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Glossary of Terms

The following terms are used in this report:

A	Ampere – SI unit for Current
AC	Alternating Current
BYD	Build Your Dreams Auto
CB	Circuit Breaker
CHE	Cargo Handling Equipment
CMS	Container Main Substation
CO_2e	Carbon Dioxide Equivalent
DC	Direct Current
DLM	Dynamic Load Management
DPWV	DP World Vancouver
DGE	Diesel Gallons Equivalent
EER	Energy Economy Ratio
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GCWR	Gross Combined Weight Rating
ICE	Internal Combustion Engine
IEEE	Institute of Electrical and Electronics Engineers
ITV	Internal Transfer Vehicle
LGS	Large General Service
BC MoE	BC Ministry of Environment
MTBF	Mean Time Between Failure
NRDE	Non-Road Diesel Emissions
O&M	Operations & Maintenance
pf	Power Factor
POLA	Port of Los Angeles

POLB	Port of Long Beach
RMG	Rail Mounted Gantry
ROM	Rough Order Magnitude
SAE	Society of Automotive Engineers
SLD	Single Line Diagram
STS	Ship-to-Shore
TRL	Technology Readiness Level
UTR	Utility Tractor Rig
V	Volts – SI unit for Voltage
VA	Volt Ampere – SI unit for Apparent Power
VFPA	Vancouver Fraser Port Authority
W	Watts – SI unit for Active Power
XFMR	Transformer

1 Executive Summary

The Vancouver Fraser Port Authority (VFPA) and the Centerm container terminal operator, DP World Vancouver (DPWV), in partnership with BC Hydro are considering the installation of battery electric yard tractors and the associated electric vehicle (EV) charging equipment and supporting electrical infrastructure at the Centerm Terminal to replace DP World Vancouver's existing fleet of diesel-powered yard tractors.

Battery electric yard tractors represent an emerging technology that is nearing commercialization. Several manufacturers currently have products on the market and are continuing to further develop this technology, and several terminal operators in North America are undertaking pilot projects to determine if these tractors comply with the harsh operational requirements posed by container terminal operations. Any potential battery electric yard tractor will need to exhibit equal or better performance than the existing diesel vehicles before being considered for replacement.

There are 60 diesel powered yard tractors currently being utilized at the Centerm Terminal. These trucks are used on the site for moving containers between container piles, the intermodal rail yard, and the ship-to-shore (STS) quay cranes for loading and offloading vessels and rail cars. These yard tractors can potentially operate up to 24 hours a day in the downtown area of Vancouver and add to the overall greenhouse gas (GHG) emissions and noise pollution in the area.

VFPA and DP World Vancouver are currently considering a pilot implementation of ten (10) battery electric yard tractors and the associated EV charging infrastructure, with consideration for full implementation of 60 battery electric yard tractors at a future date to fully replace the existing fleet of diesel vehicles. The Centerm Expansion Project (CEP) that is currently underway will result in significant modifications to the terminal layout as well as the electrical infrastructure and systems installed at the container terminal. As this project will involve significant civil works, including underground trenching for new electrical duct banks and a reconfiguration of the container yard layout, as well as significant electrical upgrades, it is an ideal opportunity to include the required underground ducting as well as modifications to the site's power distribution system to facilitate the installation of the charging systems required to support battery electric yard tractors. The charging network is proposed to be located at the reconfigured northeast corner of the container terminal property where a new yard tractor parking area will be constructed as part of the CEP project that is currently underway.

In order to evaluate any potential battery electric yard tractor's suitability for use at Centerm, a baseline measurement of the existing diesel tractors energy usage and GHG emissions has been prepared. This analysis has determined that the existing fleet of yard tractors at Centerm consume around 10,213.2 MWh/year of energy and contribute around 2,798.42 tCO_2e/year.

DP World Vancouver provided the following operational requirements that a potential battery electric yard tractor will need to comply with in order to be considered for replacement of an existing diesel tractor:

- Capable of operating for up to three, 8 hour shifts per day (with most activity occurring between 6 AM and 1 AM), with charging opportunities of maximum 1 hour per shift
- Capable of towing a maximum load of 60,000 kg (132,000 lbs)
- 10 year equipment service lifetime

In order to comply with these requirements, the battery capacity and DC fast charging station power requirements were investigated. It is recommended that a battery electric yard tractor suitable for use at the Centerm Terminal comply with the following specifications, at a minimum:

- 250 kWh battery capacity for battery electric vehicle
- Battery electric vehicle capable of charging via Level 3 DC fast charging technology
- 250 kW per each DC fast charging station

Consumer battery electric vehicles are typically found to be around 2.5 to 3 times more efficient than an equivalent Internal Combustion Engine (ICE) vehicle when used in the same operating conditions. However, pilot projects undertaken by the California Air Resources Board (CARB) have determined that battery electric yard tractors

operating in a container terminal setting could potentially reach efficiency values between 5.3 and 7.0. These larger efficiency ratios appear to be strongly correlated with the relatively slower average speed of vehicles being used in the operational profile of a container terminal. This slower average speed is an indicator of high levels of coasting, idling, and stop and go operation. All these factors which are inherent to yard tractors operating in container terminal applications act to increase the energy efficiency difference between the existing diesel ICE yard tractors and the proposed battery electric vehicles. Taking this into consideration, it is estimated that the full replacement of the existing diesel fleet with battery electric yard tractors would results in an annual energy consumption of 1,927.2 MWh/year and contribute around 20.4 tCO_2e/year, representing an approximate 81% decrease in annual energy usage and an approximate 99% decrease in annual greenhouse gas emission contributions from the yard tractor fleet.

In order to install the 12.5 kV feeders to the proposed EV charging substations, the installation of electrical ducts between the Centerm Container Main Substation (CMS) and the proposed EV charging substations location will be required. At this stage, it is important to include the installation of the ducts required for the battery electrical charging infrastructure to take advantage of the cost savings that will be realized by installing these ducts at the same time as the other ducts included in the CEP project.

It is estimated that the installation of ten (10) battery electric yard tractors will require 2.5 MW of power and the full implementation of 60 vehicles would require 15 MW with all vehicles charging concurrently. These proposed battery electric yard tractors will charge during shift breaks and between shifts. During these times the terminal electrical load will be the largest as most of the yard tractors will be charging concurrently, however there will be minimal use of other electrified cargo handling equipment (CHE) including the quay cranes and the Rail Mounted Gantries (RMG). Based on this staggered usage of electrical energy, the peak demand for the existing 12.5 kV BC Hydro services will be maintained within capacity of the two (2) existing service feeders at Centerm Terminal. However, it is recommended that other methods and options for the charging of the battery electric yard tractors be investigated during the detailed design that could potentially mitigate the high demand charge associated with the concurrent charging of all vehicles. One potential option would be to have DP World Vancouver personnel employed to manage the plugging and charging of the yard tractors. This would include the implementation of approximately ten (10) additional yard tractors which are charged during a shift and are continually swapped with depleted yard tractors in operation, as required. An operation conducted in this way would only require approximately ten (10) charging stations and would result in a maximum daily demand of approximately 2.5 MW. Another option would be to install a dynamic load management (DLM) system to optimize and evenly distribute the charging of the yard tractors while also ensuring that the total charging load does not exceed the capacity of the system. These methods could be employed to minimize the costs associated with BC Hydro demand charges.

