PROJECT GRYPHON:
Life Cycle Assessment (LCA) of electric vs. diesel all-terrain vehicles

Travis Wade

University of British Columbia

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Executive Summary

The purpose of this paper is to review the environmental, economic, and social impacts of utilizing electric all-terrain vehicles in place of the current diesel all-terrain vehicles. The analysis considers eight units currently in operation at UBC over a seven-year lifetime. The units considered all perform various functions around campus that range from towing trailers with equipment, picking up leaves, laying salt on the ground, snow removal, and moving goods from place to place. An analysis was completed looking at the production of the different motor types, the use of the vehicle, and the end of the life. The main goal is to determine the GHG emission reduction.

After conducting an analysis it has been found that operational cost will be fairly similar due to battery replacement occurring three times in the seven-year life of the vehicle at UBC. The upfront cost is $8000 less for the electric. The GHG emission reduction at the campus based on the analysis is 90 tonnes less, which equates to a 0.14% reduction for the entire campus based on 2012 figures.

The recommendation is to acquire 1 unit for demo on campus to determine if it's abilities will uphold the demands of the UBC operations staff. Electric all-terrain vehicles previously tested on campus have not met the requirements of the operations staff, and therefore have not been considered as an option. This paper has suggested a different unit that has further range and more power. However, the autonomy of this vehicle is noted in section 4 of the paper, and it shows that when varying terrains, loads, and towing are considered its ability to perform the task for the expected period of time is reduced by 25-35%, which needs to be closely considered before UBC operations moves forward with a fleet replacement of electric units. Furthermore, UBC operators have mentioned that space for these vehicles may be an issue due to requiring individual spaces for charging. Currently the diesel RTV units are parked in a condensed manner to save space. See photo below. The conversion to electric will have to consider space for the units, and will have to look at developing charging stations that will have an upfront cost to install.

1 Introduction

1.1 Background

The climate on planet earth is rapidly changing relative to the last 60 years due to the combustion of fossil fuels. The average temperature of the plant is increasing and will soon hit levels that will be considered dangerous to the balance of natural dynamic systems and processes. The result will be sea level raise, intense weather patterns, shifting agricultural production and human establishments along coastal regions. Solutions to mitigate significant climate change can be addressed immediately by making adjustments in day-to-day operations to reduce the dependency of fossil fuel resources.
In 2010, UBC's Vancouver Campus Climate Action Plan committed to greenhouse gas (GHG) emission reduction targets—33 per cent by 2015, 67 per cent by 2020, and 100 per cent by 2050, compared to 2007 levels. There are many opportunities that will need to be implemented to meet this goal, and this paper will review one option that is currently being considered; which is to look at all alternatively fueled vehicles for operational use. The purpose of this paper is to review the replacement of garden/landscape vehicles with electric equivalent by addressing the economic, environmental and social impacts. To accurately analyze these various impacts, an LCA of current diesel garden/landscape vehicles and their electric equivalents has been developed to further understand the benefits and impacts of switching to electric.

1.2 Purpose of LCA

Life cycle assessment (LCA) is defined by ISO 14040 (1997): "LCA is a techniques for assessing the environmental aspects and potential impacts associated with a product by: compiling an inventory of relevant inputs and outputs of a product system; evaluation the potential environmental impacts associated with those inputs and outputs; interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study". The life cycle includes the extraction of resources, processing of materials and product parts, manufacturing of products, use of products and the waste management with all the transports involved in the system, therefore, well known as "cradle to grave" (Baumann & Tillman, 2004). The first step is to develop the goal and scope of the study, which will be used to determine what data to collect for properly conducting the analysis. The data will be a collection of raw materials, including energy carries, products, and solid water and emissions to air and water. Utilizing an LCA helps encompass large and complex environmental issues into a functional unit that can be used as a decision-making tool to determine the most environmentally sustainable option.

2 Goal and scope definition

2.1 Goal

The goal of this LCA was to evaluate the environmental impacts of garden and landscape vehicles at UBC running on diesel fuel and the electric equivalent that operates using a sealed-lead acid battery bank. The environmental aspects will be concluded along with the analysis of the economics of the electric equivalents purchase and operating cost, and the social aspects that will consider user safety, comfort, and ergonomics, as well as the manufacturing conditions related to the electric vehicle. The goal is to formulate a triple-bottom line analysis that will contribute to the sustainability at UBC. The outcomes of this paper will be used to inform key decision-making regarding the purchasing within the UBC Building Operations, with the potential to reduce energy usage, ecological footprint and cost savings.

2.2 Scope and system diagram

The analysis will consider an existing diesel garden and landscape vehicle and the electric equivalent. These vehicles are used for collecting leaves, snow removal, and transportation of various items and materials around the university campus.

Existing diesel vehicle: Kubota ATV

Electric replacement equivalent: Alke ATX240E

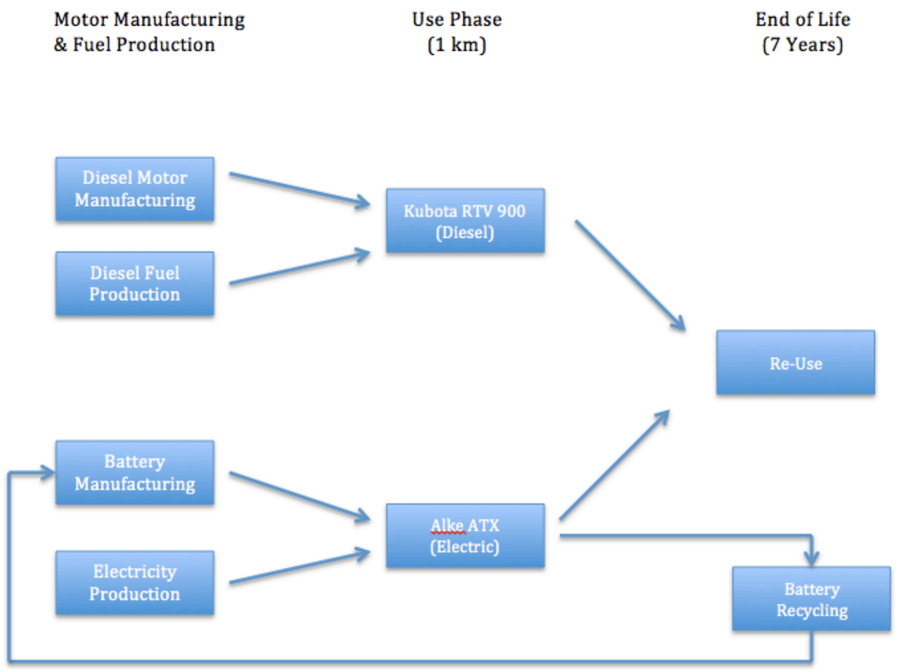
The scope of the LCA will include a triple-bottom line analysis of the environmental, economic and social impacts of both options.

The environmental scope of analysis will review this comparison over a 7-year time frame based on UBC building operations fleet turnover. This scope includes the mfg. of the vehicle motor, the use + O&M, with the end of life assumed to be re-use since the vehicles are sold during an auction. Environmental impacts associated with delivering the vehicle from the manufacturing plant to campus has been neglected since both vehicle types will require similar transportation methods

Economic analysis will consider the purchasing cost and operation and maintenance, over the 7 years. Due to changing markets and unknown variable fluctuations in the economy, the value of the vehicles at the end of 7 years has been neglected from analysis. Diesel fuel cost over the 7 years could increase by 20% relative to the current diesel rate of 1.34 per litre according to the US DOE EIA. Electric rates over the 7 years could increase by 26% relative to the current rate of $0.0574 per kWh according to the 2013 BC Hydro draft IRP. There are large uncertainties regarding both diesel and electric rate increases due to various externalities, therefore, for the sake of this analysis we will assume rate will remain at the same cost as they are today.

Social impacts will consider ergonomics, product safety, health impacts, and operation training and risk associated with changing the current RTV units to electric equivalent.

Table 1: Scope and System Diagram



The two vehicles considered share common features except for the difference in motor. Therefore, the LCA model for the two vehicles will only include components exclusive to the function of each. In the example of the diesel vehicle, the motor and the lubricant change keeping it properly functioning. For the electric, the motor is the sealed lead acid battery. These models adapt values from literature found in (Division n.d.) for lead-acid battery production and recycling, and (Li et al. 2013) Further details can be found in Section 4.

