial commitments, it is clear that significant shifts are needed across all transportation activities to meet these aggressive targets. Given that BC Hydro supplies a reliable source of nearly carbon-free electricity, electrification of activities that currently rely on diesel and other fossil fuels can make significant contributions towards achieving these targets.

---

[3] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[4] https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/sr15_headline_statements.pdf

[5] https://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=02D095CB-1%20

[6] https://www.canada.ca/content/dam/themes/environment/documents/weather1/20170125-en.pdf

[7] https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/legislation

[8] https://cleanbc.gov.bc.ca/

2.2 EMISSIONS CONTEXT

The 2015 PEI provides data for one year of port activity, and includes the number of pieces of equipment, current fossil fuel energy consumption, average age of equipment, resulting GHG emissions, and more. Table 2 summarizes the primary equipment and activities represented in the 2015 PEI, organized by five categories (marine, non-road, on-road, rail, and administration).

In 2015, activities at the port consumed over 4.2 million MWh of energy, producing almost 1.1 million tonnes of GHG emissions (excludes administration – see Figure 2 for a break down by source). Fossil fuels accounted for 97% of energy used, and this was primarily diesel. Marine activities produced the greatest GHG emissions. As shown in

Figure 3, ocean going vessels (OGV) in transit and at berth, long-haul rail and on-road heavy trucks are three of the major emitters of GHG emissions across the port.

Although activities have become more efficient over time and the intensity of emissions per tonne of cargo moved has decreased, growth in the quantities of goods and cruise passengers moved through the port has outpaced efficiency improvements, resulting in an overall 14% increase in GHG emissions between 2010 and 2015.

Table 2. Overview of Port Categories and Associated Activity Details

Category	Overview of Equipment/Activities
Marine	• 1,694 OGV vessels, representing >3,100 calls • 128 tugs • Dredge vessels • Almost all of this equipment operates on fossil fuels (cruise ships connecting to shorepower at Canada Place are an exception)
Non-Road	• 2,264 pieces of equipment (256 electric) • Includes over 750 loaders, 320 cranes and stackers, 350 terminal tractors and 350 other pieces of equipment • 29% energy consumption in this category is electric and 71% fossil-fueled
On-Road	• 1,936 drayage trucks • Also includes various light and medium-duty trucks, passenger cars, taxis, and buses that move to and from port land • 747 passenger cars, light and medium duty trucks that operate on terminals only • All of this equipment operates on fossil fuels
Rail	• 14 terminal-based switcher locomotives and gensets • Includes mainline locomotives – long-haul and switchers – operated by three Class 1 railways and one charter railway service • All of this equipment operates on fossil fuels
Administration	• Heating and electricity of buildings on port lands, and terminal lighting • Mixture of electricity and fossil fuels • Not included in this Roadmap evaluation

Figure 2. GHG emissions by source, 2015 PEI

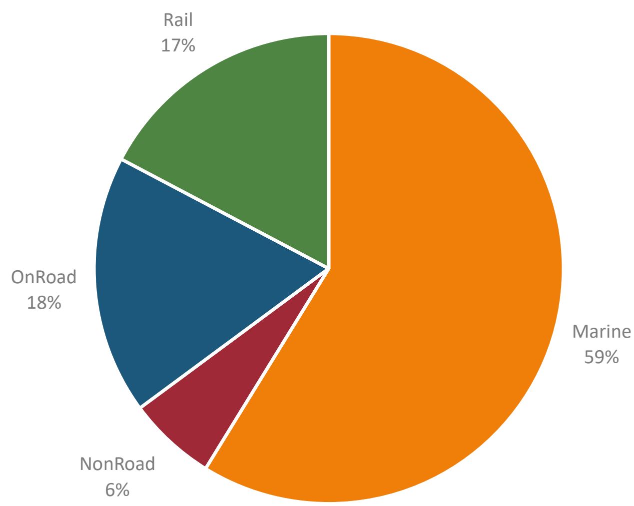
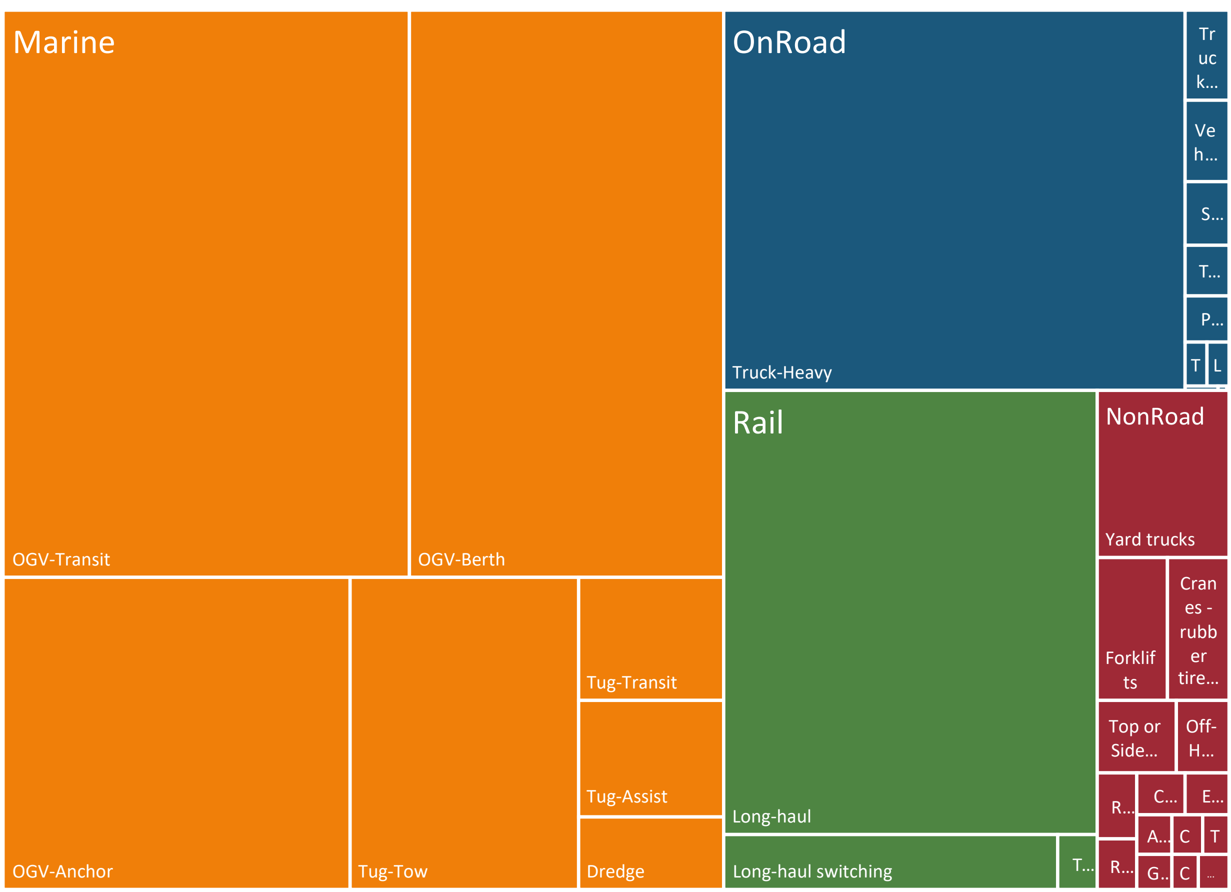


Figure 3. GHG emissions by equipment type/activity (fossil fuel only), 2015 PEI



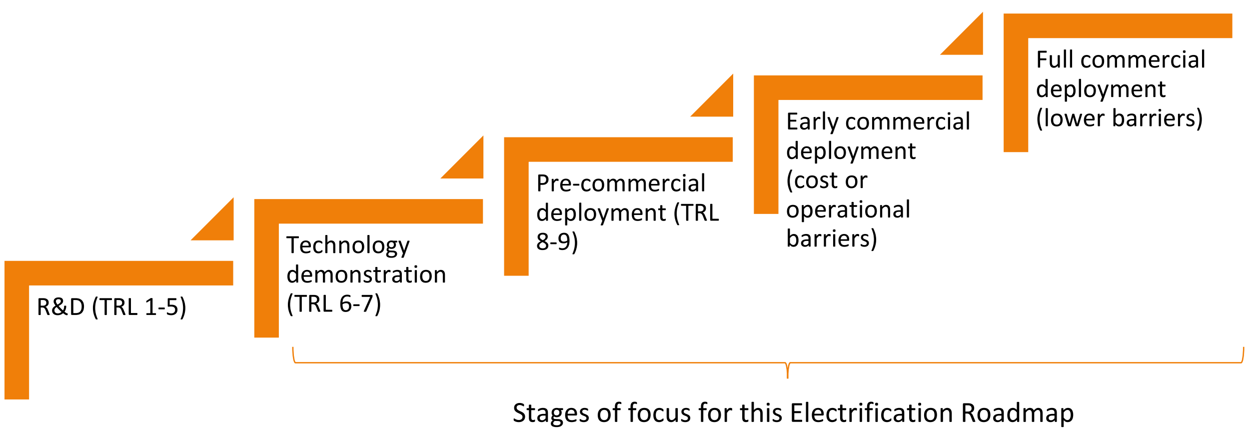
3 POTENTIAL TIMEFRAMES FOR ELECTRIFICATION

Electrification of port equipment is occurring at various rates across activity areas, where some types of equipment are in early stages of research and development, while others have reached commercial deployment. This section outlines the method and resulting estimated timeframes for electrification of equipment by activity area, based on an assessment of a set of criteria that considers technology readiness, costs, and key operational parameters. In the following section (4), these estimated timeframes are applied into a potential uptake scenario for port equipment over the next five, ten and fifteen years.

