UBC SUSTAINABILITY SCHOLAR PROGRAM 2018

Reducing Vancouver Board of Parks and Recreation Emission Footprint through Utilizing Electric Small Equipment

Prepared by: Gerardo Marquez, Greenest City Scholar, 2018
Prepared for: Carla Grimann, Fleet Supervisor, Vancouver Park Board, City of Vancouver, August, 2018

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Executive Summary

This Greenest City Scholars report was prepared to support the City of Vancouver's goal to become the Greenest City in the world by 2020. As part of the Greenest City Action Plan (GCAP) goals, the City is aiming to 'green' its operations by reducing GHG emissions from operations by 50% of 2007 levels and eventually eliminating fossil fuel dependency. Assuming this important target, the Vancouver Board of Parks and Recreation (Park Board) is aiming to reduce carbon dependency by exploring the feasibility of switching from gas-powered to electric equipment.

The Park Board uses four primary types of small gas-powered equipment (blowers, line trimmers, hedge trimmers and chainsaws) which have an average fuel consumption of almost 96000 L/yr, produce almost 600 Tons of CO_2e. This amount of GHG emissions is equivalent to the total CO_2 emissions of 230 cars.

The electric equipment proved to be an excellent option to invest to reduce carbon intensity, noise level and heath effect of the operators exposed directly to the gas exhaust. After evaluation the Life Cycle Analysis (LCA) of the battery production and recycling, its GHG emissions reaches only between 1.5-1.8% of the emission generated by the existing gas-powered equipment.

The capital cost of the electric equipment are C$ 328,582.00 (Stihl) and C$ 463,320.00 (Husqvarna), however, the investment is totally recovered after the second year due to the operating costs savings. The Return of Invest ROI become positive for both brands, having a ROI of 71.32% (Husqvarna) and 141.15% (Stihl).

Finally, it was found through the surveys that most operator prefer Husqvarna for its performance and comfort. However, both brands fulfill the minimum requirements according the use demanded by the Park Board daily operations.

1. INTRODUCTION

Under the Framework of the Greenest City Action Plan the Vancouver Board of Parks and Recreation (Park Board), is taking action to achieve the City's Green Operations goal in support of making Vancouver the Greenest City in the world by 2020. Reducing their emissions footprint through utilizing electric small equipment enables the Vancouver Board of Parks and Recreation to demonstrate its commitment to reducing dependence on fossil fuels used by electric blowers, trimmers and chainsaw.

This project intends to evaluate the technical and economic benefits of adopting small electric equipment for the Park Board and the community. Other benefits include reducing the harmful health impacts caused by equipment noise, exhaust and hand arm vibration (HAV).

1.1. Background

Canada's Air Pollutant Emission Inventory (APEI) is a comprehensive inventory of air pollutant emissions at the national and provincial/territorial levels. The APEI compiles emissions of 17 air pollutants that contribute to smog, acid rain and diminished air quality, including Smog precursors: total particulate matter (TPM), particulate matter (PM) less than or equal to 10 microns (PM10), PM less than or equal to 2.5 microns (PM2.5), Sulphur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO) and ammonia (NH3) (Canada Government, 2018).

The figure 1 shows the contribution of transportation, off-road vehicles and mobile equipment to national air pollutant emissions by transportation mode (Canada Government, 2015).

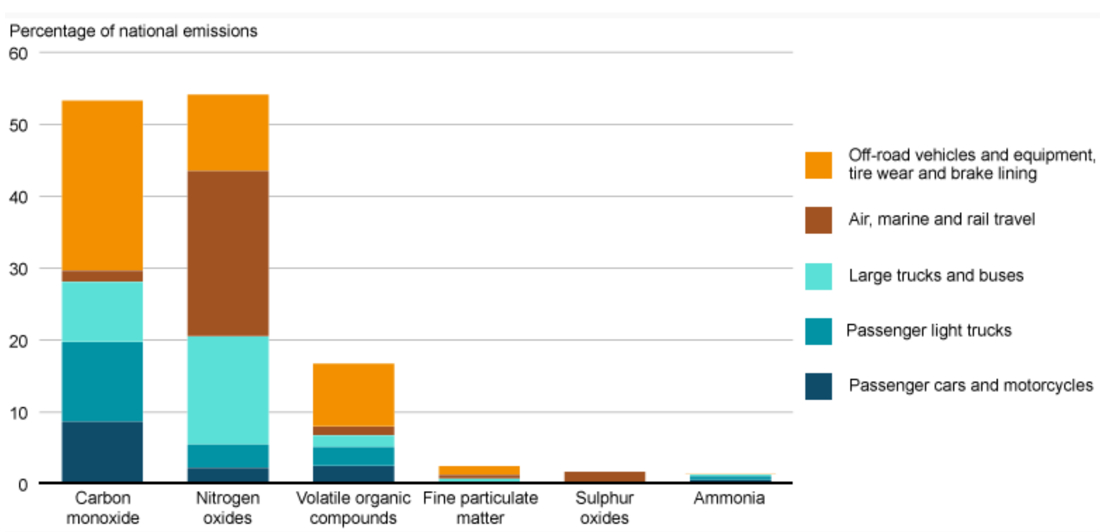


Figure 1 Greenest Standing Committee on Policy and Strategic Priorities [Canada Government, 2015]

Parks and Recreation is one of six departments with major operational impacts on greenhouse gas emissions, representing a 30% of global GHG emissions of Parks Board at City of Vancouver. Figure 2 shows the corporate GHG emissions by department and the significant contribution made by park operations. Although most of the emissions are from the operation of community centers, small equipment such as chainsaws, lawnmowers and trimmers have also been identified as contributors.

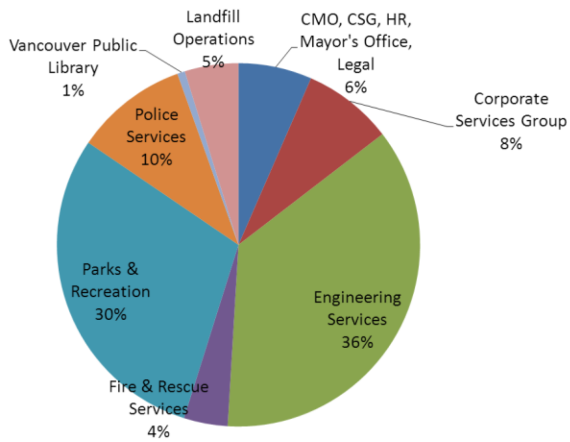


Figure 2 Corporate GHG Emissions by Department, Excluding Landfill Gas Emissions [Canada Government, 2015]

The chart below describes the GHG emission reduction of the Parks Board, since 2014, from 2007 baseline and the GHG target reduction for 2020. Even though, the significant reduction, Park Boards is still at half way point, which indicates the necessity of increases effort and diversify reduction mechanisms. Among the equipment used by the Parks Board, small equipment represents an important source GHG emission, being called small equipment all the equipment used to mow grass & shrubs, cut tree branches and electric cleaning equipment

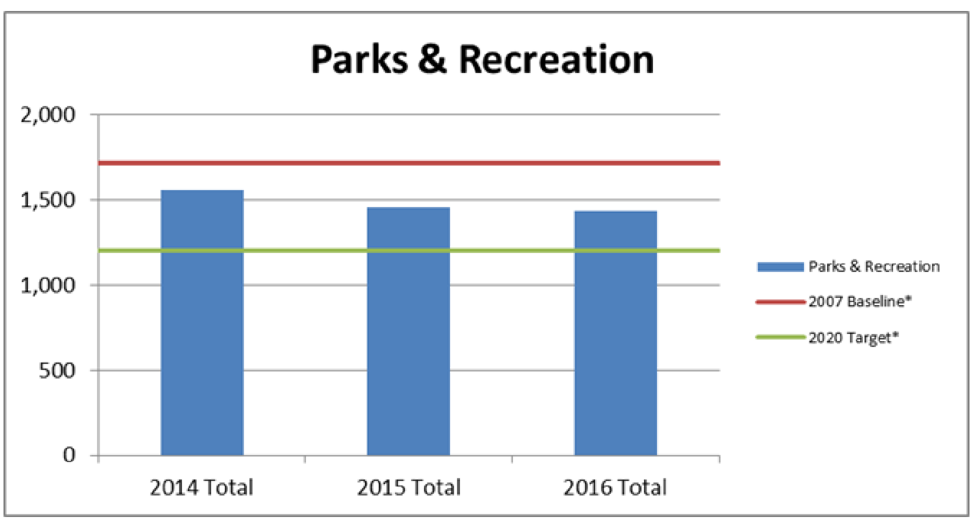


Figure 3 Parks fleet fuel GHG emissions [City of Vancouver, Green Operations]

1.2. Approach

This study is supported on relevant information and data collected through the following actions:

- Interview on stakeholders regarding usability
- Site tours on locations to collecting usage information of gas powered equipment
- Development and administration of survey of gas powered equipment used electric equipment testing on field.
- Measure the current footprint of small equipment
- Research on worldwide case studies demonstrating small electric equipment for similar uses
- Analyze on technical and economic information.
- Research on Risk and Health benefits
- Life Cycle Analysis of small equipment batteries

1.3. Findings

- There are in total 421 small gas powered equipment in service in all the City of Vancouver's Park Board Yards. The total average annual fuel consumption is 95992 litres per year.
- The Park Board uses four primary types of small gas powered-equipment, line trimmers and Blowers are used the most.
- The annual average GHG emissions of all the small equipment reach almost 600 Tons of CO_2e, representing the total CO_2 emissions of 230 cars.
- Most operators have a clear preference on electrical equipment over the gas powered and Stihl electric equipment. The big majority of operators find that all equipment work properly. The majority of staff prefers Husqvarna equipment with 67% replying positively to trying an electric Husqvarna over the Stihl electric equipment. Noise and non-gas exhausts are the best indicators.
- The analysis of the LCA of the battery equipment GHG emissions from battery production and recycling is 10793.29 kg CO_2e (Husqvarna) and 8969.15 kg CO_2e (Stihl).
- The total annual average operating costs of the gas-powered equipment are 400,708.5 dollars per year. The total annual average cost of the electric equipment would be 4,468.6 dollars per year (Husqvarna) and 3,748.65 dollars per year (Stihl).
- Even though the capital costs of electric equipment are higher, the operating costs make these options economical viable. The Return of Invest for Stihl and Husqvarna options (Table 16) is positive in the first year for Stihl. In the second year both equipment have a positive ROI of 71.32% (Husqvarna) and 141.15% (Stihl).