2.3 Functional Unit

The functional unit is used to link the inputs and outputs in the system boundaries, relevant to the performance of the products. The current RTV vehicles perform multiple functions all year that shift depending on the various weather conditions. The function of these vehicles is to ensure the campus is grounds are maintained. This includes, snow removal in the winter months, leaf removal in the fall months, and general transportation of materials to and from areas of campus that are used for completing various jobs as needed. The replacement unit has the same carrying capacity in terms of volume and weight; therefore the duties will not be compromised with making the switch to an electric vehicle. Thus the functional unit used for comparison will be 1 km traveled.

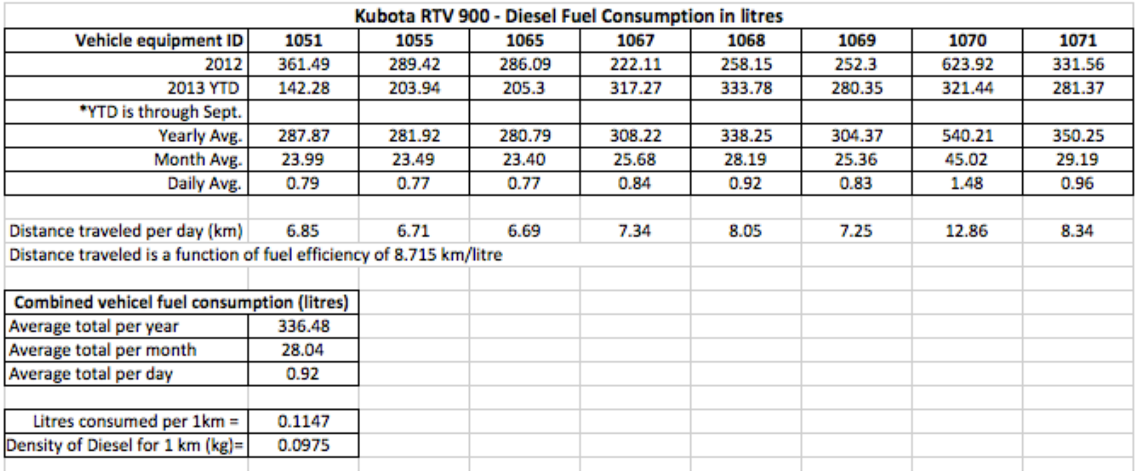
2.4 Life Cycle Inventory Analysis

The life cycle inventory analysis is a cumulative and iterative process. The activities of the LCI include: 1. Construct a flowchart according to the system boundaries decided on in the goal and scope definition. 2. Data Collection for all activities in the product system followed by documentation of collected data. 3. Calculation of the environmental loads (resources use and pollutant emission) of the system in relation to the functional unit (Baumann & Tillman, 2004).

3 Diesel Vehicle

This analysis will be reviewing 8 RTV units currently in operation. The table below shows each vehicle and the diesel consumption in 2012 and the 2013 YTD figures for consumption. Given the density of diesel at 0.85 kg/litre and an fuel efficiency of 8.715 km/litre (0.1147 litre/km) based on maximum operating conditions of the current vehicles the model will determine the environmental impacts based on 1 km of travel. To travel 1 km requires 0.097 kg of diesel. This data will be used below in for analysis of environmental impacts based on traveling 1 km.

Table 2



Kubota RTV 900 - Diesel Fuel Consumption in litres

Vehicle equipment ID	1051	1055	1065	1067	1068	1069	1070	1071
2012	361.49	289.42	286.09	222.11	258.15	252.3	623.92	331.56
2013 YTD	142.28	203.94	205.3	317.27	333.78	280.35	321.44	281.37
*YTD is through Sept.								
Yearly Avg.	287.87	281.92	280.79	308.22	338.25	304.37	540.21	350.25
Month Avg.	23.99	23.49	23.40	25.68	28.19	25.36	45.02	29.19
Daily Avg.	0.79	0.77	0.77	0.84	0.92	0.83	1.48	0.96
Distance traveled per day (km)	6.85	6.71	6.69	7.34	8.05	7.25	12.86	8.34

Distance traveled is a function of fuel efficiency of 8.715 km/litre

Combined vehicel fuel consumption (litres)	
Average total per year	336.48
Average total per month	28.04
Average total per day	0.92

Litres consumed per 1km =	0.1147
Density of Diesel for 1 km (kg)=	0.0975

3.1 Diesel Vehicle Environmental Analysis

The diesel engine component's considered in this LCA model include cylinder block, cylinder head, crankshaft, connection rod, timing gear box, fly wheel housing, and fly wheel, also know as "seven pieces". Figure 1 below has been utilized from (Li et al. 2013), which analyzes the same seven components for a 290 hp engine. The engine used by the UBC RTV unit is 21.6 hp. For these seven components steel, cast iron, aluminum, and alloy are used. For this LCA the raw material required will be assumed to use 7.45% (290hp/21.6hp) of those used in the study done by (Li et al. 2013). Therefore to produce 1 diesel engine will require the raw materials of steel (14.02 kg), cast iron (43.16 kg), aluminum (2.97 kg), and alloy (2.45 kg) account for 98.9% of the total engine material (62.6 kg). The additional 1.1% is negligible.

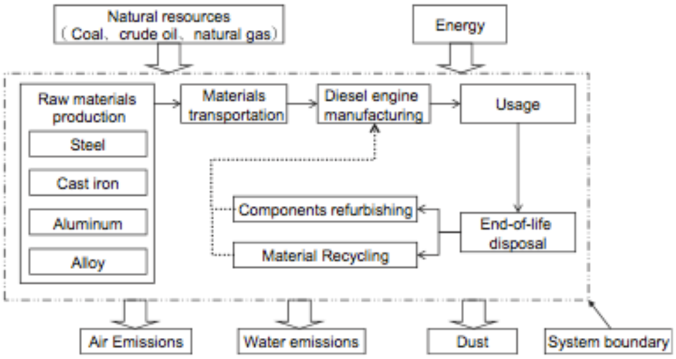


Fig. 1. A simplified life cycle of diesel engine, indicating the system boundary.

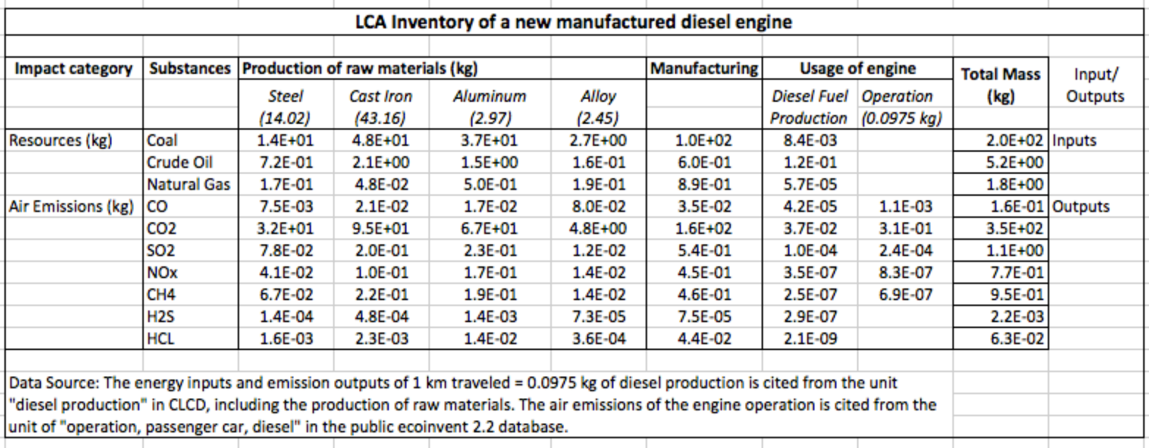
The system boundary spans raw material extraction, material productions, and components manufacturing to produce 1 engine. Items such as transporting the raw materials to manufacturing of the motor, and then the transportation for building the motor to assembly and assembly to distribution and distribution to the university of British Columbia has been neglected in this study. The reason it has

been neglected is because those processes occur for both vehicle types, and manufacturing occurs in the various Asian countries.
The production of diesel fuel is also considered in the inventory analysis.