In order to understand the costs involved for implementing battery electric yard tractors at Centerm, a Rough Order Magnitude (ROM) cost estimate has been prepared which includes the capital costs to install the required electrical infrastructure as well as the battery electric vehicles themselves, and the operations and maintenance costs required to maintain the systems. These costs have been compared with the baseline costs for the existing diesel vehicle fleet and have been prepared for the pilot implementation of ten vehicles as well as the full replacement of all 60 vehicles and forecasted over a 10 year span using an annual inflation rate of 2%.

The table below provides a summary of the capital costs and O&M costs forecasted over a 10 year span for the initial pilot of 10 vehicles. The diesel baseline estimate has been based on current diesel fuel costs. It is understood that DP World Vancouver replaces the existing diesel yard tractors on 5 year intervals so the baseline capital cost estimate has included two replacements over the 10 year span. The life span of electric yard tractors is 10 years and they only require a replacement of the batteries after 5 years. The baseline cost also includes the estimated salaries for fuelling personnel responsible for the fueling of the existing diesel yard tractors.

The life cycle costs for the battery electric yard tractor system (10 vehicles) have been based on the following information:

- Energy costs using the proposed BC Hydro Demand Transition Rate for fleet electrification.

- Maintenance costs for electrical infrastructure, including the electric vehicle fast charging stations and the electric vehicle charging substations required to be installed in the yard tractor parking area at the northeast corner of the Centerm Terminal.
- Maintenance costs for the battery electric vehicles themselves, estimated to be 70% of the maintenance costs for the diesel baseline
- Replacement of the battery system in the vehicles will be required 5 years into the 10 year lifespan of the vehicles.
- The capital costs include the installation of underground duct bank system, cabling, one of the two 12.5 kV – 480 V (or 600 V) EV charging substations, ten (10) EV charging stations, and ten (10) battery electric vehicles.

A detailed summary of the capital costs for the electrical infrastructure required to support the battery electric yard tractors is included in Appendix C and the detailed calculation for baseline diesel and electricity costs in included in Appendix D.

Life Cycle Total Cost (10 Yard Tractors, 10 Years)

Expenditure	**Diesel Baseline (10 vehicles)**	**Battery Electric (10 vehicles)**
Energy (Fuel)	$ 2,734,102	$ 2,408,607
Fueling Cost	$ 1,139,209	N/A
Maintenance (Electrical Infrastructure)	N/A	$ 218,994
Maintenance (Yard Tractors)	$ 1,313,967	$ 919,777
Battery Replacement at midspan of equipment life (year 5)	N/A	$ 1,670,000
Total O&M Costs	**$ 5,187,277**	**$ 5,217,378**
Capital Cost (Yard Tractors)	$ 2 x 2,000,000	$ 5,000,000
Capital Cost (Infrastructure)	N/A	$ 7,449,914
Total Cost of Ownership	**$ 9,187,277**	**$ 17,667,292**
Incremental Cost	-	**$ 8,480,014 (92%)**

Of the estimated $7,449,914 in infrastructures costs for Phase 1, $878,071 represents the cost for the high voltage duct bank and associated electrical manhole/vaults that are recommended to be installed during the CEP construction phase. The remainder of the work could be completed after the CEP project is completed with minimal interruptions to DP World Vancouver Terminal operations.

Based on this technical report, the conversion of the yard tractor fleet at Centerm from diesel to battery electric technology is feasible, provided that technology development stays on track, and has the potential to significantly reduce the greenhouse gas emissions and energy usage of the yard tractor fleet. While a battery electric yard tractor complying with DP World Vancouver's operational requirements is not currently available, manufacturers are actively developing the technology, including larger battery capacities, higher charging power, the capability for DC fast charging, and higher motor power ratings. It is anticipated that by the time the CEP project is completed around September 2021, battery electric yard tractors that meet all of DP Word Vancouver's operational requirements will be available on the market.

2 Overview

The Vancouver Fraser Port Authority (VFPA) and the Centerm container terminal operator, DP World Vancouver (DP World Vancouver), in partnership with BC Hydro are considering the installation of battery electric yard tractors and the associated electric vehicle (EV) charging equipment and supporting electrical infrastructure at the Centerm container terminal.

The electrification of the terminal's yard tractors, (also called yard trucks, terminal tractors, Internal Transfer Vehicles (ITV), and hostlers) has been identified as an emerging technology that is nearing commercialization (TRL 8 – pre-commercial), as manufacturers are actively developing and some currently have viable products ready for demonstration. VFPA and DP World Vancouver are interested in trialing this technology with the goal of moving away from the terminal's current fleet of diesel fueled yard tractors.

This emerging technology has the potential to meet DP World Vancouver's operational requirements by the time construction of the Centerm Expansion Project (CEP) is complete (estimated completion around September 2021). Provided that this battery electric technology can meet DP World Vancouver's operational requirements, VFPA, as a partner in the Centerm Expansion Project, would like to include the installation of the required infrastructure to implement a yard tractor electrical charging network as part of the CEP.

The Centerm Expansion Project that is currently underway will result in significant modifications to the terminal layout as well as the electrical infrastructure and systems installed at the container terminal. As this project will involve significant civil works, including underground trenching for new electrical duct banks and a reconfiguration of the container yard layout, as well as significant electrical upgrades, it is an ideal opportunity to include the required underground ducting as well as modifications to the site's power distribution system to facilitate the installation of the charging systems required to support battery electric yard tractors.

An initial pilot deployment is being considered that would include the supply of ten (10) battery electric yard tractors and the associated EV charging equipment required to operate them.

This project is being undertaken as part of BC Hydro's Low-carbon Electrification (LCE) program and will address the requirements noted in BC Hydro's document CEM-9462-OPE-FMG-504, *"C&EM Engineering Guideline – Industrial Low-carbon Electrification Study",* as applicable.

This report includes a review of the existing site conditions and infrastructure, as well as planned future Centerm terminal electrical demands, for determining the suitability of adding new charging stations at the reconfigured container yard tractor parking lot location. Load calculations and analyses based on current loads and the anticipated charging frequency and durations are provided. As part of this study, preliminary design drawings have been prepared, including underground duct bank routing plans and single line diagrams for the proposed power distribution upgrades required to supply the proposed EV charging infrastructure. Capital and operations and maintenance (O&M) cost estimates have also been prepared for the proposed implementation.

2.1 Background Information

The following information was provided to PBX and was used in the production of this report:

- *Vancouver Fraser Port Authority Kalmar Yard Truck Electrification Demonstration Business Cases*, report prepared by EELO Solutions and Pinna Sustainability, dated March 29, 2019.
- *2018 Feasibility Assessment for Cargo-Handling Equipment*, report prepared by Tetra Tech / Gladstein, Neandross & Associates, dated April 2019.
- *Zero/Near-Zero Emissions Yard Tractor Testing & Demonstration Guidelines*, report prepared by Port of Long Beach and Port of Los Angeles, dated September 2017.

3 Statement of Limitations

PBX have used information provided by the VFPA and DP World Vancouver to make assumptions with respect to existing conditions and conditions that may exist in the future. While PBX believes the assumptions made are reasonable for the purposes of this report, it makes no representation that the conditions assumed will occur. PBX relied on information provided to us without independent verification and cannot guarantee its accuracy or completeness. Therefore, actual results may vary from those projected to the extent that actual future conditions differ from those assumed in the Study or from the information provided to PBX.