3.1 APPROACH

Figure 4 provides a conceptual sequence of technology development and deployment from concept to commercial product. As discussed in Section 1, VFPA and BC Hydro do not directly own, operate or make purchase decisions about equipment, nor are they involved with research and development of new technology. However, both entities can play a role in facilitating the uptake of new technology that has reached at least a technology readiness level of 6 or higher – shown as the last four stages.

Figure 4. Sequence of technology development and deployment, with the Roadmap focusing on the pre-commercial and commercial deployment stages



This Roadmap estimates the potential timeframes for electrification of each key activity represented in the Port Emission Inventory, focusing on equipment that is in pre, early or full commercial deployment stages. The following steps were taken:

1. Estimate Technology Readiness Level (TRL), and focus only on equipment with potential for commercial deployment by 2030;
2. Estimate capital and lifetime fuel costs relative to the purchase of new diesel equipment; and
3. Identify potential operational barriers (shift length, loads and terminal layout) that may impede the uptake of electric equipment by 2030.

The result of these steps is estimated timeframes for commercialization by activity area – clarifying the areas where VFPA and BC Hydro can focus efforts to support electrification of port activities.

3.2 Technology Readiness Level

3.2.1 Equipment Technology Readiness Level

Activities that use energy for port-related business are captured in the 2015 PEI and are listed in Appendix A. A preliminary review was conducted on each of these activities to determine the stage of development of electric technology that could replace fossil-fuel equipment of similar capacity and capability. The following steps were undertaken for this review:

a) Identify the most promising technology (if any) that meets the activity requirements.
b) Estimate TRL of this technology on a scale of 1 to 9, based on Natural Resources Canada TRL definitions, where 1 to 5 represent progressive stages of research and development, 6 and 7 represent technology demonstration, and 8 and 9 represent pre-commercial deployment (Appendix B).
c) Classify each activity as:
    - 8+: Good potential for commercialization by 2025 (currently in pre-commercial deployment)
    - 6-8: Good potential for commercialization by 2030 (currently in demonstration)
    - <6: Likely to commercialize post-2030 (currently in research and development)

3.2.2 Technology Readiness of Charging Infrastructure

Electrification of all activities requires new charging infrastructure. There are four options for equipment that will need to be charged:[9]

1. For battery powered electric equipment, a stand-alone charging facility is required.
2. For grid connected electric equipment, an electrical connection is required.
3. For opportunity charging options such as induction charging, wireless charging pads, or automated charging connection points are required.[10]
4. For hydrogen fuel cells, a hydrogen fueling station is required.

---

[9] Note that not all equipment included in this assessment is expected to charge on port land. For example, heavy-duty trucks are unlikely to charge on port land for operational reasons – they are not idle at port terminals for sufficient time to charge and are more likely to charge at their overnight parking locations throughout the region.

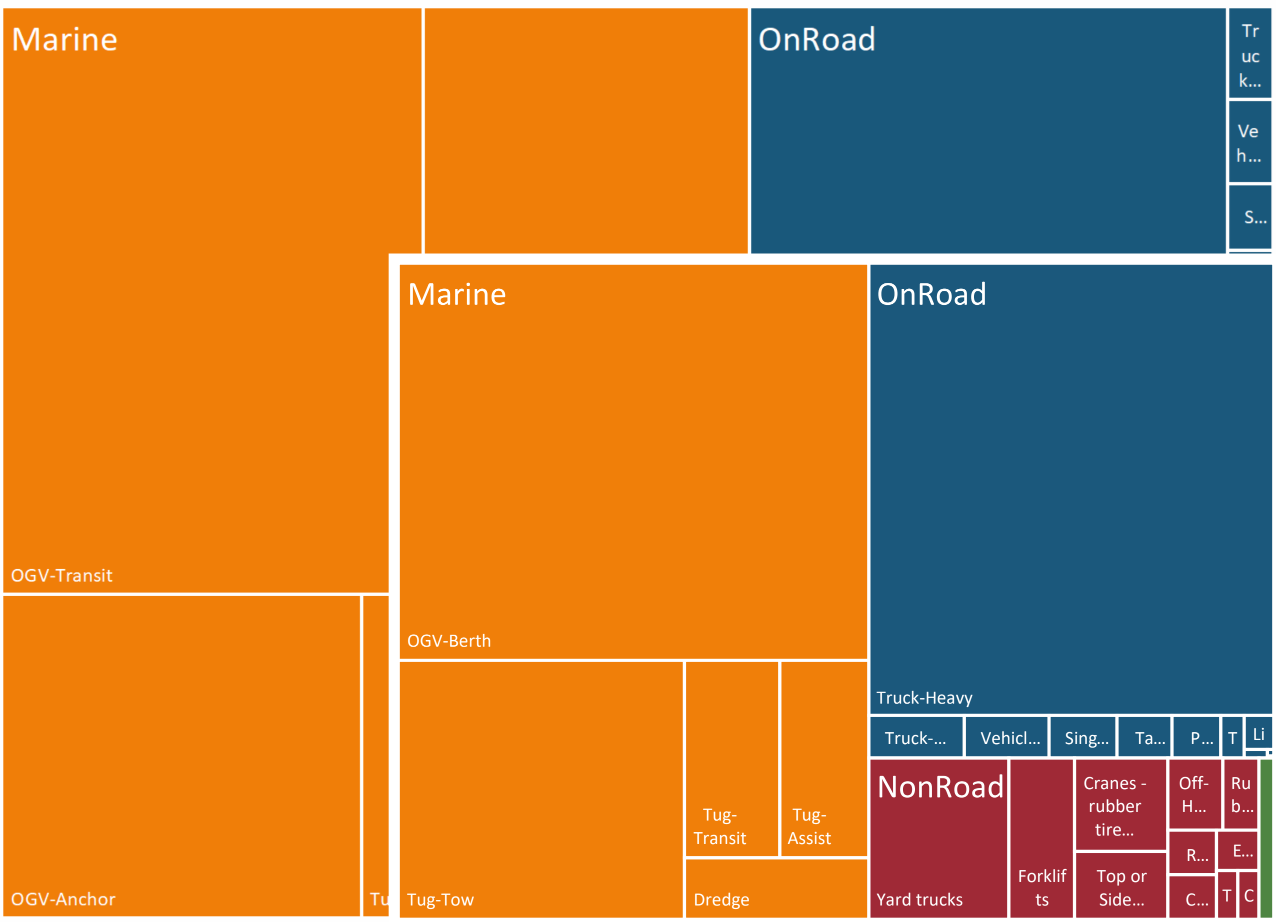
[10] For example, the Port of Los Angeles has a demonstration project to test a Cavotec Automatic SmartCharging System where an articulated arm plugs into the equipment once the equipment is driven into place, avoiding the need for labour to do the plugging in.

In this study, it is assumed that if the equipment has reached a TRL for demonstration, the associated charging technology has been commercialized. Induction charging for industrial applications is still under development (not yet TRL 6) and is evaluated as part of the operational barrier assessment in Section 3.5.

3.2.3 Resulting Roadmap emissions

As a result of the technology readiness assessment outlined above, all equipment with a TRL less than six was assumed to be beyond the 2030 timeframe and was excluded from the remaining analysis. As a result, activities that produce approximately half of GHG emissions at the port are unlikely to have commercially viable electric alternatives within the 2030 timeframe. The remaining "Roadmap emissions" are shown in Figure 5, relative to the total PEI 2015 emissions.

Figure 5. 2015 PEI GHG emissions (background) overlaid by the "Roadmap emissions" – i.e., emissions associated with activities that have technical potential for commercial electrification by 2030



3.3 CAPITAL AND LIFETIME FUEL COSTS

Once the TRL was evaluated, capital costs and incremental costs of electric equipment over new diesel equipment were estimated for each activity. Note that maintenance costs have not been factored into this Roadmap assessment due to the uncertainty of these costs over time. Although it is anticipated that electrification will result in reduced maintenance costs (no need to change starter motors, fuel filters and less frequent downtime for parts replacement and servicing), electric equipment have not been deployed in a port environment for sufficient time to reasonably estimate these costs. Cost estimation included these steps:

a) Identify capital costs for new electric and new diesel equipment in 2018
b) Identify or estimate capital cost for "behind the meter" charging infrastructure in 2018, as available
c) Estimate lifespan of diesel equipment based on typical age of equipment in the PEI, and assume same lifespan for electric equipment
d) Estimate annual energy use (convert average estimated energy use from the PEI into litres of diesel, and estimate equivalent kWh of electricity using an assumed efficiency of one-third)[11]
e) Calculate incremental cost of electrification using simple lifecycle costs (equipment and charging capital cost plus fuel cost over lifespan)
f) Classify incremental cost as:
    - <50%: Potential for policy or incentive funding to support uptake by 2025
    - 50-100%: Potential for policy or incentive funding to support uptake by 2030
    - >100%: Lower potential for policy or incentive funding to support uptake prior to 2030

Note that cost associated with battery replacement during the equipment lifetime is excluded from this study. In some cases, the current rate of equipment turnover for diesel vehicles (e.g. five to seven years for yard trucks), may be similar to the lifespan of the battery and so may be addressed through assumed equipment lifespan estimated in (c) above.