3.1.1 Diesel vehicle inventory and impact analysis

The LCA inventory of a diesel engine manufacturing and the use of that engine are calculated below. The raw material assumptions and manufacturing processes has been reviewed in a similar LCA and that data has been interpolated for the use of this study (Li et al. 2013).

Table 3



LCA Inventory of a new manufactured diesel engine

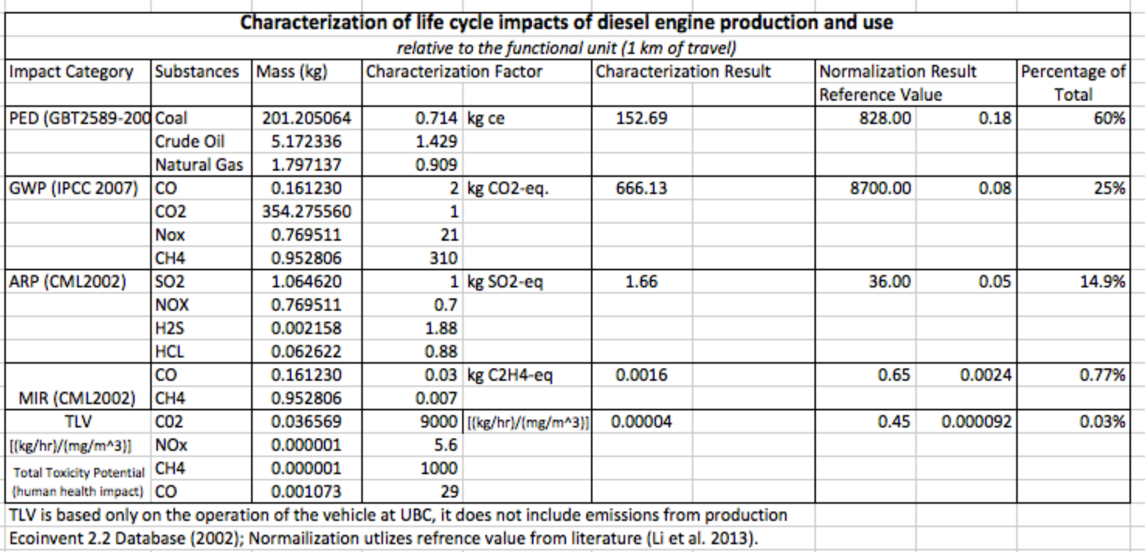
Impact category	Substances	Production of raw materials (kg)				Manufacturing	Usage of engine		Total Mass (kg)	Input/ Outputs
		Steel (14.02)	*Cast Iron (43.16)*	*Aluminum (2.97)*	*Alloy (2.45)*		*Diesel Fuel Production*	*Operation (0.0975 kg)*		
Resources (kg)	Coal	1.4E+01	4.8E+01	3.7E+01	2.7E+00	1.0E+02	8.4E-03		2.0E+02	Inputs
	Crude Oil	7.2E-01	2.1E+00	1.5E+00	1.6E-01	6.0E-01	1.2E-01		5.2E+00	
	Natural Gas	1.7E-01	4.8E-02	5.0E-01	1.9E-01	8.9E-01	5.7E-05		1.8E+00	
Air Emissions (kg)	CO	7.5E-03	2.1E-02	1.7E-02	8.0E-02	3.5E-02	4.2E-05	1.1E-03	1.6E-01	Outputs
	CO2	3.2E+01	9.5E+01	6.7E+01	4.8E+00	1.6E+02	3.7E-02	3.1E-01	3.5E+02	
	SO2	7.8E-02	2.0E-01	2.3E-01	1.2E-02	5.4E-01	1.0E-04	2.4E-04	1.1E+00	
	NOx	4.1E-02	1.0E-01	1.7E-01	1.4E-02	4.5E-01	3.5E-07	8.3E-07	7.7E-01	
	CH4	6.7E-02	2.2E-01	1.9E-01	1.4E-02	4.6E-01	2.5E-07	6.9E-07	9.5E-01	
	H2S	1.4E-04	4.8E-04	1.4E-03	7.3E-05	7.5E-05	2.9E-07		2.2E-03	
	HCL	1.6E-03	2.3E-03	1.4E-02	3.6E-04	4.4E-02	2.1E-09		6.3E-02	

Data Source: The energy inputs and emission outputs of 1 km traveled = 0.0975 kg of diesel production is cited from the unit "diesel production" in CLCD, including the production of raw materials. The air emissions of the engine operation is cited from the unit of "operation, passenger car, diesel" in the public ecoinvent 2.2 database.

This data looks at 1 vehicle motor that travels 1 km. The total mass is the amount of each product required to produce 1 engine to run the RTV unit 1 km. Since the operation is not over the lifetime, but the motor last over the lifetime, further analysis had been developed in the environmental impacts section to even the weighting of resource use to environmental impacts based on operational use at UBC.

This data looks at 1 vehicle motor that travels 1 km. This data was then translated used to determine the various environmental impacts. Those impacts are primary energy demand (PED), global warming potential (GWP), acid rain potential (ARP), smog formation potential relative to C2H4 (MIR), and human toxicity potential (TLV) relative to the emissions from operation at UBC. For each impact that are a number of pollutants, and to properly characterize these pollutants a characterization factor was utilized from the Eco invent software database 2.2, which utilizes IPCC 2007 data, GBT2589-2008 data, and CML 2002 data. These results where standardized using a national standardization value (1990) per (Li et al. 2013).

Table 3a



Characterization of life cycle impacts of diesel engine production and use

relative to the functional unit (1 km of travel)

Impact Category	Substances	Mass (kg)	Characterization Factor		Characterization Result	Normalization Result Reference Value		Percentage of Total
PED (GBT2589-200	Coal	201.205064	0.714	kg ce	152.69	828.00	0.18	60%
	Crude Oil	5.172336	1.429					
	Natural Gas	1.797137	0.909					
GWP (IPCC 2007)	CO	0.161230	2	kg CO2-eq.	666.13	8700.00	0.08	25%
	CO2	354.275560	1					
	Nox	0.769511	21					
	CH4	0.952806	310					
ARP (CML2002)	SO2	1.064620	1	kg SO2-eq	1.66	36.00	0.05	14.9%
	NOX	0.769511	0.7					
	H2S	0.002158	1.88					
	HCL	0.062622	0.88					
MIR (CML2002)	CO	0.161230	0.03	kg C2H4-eq	0.0016	0.65	0.0024	0.77%
	CH4	0.952806	0.007					
TLV	C02	0.036569	9000	[(kg/hr)/(mg/m^3)]	0.00004	0.45	0.000092	0.03%
[(kg/hr)/(mg/m^3)]	NOx	0.000001	5.6					
Total Toxicity Potential	CH4	0.000001	1000					
(human health impact)	CO	0.001073	29					

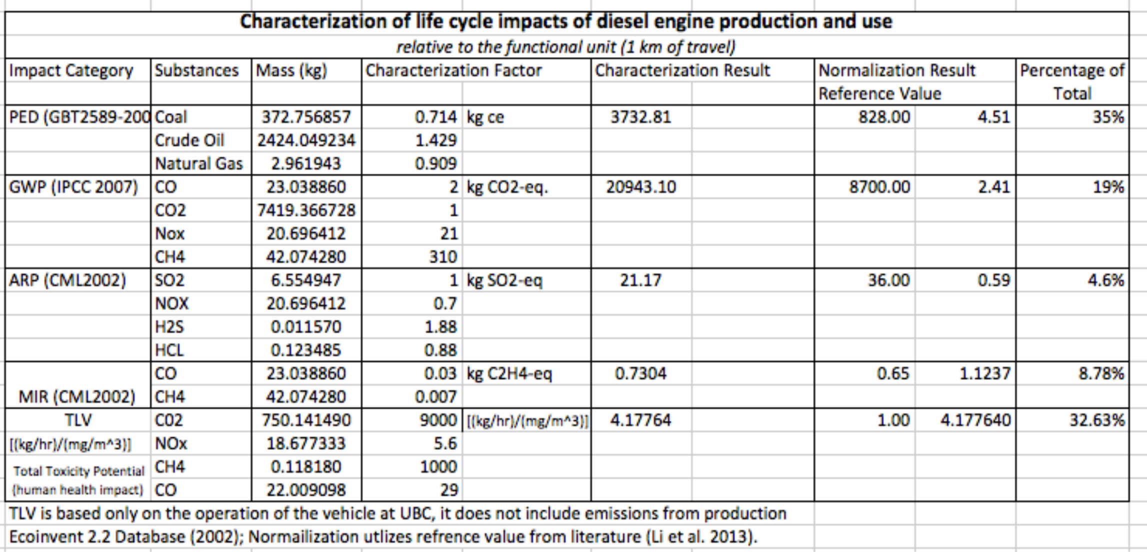
TLV is based only on the operation of the vehicle at UBC, it does not include emissions from production

Ecoinvent 2.2 Database (2002); Normailization utlizes refrence value from literature (Li et al. 2013).