Estimates and projections prepared by PBX relating to performance, construction costs and operating and maintenance costs are based on experience, qualifications, and judgment as a professional engineer. PBX has no control over weather, cost and availability of labor, material and equipment, labor productivity, construction contractor's procedures and methods, unavoidable delays, construction, contractor's method of determining prices, economic conditions, government regulations and laws (including interpretation thereof), competitive bidding and market conditions or other factors affecting such estimates. Actual rates, costs, performance, schedules, etc., may vary from the data provided.

4 Project Description and System Boundary

There are 60 diesel powered yard tractors currently being utilized at the Centerm Terminal. Ten (10) of these yard tractors have Tier 0 or Tier 1 engines that are subject to annual fees under VFPA's Non-Road Diesel Emissions (NRDE) Program. These trucks are used on the site for moving containers between container piles, the intermodal rail yard, and the ship-to-shore (STS) quay cranes for loading and offloading vessels and rail cars. These terminal tractors operating for up to 24 hours a day in the downtown area of Vancouver add to the overall greenhouse gas emissions and noise pollution in the downtown east side neighbourhood.

VFPA and DP World Vancouver are currently considering a pilot implementation of ten (10) battery electric yard tractors and the associated EV charging infrastructure, with consideration for full implementation of 60 battery electric yard tractors at a future date to replace all existing diesel vehicles. The charging network is proposed to be located at the reconfigured northeast corner of the container terminal property where a new yard tractor parking area will be constructed as part of the CEP project. This report will include the consideration for the initial pilot deployment of ten (10) battery electric yard tractors, as well as the potential full adoption of battery electric yard tractors at Centerm (full replacement of all 60 existing diesel ITVs).

The Centerm Terminal is currently fed by two primary 12.5 kV BC Hydro feeders: 12F94MUR and 12F80MUR. There is also the shared UC8F11 stand-by feeder currently used for maintenance and emergency purposes only. As part of the Centerm Expansion Project (CEP) this feeder will be potentially utilized to provide interruptible power to the new shore power infrastructure that will be installed at the new Berth 6. Existing Canada Place stand-by feeder 12F71MUR is currently being used to provide interruptible power to the shore power equipment located at Berth 5.

5 Baseline Operations

In order to develop the baseline energy usage and greenhouse gas (GHG) emissions of the existing yard tractors, DP World Vancouver provided an average value of 16,000 litres of diesel fuel consumption per year per diesel yard tractor. Using this value along with the energy density of diesel fuel, the annual energy usage of one diesel yard tractor can be determined as follows,

$$\frac{16{,}000\ L}{year} \times \frac{38.3\ MJ}{1\ L} \times \frac{1\ Wh}{3{,}600\ J} = 170.22\ \frac{MWh}{year}$$

In order to determine a value for GHG emissions, the *2016 B.C. Best Practices Methodology for Quantifying Greenhouse Gas Emissions* document published by the BC Ministry of Environment (BC MoE) was used. Table 7: Fleet Fuel Consumption provides an emission factor of 2.914 kg of CO_2e per litre for diesel an Off-Road (Vehicle/Equipment) Transport Mode. Using this Emission Factor results in the following calculation for GHG emissions per MWh of energy usage:

$$2.914\ \frac{kg\ CO_2e}{L} \times \frac{1\ L}{38.3\ MJ} \times \frac{3{,}600\ J}{1\ Wh} \times \frac{1\ t}{1{,}000\ kg} = 0.274\ \frac{t\ CO_2e}{MWh}$$

Expanding the above calculated energy usage and GHG emissions for one diesel yard tractor to the 10 yard tractors being considered for replacement as part of the initial pilot project as well as the complete replacement of all 60 existing diesel yard tractors results in the following values.

Table 1: Yearly Energy Usage and GHG Emissions of Diesel Baseline

	Energy Usage (MWh/year)	GHG Emissions (tCO_2e/year)
1 DIESEL YARD TRACTOR	170.22	46.64
10 DIESEL YARD TRACTORS	1,702.2	466.4
60 DIESEL YARD TRACTORS	10,213.2	2,798.42

The values presented in the table above are consistent with the calculated values in the *Industrial Low-carbon Electrification Project Workbook* provided by BC Hydro.

6 Electrification Opportunity Identification and Evaluation

The emerging technology of battery electric yard tractors has been identified as a potential low-carbon electrification option that VFPA and DP World Vancouver would like to investigate as a potential way to move away from the existing fleet of 60 diesel internal combustion engine (ICE) yard tractors. This transition is contingent on the proposed battery electric option meeting DP World Vancouver's operational requirements and must meet or exceed the functionality provided by the existing ICE vehicles. The key operational requirements that have been identified by DP World Vancouver are summarized in the following table.

Table 2: DP World Vancouver Yard Tractor Operational Requirements

Operating Hours (Shift Schedule)	Up to three, 8 hour shifts/day, 7 days/week (most activity occurring between 6 AM and 1 AM)
Maximum load	60,000 kg (132,000 lbs)
Number of opportunities to charge during a shift	Approximately 1 hour per shift for charging
Equipment Service Lifetime	10 years

In addition to the specific operational requirements listed above, the battery electric yard tractor should have the following performance attributes that are equal to or greater than the existing diesel powered vehicles:

- Mean Time Between Failure (MTBF) equal to our greater than existing baseline diesel yard tractor
- The battery electric yard tractor should not impose significantly more maintenance activities when compared with the diesel yard tractor
- Level of operator comfort and safety should be equal or greater than the operator experience of a diesel yard tractor

The key parameters of the proposed battery electric yard tractor option that will need to be evaluated to confirm compliance with DP World Vancouver's operational requirements are as follows:

- Yard tractor battery capacity (in kWh) to ensure adequate run time between charging opportunities

- Yard tractor EVSE charging station power (in kW) to ensure adequate power to charge yard tractors in the available charging times between and during shifts
- Yard tractor drive motor power (in kW) to ensure adequate power to haul the required 60,000 kg load

6.1 Battery Capacity

In order to determine the battery capacity that is required to ensure the battery electric yard tractor can sustain operation over a full 8-hour shift (with charging opportunities during the shift of approximately 1 hour), it is important to determine the fuel consumption of the existing diesel vehicle baseline. The value of 16,000 litres per year provided by DP World Vancouver is an adequate value to use for determining annual energy usage and GHG emission baselines as discussed in the previous section. However, it is not a good metric to use for determining the energy usage over a single 8-hour shift (7 hours of operation with 1 hour break) as it does not take into consideration the amount of time the diesel vehicle is idling (approximately 55 to 65% of the operating time), or not being used over a full year, due to maintenance, scheduling, or other factors. However, based on additional discussions with DP World Vancouver it was confirmed that hourly average fuel consumption of the trucks is 6.2 liters.

However, several studies from prior demonstrations at the Port of Los Angeles (POLA) and the Port of Long Beach (POLB) of proof-of-concept battery electric yard tractors were also reviewed as part of this report. These studies[1,2,3] state baseline maximum average diesel fuel consumption values of 10.98 L/hr for yard tractors operating on various container terminals.