1.4. BC's Electricity System

The transition away from fossil fuels will place new demands on B.C.'s electricity system. Tough conservation measures and major efficiency gains in BC's use of electricity will be necessary. However, a growing population and electrification of transportation and buildings will increase demand for electricity and will likely result in upward pressure on electricity prices due to the higher cost of acquiring new power (BC Hydro).

B.C.'s electricity needs are met primarily through hydroelectricity, which is relatively cheap in comparison to other power sources and are GHG emissions are relatively low. The hydroelectric-based power can vary significantly from year to year. Depending on the stream flows or reservoir levels, available hydro power must be supplemented through fossil-fuel and/or through increased use of B.C. thermal generation.

Figure 4 Hydro Generating Station at Campbell River [BC Hydro]

2. SMALL EQUIPMENT

The Parks Board utilizes a variety of small equipment to carry out daily functions over tis 240 locations, specifically parks, destination gardens, community centers and golf courses.

The following equipment types were analyzed for their potential to reduce GHG emissions and have a lower environmental and health impact when switched from gas powered to electric/battery powered:

- Blowers
- Trimmers
- Hedge Trimmers
- Pole Pruner
- Cut-off Saws
- Chainsaws

2.1. Stakeholder & Tour of Yards

Fraser Valley Equipment is the main supplier of small equipment. On the other hand, Stihl and Husqvarna are the two brands of equipment used by the Parks board. During the project, meetings were held with all stakeholder involved in the supply, use, maintenance and repair of the small equipment under this study, as well as other municipalities with experience in the use similar equipment, with the follow purpose:

- Understand the necessity of the operator
- Technical specification of the equipment and differences and advantage of Husqvarna and Stihl equipment
- Supply chain and level of criticality level of equipment parts
- Coordination for testing equipment
- Benefits and detriments on the usage of electric small equipment

Regarding the tour of yards to view the operation of the gas-powered and electric equipment on the field. The following locations were visit during the development of the project to interview workers, superintendent and managers regarding the equipment performance:

1. Stanley Park
2. City Hall
3. McCleery Golf Course
4. Riley Park
5. Bobolink Park

Figure 5 Locations of Interviews and Surveys

2.2. Gas Powered Equipment

The vast majority of the small equipment used by the Park Boards is gas powered. Therefore, through this study is intended to measure the number of each equipment and its GHG emissions, as well as the effect of such gasses on the operators and the community.

2.2.1. Existing Gas Equipment

From data provided at Evan Yards, there are currently 421 gas powered equipment. The Table 1 shows the type and models of the equipment used by Parks and Recreation in the different areas operated by City of Vancouver. It is also shown the total annual average consumption of gasoline of use (L/year), according evaluation on field and questions to operators in charge of fueling the tank of the equipment.

Table 1. Quantity and consumption of the gas-powered equipment used by Parks Board

Nr. Item	Description	Qty	Fuel Consumption (L/year)
TRIMMERS			
1	FS 111 R	51	67473
2	FS 240	50	66150
3	FS 560 C-EM	21	27783
	Total Trimmers	**122**	**161406**
HEDGE TRIMMERS			
1	HS 82 T & HS 82 R	30	1470
2	HL 91K	3	147
3	HL 94	6	294
	Total Hedge Trimmers	**39**	**1911**
POLE PRUNNER			
1	HT 103	8	392
2	HT 133	30	1470
	Total Pole Prunner	**38**	**1862**
CUT-OFF SAWS			
1	TS 700	2	134
2	TS 800	2	134
	Total Cut-off Saws	**4**	**268**
CHAINSAWS			
1	MS 211	20	1500
2	MS 461	29	2175
3	MS 661	14	1050
4	MS 880	13	975
	Total Chain Saws	**76**	**5700**
BLOWERS			
1	BG 86	8	5408
2	SH 56 C-E	16	10816
3	BR 200	110	74360
4	BR 500	8	5408
	Total Blowers	**142**	**95992**

2.2.2. Gas-Powered Equipment Operability

Operators and superintendents at different Park Board locations were given a survey to evaluate the operability and performance of small gas-powered equipment and get a better understanding of the different usages according the activities required at the city.

The Park Board uses four primary types of small gas powered-equipment, line trimmers and Blowers are used the most. Figure 7 shows percentage of average use of the four types during a year.

Among the most important finding obtained through the surveys are:

1. Line trimmers are used mainly at the beginning of spring, summer and fall.

2. All small gas-powered equipment on use are made by Stihl

3. Most equipment operators agree that the performance of the equipment is acceptable; however some blower models are heavy.

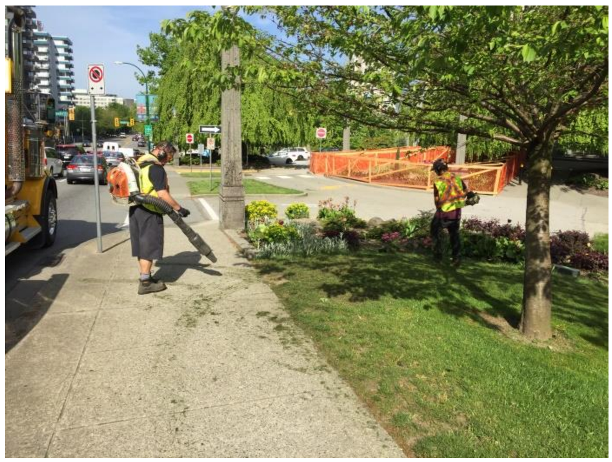


Figure 6 Gas-powered equipment operation at Vancouver City Hall

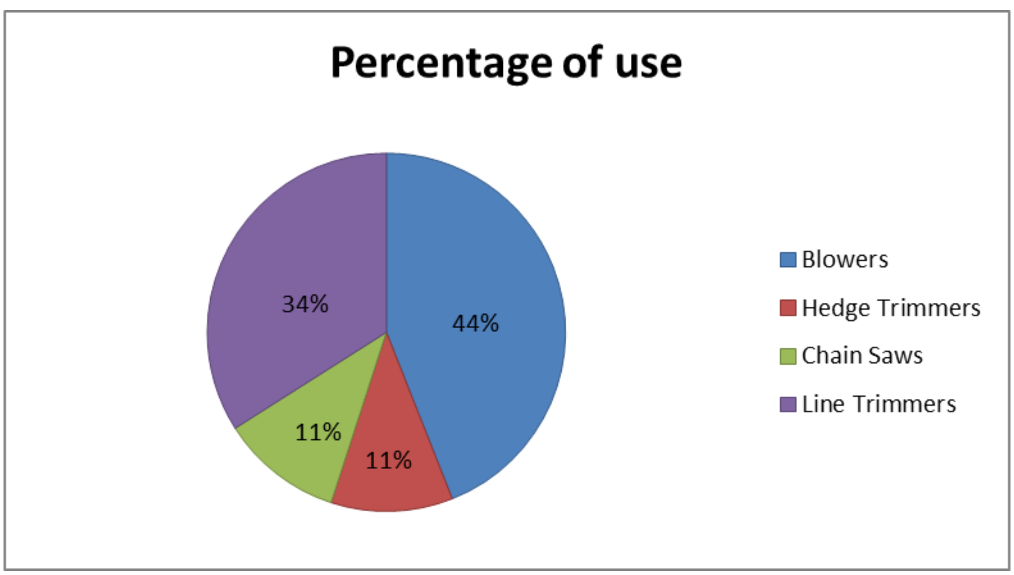
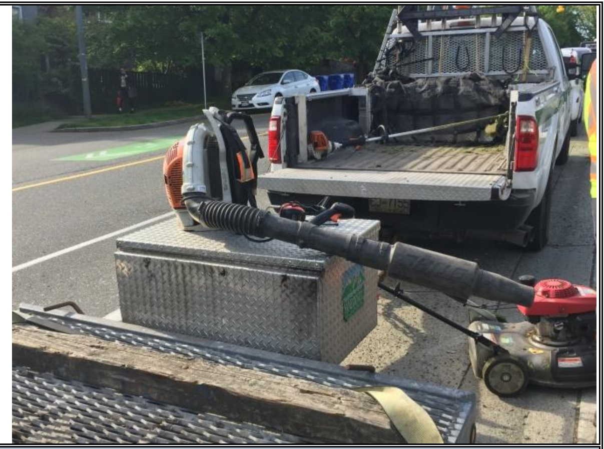


Figure 7 Percentage use of gas-powered equipment during the year

Trimmer operation at Stanley Park



Blower at City Hall

Equipment storage at Riley Park

Equipment operation

Figure 8 Gas-powered equipment at different locations

2.2.3. Current Carb

Greenhouse gases vary in their ability to trap heat in the atmosphere (radiative forcing). "Global warming potential" (GWP) is a measure of this ability. The GWP of a GHG accounts for both the immediate radiative forcing due to an increase in the concentration of the gas in the atmosphere, and the lifetime of the gas. The GWP for each GHG is expressed as the ratio of its heat trapping ability relative to that for CO_2. Recent updates to British Columbia's GWPs have been made in line with updates by the United Nations Framework Convention on Climate Change and the Canadian Federal Government, to GWPs approved by the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (Best Practice Methodology). Carbon footprint is the total emission of caused by the Parks Board during one year of operating small-powered equipment, expressed as Carbon Dioxide equivalent (CO_2e).