Normalization is used to express indicator data of different units in a dimensionless unit so that it can be compared. For the normalization of this data, a reference value was selected from literature, and is cited in this paper as (Wenzel et. al 1997)

Due to the functional unit looking at only 1 km traveled and not the lifetime this data is skewed toward the primary energy demand to produce this engine. With the model ran over the lifetime of 7 years of 1 vehicle at UBC based on the average fuel used in 1 year we can see that the results below.

Table 4



Characterization of life cycle impacts of diesel engine production and use

relative to the functional unit (1 km of travel)

Impact Category	Substances	Mass (kg)	Characterization Factor		Characterization Result	Normalization Result Reference Value		Percentage of Total
PED (GBT2589-200	Coal	372.756857	0.714	kg ce	3732.81	828.00	4.51	35%
	Crude Oil	2424.049234	1.429					
	Natural Gas	2.961943	0.909					
GWP (IPCC 2007)	CO	23.038860	2	kg CO2-eq.	20943.10	8700.00	2.41	19%
	CO2	7419.366728	1					
	Nox	20.696412	21					
	CH4	42.074280	310					
ARP (CML2002)	SO2	6.554947	1	kg SO2-eq	21.17	36.00	0.59	4.6%
	NOX	20.696412	0.7					
	H2S	0.011570	1.88					
	HCL	0.123485	0.88					
MIR (CML2002)	CO	23.038860	0.03	kg C2H4-eq	0.7304	0.65	1.1237	8.78%
	CH4	42.074280	0.007					
TLV	C02	750.141490	9000	[(kg/hr)/(mg/m^3)]	4.17764	1.00	4.177640	32.63%
[(kg/hr)/(mg/m^3)]	NOx	18.677333	5.6					
Total Toxicity Potential	CH4	0.118180	1000					
(human health impact)	CO	22.009098	29					

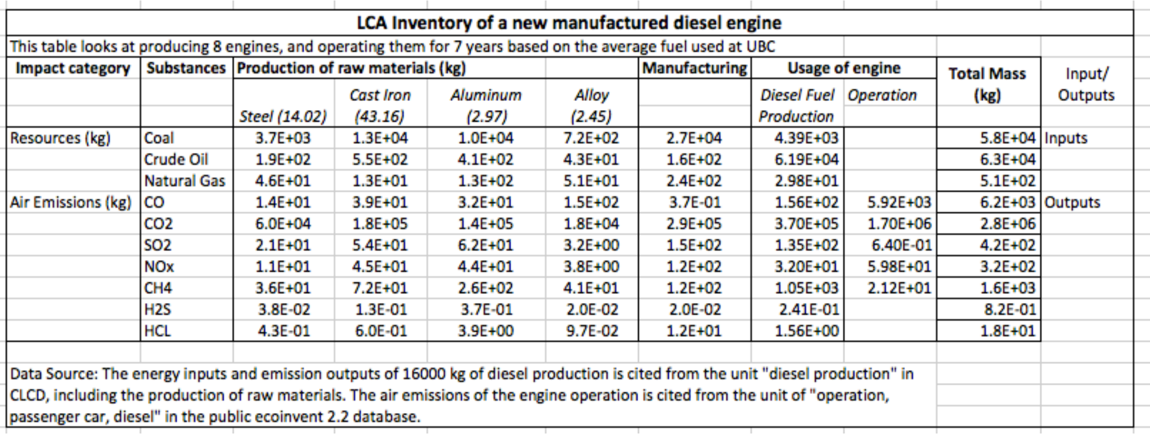
TLV is based only on the operation of the vehicle at UBC, it does not include emissions from production

Ecoinvent 2.2 Database (2002); Normailization utlizes refrence value from literature (Li et al. 2013).

Over the span of the vehicle lifetime at UBC 2000 kg of diesel fuel will be consumed, thus looking at the analysis over 7 years gives a better view of the environmental impacts associated with operating that vehicle.

For the entire fleet of 8 vehicles used over the lifetime of 7 years the table is shown below. This includes the production of 8 diesel motors.

Table 5



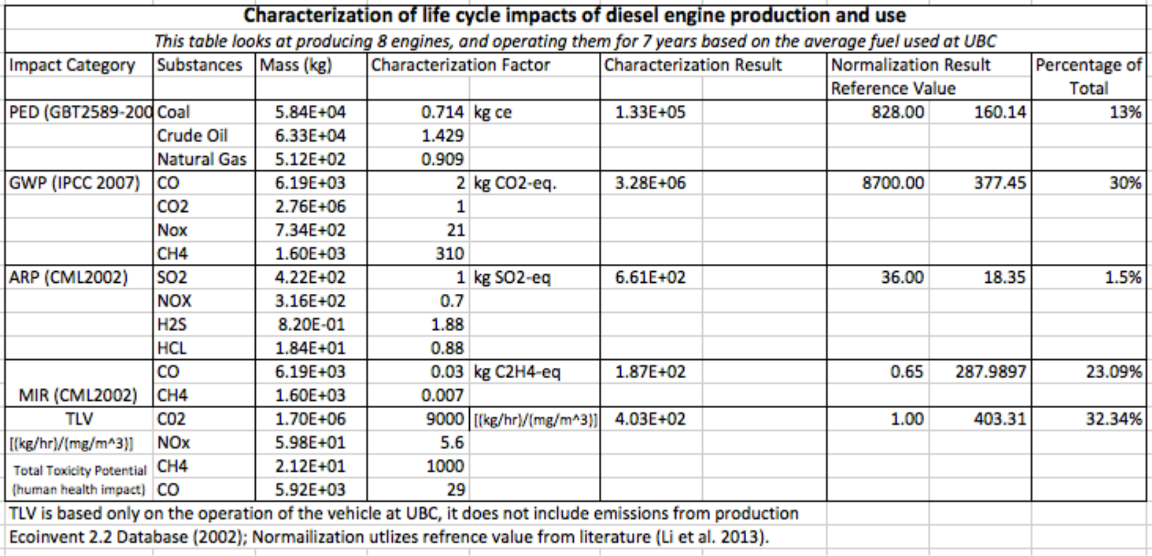
LCA Inventory of a new manufactured diesel engine

This table looks at producing 8 engines, and operating them for 7 years based on the average fuel used at UBC

Impact category	**Substances**	**Production of raw materials (kg)**				**Manufacturing**	**Usage of engine**		**Total Mass (kg)**	Input/ Outputs
		Steel (14.02)	*Cast Iron (43.16)*	*Aluminum (2.97)*	*Alloy (2.45)*		*Diesel Fuel Production*	*Operation*		
Resources (kg)	Coal	3.7E+03	1.3E+04	1.0E+04	7.2E+02	2.7E+04	4.39E+03		5.8E+04	Inputs
	Crude Oil	1.9E+02	5.5E+02	4.1E+02	4.3E+01	1.6E+02	6.19E+04		6.3E+04	
	Natural Gas	4.6E+01	1.3E+01	1.3E+02	5.1E+01	2.4E+02	2.98E+01		5.1E+02	
Air Emissions (kg)	CO	1.4E+01	3.9E+01	3.2E+01	1.5E+02	3.7E-01	1.56E+02	5.92E+03	6.2E+03	Outputs
	CO2	6.0E+04	1.8E+05	1.4E+05	1.8E+04	2.9E+05	3.70E+05	1.70E+06	2.8E+06	
	SO2	2.1E+01	5.4E+01	6.2E+01	3.2E+00	1.5E+02	1.35E+02	6.40E-01	4.2E+02	
	NOx	1.1E+01	4.5E+01	4.4E+01	3.8E+00	1.2E+02	3.20E+01	5.98E+01	3.2E+02	
	CH4	3.6E+01	7.2E+01	2.6E+02	4.1E+01	1.2E+02	1.05E+03	2.12E+01	1.6E+03	
	H2S	3.8E-02	1.3E-01	3.7E-01	2.0E-02	2.0E-02	2.41E-01		8.2E-01	
	HCL	4.3E-01	6.0E-01	3.9E+00	9.7E-02	1.2E+01	1.56E+00		1.8E+01	

Data Source: The energy inputs and emission outputs of 16000 kg of diesel production is cited from the unit "diesel production" in CLCD, including the production of raw materials. The air emissions of the engine operation is cited from the unit of "operation, passenger car, diesel" in the public ecoinvent 2.2 database.