Base on this scenario, the maximum energy consumed during a shift by a truck which is operated continuously is:

$$\frac{10.98\ L}{hr} \times \frac{10.64\ kwh}{L} \times \frac{7\ hr\ op.}{shift} = \frac{817.79\ kWh}{shift}$$

A report[4] prepared by the California Air Resources Board (CARB) summarized the results of a pilot project where TransPower, a company developing battery electric vehicle technology, demonstrated two proof-of-concept battery electric yard tractors at POLA and one at an IKEA warehouse in California. This study determined that battery electric yard tractors could potentially reach Energy Economy Ratios (EER) of between 5.3 and 7.0. Consumer battery electric vehicles are typically found to be around 2.5 to 3 times more efficient than an equivalent ICE vehicle when used in the same operating conditions. The studies and pilot projects undertaken by CARB describe that the increased efficiency values for battery electric yard tractors when used in a container terminal setting appears to be strongly correlated with the relatively slower average speed of vehicles being used in the operational profile of a container terminal setting. This slower average speed is an indicator of high levels of coasting, idling, and stop and go operation. All these factors which are inherent to yard tractors operating in container terminal applications act to increase the energy efficiency difference between the existing diesel ICE yard tractors and the proposed battery electric vehicles. For the purposes of this study, the more conservative EER value of 5.3 has been used.

Using the energy consumption per shift of the DP World Vancouver diesel yard tractor calculated above, and the EER value of 5.3 reported by CARB, the anticipated approximate energy consumption per shift of the battery electric yard tractor can be determined as follows,

$$\frac{817.79\ \frac{kWh\ (DIESEL)}{shift}}{5.3\ EER} = 154.3\ \frac{kWh\ (ELECTRIC)}{shift}$$

[1] Calstart, "Hybrid Yard Hostler Demonstration and Commercialization Project", March 2011.
https://cleanairactionplan.org/documents/hybrid-yard-hostler-demonstration-and-commercialization-project-revised-final-report-august-2012.pdf/
[2] TIAX, "Pluggable Hybrid Electrical Terminal Tractor (PHETT) Demonstration at the Port of Long Beach", September 2009.
https://cleanairactionplan.org/documents/capacity-plug-in-hybrid-terminal-tractor-phett-demonstration-polb-final-report.pdf/
[3] Calstart, "Liquefied Natural Gas (LNG) Yard Hostler Demonstration and Commercialization Project", August 2008.
https://cleanairactionplan.org/documents/sound-energy-solutions-ses-liquefied-natural-gas-lng-yard-hostler-demonstration-and-commercialization-project-1-final-report-august-2008.pdf/
[4] California Air Resources Board, "Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles", May 2018.
https://ww2.arb.ca.gov/sites/default/files/2018-11/180124hdbevefficiency.pdf

The EER value should be considered approximate and, while it was determined from an actual pilot study undertaken by CARB using demonstration battery electric yard tractors, there are specific operational requirements that DP World Vancouver have identified that need to be considered.

DP World Vancouver have stated that a maximum towing load of 60,000 kg (132,000 lbs) is an operational requirement that must be met by any potential battery electric yard tractor to be considered for implementation at the Centerm container terminal. This is significantly higher than the 72,000 lb maximum load that was considered in CARB's demonstration studies. Additionally, DP World Vancouver have stated that a 20-30 minute charging time between shifts and during the lunch break is an operational requirement, while the CARB study, based on POLB operational requirements, specified that a 1 hour charging window is available between the 1st and 2nd shift, and a 4 hour window is available between the 2nd and 3rd shifts.

Notwithstanding the above noted differences in operational requirements between DP World Vancouver and POLA/POLB, it is recommended that a battery capacity of around 250 kWh be considered as a requirement for any potential battery electric vehicle being implemented at DP World Vancouver.

6.2 EVSE Charging Station Power

The second key parameter that must be determined in order to confirm compliance with DP World Vancouver's operational requirements is the size of the required EVSE charging stations to ensure that the battery electric yard tractors can be charged to a suitable level during the available opportunity charging times during shifts and between shifts.

DP World Vancouver have stated that during a typical 8-hour shift there are two charge opportunities of less than 1 hour total to charge the battery electric yard tractor. Based on this information, a charging station of approximately 250 kW will be required based on the following calculation,

$$\frac{250\ kwh}{1\ hr} = 250\ kw$$

The above calculation illustrates a simplified model of EV charging that does not take into consideration the time/charging rate curve of lithium ion battery systems for electric vehicles. This curve is typically signified by a ramp up time during which the vehicle's battery charging system determines the maximum charging rate that the battery system can safely support based on the vehicle's current state of charge, ambient temperature, electrical current available, battery voltage, and other factors. Once the battery system reaches around 80%, the charging rate decreases significantly in order to protect the batteries. For some EV systems, charging the final 20% of the batteries can take as long as the first 80%.

Notwithstanding this simplified calculation, provision for 250 kW minimum EVSE capacity is recommended for the purposes of this feasibility study. This value exceeds the capacity of current day on-board AC to DC charger technology and necessitates the use of DC fast charging equipment. As such, any potential battery electric yard tractor must support charging via this technology.

Another factor that needs to be considered regarding the EV charging equipment is the connection between the battery electric yard tractors and EVSE that will be required. The nature of the fleet operation and shift schedules at Centerm are similar to other container terminals and result in a large quantity of vehicles returning to the parking/fueling area during lunch breaks and at the end of a shift. As such, having one fueling person or a fueling crew in charge of plugging the fleet of yard tractors into the EV charging stations during lunch breaks and at the end of a shift is not feasible due to the sequential nature of this procedure. The large number of trucks requiring connection to EV charging stations, and the time required for each vehicle to be physically plugged in could take a significant amount of time that directly impacts the time available for charging the vehicles. It is for these reasons that a system that automatically connects the EVSE to the battery electric yard tractor should be considered as an additional requirement for the implementation of battery electric yard tractors at Centerm.

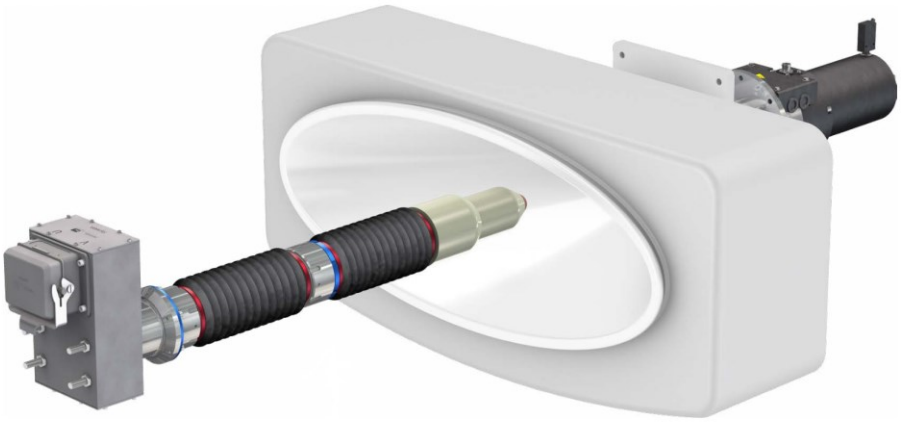
The SAE J3105 standard is currently being developed and is close to the publication stage. This standard will address the recommended practices for the physical, electrical, functional, testing, and performance requirements for DC

high power transfer to electrified buses and other heavy-duty vehicles. This standard will address various infrastructure-to-vehicle connection technologies including infrastructure and vehicle mounted pantograph systems. SAE J3105/3 will be one of the subdocuments included in this standard and will specifically address enclosed pin and socket connections, one of the infrastructure-to-vehicle connection types that are included in the J3105 standard.