Figure 8 shows the exhaust gases location of a line trimmer and a blower. Under operation these exhaust location are at short distance to the head of the operator, making it difficult not to breathe the gases.

Line trimmer exhaust combustion gases	Gasoline Tank at Stanley Park offices

Figure 9 Small equipment combustion gases

Local Government in British Columbia signed the Climate Action Chapter (CAC), committing to develop strategies for measuring and reporting on their community's GHG emissions profile. The three principal gasses associated with full combustion for energy are CO_2, CH_4 and N_2O. Specifically, for the combustion of the gas-powered equipment, the primary GHGs emitted in significant amounts are CO_2 and CH_4.

2.2.3.1. GHG Emissions Calculations

To calculate GHG emissions of Park Board small gas-powered equipment, produces emission specifications obtained from Stihl were converted to determine fuel consumption.

A list of emission specification for each type of equipment is provided in Appendix B.

Based on the data provided and the average annual use of the small equipment at Park Boards, it is determined the total CO_2e using the B.C. Best Practice Methodology for quantifying GHG emissions and under the Public-Sector Organizations (Fleet, specifically, Off-road vehicle and equipment, section 4), described in the following procedure:

Table 2. Emissions in Tons of CO_2e

Type of equipment & Model	Average annual GHG emissions			
	kg CO2	**kg CH4**	**kg N2O**	**kg CO_2e**
TRIMMERS				
FS 111 R	148440.6	182.1771	3.37365	150599.7
FS 240	145530	178.605	3.3075	147646.8
FS 560 C-EM	61122.6	75.0141	1.38915	62011.66
HEDGE TRIMMERS				
HS 82 T & HS 82 R	3234	3.969	0.0735	3281.04
HL 91K	323.4	0.3969	0.00735	328.104
HL 94	646.8	0.7938	0.0147	656.208
POLE PRUNNER				
HT 103	862.4	1.0584	0.0196	874.944
HT 133	3234	3.969	0.0735	3281.04
CUT-OFF SAWS				
TS 700	294.8	0.3618	0.0067	299.088
TS 800	294.8	0.3618	0.0067	299.088
CHAINSAWS				
MS 211	3300	4.05	0.075	3348
MS 461	4785	5.8725	0.10875	4854.6
MS 661	2310	2.835	0.0525	2343.6
MS 880	2145	2.6325	0.04875	2176.2
BLOWERS				
BG 86	11897.6	14.6016	0.2704	12070.66
SH 56 C-E	23795.2	29.2032	0.5408	24141.31
BR 200	163592	200.772	3.718	165971.5
BR 500	11897.6	14.6016	0.2704	12070.66
		Total kg CO_2e/year		596254.2
		Total t CO_2e/year		**596.2542**

The table 3 shows that annual average GHG emissions reached almost 600 Tons of CO_2e.

2.2.3.2. Healthy Effects on workers

Based on studies done on the contribution of gas-powered lawn and garden equipment (GLGE) to air pollutant emissions in the United States and Canada, it has been determined that lawn gas powered equipment is a source of high levels of localized emissions that includes hazardous air pollutants and criteria pollutants.

Workers using commercial equipment are exposed when they are close to the emitting sources several hours each day, several days a week in seasons of use. Other members of the public, including children, may also be exposed to high levels of emissions from commercial landscape maintenance equipment (GLME) such as leaf blowers, trimmers, and mowers, used routinely around residential neighborhoods, schools, parks, and other public spaces (McConnell, 2015).

2.3. Electric Equipment

The use of small electric equipment by the Parks Board is not new. Some departments, such as Urban Forestry located at Evans Yard, have already adopted the use of small electric equipment in their daily activities. Several municipalities in North America and Europe have been working for many years with such equipment.

In order to find out the operational benefits and its disadvantages, several activities were held to perform the evaluation of small electric equipment existing in the market. Such activities and important findings are mentioned in Appendix C.

2.3.1. Testing of Electric Equipment

Through the coordination with representative of Husqvarna and Stihl equipment, operators were provided an opportunity to try for several days different small electric equipment and ask questions about the applicability of equipment to their work and its benefits perception in compared with the gas-powered equipment.

2.3.1.1. Stihl Electric Equipment

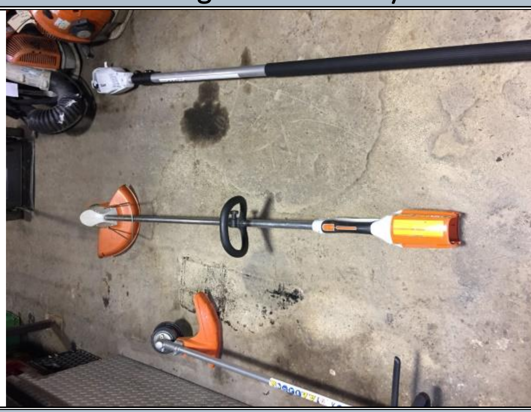
In the table 3 and figure 10 are shown the Stihl equipment used during the period of test at different parks location.

Table 3. Stihl equipment tested

STIHL Small Electric Units				
Item	Qty.	Equipment	Model	Serial Number
1	1	Blower	BGA 85	432 982 036
2	1	Blower	BGA 100	435 324 877
3	1	Backpack Battery	AR 1000	981 251 070
4	1	Backpack Battery	AR 3000	981 236 028
5	1	Pole Pruner Saw	HTA 85	438 054 259
6	1	Extension Hedge Trimmer	HLA 85	434 917 810
7	1	Trimmer	FSA 130	436 463 195
8	1	Chain Saw	MSA 200	434 071 101
9	1	Trimmer	FSA 85	433 085 210
10	1	Hedge Trimmer	HSA 66	436 048 751
11	4	Battery Chargers	AL 300	-
12	2	Battery Chargers	AL 500	-
13	6	Batteries	AP 300	922 059 250
14				922 059 254
15				922 059 257
16				922 059 260
17				922 059 261
18				922 059 263

Chargers and battery

Electric blower



Line Trimmer

Top Handle Saw

Back Pack (battery)

Saw

Figure 10 Stihl electric equipment used for testing at different locations

2.3.1.2. Husqvarna Electric Equipment

In the table 4 and figure 11 are shown the Husqvarna equipment used during the period of test at different parks location.

Table 4. Husqvarna equipment tested

Husqvarna Small Electric Units				
Item	Qty.	Equipment	Model	Serial Number
1	1	Pro Blower	436LiB	20165100489
2	1	Pro Saw Rear Handle	536LiXP	20173200012
3	1	Pro Top Handle Saw	T536LiXP	20171400227
4	1	Pro Trimmer	536LiLx	20180400065
5	1	Pro Hedge 24”	536LiHD60X	20180500075
6	1	Pro Hedge 22”	536LiHE3	20165000018
7	4	Battery	Bli300	20180308515
8				20180308516
9				20180308456
10				20180308520
11	2	Battery	Bli150	50154822074
12				50154822073
13	2	Charger	QC500	20173510383
14				20173208873
15	1	Backpack Battery	Bli950X	

Batteries

Electric blower

	
Back Pack	Chargers and bateries
	
Back Pack (battery)	Line Trimmer
	
Saws	

Figure 11 Husqvarna electric equipment used for testing at different

2.3.2. Electric Equipment Evaluation

In order to get feedback of the equipment tests, operators and superintendents at different Park Board locations were given a survey designed to evaluate the operability and performance of the electric equipment described in sections 2.3.1.1 and 2.3.1.2.

The survey included questions related to, the use of electric equipment; the perception of operators regarding the battery duration; recharging time; power of the equipment; ergonomic &

comfort; concerns that they might have regarding the use electric equipment; and general opinion of their preferences.

This survey received feedback from five different locations (see figure 5) and it was intended for approximately 40 operators, 35 of which responded the survey.

Most operators have a clear preference on Husqvarna electrical equipment over the gas powered and Stihl electric equipment (Figure 18). Comparing the operability and performance of both electric equipment, line trimmers have the best evaluation in terms of noise, vibration, weight control and power (Figure 12-16).