Table 6



Characterization of life cycle impacts of diesel engine production and use

This table looks at producing 8 engines, and operating them for 7 years based on the average fuel used at UBC

Impact Category	Substances	Mass (kg)	Characterization Factor		Characterization Result	Normalization Result Reference Value		Percentage of Total
PED (GBT2589-200	Coal	5.84E+04	0.714	kg ce	1.33E+05	828.00	160.14	13%
	Crude Oil	6.33E+04	1.429					
	Natural Gas	5.12E+02	0.909					
GWP (IPCC 2007)	CO	6.19E+03	2	kg CO2-eq.	3.28E+06	8700.00	377.45	30%
	CO2	2.76E+06	1					
	Nox	7.34E+02	21					
	CH4	1.60E+03	310					
ARP (CML2002)	SO2	4.22E+02	1	kg SO2-eq	6.61E+02	36.00	18.35	1.5%
	NOX	3.16E+02	0.7					
	H2S	8.20E-01	1.88					
	HCL	1.84E+01	0.88					
MIR (CML2002)	CO	6.19E+03	0.03	kg C2H4-eq	1.87E+02	0.65	287.9897	23.09%
	CH4	1.60E+03	0.007					
TLV	C02	1.70E+06	9000	[(kg/hr)/(mg/m^3)]	4.03E+02	1.00	403.31	32.34%
[(kg/hr)/(mg/m^3)]	NOx	5.98E+01	5.6					
Total Toxicity Potential	CH4	2.12E+01	1000					
(human health impact)	CO	5.92E+03	29					

TLV is based only on the operation of the vehicle at UBC, it does not include emissions from production

Ecoinvent 2.2 Database (2002); Normailization utlizes refrence value from literature (Li et al. 2013).

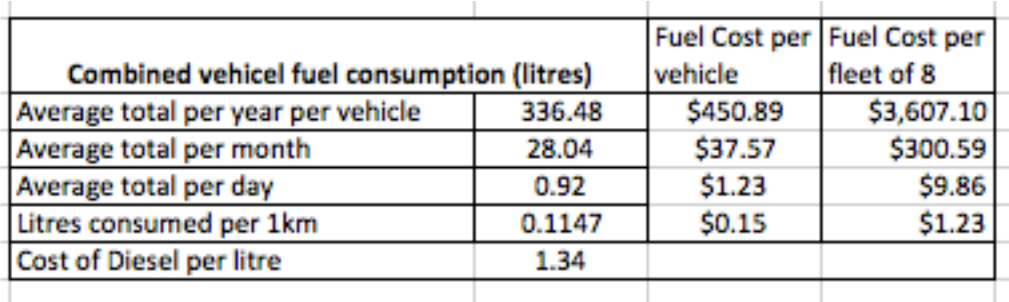
This analysis shows the lifetime of the vehicle fleet, and the relative effects that have occurred due to the operation and manufacturing to provide these 8 vehicles operation for the 7 years.

The numbers have been extrapolated been based on previous LCA studies. A sample calculation has been provided in the methodology section of the appendix.

3.2 Diesel vehicle economics

Current operations at UBC tracks fuel consumption per vehicle type. The cost of diesel has been provided by building operations at 1.34/litre. The cost of diesel is expected to rise over the next 7 years, but the uncertainties behind the actual raise are too significant to account for in the analysis. Therefore, the current price is assumed to stay level for the time frame of this analysis.

Table 7



Combined vehicel fuel consumption (litres)		Fuel Cost per vehicle	Fuel Cost per fleet of 8
Average total per year per vehicle	336.48	$450.89	$3,607.10
Average total per month	28.04	$37.57	$300.59
Average total per day	0.92	$1.23	$9.86
Litres consumed per 1km	0.1147	$0.15	$1.23
Cost of Diesel per litre	1.34		

The purchase cost of 1 of these vehicles is $25,687. The entire fleet cost is $205,496 with an operation cost of all vehicles over the 7 years $25,249. The total cost to own and operate this fleet over the expected lifetime of 7 years = $240,746. This cost neglects maintenance of the vehicles tires, and components since these are assumed equal between the two vehicles. External costs that contribute to the operation of this vehicle include fluid changes. These cost have been assumed that vehicles have their oil changed 4 times per year for 7 years for 8 vehicles has been estimated at $14,895,this neglects labor cost. At the end of 7 years, the vehicles are sold at an auction and continue their life at other campuses or facilities. The prices these units are sold for varies, and for the sake of this analysis is not included since the electric equivalent will also be sold at the end of the 7 years.

3.3 Diesel vehicle social impacts

Social impacts will consider ergonomics, product safety, and health impacts of the current diesel RTV units. The vehicles preform a variety of task throughout the year at UBC of which the operators of the vehicles are located within a closed cabin. The closed cabin provides shelter from changing whether conditions, and reduces the noise of the engine for the operator. The cabin can create some visual limitations, but this has not been an issue according to the operators that have been surveyed. The operators concerns with these vehicles are minimal compared to the concerns related to the mowing counter part.

The only issues that were raised by the operators were concerns about the changing landscape that made their job duties more complex and time consuming. The complex and increase in time to complete a job are results of development plans neglecting the challenges of maintenance work. Jeff Nulty has noted challenges and issues in a campus report in June of 2013. The majority of the report focused on issues related to mowing areas being changed. Over time the area of lawn has been reduced and more masonry has been included on campus. As a result more time is being spent doing physical labor, which has inherent risk of increased musculoskeletal strain on employee bodies.

The function of the RTV unit still holds up to the job, but externalities not associated with the performance of the vehicle have increased. Therefore, careful consideration of future campus planning should review the impacts associated with worker capabilities and the ergonomic stressors of the physical job duties.

4 Electric Vehicle

The need to shift current infrastructure away from fossil fuel dependency is increasing, and electric vehicles are becoming a viable solution to go to. Performance improvements in batteries, and the ability to integrate renewable technology as a power source for charging the batteries has shown significant reductions in C02 emissions compared to diesel and gasoline counter parts. The building operations at UBC maintains roughly $14\ \mathrm{km}^2$ of land through out the year. To successfully manage this amount of land requires reliable equipment and tools. In addition to providing a safe, clean, and functioning campus, the building operations is continually looking for way to reduce emissions of their daily duties. An area of operations that is being consider to reduce emissions is the use of diesel all-terrain vehicles that perform a wide range of functions that consist of general transportation of good, garden maintenance, snow removal, and use of trailers to move loads of commodities around campus. These functions are critical, and the performance of the vehicle needs to be reliable, consistent and capable to handle various landscapes, and demands of the wide range of duties.

Reviewing current market options for high performance electric all terrain vehicles is limited to only a handful of options. Those options are:

1. John Deere – Gator TE
2. Alke – ATX
3. Polaris – Ranger
4. Titan UTV

Option #1 is currently being tested on campus, and the results are sub-par at best. The operators have tried it, and have not been pleased with the performance because of a lack of power. The other 3 options were reviewed based on battery life, performance claims, load capacity, and capable functionalities. The scope of this analysis will be looking at the Alke – ATX because the features closely resemble current operations and performance claims exceed the competitors. When using this vehicle, things to consider that will effect performance is the vehicle Autonomy. Due to the number of variables that reduce performance of the vehicle it has been assumed for the analysis that the vehicle will drain the battery each day. Below is a sample of the vehicle autonomy factors associated with the electric vehicle.

Vehicle autonomy analysis

Autonomy for Alkè vehicles using ODYSSEY batteries may vary due to several factors: battery charge, temperature, road conditions (off-road, slopes, stop&go, …), driving style (acceleration, regeneration vs braking, …), payload, towing, devices activated (electric heater, lights, …), tyre inflation, etc.