3.4 POTENTIAL OPERATIONAL BARRIERS

Finally, each activity was reviewed for significant operational barriers. Some of the activities include broad ranges of operational requirements (loads, idle times, shift lengths, consecutive shifts, labour agreements, daily kilometres, etc.), and thus need to be further disaggregated to be able to conduct a reasonable assessment of potential for electrification across these activities. These criteria are described as follows:

[11] In general, fossil fuel vehicles use three times more energy than a comparable electric vehicle, based on Natural Resources Canada's 2019 Fuel Consumption Guide.

a) Estimate whether stored energy in the most promising technology available is sufficient to last a shift, and determine if equipment is able to operate in the existing terminal footprint.
   - Yes: Potential for implementation by 2025
   - No: See (b)

b) Identify infrastructure needed to support electrification of this activity: are different or additional type(s) of charging required to meet operational needs (e.g. opportunity charging, grid-connect rail/wire/catenary, battery swapping)? Is a different terminal layout needed? Does the labour agreement restrict uptake? Estimate level of complexity as:
   - 1: Potential for implementation by 2025
   - 2: Potential for implementation by 2030
   - 3: Potential for implementation is likely beyond 2030

3.5 RESULTS AND ESTIMATED COMMERCIALIZATION TIMEFRAMES

Table 3 summarizes the results of the assessment outlined above for each activity with TRL of 6 or higher. Collectively, these activities represent half of GHG emissions based on the 2015 PEI. Activities with green across the criteria are likely to be commercially deployed by 2025 (e.g. passenger and light duty vehicles, heavy-duty vehicles travelling short distances, small forklifts, small yard trucks and shorepower for cruise and container ships). Activities with cost or operational barriers that have potential to be commercially deployed by 2030 are in highlighted in orange. Activities with red are likely to be commercially deployed post 2030.

Based on these results of the analysis shown in Table 3, the timeframe of commercialization was estimated for each activity and is presented in Table 4 below. These timeframes serve as the basis for developing the potential electrification uptake scenario presented in Section 4. All activities previously determined to have a TRL of less than 6 are not included in the tables (including but not limited to OGVs in transit, tugs in assist, long-haul rail).

Table 3. Results of the evaluation for electrification potential for activities with a TRL of six or greater

	Equipment / Activity	1. Equipment TRL	2. Incremental lifecycle cost [1]	3a. Operational: Stored energy	3b. Operational: Complexity	Commentary
On Road	Truck – Heavy <200 km	8	30%	Yes	1	Battery electric passenger vehicles are readily available and ranges are extending rapidly. Light and medium duty vehicles are advancing and ranges improving, with a variety of OEMs offering models in the next few years. Class 8 drayage trucks are showing strong progress although ranges are still limited. This on-going range challenge may limit drayage trucks to short haul operations in the near term. Range extension with hydrogen fuel cells is currently in development.
	Truck – Heavy 200-300 km	8	~50%	No	2	
	Truck – Heavy 301-400 km	8	~50%	No	3	
	Truck – Heavy > 400 km	7	~100%	No	3	
	Truck-Light	8	0%	Yes	1	
	Truck-Medium	8	20%	Yes	1	
	Vehicle – Passenger	9	0%	Yes	1	
Non Road	Crane Other	6	[2]		2	Electrification of non-road equipment continues to evolve with major manufacturers working on the development of various heavy-duty vehicles. Currently, small forklifts are in widespread operation and medium sized forklifts are expected to meet the demands of the job by 2025. Battery capacity is the major barrier to fully implementing electric heavy-duty equipment into port operations although advancements in battery technology are expected to improve by 2030. RTGs can be retrofit to electric, but require substantial infrastructure.
	Dozer	6	[2]		2	
	Excavator	6	[2]		2	
	Forklifts <100 kW	9	20%	Yes	1	
	Forklifts 100+ kW	8	30%	No	1	
	Off-Hwy Trucks	6	[2]		2	
	RTG-cable reel retrofit	9	[3]	Yes	1	
	Rubber Tire Loaders	6	[2]		2	
	Top/Side/Reach stackers	6	~50%	No	2	
	Yard Trucks < 150 kW	7	~50%	Yes	1	
	Yard Trucks > 150 kW	7	~50%	No	1	
Rail	Terminal-owned switchers	6	[2]	No	3	Hydrogen fuel cell-electric switcher engines are in development, commercialization of the technology will likely occur post-2030.
	Long-haul switchers	6	[2]	No	3+[4]	

Sustainability

EELO SOLUTIONS

	Equipment / Activity	1. Equipment TRL	2. Incremental lifecycle cost [1]	3a. Operational: Stored energy	3b. Operational: Complexity	Commentary
Marine	Dredge	9	[5]	No	3	Shorepower for OGVs is currently commercially available, however, only container and cruise vessels are currently equipped for shorepower. There is low adoption potential for breakbulk vessels due to low energy draw while at berth (0.75 MW), short berth times, and multiple terminal visits within the port. Electric tugs are in development. Navtek ZeeTug is currently under construction and will use Corvus Energy's batteries. Limited information available at this time. Electric dredgers connected to the grid onshore are also commercially available, but can only be used in limited locations.
	Shorepower-Container/Cruise	9	In place	Yes	1	
	Shorepower-Breakbulk	9	high	N/A	N/A	
	Tug-Assist	[6]	N/A	N/A	N/A	
	Tug-Tow	[6]	N/A	N/A	N/A	
	Tug-Transit	6	TBD	No	3	

Table Legend:
3a. Operational: Stored Energy: Yes = meets operational requirements by 2025; No = does not meet operational requirements, see 3b for further details.
3b. Site infrastructure complexity: 1 = by 2025, 2 = by 2030, 3 = 2030+

Table Notes:
[1] Rounded to the nearest 5%.
[2] The development of this equipment is underway; however, it is too early to estimate equipment costs.
[3] Incremental cost is highly dependent on the site configuration. The cost of retrofitting an existing diesel RTG with a cable reel and battery is approximately $800,000. However, the infrastructure required for the cable is dependent on the configuration of individual sites and therefore not estimated.
[4] Battery electric options for long haul rail are currently many years away before becoming feasible. Catenary electric versions for long haul rail exist in Sweden and other countries, however, to date mainline rail companies in North America have not initiated investment in catenary rail lines.
[5] Cost for electric dredges are application specific and therefore no estimate was obtained.
[6] Currently there is an electric tug under development in Turkey, however, limited information is available at this time so it is assumed that the technology is not capable of operating as assist and under tow conditions.

Table 4. Estimated timeframe for electrification of activities that have potential for commercialization by 2030

	Equipment / Activity	2020 – 2025	2025 – 2030	2030 – 2035
On-Road	Truck – Light – On Terminal	Early	Full	
	Truck - Heavy <200 km	Early	Full	
	Truck - Heavy 200-300 km	Early	Full	
	Truck - Heavy 301-400 km	Pre-commercial	Early	Full
	Truck - Heavy > 400 km	Pre-commercial	Early	Full
	Truck-Light	Early	Full	
	Truck-Medium	Early	Full	
	Vehicle – Passenger – On Road	Full		
	Vehicle – Passenger – On Terminal	Full		
Non-Road	Crane Other	Pre-commercial	Early	Full
	Dozer	Pre-commercial	Early	Full
	Excavator	Pre-commercial	Early	Full
	Forklifts <100 kW	Full		
	Forklifts 100+ kW	Early	Full	
	Off-Hwy Trucks	Pre-commercial	Early	Full
	Skid Steer Loader (small)	Full		
	RTG-cable reel retrofit	Early	Full	
	Rubber Tire Loaders	Pre-commercial	Early	Full
	Top/Side/Reach stackers	Pre-commercial	Early	Full
	Yard Trucks < 150 kW	Early	Full	
	Yard Trucks > 150 kW	Early	Full	
Rail	Terminal-owned switchers		Pre-commercial	Early
	Long-haul switchers			Pre-commercial
Marine	Shorepower-Container/Cruise	Full		
	Shorepower-Breakbulk		Early	
	Tug-Assist			Pre-commercial
	Tug-Tow			Pre-commercial
	Tug- Transit		Pre-commercial	Early
	Key	**Pre-commercial deployment**	**Early deployment (cost/operational barriers**	**Full deployment (other barriers)**

4 ELECTRIFICATION SCENARIO FOR PORT OF VANCOUVER

Estimating the electrification uptake rate for 2025, 2030 and beyond is based on the activity-based assessment in the previous section. To aid with strategy developing and implementation, a scenario for electrification uptake potential is developed based on BC Hydro geographic regions and grouping activities across each region together. In this section, a consolidated and cumulative view of estimated impacts on electrification for the electrical grid, cost and GHG emissions reductions is summarized for the next five, ten and fifteen years.

4.1 APPROACH

This Roadmap estimates the potential electrification at each geographical location and the following steps were taken:

a) Allocate terminal activities to four BC Hydro Districts (see Appendix D for maps): North Shore, Vancouver Burnaby, Coquitlam, and Surrey.
b) Group activities that are not attributed to a specific tenant or geographic location in the 2015 PEI data are grouped into a fifth category called "Across Region." This group includes tug boat activity, heavy-duty trucks, and a small number of on-terminal vehicles not allocated to specific tenants.
c) Assign an uptake rate for each activity based on the outcome of Section 3. Refer to Appendix E for specific uptake rates.
d) Estimate the cumulative electricity consumption increase, electrical demand increase, GHG reductions, and cost increase in each district for 2025, 2030, and beyond.

4.2 SCENARIO ASSUMPTIONS

Key assumptions for the electrification scenario for 2025, 2030, and 2035 are listed below. The spreadsheet tool provided with this report can be modified to reflect a different set of assumptions.

- Electricity equipment energy consumption is one-third [12] of the equivalent diesel energy consumption for the same activity.
- Average annual operating hours for each activity in each geographic district[13] and the number of equipment count are used to determine the utilization rate and their theoretical maximum electrical demand increases.
- No more than 50% of the electric equipment would be charging at the same time.

[12] In general, fossil fuel vehicles use three times more energy than a comparable electric vehicle, based on Natural Resources Canada's 2019 Fuel Consumption Guide.