This infrastructure-to-vehicle connection method is a potential option for the connection between the DC fast charging stations and the battery electric yard tractors. The Port of Long Beach is currently undertaking a project to install 33 DC high power charging stations which will utilize this enclosed pin and socket connection technology to automate the connection between the charging station and the yard tractor[5] using a product called the Automatic Rapid Charging Solution QCC by a company called Stäubli Electrical Connectors. This product consists of three components as follows:

- Pin style plug with automated driver, connected to the DC fast charging station infrastructure
- Socket, to accept the pin style plug, integrated into the battery electric yard tractor vehicle
- Funnel, to guide the plug into the socket and account for slight misalignment between plug and socket, mounted on the battery electric yard tractor vehicle

Please refer to the figure below detailing the three components of the enclosed pin and socket connection product from Stäubli Electrical Connectors. This product, along with other potential options for the automated connection between charging station and vehicle should be investigated as part of the detailed design.



6.3 Electric Motor Power

Determination of the electric motor power that is required to meet DP World Vancouver's operational requirements is beyond the scope of this feasibility study. However, in order to match the power of the top model Kalmar Ottawa T2 diesel baseline model (250 hp), an electric motor of at least 186 kW will be required. The maximum load value of 60,000 kg that was provided by DP World Vancouver as an operational requirement is significantly higher than the maximum load capabilities of any of the three existing battery electric yard tractors investigated as part of this feasibility study. Note that manufacturers are actively developing battery electric yard tractors and models with higher load capabilities are likely to be developed and released in the next few years.

[5] POWER Magazine, "Tritium and Stäubli to install largest automated electrical vehicle charging system at Port of Long Beach", July 22, 2018.
https://www.powermag.com/press-releases/tritium-and-staubli-to-install-largest-automated-electric-vehicle-charging-system-at-port-of-long-beach/

6.4 Existing Battery Electric Yard Tractor Products

There are three existing battery electric yard tractor vehicles that were investigated as part of this feasibility study and specification sheets and other available information have been included in Appendix B. The diesel baseline yard tractor vehicle, the Kalmar Ottawa T2 has also been included in Appendix B for reference purposes. Please refer to the table below for a comparison between the various battery electric vehicles and the diesel baseline. Please note that limited information regarding the Orange EV yard tractor is published online.

Table 3: Battery Electric and Diesel Baseline Yard Tractor Comparison

Model	Kalmar T2	Kalmar T2E	BYD 8Y	Orange EV
Fuel Type	Diesel (Baseline)	Battery Electric	Battery Electric	Battery Electric
Engine Power	250 hp 186 kW	215 hp 160 kW	241 hp 180 kW	Not Available
GCWR	132,000 lbs	81,000 lbs	102,000 lbs	81,000 lbs
Fuel Capacity OR Battery Capacity	50 gal	Standard: 132 kWh ≈ 17 DGE @ EER = 5.3 Optional: 176 kWh ≈ 23 DGE @ EER = 5.3 Optional: 220 kWh ≈ 30 DGE @ EER = 5.3	217 kWh ≈ 30 DGE @ EER = 5.3	Standard: 80 kWh ≈ 10 DGE @ EER = 5.3 Extended: 160 kWh ≈ 20 DGE @ EER = 5.3
Maximum charging rate	n/a	70 kW	200 kW	80 kW

As described in the table, none of the existing battery electric yard tractors investigated as part of this feasibility study comply with the operational requirement of a GCWR of at least 132,000 lbs specified by DP World Vancouver. This weight corresponds to two 20' grain containers weighing 66,000 lbs each and has been identified by DP World Vancouver to be considered as typical operation. The BYD 8Y yard tractor is the only offering that supports DC fast charging at a rate up to 200 kW. The Kalmar and Orange EV yard tractors only support AC charging at a rate that is not sufficient to charge the battery system in the available time during and between shifts.

While a battery electric yard tractor meeting DP World Vancouver's operational requirements is not currently available, manufacturers are actively developing battery electric technology for yard tractor and container terminal operations and are developing products with higher battery storage capacities, DC fast charging capabilities[6], and higher motor power ratings. Pilot projects undertaken at the Port of Los Angeles and the Port of Long Beach have provided valuable information to manufacturers to clarify how the duty cycles inherent in container terminal operations impact the required battery capacity, power rating, and EVSE charging infrastructure.

By the time the CEP project is completed around September 2021, it is likely that there will be battery electric yard tractors available that fully comply with all DP World Vancouver's operational requirements. It is therefore recommended that the required electrical infrastructure upgrades proceed as part of the CEP project to prepare for the implementation of battery electric yard tractors at the Centerm Terminal.

[6] Cummins, 'Cummins to Supply Kalmar with Driveline for New Electrical Terminal Tractor', *Cummins*, 14 February 2019, https://www.cummins.com/news/releases/2019/02/14/cummins-supply-kalmar-driveline-new-electric-terminal-tractor, (accessed 18 October 2019).

6.5 Energy Usage and Greenhouse Gas Emissions of Electrification Option

The baseline energy consumption of one existing diesel yard tractor was calculated to be around 170.22 MWh/year. This value was based on the reported value of 16,000 L of diesel fuel consumed per year that was provided by DP World Vancouver, and it was calculated as follows:

$$\frac{16{,}000\ L}{year} \times \frac{10.64\ kWh}{L} = \frac{170.22\ MWh}{year}$$

Utilizing the Energy Economy Ratio (EER) of 5.3 from above results in the following anticipated annual energy consumption for one (1) battery electric yard tractor,

$$\frac{170.22\ \frac{MWh\ (DIESEL)}{year}}{5.3\ EER} = 32.12\ \frac{MWh\ (ELECTRIC)}{year}$$

This value indicates that transitioning to battery electric yard tractors could save approximately 138.1 MWh per year per battery electric yard tractor.

In order to determine the approximate value for GHG emissions when transitioning from the existing diesel fleet to a battery electric fleet of yard tractors, the *2016 B.C. Best Practices Methodology for Quantifying Greenhouse Gas Emissions* document published by the BC Ministry of Environment (BC MoE) was used. Table 3: Purchased Electricity provides an emission factor of 10.67 tonnes of CO_2e per GWh of purchased electricity from BC Hydro. Using this Emission Factor results in the following calculation for GHG emissions per year per battery electric yard tractor:

$$10.67\ \frac{\text{t}\ CO_2e}{GWh} \times \frac{32.12\ \text{MWh}}{\text{year}} \times \frac{1\ \text{GWh}}{1{,}000\ \text{MWh}} = 0.34\ \frac{t\ CO_2e}{year}\ per\ electric\ yard\ tractor$$

Expanding the above calculated energy usage and GHG emissions for one battery electric yard tractor to the ten (10) yard tractors being considered for replacement as part of the initial pilot project as well as the complete replacement of all 60 existing diesel yard tractors results in the following values in Tables 4 and 5.

Table 4: Yearly Energy Usage of Battery Electric Electrification Option

	Energy Usage (MWh/year)	**Energy Saving Compared to Existing Diesel Baseline (MWh/year)**
1 BE YARD TRACTOR	32.12	138.1
10 BE YARD TRACTORS	321.2	1,381
60 BE YARD TRACTORS	1,927.2	8,286

Table 5: Yearly GHG Emissions of Battery Electric Electrification Option

	GHG Emissions (tCO_2e/year)	**GHG Emission Saving Compared to Existing Diesel Baseline (tCO_2e/year)**
1 BE YARD TRACTOR	0.34	46.3
10 BE YARD TRACTORS	3.4	463
60 BE YARD TRACTORS	20.4	2,778

To summarize the results in this section, transitioning from the existing fleet of diesel yard tractors to battery electric yard tractors at the Centerm container terminal would result in an approximate 81% decrease in annual energy usage and an approximate 99% decrease in annual greenhouse gas emission contributions from the yard tractor fleet.