On ATX vehicles we can make direct comparison against standard lead acid batteries because both solutions are available. We see for instance on the ATX200E configuration that even if the amount of power stored by the ODYSSEY batteries is little bit lower (180A against 200A in C5, 25°C), based on the fact that ODYSSEY works with a flat Voltage curve like advanced Lithium solutions do, the electric motor efficiency is higher and the ODYSSEY solution can deliver at the end a greater autonomy (+5/10% at 25°C).

We have a second positive effect given by the good performance at low temperature, here are side by side performance of standard lead acid batteries mounted on ATX200E (Trojan TE35) and ODYSSEY:

Temp.	Loss of autonomy lead acid solution (Trojan TE35)	Loss of autonomy ODYSSEY solution (data in C5)
25° C	0%	0%
10° C	15%	5%
0° C	30%	10%
-10° C	40%	15%
-20° C	52%	20%
-30° C	65%	25%

Even if it is impossible to predict in advance any type of environment and working condition we try to summarize some empirical figures found with the experience on the field or specific calculations. Please take carefully this data, it is given only to provide an indication to understand which situation is more critical for the vehicle autonomy (often more elements are influencing the autonomy at the same time).

We have to make two different analysis in relation to ATX and XT models:

ATX100E, 200E, 280E with ODYSSEY

Critical factor	Details		Loss of autonomy*		
Ground condition	Ground condition can affect in a very strong way the vehicle consumption.		Rough terrain: > 20% Gravel, stones: > 30% Sand, snow: > 40%		
Slopes	5% slope 10% slope 15% slope 20% slope 30% slope		72% 84% 87% 90% 94%		
			20km/h	**25km/h**	**30km/h**
Load on cargo bed	250kg	10 stop&go 20 stop&go 30 stop&go	2% 3% 6%	3% 6% 9%	5% 9% 15%
	500kg	10 stop&go 20 stop&go 30 stop&go	2% 4% 6%	3% 7% 10%	6% 12% 18%
	750kg **(only 280E)**	10 stop&go 20 stop&go 30 stop&go	3% 6% 9%	5% 9% 14%	
	1.000kg **(only 280E)**	10 stop&go 20 stop&go 30 stop&go	3% 6% 9%	5% 10% 15%	
Towing **	1.000kg	10 stop&go 20 stop&go 30 stop&go	3% 5% 8%	4% 8% 13%	7% 13% 20%
	2.000kg	10 stop&go 20 stop&go 30 stop&go	4% 8% 12%	6% 13% 19%	10% 20% 30%
	3.000kg **(only 280E)**	10 stop&go 20 stop&go 30 stop&go	5% 11% 16%	9% 18% 26%	
Tyre inflation	Bad tyre inflation can provide higher friction with the ground increasing the vehicle consumption		5%		
Driving style	Strong acceleration and the use of normal brakes instead of regenerative brake given by the motor reduce the total autonomy		15% on flat, higher with slopes		
Continuous drive	Stops provide benefit to batteries because chemicals inside them recovers energy, a continuous drive reduce the total autonomy.		5%		
Quick consumption **(heavy duty operations / high speed)**	A continuous drive in hard conditions causes the use of the batteries at a lower "C" coefficient, the energy supplied in such situation is lower (the energy delivered by a battery discharged in 5 hours is in fact superior to the one of the same battery discharged more quickly in 1 hour).		**Compared to C5 coefficient (discharge in 5 hrs)** C4 (4hrs): 2.6% C3 (3hrs): 6.2% C2 (2hrs): 11.8% C1 (1hrs): 23.3% C0.5 (30min): 36.1%		

* Loss of autonomy is compared to battery autonomy expected in standard condition: 25°C, flat asphalted ground, on board electric devices off, conservative driving style, no load (only driver), 30 min drive / 30 min stop as drive cycle, 1 stop&go, speed = 50% of max speed.

** Data given for towing activities refers to the usage of automotive high quality trailers with balanced load and indipendent brakes. The usage of a trailer in condition not standard (see above) can worsen the consumption in a strong way because each critical factor affect both the vehicle and the trailer.

From these two charts we can see that most critical elements are ground conditions, the presence of slopes and high speed connected to many stop&go.

The value for the loss of autonomy when facing slopes is given in relation to a full route made with such constant slope percentage. It means for instance if you drive an infinite 5% ramp and the autonomy in standard condition is 100km, you get only 28km as result (-72%). On real life such ramps are not present but this data gives immediately an idea about the large amount of energy needed when driving uphill.

4.1 Electric vehicle environmental analysis

The environmental analysis will consider the use of the vehicle over 7 years, and the production and recycling of lead-acid batteries. The vehicle would utilize electric power from BC hydro to charge the batteries. The batteries can be cycled 1000 times before requiring replacement. Due to the various functions, and demands of the vehicle, the battery will require a full charge every day, thus, a life span of 2.75 years. The analysis assumes the battery will be replaced 3 times over the 7-year life to account for uncertainties in operator use. The lead-acid batteries can be disposed of through risk management services that have established networks with Metalax that will recycle the batteries. The system boundary for cradle-to-gate of the battery can be seen below (Division n.d.) The inventory analysis will consider the components of a lead acid battery that are required in manufacturing. 50% of the components are considered to come from recycling since 60-80% of lead acid battery components can be recycled.

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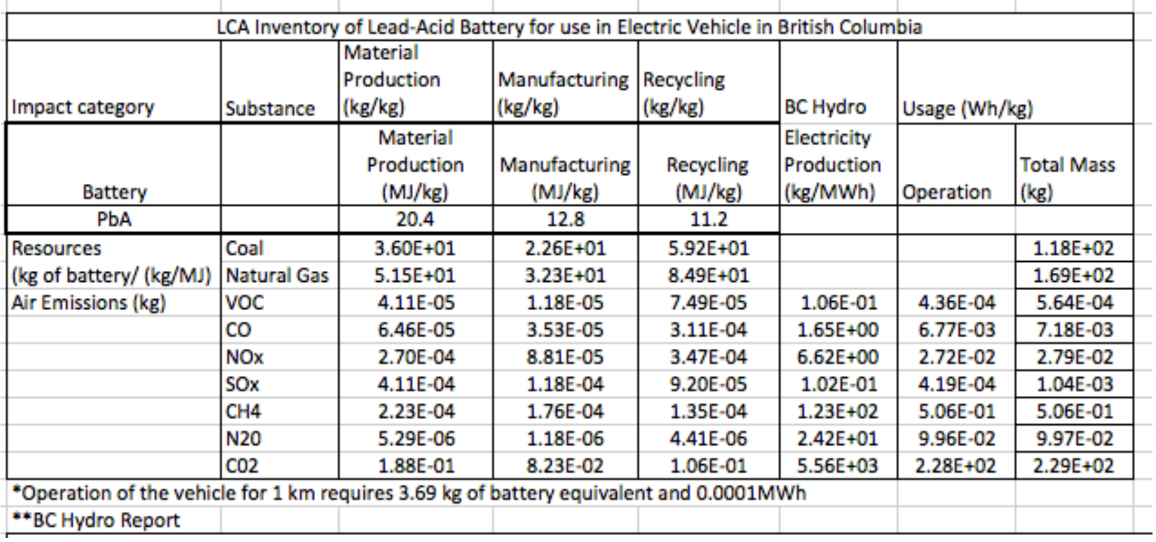
FIGURE 2 Boundaries Assumed for the Cradle-to-Gate Study Evaluation

4.1.1 Electric vehicle inventory and impact analysis

The Electric Vehicle impacts are most significant when it comes to the battery life and having to recycle it, and manufacture a new one. The operational impacts are a function of where the electricity is produced, and how it is produced. For UBC, they utilize BC Hydropower, which has lower impacts that all other utility companies due to using hydropower. The Impacts with Hydropower are from the construction of the hydro plant, and the operational impacts of turbines, and delivery of a unit of electricity. Utilizing the BC Hydro accountability reports of 2011 to account for emission of producing a GWh of energy, environmental impacts were calculated. The results are shown below in tables.