[13] Average annual operating hours for non-road equipment were calculated from the Port's NRDE database.

- The actual electrical demand increase is 50% of the theoretical maximum electrical demand increase multiplied by the uptake rate.
- Three exceptions:
    - Cruise and container shorepower demand increase is independent of the uptake rate. Each cruise shorepower charging station has a maximum demand increase of 11 MW and each container shorepower charging station has a maximum demand increase of 3 MW. Note that actual shorepower feeders are 10 and 12 MW (cruise ships) and 7.5 MVA (container), however, maximum demand increase is based on use records.
    - Annual operating hours for each drayage truck is 2,500 hours per year.
    - Annual operating hours for light and medium trucks and passenger vehicles operating within the PEI boundary is 2,920 hours per year.
- Number of trucks and passenger vehicles within the PEI boundary is based on an average annual mileage and vehicle fuel efficiency as per NRCan's 2018 Fuel Consumption Guide.
- Number of drayage trucks are distributed evenly for those that travel less than 200 km per day, 201 km to 300 km per day, and 301 km to 400 km per day.[14] The number of drayage trucks over 400 km per day is less than 10% of the entire fleet. Other heavy trucks were distributed in the same manner.

4.3 Scenario results

The two figures below demonstrate the GHG emissions reduction and the electrical demand increase for each activity in four geographic districts and for activities across the region. Shorepower applications have a significant impact on grid electrical demand increase and their electrical demands are independent of the uptake rate. This results in the imbalance of GHG reductions and electrical demand increase at the Vancouver-Burnaby and Surrey districts compared to across the region activities.

[14] Based on analysis of drayage truck GPS data tracked by VFPA.

Figure 6. Estimated Annual Greenhouse Gas Emissions Reduction, relative to 2015

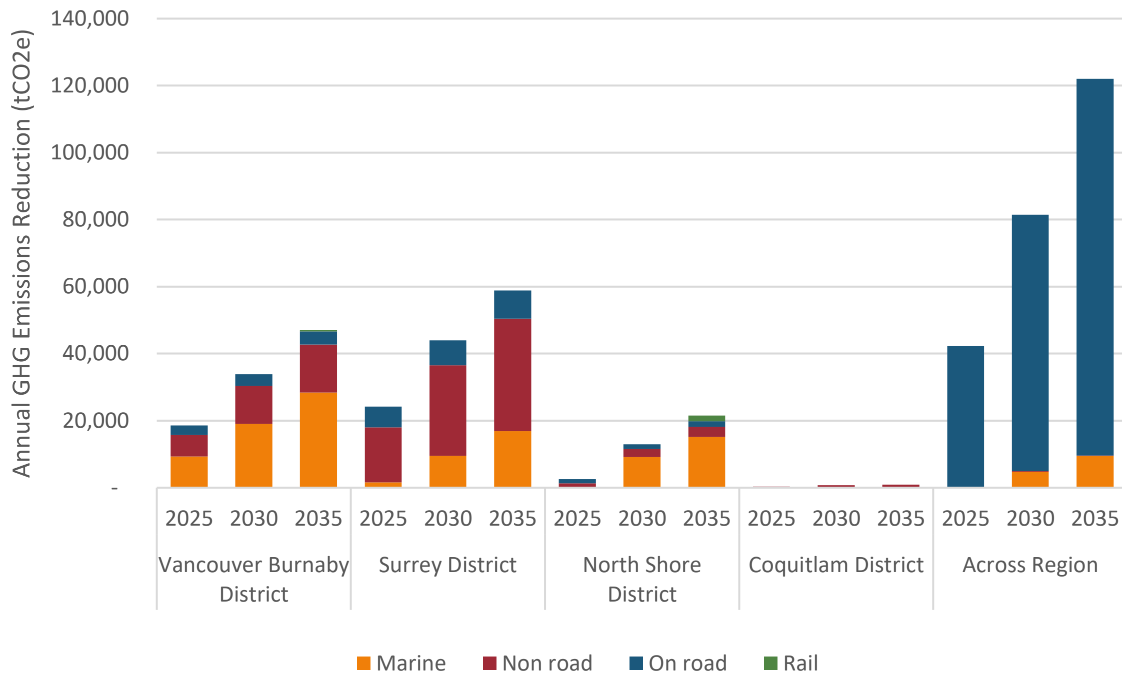
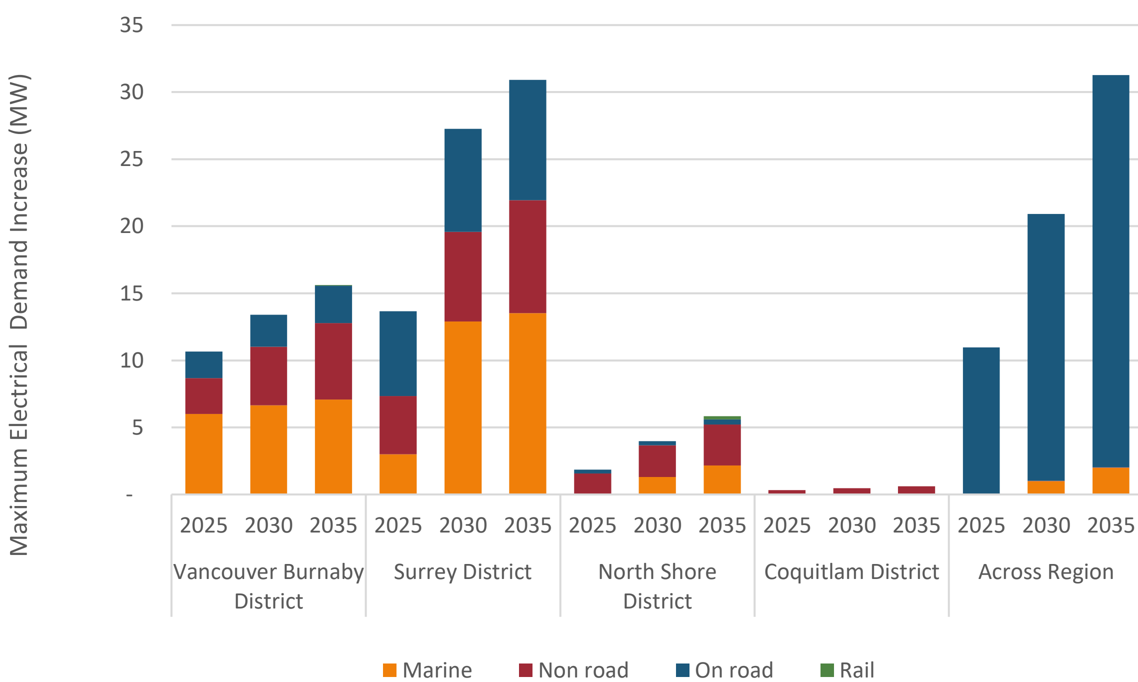
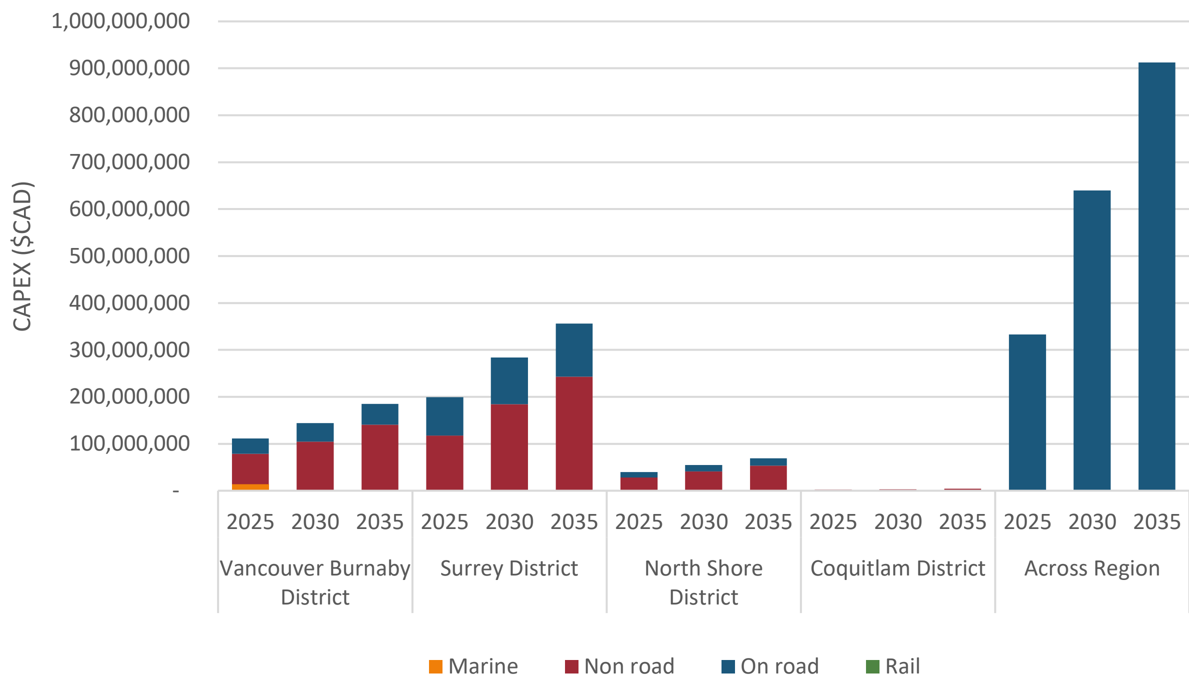


Figure 7. Estimated Electrical Demand Increase



The figure below outlines the cumulative capital cost implication to achieve the GHG emissions reduction and electrical load increase. The estimated cost includes only the capital expenditure on the equipment being replaced.