6.6 Capital Cost Estimate

A capital cost estimate has been developed for the electrification option and has been included in Appendix C. This cost estimate builds on the cost estimate included in the *"Vancouver Fraser Port Authority Kalmar Yard Truck Electrification Demonstration Business Cases"* prepared by Pinna Sustainability and EELO Solutions, dated March 29, 2019 and prepared for the VFPA and BC Hydro. This cost estimate has further expanded on the civil and electrical construction works that will be required for the implementation of battery electric yard tractors at the Centerm Terminal. The capital cost estimate has been presented in two phases as follows:

- **Phase 1:** Battery Electric Yard Tractor Pilot Implementation (10 yard tractors and associated infrastructure)
- **Phase 2:** Battery Electric Yard Tractor Full Implementation (Additional 50 yard tractors and associated infrastructure required to build out the entire 60 vehicle fleet)

The Phase 1 capital cost estimate includes all required underground high voltage electrical ducting required for the full 60 vehicle implementation. It is recommended that this electrical pre-ducting be included as part of the Phase 1 works and to take place as part of the Centerm Expansion Project (CEP) construction phase. It is significantly more cost effective to complete the electrical pre-ducting during the CEP project, which already includes a significant portion of trenching for new duct banks between the CMS and the proposed yard tractor parking lot in the northeast corner of the terminal yard. The ducts that are required for the EVSE system are proposed to be routed within the same duct banks installed for CEP wherever possible to achieve cost savings. Phase 1 also includes the installation of only one (1) of the two (2) required substations at the proposed yard tractor parking lot in the northeast corner of the terminal yard and does not include the additional substation that will be required at the existing transformer yard near the CMS, as discussed in Section 7.

The Phase 2 capital cost estimate includes the second substation that will be required at the proposed yard tractor parking lot as well as the expansion of the CMS to the existing transformer yard near the CMS. The additional 50 charging stations required to build out the full 60 vehicle fleet of battery electric yard tractors are also included in Phase 2.

As the initial baseline for this study is the existing diesel vehicle fleet, the baseline capital cost estimate for Phase 1 is considered to be $2,000,000 and consists of the purchase of ten (10) new diesel yard tractors ($200,000 each).

The baseline capital cost estimate for Phase 2 is considered to be $10,000,000 and consists of the purchase of 50 new diesel yard tractors.

6.7 10 Year Operating & Maintenance Cost Estimate

An operating and maintenance cost estimate has been developed for the electrification option. This cost estimate builds on the cost estimate included in the *"Vancouver Fraser Port Authority Kalmar Yard Truck Electrification Demonstration Business Cases"* prepared by Pinna Sustainability and EELO Solutions, dated March 29, 2019 and prepared for the VFPA and BC Hydro.

This cost estimate provides a comparison between the O&M costs for the existing baseline diesel yard tractors and the proposed battery electric yard tractors and has been completed for the initial pilot implementation of ten (10) battery electric vehicles considering a ten (10) year span (starting in 2021) and assuming an inflation rate of 2%.

BC Hydro electrical energy costs have been calculated based on the Demand Transition Rate for fleet electrification proposed by BC Hydro[7]. For the detailed calculations pertaining to the baseline diesel costs, BC Hydro energy costs, and BC Hydro demand costs refer to the calculation spreadsheet included in Appendix D.

As noted in the *"Vancouver Fraser Port Authority Kalmar Yard Truck Electrification Demonstration Business Cases"* it is anticipated that the battery system of the battery electric yard tractors will require replacement halfway through the 10 year lifespan of the vehicles.

The Life Cycle Total Cost (10 Yard Tractors, 10 Years) table below provides a summary of the capital costs and O&M costs forecasted over a 10 year span for the initial pilot of 10 vehicles. The diesel baseline estimate has been based on current diesel fuel costs. It is understood that DP World Vancouver replaces diesel yard tractors on 5 year intervals so the baseline capital cost estimate has included two replacements over the 10 year span. The baseline cost also includes the estimated salaries for fuelling personnel responsible for the fueling of the existing diesel yard tractors.

The life cycle costs for the battery electric yard tractor system (10 vehicles) have been based on the following information:

- Energy costs using the proposed BC Hydro Demand Transition Rate for fleet electrification.
- Maintenance costs for electrical infrastructure, including the electric vehicle fast charging stations and the electric vehicle charging substations required to be installed in the yard tractor parking area at the northeast corner of the Centerm Terminal.
- Maintenance costs for the battery electric vehicles themselves, estimated to be 70% of the maintenance costs for the diesel baseline
- Replacement of the battery system in the vehicles will be required 5 years into the 10 year lifespan of the vehicles.
- The capital costs include the installation of underground duct bank system, cabling, one of the two 12.5 kV – 480 V (or 600 V) EV charging substations, ten (10) EV charging stations, and ten (10) battery electric vehicles.

Table 6: Life Cycle Total Cost (10 Yard Tractors, 10 Years)

Expenditure	**Diesel Baseline (10 vehicles)**	**Battery Electric (10 vehicles)**
Energy (Fuel)	$ 2,734,102	$ 2,408,607
Fueling Cost	$ 1,139,209	N/A
Maintenance (Electrical Infrastructure)	N/A	$ 218,994
Maintenance (Yard Tractors)	$ 1,313,967	$ 919,777
Battery Replacement at midspan of equipment life (year 5)	N/A	$ 1,670,000
Total O&M Costs	**$ 5,187,277**	**$ 5,217,378**
Capital Cost (Yard Tractors)	$ 2 x 2,000,000	$ 5,000,000
Capital Cost (Infrastructure)	N/A	$ 7,449,914
Total Cost of Ownership	**$ 9,187,277**	**$ 17,667,292**
Incremental Cost	-	**$ 8,480,014 (92%)**

[7] BC Hydro, 'BC Hydro Fleet Electrification Rate Application', August 7, 2019
https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/regulatory-planning-documents/regulatory-filings/rd/00-2019-08-07-bchydro-fleet-electrification-rate-design-application.pdf

Of the estimated $7,449,914 in infrastructures costs for Phase 1, $878,071 represents the cost for the high voltage duct bank and associated electrical manhole/vaults that are recommended to be installed during the CEP construction phase. The remainder of the work could be completed after the CEP project is completed with minimal interruptions to DP World Vancouver Terminal operations.

The Life Cycle Total Cost (50 Yard Tractors, 10 Years) table below provides a summary of the capital costs and O&M costs forecasted over a 10 year span for the Phase 2 implementation of the remaining 50 yard tractors to build out the entire 60 yard tractor fleet.

The diesel baseline estimate has been based on current diesel fuel costs. It is understood that DP World Vancouver replaces diesel yard tractors on 5 year intervals so the baseline capital cost estimate has included two replacements over the 10 year span. The baseline cost also includes the estimated salaries for fuelling personnel responsible for the fueling of the existing diesel yard tractors.