Table 8



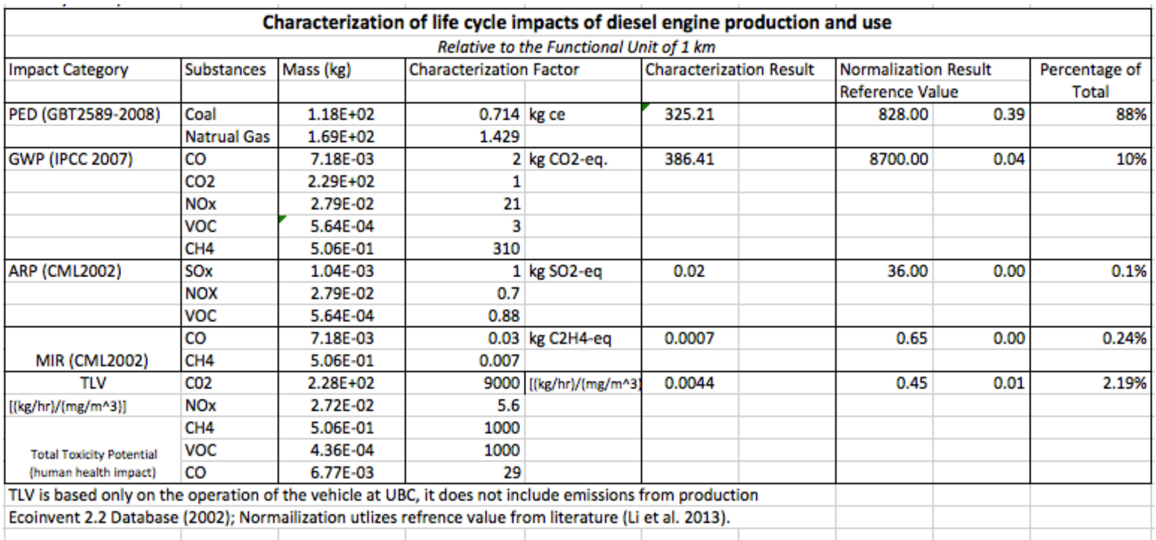
LCA Inventory of Lead-Acid Battery for use in Electric Vehicle in British Columbia							
Impact category	Substance	Material Production (kg/kg)	Manufacturing (kg/kg)	Recycling (kg/kg)	BC Hydro	Usage (Wh/kg)	
Battery		Material Production (MJ/kg)	Manufacturing (MJ/kg)	Recycling (MJ/kg)	Electricity Production (kg/MWh)	Operation	Total Mass (kg)
PbA		20.4	12.8	11.2			
Resources	Coal	3.60E+01	2.26E+01	5.92E+01			1.18E+02
(kg of battery/ (kg/MJ)	Natural Gas	5.15E+01	3.23E+01	8.49E+01			1.69E+02
Air Emissions (kg)	VOC	4.11E-05	1.18E-05	7.49E-05	1.06E-01	4.36E-04	5.64E-04
	CO	6.46E-05	3.53E-05	3.11E-04	1.65E+00	6.77E-03	7.18E-03
	NOx	2.70E-04	8.81E-05	3.47E-04	6.62E+00	2.72E-02	2.79E-02
	SOx	4.11E-04	1.18E-04	9.20E-05	1.02E-01	4.19E-04	1.04E-03
	CH4	2.23E-04	1.76E-04	1.35E-04	1.23E+02	5.06E-01	5.06E-01
	N20	5.29E-06	1.18E-06	4.41E-06	2.42E+01	9.96E-02	9.97E-02
	C02	1.88E-01	8.23E-02	1.06E-01	5.56E+03	2.28E+02	2.29E+02

*Operation of the vehicle for 1 km requires 3.69 kg of battery equivalent and 0.0001MWh

**BC Hydro Report

This tables utilizes data from previous LCA on battery manufacturing and recycling (Division n.d.). Utilizing their research and battery analysis, an interpolation was completed to integrate the functional unit of the electric vehicle data provided by Alke and the batteries used in their vehicles.

Table 9



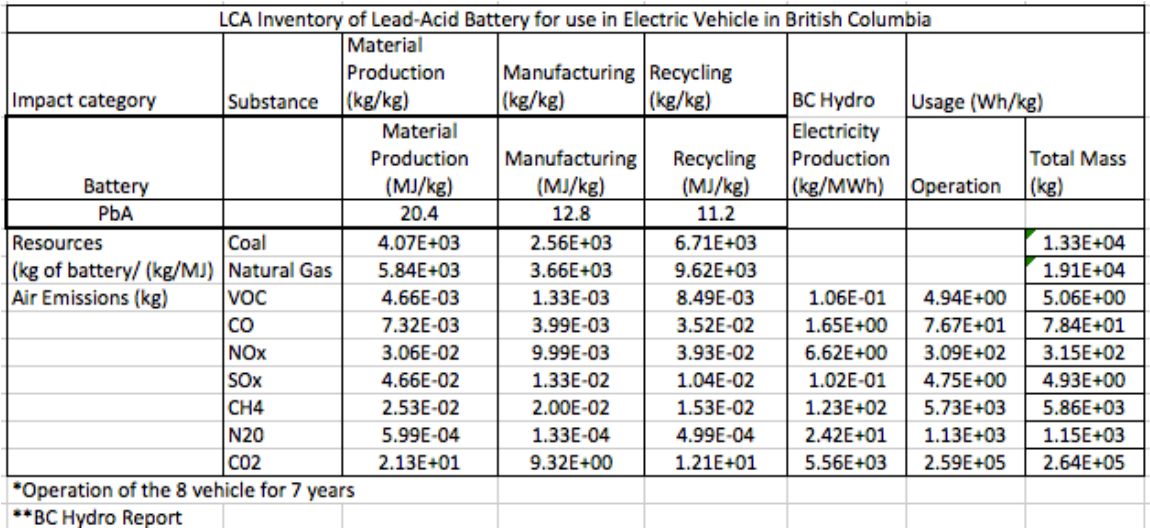
Characterization of life cycle impacts of diesel engine production and use *Relative to the Functional Unit of 1 km*								
Impact Category	Substances	Mass (kg)	Characterization Factor		Characterization Result	Normalization Result		Percentage of Total
						Reference Value		
PED (GBT2589-2008)	Coal	1.18E+02	0.714	kg ce	325.21	828.00	0.39	88%
	Natrual Gas	1.69E+02	1.429					
GWP (IPCC 2007)	CO	7.18E-03	2	kg CO2-eq.	386.41	8700.00	0.04	10%
	CO2	2.29E+02	1					
	NOx	2.79E-02	21					
	VOC	5.64E-04	3					
	CH4	5.06E-01	310					
ARP (CML2002)	SOx	1.04E-03	1	kg SO2-eq	0.02	36.00	0.00	0.1%
	NOX	2.79E-02	0.7					
	VOC	5.64E-04	0.88					
MIR (CML2002)	CO	7.18E-03	0.03	kg C2H4-eq	0.0007	0.65	0.00	0.24%
	CH4	5.06E-01	0.007					
TLV	C02	2.28E+02	9000	[(kg/hr)/(mg/m^3)	0.0044	0.45	0.01	2.19%
[(kg/hr)/(mg/m^3)]	NOx	2.72E-02	5.6					
	CH4	5.06E-01	1000					
Total Toxicity Potential (human health impact)	VOC	4.36E-04	1000					
	CO	6.77E-03	29					

TLV is based only on the operation of the vehicle at UBC, it does not include emissions from production

Ecoinvent 2.2 Database (2002); Normailization utlizes refrence value from literature (Li et al. 2013).

Reviewing these numbers shows us that the operation of 1 km significantly underestimates the impacts. The reason is because in order to travel 1 km, and entire manufacturing process needs to be complete. Therefore all the impacts are heavily weighted on the PED (process energy demand) Therefore, the following analysis was completed to show the overall impacts of the fleet of 8 vehicles over the 7 years.