Figure 8. Capital Expenditure for Electrification



The approximate cost to achieve the electrification transition in this scenario by 2025 is $686M.[15] This will result in a GHG emissions reduction of 88,000 tCO_2e or 8% of the total Port emissions (and 17% of Roadmap emissions). An additional $440M is required to achieve the 2030 electrification transition. This cost analysis excludes other savings and benefits of transitioning to electric vehicles:

- Electrical engines are more than three times more efficient. The electricity cost to fully charge an electric vehicle in BC is lower than the diesel equivalent cost. This means the lifecycle cost of an electric vehicle can be lower than the diesel equipment in some activities.
- There are reduced maintenance requirements with less moving parts in the electric engine. For example, no engine oil is required in an electric fleet.
- There are other benefits of electrification:
  - Elimination of diesel particulate matters and other criteria air contaminants.
  - Reduced noise level and vibration in the work area.
  - Potentially more up-time and availability with less maintenance requirements. This can also lead to fewer equipment required per activity.

[15] Capital costs were not obtained for some equipment categories, and therefore this underestimates the total capex of the 2025 scenario. Missing capital cost categories are: rubber tire loaders, dozers, excavators, crane other, off-hwy truck, skid steer.

4.4 BC HYDRO CAPACITY CONSIDERATIONS

As part of this Roadmap process, BC Hydro conducted a cursory review to indicate whether current system capacity can meet the needs of the twelve port tenant sites that are anticipated to have the largest maximum demand increased based on the scenario outlined in this section. As a result of this review, six of these sites were identified as having sufficient substation and feeder capacity, three were identified as having either low feeder or low substation capacity, and three were identified as exceeding either the feeder or substation capacity by 2025. Details are outlined in Appendix F. These findings demonstrate the importance of ongoing collaboration between VFPA, BC Hydro and industry to ensure key system constraints are addressed in order to support electrification of equipment as it becomes commercially viable.

4.5 GROWTH CONSIDERATIONS

Growth forecast for Port of Vancouver

VFPA anticipates continued growth in commodity throughput over the Roadmap timeline and expects nearly 200 million metric tonnes of cargo to pass through the port by 2030.[16] Until recent years, GHG emissions have grown as cargo throughput increased. More recently, GHG emissions intensity has declined due to efficiency improvements, however, overall GHG emissions continue to grow. Electrification of port activities is a significant opportunity to realize an overall decline in GHG emissions, in the context of growing commodity throughput.

This Roadmap, as described earlier, provides estimates for electrification of the fleet of equipment in place in 2015, and does not include potential for additional demand due to growth in throughput. As a result, if the scenario outlined above comes to fruition, and new equipment added to fleets is primarily electric, then potential demand for electricity may be higher than provided in the scenario. Currently, it is difficult to estimate the demand increase without more substantial analysis as this depends on many factors, including but not limited to, cargo throughput, efficiency of tenant operations, tenant expansion plans, electric equipment adoption rate, and the overall impact on operations as electric equipment replaces diesel equipment.

Roberts Bank Terminal 2 Expansion

Roberts Bank Terminal 2 (RBT2) expansion project will add three new berths at the container terminal at Roberts Bank in Delta. It is projected to increase container capacity by 2.4 million twenty-foot equivalent unit containers (MTEU). As currently planned, T2 will include three shorepower capable berths. This has been included in the load profile defined for 2012 and submitted to BC Hydro. At the time of project submission to BC Hydro and other regulators, the T2 expansion was expected to use the available technology of the time, e.g. primarily diesel equipment. It is possible that this could change as electric

[16] 2015 Port Emissions Inventory, GHG Emissions and Cargo Throughput, 2010-2030, page 17.

equipment becomes more readily available and costs decline. The 2012 estimate of equipment needed for the T2 project include:[17]

- 1 RTG crane
- 1 Top pick
- 86 Automated shuttle carriers
- 46 Yard trucks
- 10 Forklifts, manlifts, aerial lifts
- 2 General industrial equipment

This equipment, if electric, has the potential to increase the maximum demand at the site. However, the demand would be a small incremental demand relative to the three shorepower connections included in the plans. At this time, the electrification of T2 has not been included in the Roadmap analysis.

[17] Port Metro Vancouver SENES Consultants RBT2 – Air Quality Study – Appendix A, Table 3.1, November 2014

5 Strategies to Support Electrification

In order to achieve the estimated levels of uptake outlined in the scenario in Section 4, many challenges and barriers need to be overcome. VFPA and BC Hydro can play a role in assisting with overcoming these challenges and barriers through strategic implementation of various supportive actions. In the following table, stages of technology development from research and development through to full commercial deployment are highlighted in parallel with the types of supportive actions that can be undertaken by VFPA and BC Hydro for technologies at a given stage. The majority of actions that can be undertaken by VFPA and BC Hydro begin when the technology is ready for demonstration in port operating environment (TRL 7 and beyond), while other levels of government can implement strategies at each stage of development beginning at initial research and development. This model provided a guide for developing the strategies outlined in the rest of this section.

Table 5. Types of supportive strategies various agencies can undertake by stage of deployment

<table>
<tr><th></th><th>R&D (TRL 1-5)</th><th>Technology demonstration (TRL 6-7)</th><th>Pre-commercial deployment (TRL 8-9)</th><th>Early commercial deployment (higher barrier)</th><th>Full commercial deployment (lower barrier)</th></tr>
<tr><td>Provincial / Federal Government</td><td>Support R&D</td><td>Support technology demonstration</td><td colspan="2">Support capital investment</td><td>Incentive programs (e.g. SUVI)</td></tr>
<tr><td rowspan="5">VFPA</td><td></td><td>Monitor technology</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Feasibility studies, pilot project management, funding coordination</td></tr>
<tr><td></td><td></td><td colspan="3">Review and update policies to address barriers</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Education</td></tr>
<tr><td></td><td></td><td></td><td></td><td>VFPA incentive and fee programs</td></tr>
<tr><td rowspan="4">BC Hydro</td><td></td><td></td><td colspan="2">Infrastructure planning</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Infrastructure deployment</td></tr>
<tr><td></td><td></td><td colspan="3">Review and update policies to address barriers</td></tr>
<tr><td></td><td colspan="3">BC Hydro programs</td><td></td></tr>
</table>

Table 6 provides a summary of all strategies presented in this section, together with columns indicating which organization will take a lead role and where a supportive role is also important for the successful execution of the strategy.

Table 6. Summary of Roadmap Strategies with lead and supportive roles identified

	Lead Role	Support Role
5.1 General strategies to support electrification at the Port of Vancouver		
Lobby government for funding	VFPA, BC Hydro co-develop and execute	
Electricity rate and policies for electric vehicle charging	BC Hydro	
Policy for terminal expansion projects	VFPA	
Electrical planning with emerging technologies	BC Hydro	VFPA
5.2 Strategies to support on-road vehicle electrification		
Passenger vehicle and light truck electrification	VFPA	
Heavy duty truck pilot project	VFPA	BC Hydro
Monitor technology developments	VFPA	BC Hydro
5.3 Strategies to support non-road equipment electrification		
Universal charging guidelines or standards	VFPA	BC Hydro
Fees and lease terms	VFPA	
Terminal engagement	VFPA	
Bulk purchasing or service agreement coordination	VFPA	
Yard truck and large forklift pilot projects	VFPA	BC Hydro
Side/Top picks and reach stacker studies	VFPA	BC Hydro
eRTG infrastructure planning	VFPA	
5.4 Strategies to support shorepower		
New terminal planning (T2)	VFPA	
New shorepower connection (Centerm berth 6)	VFPA	
Upstream infrastructure capacity (Vanterm)	BC Hydro	
Monitor other sectors	VFPA	
Ship incentive program	VFPA	BC Hydro

5.1 General Strategies to Support Electrification at the Port of Vancouver

VFPA and BC Hydro can play an important role in supporting electrification of all types of activities at the port, where suitable technology is available for deployment. There are several strategies specific to each sector outlined below, and additionally, there are overarching strategies that can support electrification of all sectors, including:

- **Lobby government for funding**: Prepare communications strategy with key messages for provincial and federal governments in order to: a) identify funding support for installation of charging infrastructure and to assist with meeting the capital investment gap between diesel trucks being added to the fleet that serves the port[18] and new electric trucks in pilot projects; and b) put forward policy changes that will accelerate uptake of electrification (also see next strategy on electricity rate for EV charging). For example, the existing Special Use Vehicle Incentive

[18] Note that diesel trucks that are added to the VFPA Truck Licensing System are typically five-year old highway trucks, which are purchased at half the value of a new diesel truck. This results in an even larger capital investment gap if purchasing a new electric truck in place of a used diesel truck.

program offered by the BC government can be updated to support emerging medium and heavy-duty trucks.[19]

  - VFPA and BC Hydro to co-develop and execute

- **Electricity rate and policies for electric vehicle charging**: Develop rates and associated policies to support electric vehicle charging, and to enable a simple system to address cost allocation challenges. That is, for equipment owners/operators that are not the utility customer, a clear policy and mechanism is needed to enable appropriate parties to pay for the electricity when charging vehicles.
  - BC Hydro to lead
- **Electrical planning of substations and distribution**: Evaluate potential load demand for electrification of port equipment and incorporate this into BC Hydro electricity distribution planning.
  - BC Hydro to lead
- **Policy for terminal expansion projects**: Review and update policies that require or encourage use of electric equipment in terminal expansion projects, where appropriate technology is commercially available.
  - VFPA to lead
- **Electrical planning with emerging technologies**: Monitor emerging technologies such as utility-scale energy storage systems and smart chargers and evaluate potential load demand from implementation.
  - BC Hydro to lead with VFPA participation

5.2 Strategies to Support On-Road Vehicle Electrification

On-road vehicles represented in the 2015 PEI include passenger cars and trucks, buses, single unit trucks, and light, medium and heavy-duty trucks. Passenger vehicles are anticipated to be in full commercial deployment by 2025, while the light, medium and heavy-duty trucks will likely be in the early commercial deployment as manufacturers continue to ramp up to full production during this time period.