The life cycle costs for the battery electric yard tractor system (50 vehicles) have been based on the following information:

- Energy costs using the proposed BC Hydro Demand Transition Rate for fleet electrification.
- Maintenance costs for electrical infrastructure, including the electric vehicle fast charging stations and the electric vehicle charging substations required to be installed in the yard tractor parking area at the northeast corner of the Centerm Terminal.
- Maintenance costs for the battery electric vehicles themselves, estimated to be 70% of the maintenance costs for the diesel baseline
- Replacement of the battery system in the vehicles will be required 5 years into the 10 year lifespan of the vehicles.
- The capital costs include the installation the second 12.5 kV – 480 V (or 600 V) EV charging substation, the extension of the Container Main Substation (CMS), 50 EV charging stations, and 50 battery electric vehicles.

Table 7: Life Cycle Total Cost (50 Yard Tractors, 10 Years)

Expenditure	**Diesel Baseline (50 vehicles)**	**Battery Electric (50 vehicles)**
Energy (Fuel)	$ 13,670,508	$ 12,043,033
Fueling Cost	$ 1,139,209	N/A
Maintenance (Electrical Infrastructure)	N/A	$ 656,983
Maintenance (Yard Tractors)	$ 6,569,833	$ 4,598,883
Battery Replacement at midspan of equipment life (year 5)	N/A	$ 8,350,000
Total O&M Costs	**$ 21,379,550**	**$ 25,648,899**
Capital Cost (Additional 50 Yard Tractors)	$ 2 x 10,000,000	$ 25,000,000
Capital Cost (Infrastructure)	N/A	$ 17,574,570
Total Cost of Ownership	**$ 41,379,550**	**$ 68,223,469**
Incremental Cost	-	**$ 26,843,920 (65%)**

6.8 Non-Energy Benefits

In addition to the energy reduction and GHG emissions reductions which will be realized by transitioning to a battery electric yard tractor fleet, there are several other non-energy related benefits as follows:

- Air quality improvement at Centerm and the surrounding Vancouver downtown east side area due to elimination of diesel emissions from yard tractor fleet.
- Decreased interior and exterior noise levels resulting in increased driver comfort as well as a potentially smoother driving experience.

7 Electrical Connections

Based on the anticipated power requirement of 250kW per each EV charging station as described in the previous section, the following table summarizes the total power requirements for the 10 yard tractors being considered for replacement as part of the initial pilot project and the complete replacement of all 60 existing diesel yard tractors in the future.

Table 8: Power Requirements for EV Charging Infrastructure

	Power Required (kW)
1 EV CHARGING STATION	250
10 EV CHARGING STATIONS	2,500
60 EV CHARGING STATIONS	15,000

The proposed battery electric yard tractors will charge during shift breaks and between shifts. During these times the terminal electrical load will be the largest as most of the yard tractors will be charging concurrently. During these periods there will be minimal use of other electrified CHE including the quay cranes and the RMGs. Based on this staggered usage of electrical energy, the peak demand for the existing 12.5 kV BC Hydro services will be maintained within capacity of the two (2) existing service feeders at Centerm Terminal (250 kW * 60 Terminal Tractors / 2 Feeders = 7,500 kW/Feeder).

However, it is recommended that other methods and options for the charging of the battery electric yard tractors be investigated during the detailed design that could potentially mitigate the high demand associated with the concurrent charging of all battery electric yard tractors. One potential option would be to have DP World Vancouver personnel employed to manage the plugging and charging of the yard tractors, similar to the existing diesel vehicle fueling role. This would include the implementation of approximately ten (10) additional yard tractors which are charged during a shift and are continually swapped with depleted yard tractors in operation, as required. An operation conducted in this way would only require approximately ten (10) charging stations and would result in a maximum daily demand of approximately 2.5 MW.

Another potential option could be to install a dynamic load management (DLM) system to optimize and evenly distribute the charging of the yard tractors while also ensuring that the total charging load does not exceed the capacity of the system. These methods could be employed to minimize the costs associated with BC Hydro demand charges.

The Centerm Terminal is currently fed by two primary 12.5kV BC Hydro feeders: 12F94MUR and 12F80MUR. There is also the shared UC8F11 stand-by feeder currently used for maintenance and emergency purposes only. As part of the Centerm Expansion Project (CEP) this feeder will be utilized to provide interruptible power to the new shore power infrastructure that will be installed at the new Berth 6. The existing Canada Place stand-by feeder 12F71MUR is currently being used to provide interruptible power to the shore power equipment located at Berth 5.

The existing main substation for the Centerm Terminal is the Container Main Substation (CMS) located at the south side of the terminal site, near the Dunlevy entrance gate. This substation contains the incoming BC Hydro service feeders 12F94MUR, 12F80MUR, and UC8F11 noted above. As part of the Centerm Expansion Project, an additional dedicated 12.5kV BC Hydro service will be installed and connected to the existing bus section C switchgear line-up to feed quay crane and Rail Mounted Gantry (RMG) loads. The CEP project will also include the installation of new 12.5kV circuit breakers to accommodate quay cranes and RMGs within the existing switchgear line-up. At the end of the project, there will be one (1) spare circuit breaker in bus section C. This feeder from this spare breaker (CM-12K-CB20) feeds crane pit 1A (CRNP-1A) but does not contain a crane receptacle and does not provide power to any equipment. This spare breaker could temporarily be used to provide power to the battery electric yard tractor charging substation installed during the initial pilot implementation of ten (10) vehicles.

Bus section A cannot be utilized for power to the battery electric vehicle charging system as it is a shared feeder that feeds the reefer tower infrastructure and will be at capacity.

As the complete replacement of all 60 existing diesel yard tractors with battery electric yard tractors will require the installation of two (2) 12.5kV circuit breakers and the associated feeders, with each feeder carrying half of the total load (approximately 7.5 MW), there is no spare space available in the existing substation to accommodate the required circuit breakers. However, the initial pilot implementation of only ten (10) battery electric yard tractors and one substation can be accommodated with the existing spare CRNP-1A circuit breaker in the CMS as noted above, and this is the recommended approach for the installation of the initial pilot deployment.

However, the full implementation of 60 battery electric yard tractors will require the installation of a new substation. This substation is proposed for installation next to the CMS in the existing transformer yard on the east side of the CMS. The transformer yard currently contains two (2) 12.5kV – 4160V transformers and a capacitor bank. As part of the CEP project, these transformers and the capacitor bank will be demolished which will result in adequate space for the installation of a new substation. This substation is proposed to include several spare circuit breaker cells to facilitate future expansion of other CHE electrification at the Centerm Terminal as well as other potential future loads. However, as noted above, the initial pilot implementation does not require the installation of this substation, and it is recommended to include the installation of the new substation only when the full implementation for the replacement of all 60 yard tractors is undertaken.

7.1 Yard Tractor Charging Station Power Distribution System

The CEP project design includes the construction of a new yard tractor parking lot area at the northeast corner of the Centerm Terminal and will include 63 yard tractor parking stalls. In order to provide power to the proposed EV charging stations in this area, the full implementation of 60 battery electric yard tractors will require the installation of two (2) substations in this area to step down the power from 12.5 kV voltage from the CMS to 480V (or 600V), to feed the EV DC fast charging stations. The initial pilot implementation of 10 vehicles will only require the installation of one (1) substation in this area. New ducts will also be required from the CMS to this area to install the required 12.5kV feeders to supply power to the substations in this area. Each of these substations will likely take up one of the existing parking stalls leaving a total of 61 stalls for parking of yard tractors. The location of these substations shall be further reviewed during the detailed design phase and discussed with DP World Vancouver to confirm acceptable locations taking into consideration the operational requirements of the terminal operator.