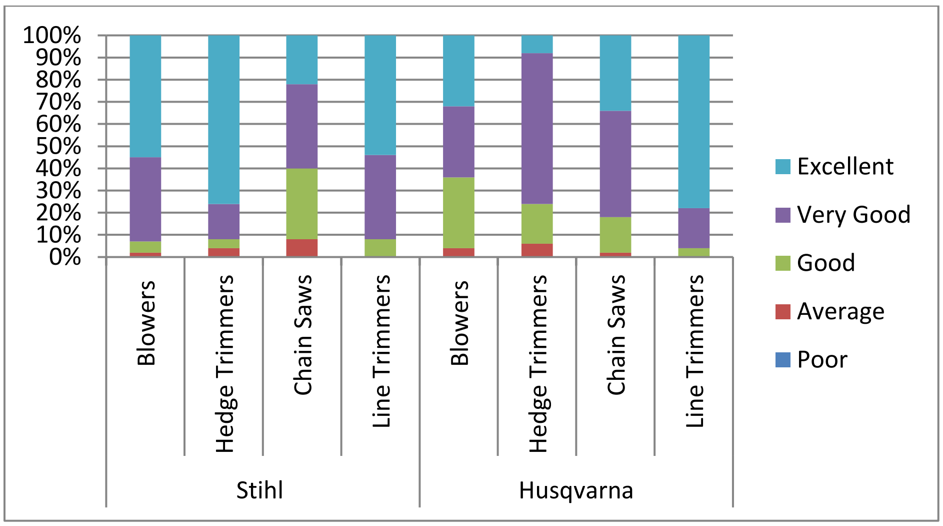


Figure 12 Vibration

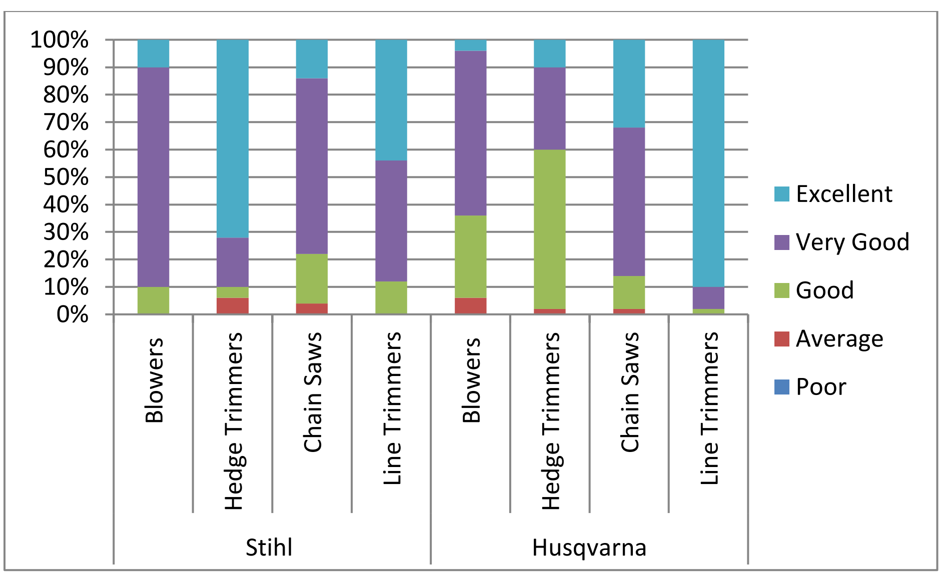


Figure 13 Noise Level

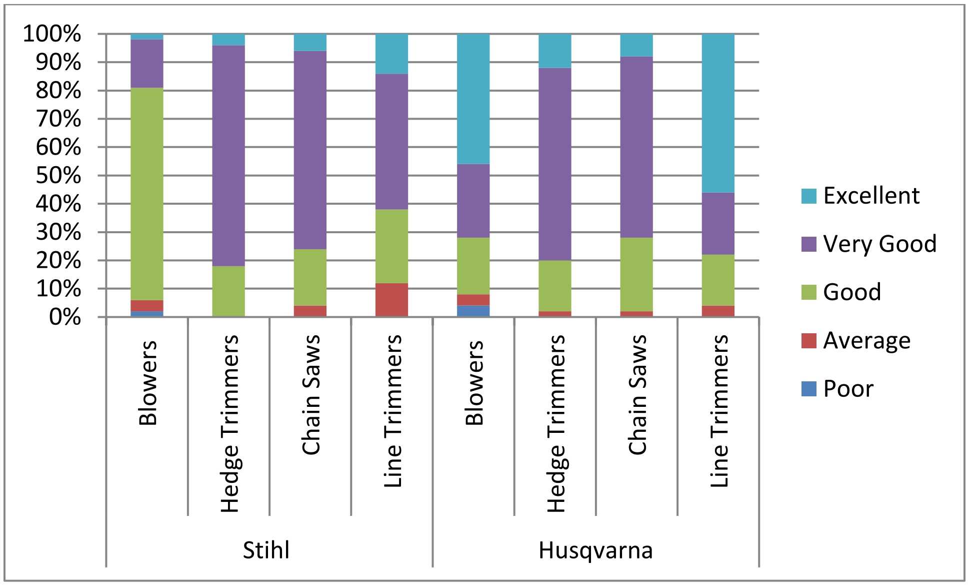


Figure 14 Weight / balance

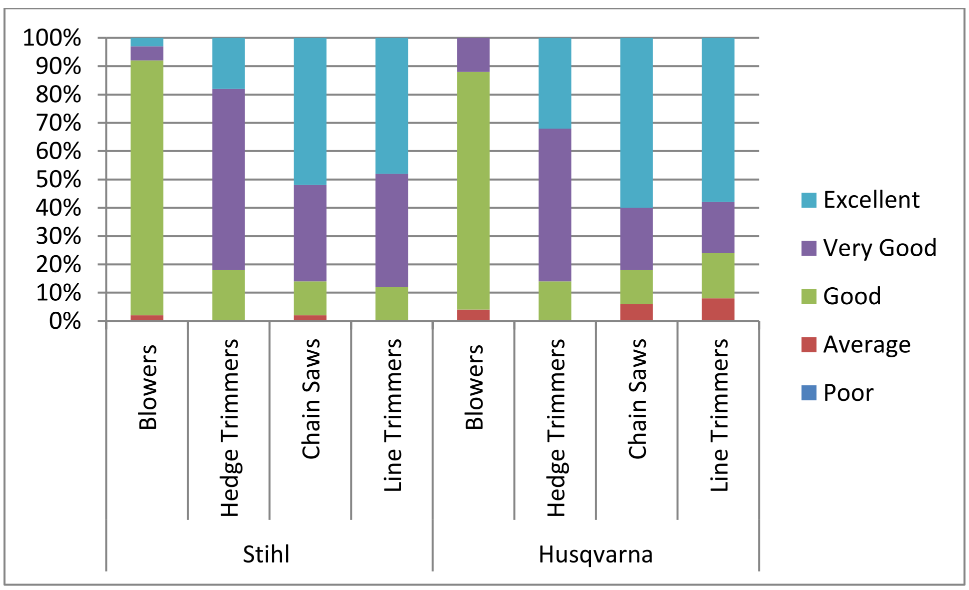


Figure 15 Control

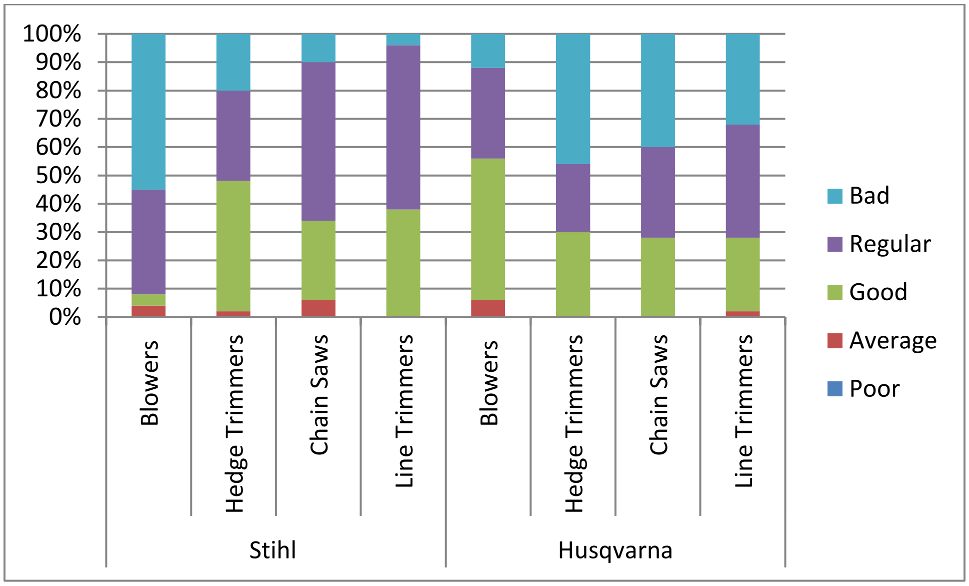


Figure 16 Power

The big majority of operators find that all equipment work properly (100% for Husqvarna's line trimmer, blowers and hedge trimmers), see figure 17.

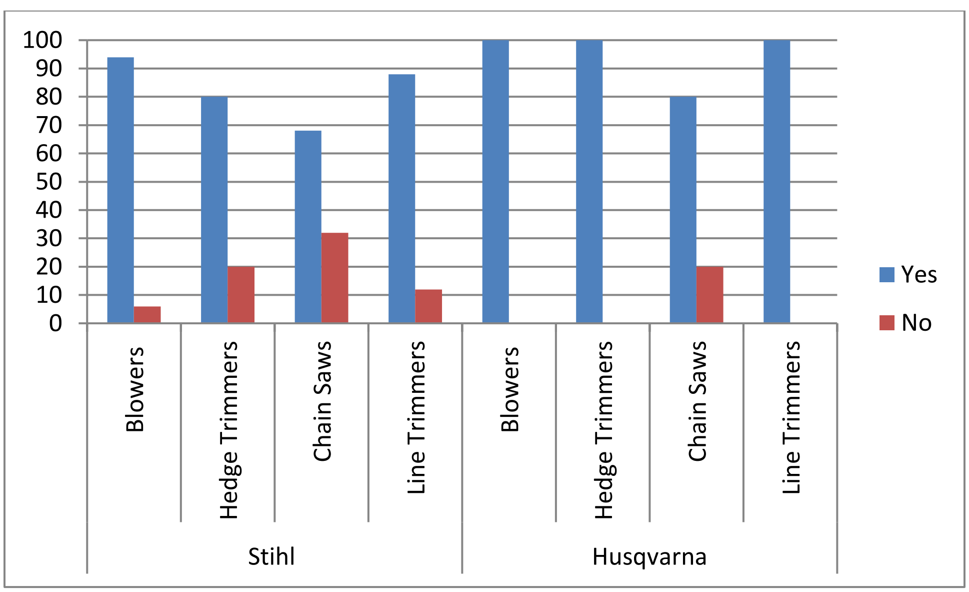


Figure 17 Work Properly

Operators find that all Husqvarna' devices has a better performance than gas powered equipment (80% performance better in the case of hedge trimmer).