Heavy duty trucks that need to travel over 200 km per day are expected to be at pre-commercial deployment due to insufficient battery capacity and the early stage of testing of range-extending capabilities through hydrogen or the cost and complexity of opportunistic charging opportunities (e.g. induction or catenary options on high-use road segments).

With respect to charging infrastructure, only a small portion of on-road vehicles are based on terminals (i.e. on port land). Since the vast majority of on-road vehicles are based off of port lands, most of the electric charging infrastructure required to support these vehicles will be needed at truck warehouses

[19] For a list of existing incentives, visit https://pluginbc.ca/suvi/

and commercial vehicle parking locations throughout the region. At this time, charging infrastructure needs on terminals will be focused on meeting the terminal-based and employee commuting charging needs only.

The following strategies will be employed to support on-road vehicle electrification at the port by 2025:

- **Passenger vehicle and light truck electrification**: Encourage the replacement of terminal-based light-duty vehicles with electric models through education about available incentives, award and recognition programs for tenants, and other engagement methods. As noted above, work with tenants where needed to facilitate installation of sufficient charging infrastructure to support this transition.
    - VFPA to lead
- **Heavy duty truck pilot project**: Develop a pilot project for heavy duty trucks travelling less than 200 km per day. This may involve seeking funding from senior governments to offset capital costs, working with trucking companies to identify best opportunities for electrification, preparing business cases, identifying qualifying vendors, and assessing charging infrastructure requirements.
    - VFPA to lead, BC Hydro to support with charging infrastructure requirements assessment
- **Monitor technology developments**: For longer range heavy-duty trucks (travelling more than 200 km per day), continue to engage with vendors, OEMs, and ports in other jurisdictions that are supporting truck electrification to monitor the stage of technical development, and to identify opportunities for feasibility studies or pilot projects as the technology matures. An important aspect of this will be understanding the evolution of charging standards and the implications for charging this equipment under the BC Hydro standard service (e.g. will there be additional costs to include voltage conversion for compatibility with the BC Hydro grid?).
    - VFPA to lead, BC Hydro to support with charging infrastructure and service requirements

5.3 Strategies to Support Non-Road Equipment Electrification

Non-road equipment at the port includes a broad variety of equipment types, engine sizes and operating requirements[20] to serve the variety of commodities handled across the port terminals. As shown in Section 3, the following equipment categories were deemed to have potential for electrification by 2030, based on the technology readiness review: forklifts, top picks, side picks, reach stackers, yard trucks and rubber-tired gantry cranes (grid-connected). For battery electric equipment: small forklifts are expected to reach full commercial deployment by 2025, while larger forklifts and yard trucks are anticipated to be in early commercial deployment in this timeframe due to high capital costs relative to new diesel equipment and due to the need for larger battery capacity or opportunity charging to meet operational needs. Side/top picks and reach stackers are anticipated to be in pre-commercial

[20] For example, some terminals operate one 8-hour shift, some operate two consecutive 8-hour shifts, and a few operate three consecutive 8-hour shifts (effectively operating 24 hours per day, 7 days per week).

deployment for this time period (at this time an existing reach stacker is being retrofit for a pilot project over the next two years at the Port of Los Angeles).

All battery electric non-road equipment will need to be charged on port land, and thus significant charging infrastructure needs to be installed for each terminal to serve this demand.

Electric rubber-tired gantry cranes (eRTGs) are currently available and deployed at several port terminals internationally. Due to the high load requirements, eRTGs are grid-connected, either through a busbar system (where space allows) or through underground, side or top cables (may fit in more restricted spaces), and may be equipped with a small diesel engine to move between stacks when not carrying a load. These are at full commercial deployment by 2025, though may continue to meet operational barriers at specific terminals with very restrictive layouts.

The following strategies will be employed to support non-road vehicle electrification at the port by 2025:

- **Universal charging guidelines or standards**: Define and establish universal charging guidelines or standards for port properties to ensure compatibility at all sites. For example, the Ports of LA and Long Beach established the following standard in advance of conducting demonstration projects:

  > "The EVSE interface to be provided by the Ports is a 480-volt, 250-ampere, three-phase electric service. Zero/near-zero vehicles that include a plug-in recharging capability should ensure the onboard or off- board recharging systems are compatible with the Port's electric service. "[21]

  - VFPA to lead, with input from BC Hydro
- **Fees and lease terms**: Review tenant fee structure and lease terms during renewal to identify existing barriers and/or potential to incentivize electrification of site equipment through updated terms or fee structures.
  - VFPA to lead
- **Terminal engagement**: Communicate regularly with terminal operators and owners to identify and address barriers to electrification. Topics may include raising awareness of pilot projects, funding opportunities and incentive programs, developing and transferring learning through case studies, reviewing labour agreements to address safety or other labour-related barriers, etc.
  - VFPA to lead
- **Bulk purchasing or service agreement coordination**: Through engagement with tenants, identify equipment types that are most prevalent at the port and work with vendors to coordinate bulk purchasing agreements where appropriate. Additionally, coordinate between tenants and select vendors to establish service guarantees and/or battery replacement warranties.
  - VFPA to lead
- **Yard truck and large forklift pilot projects**: Develop pilot projects for yard trucks and large forklifts. This may involve seeking funding from senior governments to offset capital costs, engaging

[21] ZERO/NEAR-ZERO EMISSIONS YARD TRACTOR TESTING & DEMONSTRATION GUIDELINES, Port of Long Beach and Port of Los Angeles, September 2017.

terminal operators that are willing to participate in the pilot project, establishing testing and demonstration guidelines together with terminal operators, identifying qualified vendors, preparing business cases, and assessing charging infrastructure requirements.

  - VFPA to lead, BC Hydro to support with charging infrastructure requirements assessment

- **Side/Top picks and reach stacker studies**: These equipment types are at the pre-commercial deployment stage. Monitor the demonstration project currently being deployed at Everport, Port of Los Angeles.[22] Based on findings from the POLA demonstration, conduct feasibility studies for retrofitting and testing container handlers in the Port of Vancouver.
  - VFPA to lead, BC Hydro to support with charging infrastructure requirements assessment
- **eRTG infrastructure planning**: eRTG is a commercialized technology and may be feasible in some terminals at the Port of Vancouver, though it will require significant infrastructure investment. Through previous discussions, eRTG has been deemed not feasible under the current configuration of Centerm. Continue engagement with terminal operators to identify potential sites and support site reconfiguration and redevelopment efforts to include eRTG where feasible.
  - VFPA to lead

5.4 Strategies to Support Shorepower

Shorepower is currently installed at three terminals at the Port of Vancouver – Canada Place cruise terminal, Deltaport container terminal and Centerm container terminal. Opportunities for additional shorepower are most likely to center on cruise or container ships, as no other class of ocean-going vessels are expected to be equipped with shorepower capability within the 2025 timeframe. The following strategies support additional shorepower in the 2025 timeframe:

- **New terminal planning (T2)**: Ensure shorepower capabilities are incorporated into plans for the new T2 container terminal. Preliminary planning conducted in 2012 includes three shorepower terminals.
  - VFPA to lead
- **New shorepower connection (Centerm berth 6)**: Identify funding and manage the installation of an additional shorepower connection at Centerm berth 6.
  - VFPA to lead
- **Upstream infrastructure capacity (Vanterm)**: To enable shorepower at Vanterm, enhanced substation capacity is needed on the south shore. It is anticipated that this capacity will be added beyond the 2025 timeframe. Explore options for accelerating the upgrade for this infrastructure.
  - BC Hydro to lead

[22] Everport terminal is participating in an Advanced Cargo Handling Equipment Demonstration project to retrofit a Taylor top handler with electric engine and 1 MWh battery capacity to meet operational needs for two consecutive shifts.

- **Monitor other sectors**: Although no breakbulk, bulk or auto carriers ships that visit the Port of Vancouver are currently equipped with shorepower capability, continue to monitor these sectors for indications that this will change and begin infrastructure planning to meet changing needs.
    - VFPA to lead
- **Ship incentive program**: Continue to offer incentives to shorepower capable ships that visit the port (currently offered through the EcoAction program). Review and monitor the effectiveness of the program, and investigate options for expanding the incentive program with BC Hydro. Coordinate with other ports frequently visited by ships visiting Vancouver to align incentive programs – providing enhanced benefit to those ships visiting multiple ports.
    - VFPA to lead, BC Hydro to explore additional incentive options

6 NEXT STEPS

This Port of Vancouver Electrification Roadmap provides a starting point for VFPA and BC Hydro to understand the potential for electrification of port activities by 2030, based on the current state of development of each type of technology used in those port activities, and outlines the type of supportive strategies each organization will need to undertake to support the transition. The Roadmap includes a scenario of potential uptake in order to contextualize the potential change in electrical demand that could occur over the next 5-, 10- and 15-year increments. It also provides an overview of the potential to reduce GHG emissions under the selected scenario, and an indicative level of capital investment required to achieve the levels of uptake postulated.

The potential for emission reduction is significant, and so is the initial capital cost investment required. During the early transition into electrification of port activities, government agencies will need to play a substantial support role, in collaboration with industry to achieve the ultimate goals of significantly reducing emissions from these activities.