A preliminary design detailing the proposed installation of the conduit duct bank from the CMS to the EV charging substations, as well as the proposed modifications to the CMS has been included in Appendix A.

8 Project Schedule & Risk Analysis

As noted previously in this study, the installation of the civil and electrical infrastructure that is required to implement a battery electric yard tractor charging system at Centerm Terminal is proposed to be installed as part of the Centerm Expansion Project (CEP). The first stage of the CEP electrical works includes the installation of a portion of the duct bank from the CMS to the reefer tower area and this work is scheduled to be installed in early 2020. The remaining civil and electrical works will proceed after this and the overall CEP project is anticipated to be complete around September 2021. At this stage, it is important to include the installation of the ducts required for the battery

electrical charging infrastructure to take advantage of the cost savings that will be realized by installing these ducts at the same time as the other ducts included in the CEP project.

The remainder of the installation works for the battery electric yard tractor implementation, including the installation of the required substations and charging infrastructure can be completed in the future when battery electric yard tractor technology has reached a level that meets all of DP World Vancouver's operational requirements.

A Risk Analysis has been prepared and is included in Appendix E.

9 Recommendations

Based on this technical report, the conversion of the yard tractor fleet at Centerm from diesel to battery electric technology is feasible, provided that technology development stays on track, and has the potential to significantly reduce the greenhouse gas emissions and energy usage of the yard tractor fleet. While a battery electric yard tractor complying with DP World Vancouver's operational requirements is not currently available, manufacturers are actively developing the technology, including larger battery capacities, higher charging power, the capability for DC fast charging, and higher motor power ratings. It is anticipated that by the time the CEP project is completed around September 2021, battery electric yard tractors that meet all of DP Word Vancouver's operational requirements will be available on the market.

At Centerm, conversion to battery electric yard tractors is expected to eliminate 99% of the GHG emissions and result in a 81% decrease in energy consumption associated with the yard tractor fleet making it a desirable low-carbon electrification option that aligns with VFPA's goal to be the world's most sustainable port. Based on this, PBX recommends proceeding with the required electrical infrastructure upgrades as part of the CEP project to prepare for the implementation of battery electric yard tractors at the Centerm Terminal.

However, there are several barriers to implementation that must be overcome before the implementation of battery electric yard tractors can be completed. These barriers are summarized as follows:

High Capital Expenditure: The electrical infrastructure that is required to implement battery electric yard tractors at Centerm Terminal, including underground duct banks and cabling, the Container Main Substation expansion, the required EV charging substations and charging equipment, and the battery electric yard tractors themselves, represent a large capital expenditure. Installing the required underground ducting as part of the CEP project would realize significant savings, as many of the ducts required for the battery electric charging infrastructure could be installed concurrently with the duct banks already included as part of the CEP project. This work would be difficult and more expensive to complete separately due to the scheduling and coordination issues related to the 24/7 operation of the Centerm Terminal as well as the additional cost of excavation and trenching. The CEP project has a fixed timeline and budget and the installation of yard tractor charging infrastructure would result in a scope change and potential impact on project timeline. Without BC Hydro incentives, the VFPA Infrastructure Development team would not consider proceeding with this project.

Understanding Existing Diesel Yard Tractor Consumption During One Shift: While DP World Vancouver have provided a baseline average annual fuel consumption value of 16,000 litres per year per vehicle, it is important to understand the average and maximum fuel consumption over a single shift considering the typical operations at the Centerm Terminal. For this study, the best available information has been used with reference to prior studies completed at POLA/POLB, while also considering the operational differences between those ports and Centerm. However, prior to moving forward with the pilot implementation, the existing energy consumption over a single shift at Centerm should be verified as this will inform the requirement for the battery electric yard tractor battery capacity.

Technology Development of Battery Electric Yard Tractor Meeting DP World Vancouver's Operational Requirements: As noted in this report, a number of studies have been undertaken for the Port of Long Beach and the Port of Los Angeles that have investigated the implementation of battery electric yard tractors for those container terminals. These studies have demonstrated that it is feasible to replace existing diesel vehicles with battery electric vehicles at these terminals, and a pilot installation is currently taking place at the Port of Long Beach.

However, the operational requirements for the DP World Vancouver terminal are more stringent than requirements at the Port of Long Beach. For example, the towing capacity requirement (132,000 lbs for DP World Vancouver versus 70,000 lbs for POLB) and the operating hours (24 hours/day at DP World Vancouver versus 14 hours/day at POLB) add additional requirements and constraints for the yard tractor vehicle and associated charging systems. However, note that manufacturers are actively developing battery electric yard tractors and models with higher load capabilities and battery capacity will likely be released in the next few years. It is anticipated that a yard tractor meeting DP World Vancouver's operational requirements will be available in the next two years.

High Electrical Demand Associated with Concurrent Charging of Entire Fleet

The full implementation of the entire fleet of 60 battery electric yard tractors introduces a large electrical demand of approximately 15 MW. It is recommended that other methods and options for the charging of the battery electric yard tractors be investigated during the detailed design that could potentially mitigate the high demand associated with the concurrent charging of all battery electric yard tractors. One potential option would be to have DP World Vancouver personnel employed to manage the plugging and charging of the yard tractors, similar to the existing diesel vehicle fueling role. This would include the implementation of approximately ten (10) additional yard tractors which are charged during a shift and are continually swapped with depleted yard tractors in operation, as required. An operation conducted in this way would only require approximately ten (10) charging stations and would result in a maximum daily demand of approximately 2.5 MW.

10 Exclusions & Assumptions

The following assumptions were made with respect to this study:

- Diesel fuel consumption provided by DP World Vancouver was used to determine baseline GHG emissions and energy consumption. This value was not independently verified.
- The typical hourly diesel fuel consumption included in the 2018 Draft Feasibility Assessment for Cargo-Handling Equipment was used for the calculation of the electrical tractor battery requirements, charger capacity, and the electrical tractor OPEX. These values were not independently verified.
- Where possible, the capital cost estimate has included civil and electrical works being completed concurrently with proposed CEP civil and electrical infrastructure works and includes the cost savings realized by completing this work concurrently.
- The Energy Economy Ratio (EER) of 5.3 reported by CARB was assumed to be accurate for the implementation of battery electric yard tractors at Centerm Terminal.
- The existing BC Hydro 12.5 kV service feeders have sufficient capacity to support the proposed electrical infrastructure.
- Charging time for each yard tractor will be minimum one hour per shift.
- The existing space available in the yard tractor parking area is sufficient for accommodating the installation of the EV charging substations and DC fast charging stations.
- Terminal Operator will allow access for the construction of the electrical infrastructure during the normal working hours. Night and weekend construction costs are not included in the CAPEX.
- Yard tractor maintenance costs are based on regular truck maintenance costs. Battery electric yard tractor maintenance costs are 70% of diesel tractor maintenance costs.
- Inflation rate of 2% has been assumed in preparation of cost estimates.
- BC Hydro energy and demand charges have been estimated based on proposed Demand Transition Rate for fleet electrification and not the existing Large General Service (LGS) rates.
- It has been assumed that the existing diesel trucks are fueled once per day by DP World Vancouver personnel making a salary of $100,000/year.

This study includes the following exclusions:

- Investigation of potential DC fast charging products were not investigated as part of this study. There are numerous manufacturers that sell DC fast charging stations that would be suitable for this application (Level 3 DC fast charging stations around 200 kW).
- Other brands of battery electric yard tractors were not considered as part of this study.

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