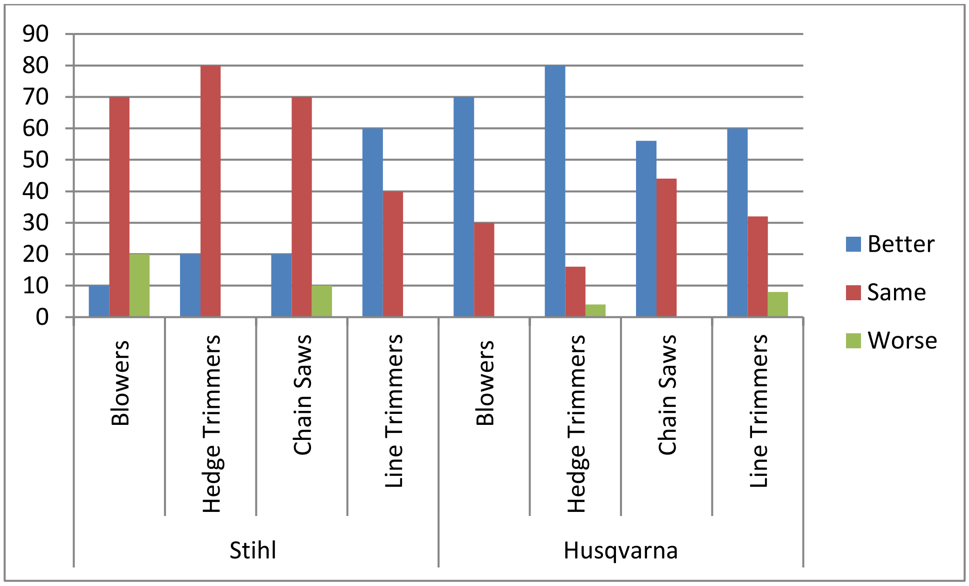


Figure 18 Performance compared with gas powered equipment

According to the operators, all equipment have a long battery duration, with exeption of the Stihl blowere, which 64% of the operators stated that lasted between 1-2 hours.

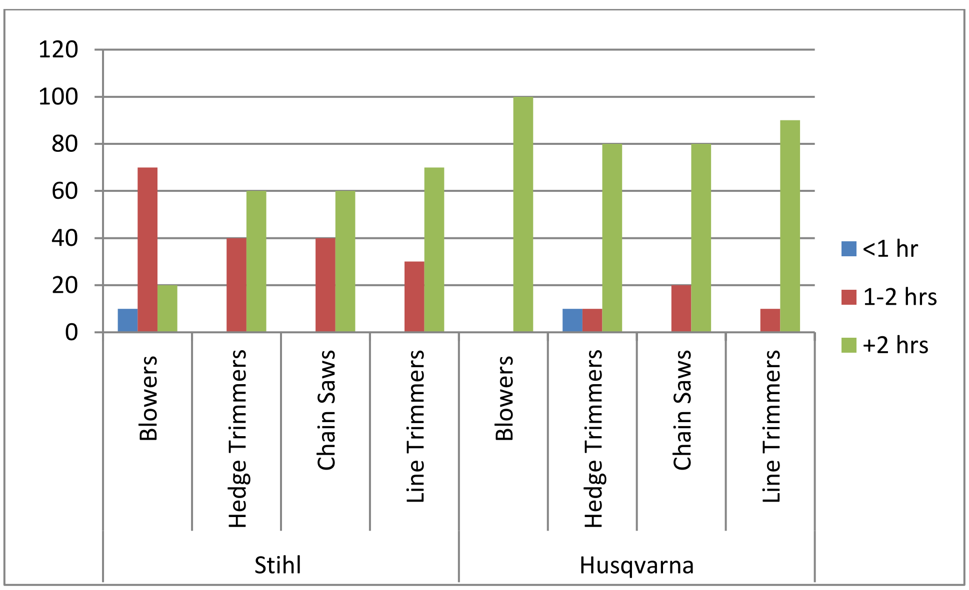


Figure 19 Battery Duration

The figure 20 indicated how fast the batteries charged. This indicator was measured to have knowledge how operators manage to charge the batteries, however, the charging time depends on the type of batteries (see table 5).

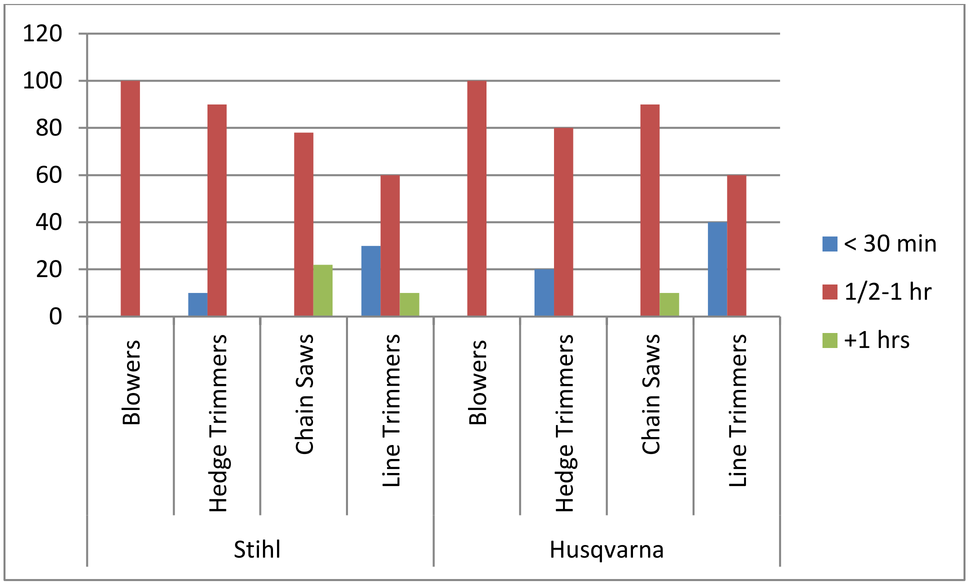


Figure 20 Time to charge

The majority of staff prefers Husqvarna equipment with 67% replying positively to trying an electric Husqvarna over the Stihl electric equipment.

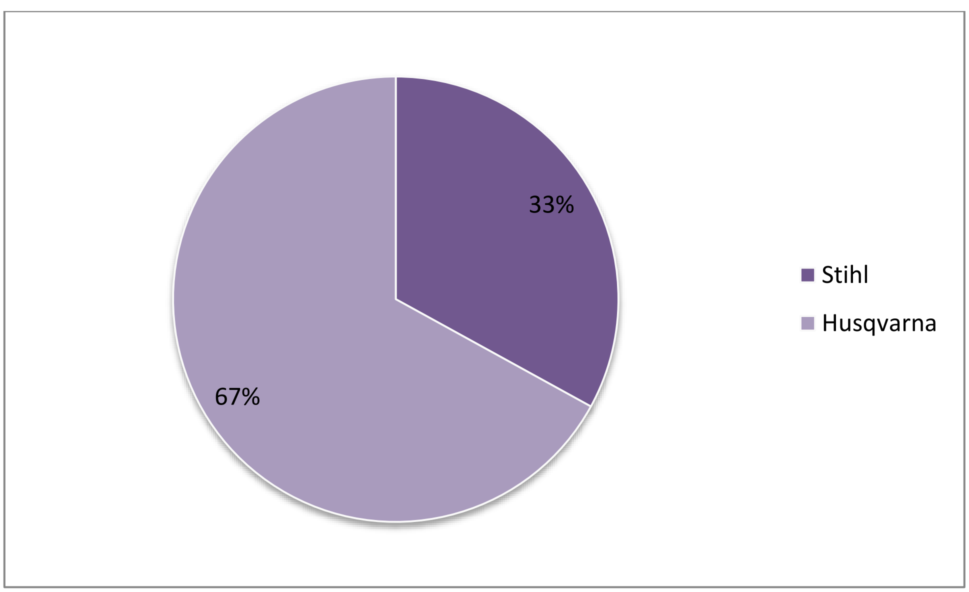


Figure 21 General Preference

To summarize, the results demonstrate that operators are inclined towards the electric equipment, especially for the Husqvarna devices). Noise and non-gas exhausts are the best indicators. The big majority of operators find that all equipment work better, 100% of the opinions believe that work better for Husqvarna's line trimmer, blowers and hedge trimmers.

	
Line Trimmer	Blower & Back Pack (battery)

Figure 22 Electric equipment operation at Bobolink Park (left) and Staley Park (right)

2.3.3. Preliminary LCA Batteries

Lawn and garden electrics equipment are powered with lithium-Ion battery (LIB), which is proved to be the best option to guarantee the best performance and durability to deliver convenient power and run time.

This section performs a literature and summary of the lithium supply into the future and examines the life cycle implications of the extraction of lithium projected over the time period where lithium demand is expected to spike.

The availability of lithium is best represented using the cumulative availability curve (Yaksic, et al.) shown in Figure 1. The cumulative availability refers to the amount of resources available to be extracted with the current technology at a given extraction price for lithium. The graph is divided into three sections denoted viable, marginal and ocean. Viable resources represent the lithium reserves for which the extraction cost is within the peak 2008 production cost of 6.4 US dollars per kilogram ($/kg). Marginal resources are those with higher production estimates than current prices. Ocean refers to the vast lithium reserves in the ocean that are potentially available for future extraction (Madhan, et al,).

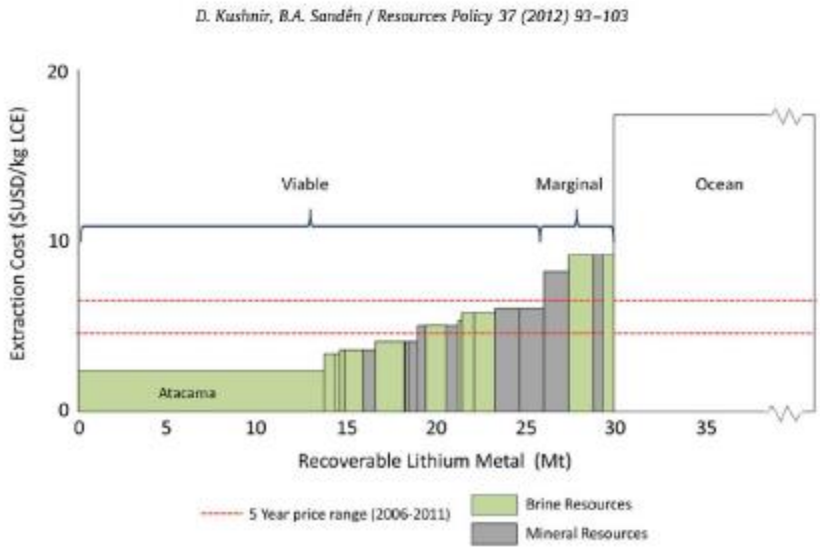


Figure 23 Cumulative availability curve of lithium [Kushnir and Sanden, 2011]

Current lithium production rate is roughly 25 kilotons per year (kt/year) as metal equivalent. While lithium has many uses, as Figure 12 demonstrates around 39% of global lithium production goes into batteries. The expected future demand growth rate of the other applications of lithium are modest and while are significant do not affect the viability of lithium batteries in electric vehicles (Kushner and Sanden, 2011).