Over the next five years, VFPA and BC Hydro will incorporate the strategies identified in this Roadmap into annual and longer-term work plans to support electrification efforts and demonstrate leadership from the Port of Vancouver in minimizing contributions to climate change from port activities.

APPENDIX A: PORT ACTIVITIES AND SECTORS

The 2015 PEI includes estimated energy and air emissions by the following activities (excludes Administration). Activities with at least TRL 6 were identified as having potential for some electrification by 2030, based on an evaluation of technical and economic criteria (Section 3 of this report). Activities already using 100% electricity are shown in green.

Category	**Equipment/Activity**	**GHG emissions (% of total)**	**Current TRL**
Marine	OGV-Transit	21%	<6
	OGV-Berth (shorepower)	17%	9
	OGV-Anchor	10%	<6
	Tug-Tow	7%	<6
	Tug-Transit	2%	6
	Tug-Assist	2%	6
	Dredge	1%	6-9
Non Road	**Yard Trucks**	2%	8
	Forklifts (all sizes)	1%	6-9
	Cranes – Rubber Tire Gantry	1%	9
	Top or side picks chassis or reach stackers	1%	6-7
	Off-highway trucks	0.3%	6
	Rubber Tire Loaders	0.2%	8
	Reach stackers	0.2%	6
	Crawler Tractors/Dozers	0.2%	6
	Excavators	0.2%	6
	Tractors/Loaders/Backhoes	0.1%	6
	Cranes – other	0.1%	6
	Skid steer loader	<0.1%	9
	Portable equipment (e.g. generator sets, welders, pumps, compressors, aerial lifts)	~0.3%	n/a
Electric Non Road	Conveyors	100% electric	9
	Cranes-rail mounted gantry		9
	Cranes-ship to shore		9
	Pumps – Transfer		9
On Road	**Truck – Heavy**	16%	6-8
	Truck - Medium	0.4%	8
	Vehicle – Pas	0.3%	9
	Taxi/bus	0.2%	8-9
	Truck-Light	0.1%	8
	Single unit truck	0.3%	8
	Passenger truck	0.2%	8
	Light commercial truck	0.1%	8
	Passenger car	<0.1%	9
	Hybrid passenger car	<0.1%	9

Category	Equipment/Activity	GHG emissions (% of total)	Current TRL
	Hybrid passenger truck	<0.1%	8
Rail	Long-haul	15%	<6
	Long-haul switching	2%	<6
	Terminal-owned switching	0.2%	6
Totals	**Roadmap emissions (%)**	**51%**	
	Roadmap emissions (tCO_2e)	**532,000**	

Note that similar equipment/activities from the 2015 PEI categories have been grouped in the Roadmap analysis.

Roadmap Activity Name	**Port Emissions Inventory Name**
Vehicle – Passenger – On Road	On Road: Vehicle-Pas On Road: Taxi/Bus
Vehicle – Passenger – On Terminal	On Road Terminal: Passenger Car On Road Terminal: Passenger Truck On Road Terminal: Hybrid Passenger Car On Road Terminal: Hybrid Passenger Truck
Truck – Light – On Terminal	On Road Terminal: Light Commercial Truck On Road Terminal: Single Unit Truck
Top/side/reach stackers	Non Road: Top or Side Picks Chassis or Reach Stackers Non Road: Reach Stackers
Rubber Tire Loaders	Backhoe Loader Rubber Tire

APPENDIX B: TECHNICAL READINESS LEVELS

Technology readiness levels are an indication of the maturity stage of development of particular technology on its way to being developed for a particular application or product. The table below provides a definition of Technology Readiness Levels 1 to 9. This table was adapted from Impact Canada's Annex B (https://impact.canada.ca/en/challenges/power-forward/applicant-guide?wbdisable=true)

Technology Readiness Level	Definition
TRL 1 – Basic Research	Scientific research begins to be translated into applied research and development.
TRL 2 – Applied Research	Basic physical principles are observed; practical applications of those characteristics can be 'invented' or identified. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.
Applied research and development	
TRL 3 – Critical Function or Proof of Concept Established	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
TRL 4 – Laboratory Testing/Validation of Component(s)/Process(es)	Basic technological components are integrated to establish that the pieces will work together.
TRL 5 – Laboratory Testing of Integrated/Semi-Integrated System	The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.
Demonstration	
TRL 6 – Prototype System Verified	Representative model or prototype system is tested in a relevant environment.
TRL 7 – Integrated Pilot System Demonstrated	Prototype near or at planned operational system, requiring demonstration of an actual system prototype in an operational environment.
Pre-commercial deployment	
TRL 8 – System Incorporated in Commercial Design	Technology is proven to work; actual technology completed and qualified through test and demonstration.
TRL 9 – System Proven and Ready for Full Commercial Deployment	Actual application of technology is in its final form; technology proven through successful operations.

APPENDIX C: SELECT EQUIPMENT DETAILS

ACTIVITY: FORKLIFTS < 100 KW

Category	Non-Road	Equipment	Forklifts	Engine size	< 100 kW
% of Port energy use	1%	Total # of units	312		
Most suitable replacement	Linde E35 (3.5 tonnes load capacity, battery: 80 V, 700-775 Ah at 5 hr)				
Operational requirements	300-1,200 hours annually, depending on site.				
Potential by 2020-2025	High	Potential by 2025-2030	High	Potential after 2030	High
Evaluation Criteria					
1. Estimated Equipment TRL	9	Forklifts <100 kW are commercially available and currently use in tenant operations.			
2. Incremental Cost	10%	Based on capital cost of $106,000. Battery replacement are estimated to be required every five years at a cost of $26,000 (over the lifetime of the equipment, two battery changes are required). Charging infrastructure estimated to cost $23,000.			
3a. Operations: Capacity	Yes	Small electric forklifts are currently in operation.			
3b. Operations: Infrastructure Complexity	1	Expected to require minimal changes to site infrastructure assuming one (or fewer) plug-in charging station per truck. If opportunity charging is installed at various locations, this may increase the complexity but also improve capacity to meet operational requirements.			

Sustainability

EELO SOLUTIONS

ACTIVITY: FORKLIFTS 100 + KW

Category	Non-Road	Equipment	Forklifts	Engine size	100-150 kW
% of Port energy use	1%	Total # of units	253		
Most suitable replacement	Kalmar ECG90-180 (9-18,000 kg)				
Operational requirements	300-1,200 hours annually, depending on site.				
Potential by 2020-2025	High	Potential by 2025-2030	High	Potential after 2030	High
Evaluation Criteria					
1. Estimated Equipment TRL	8	Forklifts 100-150 kW are near-commercial deployment.			
2. Incremental Cost	30%	Based on capital cost of $350,000. Charging infrastructure estimated to cost between $15,000-$23,000.			
3a. Operations: Capacity	No	Currently, unable to consistently meet the demands of port tenants.			
3b. Operations: Infrastructure Complexity	1	Expected to require minimal changes to site infrastructure assuming one (or fewer) plug-in charging station per truck. If opportunity charging is installed at various locations, this may increase the complexity but also improve capacity to meet operational requirements. This is expected to resolve by 2025.			

ACTIVITY: RUBBER TIRE GANTRY CRANES

Category	Non-Road	Equipment	RTG	Engine size	all
% of Port energy use	2%	Total # of units	76		
Most suitable replacement	Kalmar or Kone Cranes retrofit of existing RTG with cable reel and battery pack.				
Operational requirements	4,500 hours annually.				
Potential by 2020-2025	High	Potential by 2025-2030	High	Potential after 2030	High
Evaluation Criteria					
1. Estimated Equipment TRL	9	First retrofit orders were made in the last six months.[23] Note the most eRTGs come with small diesel engines to allow cross stack traverses. However, adding a battery pack instead of the small diesel engine is an option for an additional fee.			
2. Incremental Cost	TBD	Based on retrofit cost of $400,000. Battery packs cost an additional $400,000. Site infrastructure costs vary depending on selected configuration cable reel and site constraints.			
3a. Operations: Capacity	Yes	Cable reel plus battery configuration would meet operational requirements.			
3b. Operations: Infrastructure Complexity	1	Depends on the site. Cable reels can be installed on the top of the crane or inside the crane depending on space availability. Cable trenches are optional.			

[23] Personal communication with Jason Gasparik, Director of Sales, Ports & Terminals – Americas, Kalmar Americas, January 2019.

ACTIVITY: STACKERS (TOP, SIDE, REACH)

Category	Non-Road	Equipment	Stackers	Engine size	all
% of Port energy use	1%	Total # of units	138		
Most suitable replacement	Taylor (Everport); Fantuzzi/Transpower (OMNI); Hyster				
Operational requirements	4,500 hours annually.				
Potential by 2020-2025	High	Potential by 2025-2030	High	Potential after 2030	High
Evaluation Criteria					
1. Estimated Equipment TRL	6	Currently this is a custom solution. Stackers are not available “off the lot” as manufacturers are still in development and pilot stage. Pilot programs at POLALB starting in 2019 will evaluate the equipment.			
2. Incremental Cost	~50%	Costs are unknown at this time although estimates indicate that this equipment will cost at least 60% more than a diesel version, not including charging infrastructure.			
3a. Operations: Capacity	No	Still under development.			
3b. Operations: Infrastructure Complexity	2	Expected to be similar to operating a diesel version of the equipment. The biggest change will be the addition of a charging station and “refueling”.			