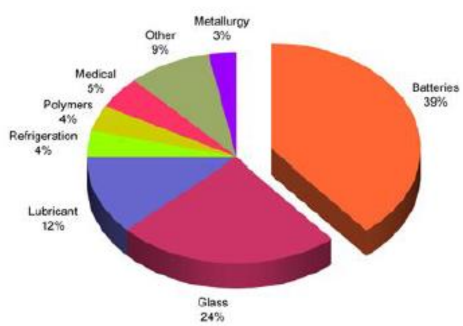


Figure 24 Proportional use of lithium in various applications in 2011 [Global Lithium LLC, 2016]

LIB manufacturing is a complex process comprised of numerous sub-processes, as depicted in Figure 13. Note that solvents are needed for the electrode material preparation process, to make the electrode material slurry for subsequent electrode coating. Currently, N-Methyl-2- Pyrolidone (NMP) is typically used for the positive electrode (hereinafter referred to as cathode) materials, while water is typically used for the anode electrode (hereinafter referred to as anode) materials (Wood III et al 2015). Due to cost and environmental concerns, NMP is usually recovered after the solvent evaporation process and reused for future LIB production (Wood III et al 2015). Also note that some of the electrode production processes, as well as the entire cell assembly process, need to take place in a dry room, in which the moisture content of the air cannot exceed 100 parts per million by volume (ppmv), to prevent LiPF6, the dominant electrolyte salt, from detrimental reaction with water (Ahmed et al 2016a).

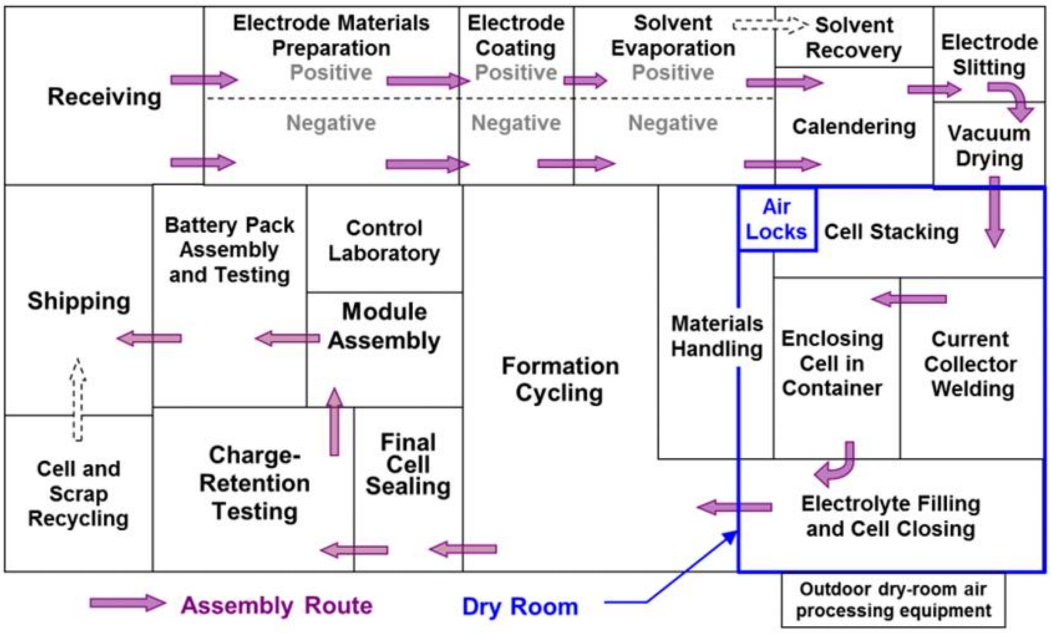


Figure 25 Process Schematic for LIB Pack Manufacturing Figure [ANL 2017]

2.3.3.1. GHG Emissions Related to the Production of Lithium-Ion Battery

The results from different assessments vary due to a number of factors including battery design, inventory data, modelling and manufacturing. Based on the review from different papers of lithium-ion batteries, GHG emissions of 150-200 kg CO2-eq/kWh battery look to correspond to the GHG burden of current battery production. Energy use for battery manufacturing with current technology is about 350 – 650 MJ/kWh battery (Romare M, 2017). For this study, it is considered the bottom limit value of the range stated by the Swedish Environmental Research Institute.

For this study, it was chosen to attempt to divide the impact between (Romare M, 2017):

1. Mining and refining
2. Material processing (includes step one plus battery grade processing)
3. Manufacturing/assembly (components to full battery)

As mentioned in section 2.3, Urban Forestry Department is currently utilizing Husqvarna electric equipment. The Technical specifications of the new model of batteries are shown in the table 10.

Table 5. Model of batteries and technical specifications

Equipment Brand	Batteries Model	Battery Voltage, V	Capacity, Ah	Energy, Wh	Weight, kgs
HUSQVARNA	BLi300	40	9.4	335	1.77
	BLi200	40	5.2	180	1.32
	BLi100	40	2.6	90	0.86
STIHL	AP 300	36	6	227	1.7
	AP 200	36	4	151	1.3
	AP 300	36	2	76	0.8

Ah is an abbreviation for ampere-hour, or amp-hour. This the total amount of charge a battery can deliver in one hour. A power tool that continuously draws 1.0A of current will completely drain a 1.0 Ah battery pack in one hour (under ideal conditions).

According section 2.2.1, four hundred twenty one gas-powered equipments are being used by Parks and Recreation in different areas operated of City of Vancouver. **For calculation of the energy consumption purpose, it is assumed the same amount of electric equipment to be replaced and the use of BLi200 and AP 200 battery model,** according technical specification shown in table 5. . Thus, the total amount of the battery power, total energy consumption and GHG emissions for the manufacturing of all the batteries are shown in the 6.

Table 6. Total GHG emissions in the manufacturing process

Equipment Brand	Batteries Model	Energy,	Total Battery Power (kWh)	Total Energy Consumption Manufacturing (MJ)	GHG emissions (kg CO_2e)
Husqvarna	BLi200	180	75.78	26523	11367
Stihl	AP 200	151	63.571	22249.85	9535.65

2.3.3.2. ***GHG Emissions of Battery Recycling***

Recycling of lithium-ion batteries is currently low at best. This cannot be ascribed only to the lack of economic incentive inherent in the battery chemistries, it also has to do with very small battery volumes reaching end of life, poor knowledge of battery content and design, and lack of proper marking of the packs and cells (Romare M, 2017).

There are a number of technologies and combinations of technologies being developed. Hydrometallurgy is close at hand, and can potentially extract more materials than pyrometallurgy, although this is currently only done at small scale. Long term it will be necessary to extract the materials in a more processed form in order to reduce the total impact of the battery. With pyro-metallurgy only cobalt, nickel and copper can be extracted from the battery and only in their elemental form (not processed for batteries) (Romare M, 2017).

The table 7 shows details from the LCA study of a pilot stage recycling technology based on hydrometallurgy is presented. The results are from the LithoRec project (Buchert, et al., 2011b) and although they are pilot scale, they give an indication of what stages that are the most energy demanding, and what materials holds most potential for greenhouse gas reduction (Romare M, 2017).

Table 7. LCA study of a pilot stage recycling technology based on hydrometallurgy [Romare M, 2017]

	/kg battery				
	Dismantling	**Cell separation**	**Cathode separation**	**Hydro-processing**	**Total**
g CO_2-eq	234	586	213	1461	2494
Energy					
Main impact from	Transport, Steel and Al recycling	Cu recycling, washing, burning of separator	Electricity	Supporting materials and electricity	
g CO_2-eq credit	-1966	-325	-269	-970	-3530
Energy					
Materials recovered	Stainless steel and plastics	Copper and Aluminium	Aluminium	Cobalt, Nickel	
Net CO_2-eq	**-1732**	**261**	**-55**	**491**	**-1035**

For recycling implementation based on hydrometallurgy process and assuming the weight of the battery according table 5, the total GHG emissions are shown in table 8.

Table 8. Batteries total GHG emissions (Recycling)

Equipment Brand	Batteries Model	Net CO2-eq/kg by recycling	GHG emissions (kg CO_2e)
Husqvarna	BLi200	1035	-575.17
Stihl	AP 200	1035	-566.5

From GHG emissions related to the battery production, assessed the causes and potential development of these, and the end of life handling, especially focusing on recycling potential, the total GHG emissions from battery production and recycling is **10793.29 kg CO_2e (Husqvarna) and 8969.15 kg CO_2e (Stihl),** see table 9.

Table 9. Batteries total GHG emissions (Manufacturing + Recycling)

Equipment Brand	Batteries Model	GHG emissions (kg CO2-eq)	GHG emissions (kg CO2-eq)	GHG emissions from battery, production + recycling (kg CO_2e)
Husqvarna	BLi200	11367	-575.17	10791.83
Stihl	AP 200	9535.65	-566.5	8969.15

3. FINANCE EVALUATION

In order to make a case for supplementing the existing Park Board fleet with small equipment a comparison of capital and operating costs should be made to understand if this is a cost-effective option. Also, an evaluation of Return of Investment ROI could be made to see the economic advantage of switching to electric equipment.

Table 10. Total capital cost of equipment (Stihl gas-powered equipment)

Nr. Item	Description	Qty	COV Price per Unit	Total Price
TRIMMERS				
1	FS 111 R	51	$ 375.00	$ 19,125.00
2	FS 240	50	$ 519.00	$ 25,950.00
3	FS 560 C-EM	21	$ 1,075.00	$ 22,575.00
	Total Trimmers	**122**	**Sub-Total**	**$ 67,650.00**
HEDGE TRIMMERS				
1	HS 82 T & HS 82 R	30	$ 504.00	$ 15,120.00
2	HL 91K	3	$ 434.00	$ 1,302.00
3	HL 94	6	$ 1,075.00	$ 6,450.00
	Total Hedge Trimmers	**39**	**Sub-Total**	**$ 22,872.00**
POLE PRUNNER				
1	HT 103	8	$ 609.00	$ 4,872.00
2	HT 133	30	$ 649.00	$ 19,470.00
	Total Pole Prunner	**38**	**Sub-Total**	**$ 24,342.00**
CUT-OFF SAWS				
1	TS 700	2	$ 1,315.00	$ 2,630.00
2	TS 800	2	$ 1,395.00	$ 2,790.00
	Total Cut-off Saws	**4**	**Sub-Total**	**$ 5,420.00**
CHAINSAWS				
1	MS 211	20	$ 312.00	$ 6,240.00
2	MS 461	29	$ 954.00	$ 27,666.00
3	MS 661	14	$ 1,199.00	$ 16,786.00
4	MS 880	13	$ 1,485.00	$ 19,305.00
	Total Chain Saws	**76**	**Sub-Total**	**$ 69,997.00**
BLOWERS				
1	BG 86	8	$ 255.00	$ 2,040.00
2	SH 56 C-E	16	$ 272.00	$ 4,352.00
3	BR 200	110	$ 305.00	$ 33,550.00
4	BR 500	8	$ 479.00	$ 3,832.00
	Total Chain Blowers	**142**	**Sub-Total**	**$ 43,774.00**
			TOTAL (CAN$)	**$ 234,055.00**

Table 11. Total capital cost of equipment (Stihl electric-powered equipment)

Nr. Item	Model	Description	Qty	FVE - COV $	Total Price
HAND HELD PRODUCTS					
1	BGA85	CORDLESS BLOWER [36]	90	$ 235.00	$ 21,150.00
2	BGA100	CORDLESS BLOWER [36]	50	$ 337.00	$ 16,850.00
3	FSA65	CORDLESS GRASS TRIMMER [48]	60	$ 219.00	$ 13,140.00
3	FSA85	CORDLESS GRASS TRIMMER [48]	60	$ 235.00	$ 14,100.00
4	HSA66	CORDLESS HEDGE TRIMMER [48]	20	$ 519.00	$ 10,380.00
5	HLA85	CORDLESS HEDGE TRIMMER [44]	24	$ 415.00	$ 9,960.00
6	HTA85	CORDLESS TELESCOPIC PRUNER [16]	40	$ 454.00	$ 18,160.00
CHAINSAWS					
1	200C10	MSA200C 10" CORDLESS CHAIN SAW	30	$ 294.00	$ 8,820.00
2	200C12	MSA200C 12" CORDLESS CHAIN SAW	30	$ 299.00	$ 8,970.00
3	200C14	MSA200C 14" CORDLESS CHAIN SAW	16	$ 302.00	$ 4,832.00
BATTERIES AND CHARGERS					
1	AL300	AL 300 FAST BATTERY CHARGER	200	$ 89.00	$ 17,800.00
2	AL500	AL 500 FAST BATTERY CHARGER	150	$ 149.00	$ 22,350.00
3	AP300	AP 300 BATTERY LITHIUM	700	$ 175.00	$ 122,500.00
4	AR1000	AR1000 BACKPACK BATTERYLITHIUM	30	$ 709.00	$ 21,270.00
5	AR3000	AR3000 BACKPACK BATTERYLITHIUM	20	$ 915.00	$ 18,300.00
				TOTAL (CAN$)	$328,582.00

The table 10, 11 and 12 shows the total capital costs (CAPEX) of the three options evaluated under this study. The **FVE - COV was provided by Fraser Valley Equipment LTD.**

- Stihl gas powered equipment CAPEX **$ 234,055.00**
- Stihl electric powered equipment CAPEX **$ 328,582.00**
- Husqvarna electric powered equipment CAPEX **$ 463,320.00**

Table 12. Total capital cost of equipment (Husqvarna electric-powered equipment)

Nr. Item	Model	Description	Qty	FVE - COV $	Total Price
HAND HELD PRODUCTS					
1	320iB	BATTERY BLOWER	90	$ 231.00	$ 20,790.00
2	436LiB	BATTERY BLOWER	50	$ 254.00	$ 12,700.00
3	536LiXP	BATTERY CHAINSAW	34	$ 399.00	$ 13,566.00
4	T536LiXP	BATTERY CHAINSAW	42	$ 399.00	$ 16,758.00
5	536LiHD60X	BATTERY HEDGE TRIMMER	20	$ 399.00	$ 7,980.00

Nr. Item	Model	Description	Qty	FVE - COV $	Total Price
HAND HELD PRODUCTS					
6	536LiHE3	BATTERY HEDGE TRIMMER	24	$ 399.00	$ 9,576.00
7	536LiLX	BATTERY TRIMMER	120	$ 276.00	$ 33,120.00
8	536LiPT5	BATTERY POLE SAW	40	$ 422.00	$ 16,880.00
BATTERIES AND CHARGERS					
1	QC500	BATTERY CHARGER	350	$ 219.00	$76,650.00
2	BLi300	BATTERY	700	$ 299.00	$209,300.00
3	BLi950X	BATTERY BACKPACK	50	$ 920.00	$46,000.00
				TOTAL (CAN$)	**$463,320.00**

The operative costs (OPEX) are calculated based on the average annual total fuel consumption of the all the equipment existing. The OPEX of the gas-powered equipment is **400,708.5 dollars per year**, see table 13.

Table 13. Operative Costs (fuel consumption gas-powered equipment)

Nr. Item	Description	Qty	Consumption (L/year)	Cost of fuel per year CAN$
TRIMMERS				
1	FS 111 R	51	67473	101209.5
2	FS 240	50	66150	99225
3	FS 560 C-EM	21	27783	41674.5
	Total Trimmers	**122**	**161406**	**242109**
HEDGE TRIMMERS				
1	HS 82 T & HS 82 R	30	1470	2205
2	HL 91K	3	147	220.5
3	HL 94	6	294	441
	Total Hedge Trimmers	**39**	**1911**	**2866.5**
POLE PRUNNER				
1	HT 103	8	392	588
2	HT 133	30	1470	2205
	Total Pole Prunner	**38**	**1862**	**2793**
CUT-OFF SAWS				
1	TS 700	2	134	201
2	TS 800	2	134	201
	Total Cut-off Saws	**4**	**268**	**402**
CHAINSAWS				
1	MS 211	20	1500	2250
2	MS 461	29	2175	3262.5
3	MS 661	14	1050	1575
4	MS 880	13	975	1462.5

Nr. Item	Description	Qty	Consumption (L/year)	Cost of fuel per year CAN$
	Total Chain Saws	**76**	**5700**	**8550**
BLOWERS				
1	BG 86	8	5408	8112
2	SH 56 C-E	16	10816	16224
3	BR 200	110	74360	111540
4	BR 500	8	5408	8112
	Total Chain Blowers	**142**	**95992**	**143988**
			TOTAL (CAN$/year)	**$ 400,708.5**

Park Board is assumed to have a large general service rate with an energy rate of $0.0567 per kWh.

Total energy consumption for battery charging of 118,216 kWh/year (according consumption mentioned in the section 2.3.4.1), assuming in average 4 hours of charging per day and 260 days per year. The total average cost would be 4,468.6 dollars per year (Husqvarna) and 3,748.65 dollars per year (Stihl).

Table 14. Total average annual costs operating costs of electric equipment

Equipment Brand	Batteries Model	Energy,	Total Battery Power (kWh)	Energy Consumption for charging (kWh/year)	Total average cost ($/year)
Husqvarna	BLi200	180	75.78	78811.2	**$ 4,468.60**
Stihl	AP 200	151	63.571	66113.84	**$ 3,748.65**

The figure 15 shows the total average annual cost of using any of the three options (CAPEX+OPEX).

Table 15. Total Cost of Gas-powered equipment per year

Equipment Brand	Capital cost	Operating costs	Total costs ($/year)
Stihl (gas-powered)	$ 234,055.00	$ 400,708.50	$ 634,763.50
Husqvarna (electric)	$ 463,320.00	$ 4,468.60	$ 467,788.60
Stihl (electric)	$ 328,582.00	$ 3,748.65	$ 332,330.65

Even though the CAPEX of electric equipment are higher, the operating costs make these options economical viable. The Return of Invest for Stihl and Husqvarna options (Table 16) is positive in the first year for Stihl. In the second year both equipment have a positive ROI of 71.32% (Husqvarna) and 141.15% (Stihl).

Table 16. Return of Invest ROI

Equipment Brand		Stihl (gas-powered)	Husqvarna (electric)	Stihl (electric)
Total costs ($/year)		634763.5	467788.6	332330.65
First Year	Investment Gain / **Loss**	-	**$ 67,080.10**	$ 68,377.85
	Return of Investment ROI	0.00%	-0.14%	20.58%
	Annualized ROI	0.00%	-0.14%	20.58%
	Profit / **Loss**	-	**14.00%**	17.00%
Second Year	Investment Gain / **Loss**	-	$ 333,628.40	$ 469,086.35
	Return of Investment ROI	0.00%	71.32%	141.15%
	Annualized ROI	0.00%	30.89%	55.29%
	Profit / **Loss**	-	42.00%	55.00%

* Average annual operating costs of running all gas-powered equipment are $400,708.50.