ACTIVITY: YARD TRUCKS

Category	Non-Road	Equipment	Yard Truck	Engine size	>150 kW
% of Port energy use	5%	Total # of units	367		
Most suitable replacement	Kalmar Ottawa T2E: 30 t GCW; 160 kW; battery 132-270 kWh				
Operational requirements	1,000-4,500 hours annually				
Potential by 2020-2025	Moderate	Potential by 2025-2030	High	Potential after 2030	High
Evaluation Criteria					
1. TRL Equipment	7	Selected due to the lack of availability in the commercial marketplace. These are still special-order vehicles.			
2. Incremental Cost	30%	Based on capital cost of $500,000. Note that some electric yard trucks have been quoted to be $300,000, including the charging unit.[24]			
3a. Operations: Capacity	No	No – due to the inability of truck to meet the operational demands of port operations. Trial with equipment to start at the Port of LA/LB in early 2019.			
3b. Operations: Infrastructure Complexity	2	Expected to require minimal changes to site infrastructure assuming one (or fewer) plug-in charging station per truck. If opportunity charging is installed at various locations, this may increase the complexity but also improve capacity to meet operational requirements.			
Other notes	• POLALB has developed testing and demonstration guidelines; file name: Yard-Tractor-Test-Protocol-FINAL POLALB.pdf				

[24] Cost of $300,000 including charging unit quoted by Mason Lift, supplier of Kalmar equipment. $500,000 is an estimate from conversations with Blair Garbutt, DP World.

ACTIVITY: HEAVY TRUCKS (< 200 KM)

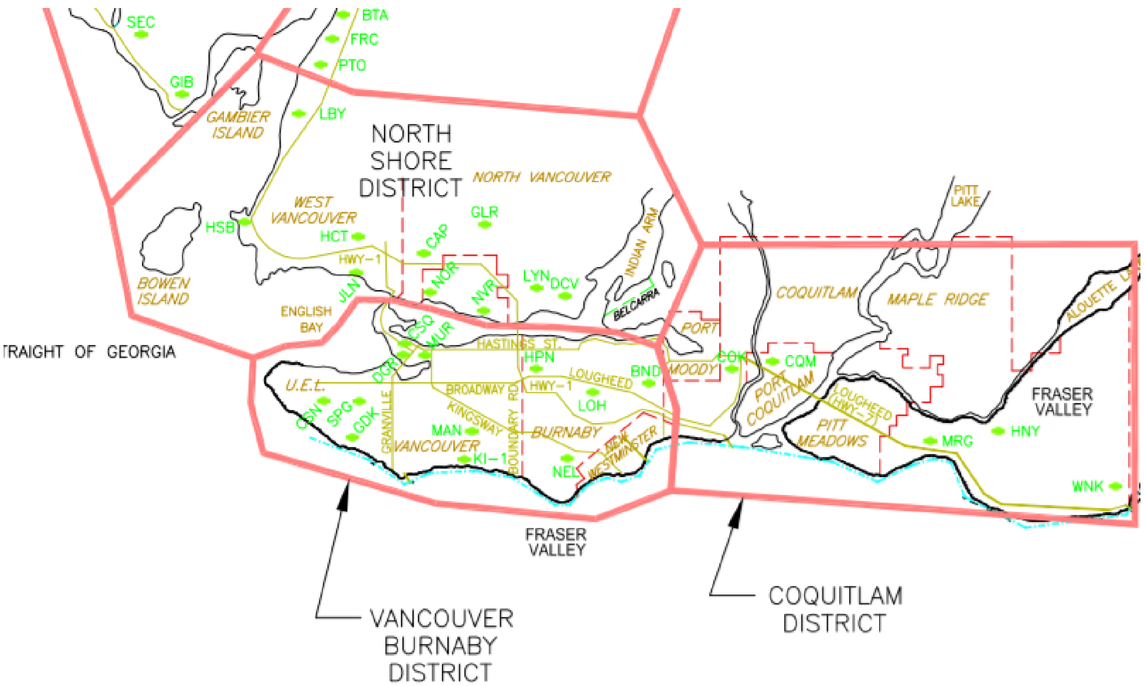
Category	On-Road	Equipment	Heavy Truck	Distance	< 200 km
% of Port energy use	16%	Total # of units	Approx. 680		
Most suitable replacement	BYD Class 8 Day Cab				
Operational requirements	Daily trips of 200 km or less.				
Potential by 2020-2025	Moderate	Potential by 2025-2030	High	Potential after 2030	High
Evaluation Criteria					
1. TRL Equipment	8	Selected due to the lack of availability in the commercial marketplace. These are still special-order vehicles.			
2. Incremental Cost	~50%	Based on estimated capital cost of $400,000.			
3a. Operations: Capacity	Yes	Trucks with the base battery configuration will likely meet the requirements of one shift of operation (i.e., up to 200 km of travel in one shift).			
3b. Operations: Infrastructure Complexity	1	Expected to require minimal changes to site infrastructure assuming one (or fewer) plug-in charging station per truck. If opportunity charging is installed at various locations, this may increase the complexity but also improve capacity to meet operational requirements.			

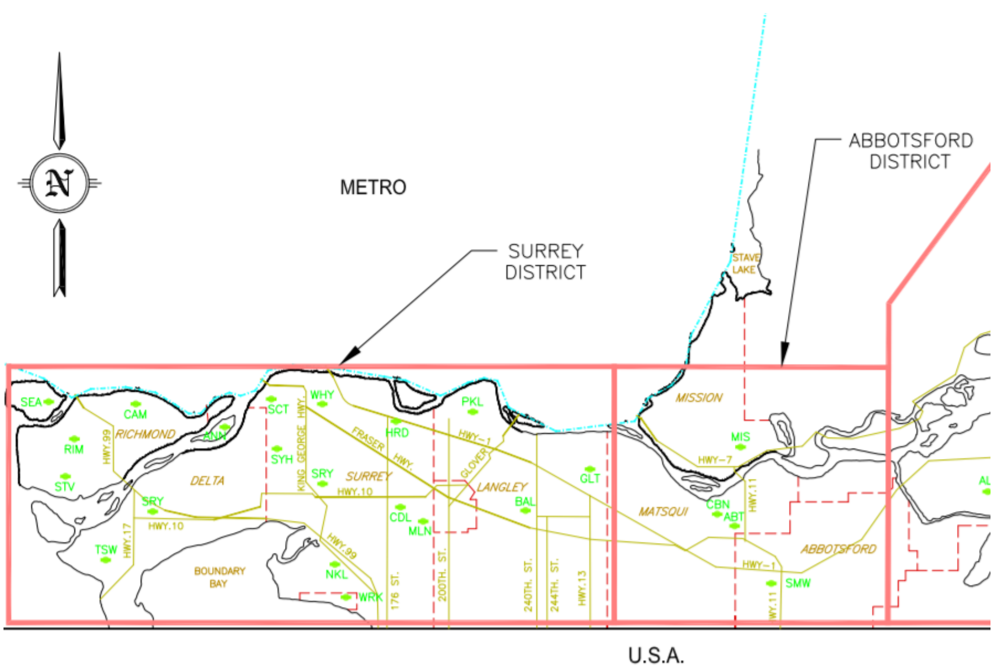
ACTIVITY: HEAVY TRUCKS (200 – 400 KM)

Category	On-Road	Equipment	Heavy Truck	Distance	200-400 km
% of Port energy use	16%	Total # of units	Approx. 1,020		
Most suitable replacement	BYD Class 8 Day Cab				
Operational requirements	Daily trips between 200-400 km.				
Potential by 2020-2025	Moderate	Potential by 2025-2030	High	Potential after 2030	High
Evaluation Criteria					
1. TRL Equipment	7	Selected due to the lack of availability in the commercial marketplace. These are still special-order vehicles.			
2. Incremental Cost	50-100%	Based on estimated capital cost of $500,000-800,000.			
3a. Operations: Capacity	No	Trucks will not be able to meet the demands of the shift without recharging.			
3b. Operations: Infrastructure Complexity	2-3	Currently, trucks are limited in ranges. Minimal changes to site infrastructure assuming one (or fewer) plug-in charging station per truck. If opportunity charging is installed at various locations, this may increase the complexity but also improve capacity to meet operational requirements.			

APPENDIX D: BC HYDRO DISTRICT MAPS

The following two maps provide an outline of the BC Hydro Districts that were overlaid onto the Port of Vancouver terminals in order to allocate demand by District.





APPENDIX E: EQUIPMENT ADOPTION RATES

	Equipment	2025	2030	2035
On-Road	Truck - Light - On Terminal	80%	90%	100%
	Truck-Heavy <200 km	50%	60%	75%
	Truck-Heavy 200-300 km	40%	50%	70%
	Truck-Heavy 301-400 km	20%	35%	50%
	Truck-Heavy > 400 km	0%	25%	40%
	Truck-Light	80%	90%	100%
	Trucks-Medium	70%	80%	90%
	Vehicle - Passenger - On Road	80%	90%	100%
	Vehicle - Passenger - On Terminal	80%	90%	100%
Non-Road	Crane Other	0%	25%	25%
	Dozer	0%	25%	25%
	Excavator	0%	50%	50%
	Forklifts <100 kW	60%	80%	100%
	Forklifts 100+ kW	50%	75%	100%
	Off-Hwy Truck	30%	50%	80%
	RTG-cable reel retrofit	10%	30%	50%
	Rubber Tire Loaders	0%	50%	50%
	Skid Steer Loaders (small loaders)	60%	80%	100%
	Top/Side/Reach stackers	50%	75%	100%
	Yard trucks < 150 kW	60%	90%	100%
	Yard trucks > 150 kW	60%	90%	100%
Rail	Terminal-owned switchers	0%	0%	100%
	Long-haul switchers	0%	0%	0%
Marine	Shorepower-Breakbulk	0%	50%	70%
	Shorepower-Container/Cruise	60%	75%	90%
	Tug-Assist	0%	0%	0%
	Tug-Tow	0%	0%	0%
	Tug-Transit	0%	25%	50%