Summary

Switching to electric equipment will allow to City of Vancouver, Park Boards, reduce a total annual average GHG emissions of almost 600 tons of CO2e, equivalent to 230 cars, contributing to meet GHG emission reduction targets and protecting operators & people's health. It also will make an economic significantly impact by saving more than 300.000 dollars per year (Husqvarna) and more than 450.000 dollars per year (Stihl) starting from the second year.

Recommendations [Next Steps]

1. Introduce the gradually electric equipment once the gas powered equipment get out of service, according operators preferences stated on the surveys statistics shown in section 2.3.2.
2. Explore the feasibility of equipping each yard with permanent stations to charge the batteries in the most convenient way.
3. Engage local operators in formal trainings to use properly the equipment, and the mechanics to perform regular maintenance.

4. Based on the results of the survey, fast charging batteries are preferred, following best practices charging procedure to allow maximum life time duration.
5. Blowers should be equipped with a backpack battery to guarantee maximum duration and performance.
6. Each equipment should have a spare battery to be used once one is discharged.

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Appendices

Appendix A. Interview Small Gas-Powered Equipment

In the figure below shows the interview format applied to small equipment operator and superintendents

Small Gas Powered Equipment Performance and Operation

Brand (circle)	Husqvarna	Stihl	OTHER (specify)
Blower	**Hedge Trimmer**	**Chain Saw**	**Line Trimmer**

Equipment Model ___________________________

Please circle

Operability					
How many hours per day you use it?	2 hours	4 hours	6 hours	8 hours	> 8 hours
How many days per week?	1 day	2 days	3 days	4 days	5 days
How much gas fuel use per day?	5 litres	10 litres	15 litres	20 litres	> 20 litres
Performance					
Does it work normally?	YES		NO		
Do you note any gas leakages?	YES		NO		
Do you note any heavy smoke for the combustion	YES		NO		

What do you like most about this piece of equipment, if anything?

What do you dislike or should be improve on this piece of equipment, if anything?

Appendix B. Small Gas-Powered Equipment Emission Factors

In the chart below shows the emission factor of all the small equipment used at Park Boards.

Transport Mode	Fuel Type	Units	Emission Factor				
			Bio CO_2	CO_2	CH_4	N_2O	CO_2e
Light-duty Vehicle[a]	Gasoline	kg/ L	0.0755	2.200	0.00023	0.00047	2.346
	Diesel	kg/ L	0.0990	2.582	0.000051	0.00022	2.649
	Propane	kg/ L	–	1.510	0.00064	0.000028	1.534
	Natural Gas[b]	kg/ kg	–	2.738	0.013	0.000086	3.089
Light-duty Truck (includes SUV and Minivan)[a]	Gasoline	kg/ L	0.0755	2.200	0.00024	0.00058	2.379
	Diesel	kg/ L	0.0990	2.582	0.000068	0.00022	2.650
	Propane	kg/ L	–	1.510	0.00064	0.000028	1.534
	Natural Gas[b]	kg/ kg	–	2.738	0.013	0.000086	3.089
Heavy-duty [a]	Gasoline	kg/ L	0.0755	2.200	0.000068	0.00020	2.262
	Diesel	kg/ L	0.0990	2.582	0.00011	0.000151	2.630
	Natural Gas[b]	kg/ kg	–	2.738	0.013	0.000086	3.089
Motorcycle	Gasoline	kg/ L	0.0755	2.200	0.00077	0.000041	2.232
Off-Road (Vehicle/ Equipment)	Gasoline	kg/ L	0.0755	2.200	0.0027	0.00005	2.283
	Diesel	kg/ L	0.0990	2.582	0.00015	0.0011	2.914
	Natural Gas[b]	kg/ kg	–	2.738	0.013	0.000086	3.089
Marine	Gasoline	kg/ L	0.0755	2.200	0.0013	0.000066	2.252
	Diesel	kg/ L	0.0990	2.582	0.00015	0.0011	2.914
Aviation	Gasoline	kg/ L	–	2.365	0.0022	0.00023	2.489
	Turbo Fuel	kg/ L	–	2.560	0.000029	0.000071	2.582
Various	Biodiesel[c]	Kg/ L	2.474	–	e	e	e
	Ethanol[d]	kg/ L	1.509	–	f	f	f

Note: emission factors for fleet fuel consumption are based on Tier 1 or Advance Control emission control technologies.

Source: Ministry of Environment British Columbia (2016)

Appendix C. Interview Small Gas Powered Equipment

The following activities were held to perform the evaluation of small electric equipment existing in the market:

1. Emails and phone conversations with municipalities adopting electric equipment
2. Meetings and phone conversations with Husqvarna & Stihl representatives,
3. Meetings with the Parks Board's main supplier of equipment
4. Interview to the Superintendent of Urban Forestry North Section

Findings and information of other municipalities using electrical small equipment:

1. Mike Parenteau (Township of Langley, phone conversation on May 3rd) stated that an evaluation of the usage of small electric equipment was performed at that municipality. As a result, recently the Township purchased 12 machines, specifically Blowers and Line Strimmer.

2. Alex Piddington-Bishop (City Gardens Supervisor, City of London, Uk; contacted by email and information received under the same way) . The department of Open Spaces cares and manages 11,000 hectares of Parks, Greenspaces, Woodlands and Commons across London and after the Royal Parks is the largest provider of green space in London. The department uses a combination of petrol, two stroke and electric grounds care equipment to maintain the sites. The make of electric grounds equipment we have been using is made by French Company called Pellenc. The department have seen good productivity with the blowers and hedge cutters but have had small issues where the connecting lead into the battery back pack that breaks very easily and is costly to repair. Currently it is in its early days and at a recent trade show Alex was very impressed with both Husqvarna and Sthil electric products. The department uses the electric blowers and hedge cutters in areas where are required to keep noise low, and here is where the advantage of electrical equipment is beneficial. Another angle that is beneficial in using battery powered equipment is that of the reduction of Hand Arm Vibration – HAVS where vibration readings for battery powered equipment is low.

Appendix D. Interview Small Electric Equipment

In the figure below shows the interview format applied to small equipment operator and superintendents

Electric Equipment Performance and Operation

Brand (circle)	Husqvarna	Stihl	OTHER (specify)
Blower	**Hedge Trimmer**	**Chain Saw**	**Line Trimmer**

Equipment Model ____________________

Please circle

Operability					
How many hours per did day you use it?	1 hours	2 hours	3-4 hours	5-6 hours	+ 6 hours
How long did the battery last?	30 min	45 min	1 hour	1,5 hours	2 hours
How long does it take to fully charge the battery?	15 min	30 min	45 min	1 hour	+ 1 hour
Performance					
Does it work properly?	YES		NO		
How was the power of the equipment?	GOOD	REGULAR	BAD		
According the use, handling and comfort, What do you think about the equipment in compare with gas powered?	BETTER	SAME	BAD		

What do you like most about this piece of equipment, if anything?

What do you dislike or should be improve on this piece of equipment, if anything?

Appendix E. Equipment Supplier, Users and Representatives

Several meeting and phone conversations were held with Husqvarna & Stihl representatives, Fraser Valley Equipment and Superintendent of Parks Boards of City of Vancouver. The purposes of the interviews were getting familiar with gas powered and electric equipment, operability, performance and costs. Specific information was obtained by:

a. Darren Nott (Representative of Husqvarna, meeting held at Evans Yards on May 10th) explained:
   - Technical specification about the most recent develops of gas powered and electric equipment with specific information from the manufacturer.
   - Provided Husqvarna electric equipment in order to be tested by the crews working at the yards.

b. John Dunn (Fraser Valley Equipment, meeting held at Evans Yards on May 17th) provided:
   - Technical specifications.
   - Main differences and advantage of Husqvarna and Stihl equipment (Fraser Valley Equipment has been supplied brand new models and replacements of gas powered Stihl machines and small quantity of electric Husqvarna Equipment).
   - Spreadsheets with Husqvarna and Stihl current line up with pricing.

c. Sean Beggs & Carl Wallace (Representative & Technical Manager of Stihl, meeting held at Evans Yards on May 24th) provided:
   - Technical and logistic information of Stihl products and replace parts often needed for either gas powered or electric equipment.
   - Electric equipment to be tested including new models.
   - Main advantage of electric equipment over gas powered equipment;

d. Troy Hudson (Superintendent of Urban Forest Street, Parks and Board, meeting held at Evans Yards on May 16th) indicated:
   - Benefits of using the electric over gas power equipment.
   - Operability, performance and brand of electric equipment used opinion for Urban Forest Street crew.

e. Farrell White (Small Equipment, Park Boards) provided:
   - List of gas powered equipment models
   - Most often parts replaced

Appendix F. List of Husqvarna Equipment tested

From: Bruce Bunn
Sent: May 9, 2018 11:25 AM
To: Darren Nott <Darren.Nott@husqvarnagroup.com>
Cc: Sandra Sebanc <sandra.sebanc@husqvarnagroup.com>
Subject: City of Vancouver - Battery Demo

Darren:

Below you will find the information on what I gave you today for the City of Vancouver. Please have them fill out the DEMO form and have them sign for these pieces. I need you to fill in the Serial Number for the Battery Backpack.

My expectation is that I receive back the same equipment, same serial numbers.

				Serial Numbers			
966729174	536LiXP	Pro Saw Rear Handle	1	20173200012			
966729272	T536LiXP	Pro Top Handle Saw	1	20171400227			
967326812	536LiLx	Pro Timmer	1	20180400065			
967252403	436LiB	Pro Blower	1	20165100489			
967276501	536LiHD60X	Pro Hedge 24"	1	20180500075			
967341512	536LiHE3	Pro Hedge 22"	1	20165000018			
967091901	Bli300	Battery	4	20180308515	20180308516	20180308456	20180308520
967071901	Bli150	Battery	2	20154822074	20154822073		
967091403	QC500	Charger	2	20173510383	20173208873		
967093201	Bli950X	Backpack Battery	1				

Bruce Bunn