Table 9



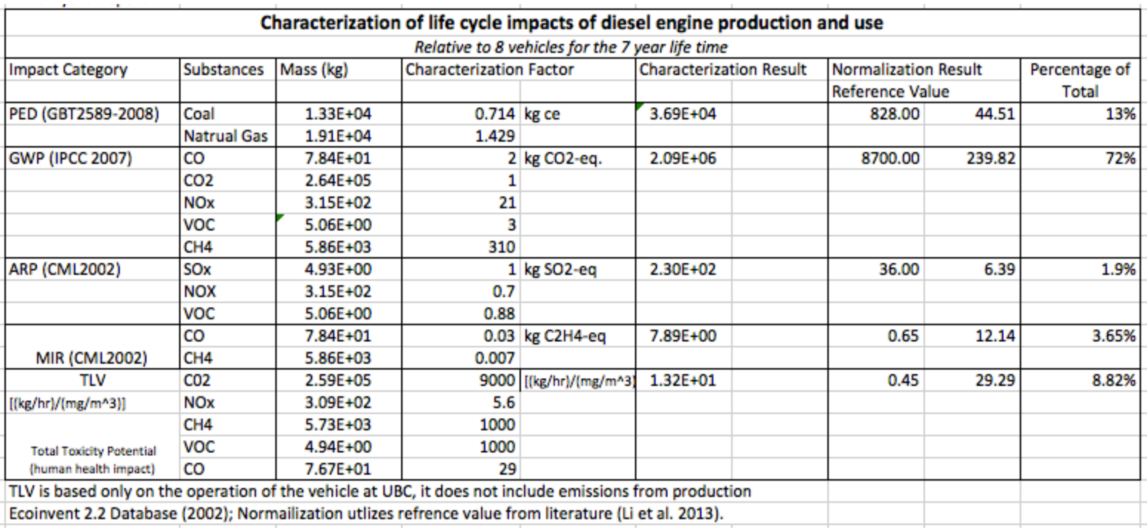
LCA Inventory of Lead-Acid Battery for use in Electric Vehicle in British Columbia

Impact category	Substance	Material Production (kg/kg)	Manufacturing (kg/kg)	Recycling (kg/kg)	BC Hydro	Usage (Wh/kg)	
Battery		Material Production (MJ/kg)	Manufacturing (MJ/kg)	Recycling (MJ/kg)	Electricity Production (kg/MWh)	Operation	Total Mass (kg)
PbA		20.4	12.8	11.2			
Resources	Coal	4.07E+03	2.56E+03	6.71E+03			1.33E+04
(kg of battery/ (kg/MJ)	Natural Gas	5.84E+03	3.66E+03	9.62E+03			1.91E+04
Air Emissions (kg)	VOC	4.66E-03	1.33E-03	8.49E-03	1.06E-01	4.94E+00	5.06E+00
	CO	7.32E-03	3.99E-03	3.52E-02	1.65E+00	7.67E+01	7.84E+01
	NOx	3.06E-02	9.99E-03	3.93E-02	6.62E+00	3.09E+02	3.15E+02
	SOx	4.66E-02	1.33E-02	1.04E-02	1.02E-01	4.75E+00	4.93E+00
	CH4	2.53E-02	2.00E-02	1.53E-02	1.23E+02	5.73E+03	5.86E+03
	N20	5.99E-04	1.33E-04	4.99E-04	2.42E+01	1.13E+03	1.15E+03
	C02	2.13E+01	9.32E+00	1.21E+01	5.56E+03	2.59E+05	2.64E+05

*Operation of the 8 vehicle for 7 years

**BC Hydro Report

Table 10



Characterization of life cycle impacts of diesel engine production and use

Relative to 8 vehicles for the 7 year life time

Impact Category	Substances	Mass (kg)	Characterization Factor		Characterization Result		Normalization Result Reference Value		Percentage of Total
PED (GBT2589-2008)	Coal	1.33E+04	0.714	kg ce	3.69E+04		828.00	44.51	13%
	Natrual Gas	1.91E+04	1.429						
GWP (IPCC 2007)	CO	7.84E+01	2	kg CO2-eq.	2.09E+06		8700.00	239.82	72%
	CO2	2.64E+05	1						
	NOx	3.15E+02	21						
	VOC	5.06E+00	3						
	CH4	5.86E+03	310						
ARP (CML2002)	SOx	4.93E+00	1	kg SO2-eq	2.30E+02		36.00	6.39	1.9%
	NOX	3.15E+02	0.7						
	VOC	5.06E+00	0.88						
MIR (CML2002)	CO	7.84E+01	0.03	kg C2H4-eq	7.89E+00		0.65	12.14	3.65%
	CH4	5.86E+03	0.007						
TLV	C02	2.59E+05	9000	[(kg/hr)/(mg/m^3)	1.32E+01		0.45	29.29	8.82%
[(kg/hr)/(mg/m^3)]	NOx	3.09E+02	5.6						
	CH4	5.73E+03	1000						
Total Toxicity Potential	VOC	4.94E+00	1000						
(human health impact)	CO	7.67E+01	29						

TLV is based only on the operation of the vehicle at UBC, it does not include emissions from production

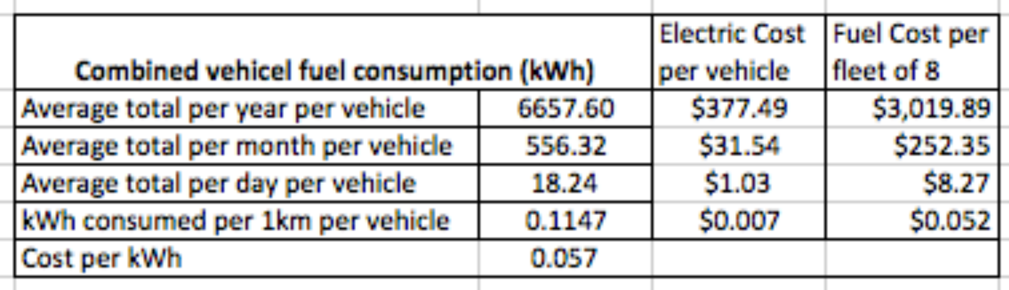
Ecoinvent 2.2 Database (2002); Normailization utlizes refrence value from literature (Li et al. 2013).

Reviewing this data, we see that once the vehicles are in operation, most of the impacts come from the energy consumption. We also see that TLV – human health impact is ~ 24% less than that of the diesel. Furthermore these TLV impacts are a function of the electricity produced by BC Hydro, and not directly from the tailpipe of the vehicle. There is 0 impact at point of use since only electric power is being used.

4.2 Electric vehicle economic analysis

The electric vehicle will utilize electricity from BC hydro the recharge the batteries each night. The assumption is that the batteries will have to be fully charged each night due to their limited range and reduce performance due to carrying loads, driving over variable landscapes, and towing trailers. The performance of the vehicles will have be tested on campus to determine the longevity in relation to the functions performed. The data tables from the manufacture assume operating the vehicle in economy mode on flat ground with no load. The reality is the functions performed will have an integrated impact on performance and to determine this over 1 day, 1 week, 2 month, or 1 year is not possible due to operator behavior, and limited understanding of how the vehicles will be used in the field. Therefore assuming full charge is the most conservative analysis to ensure the worst possible impacts are accounted for. The vehicles cost $17,500 and a replacement battery is $787. Each vehicle requires 18.24 kWh to be fully charged.

Table 11



Combined vehicel fuel consumption (kWh)		Electric Cost per vehicle	Fuel Cost per fleet of 8
Average total per year per vehicle	6657.60	$377.49	$3,019.89
Average total per month per vehicle	556.32	$31.54	$252.35
Average total per day per vehicle	18.24	$1.03	$8.27
kWh consumed per 1km per vehicle	0.1147	$0.007	$0.052
Cost per kWh	0.057		

Operating 1 vehicle for 7 years with 3 battery changes = ($377.49 x 7)+(787x3) = $5003. To operate the fleet of 8 vehicles for 7 years will be 40,024. The upfront cost of $17,500 per vehicle x 8 vehicles = $140,000. Routine maintenance such as tire changes and headlight changes is assumed to be the same as the diesel equivalent, thus has been neglected from the study.

4.3 Electric vehicle social analysis

The consideration of electric vehicles for use over diesel has positive impacts for the campus to reduce greenhouse gas emissions. By utilizing electric vehicles, the operating noise is significantly reduced, and the emissions from the tailpipe are none existent, therefore the operators will no longer be inhaling the emissions from the tail pipe. A vehicle the operates with little to no noise will allow operators to be more aware of their surroundings by eliminating the need of ear plugs and the noise of the diesel motor operating. There are no record incidences of accidents due to vehicle noise from operating. However, utilizing electric vehicles acts as a further preventive measure to eliminate that potential accident. Other benefits include having the opportunity to operate the vehicles early in the morning. Currently the vehicles must wait until 9am before they begin work. In some cases, such as snowfall it is important to clear the grounds and salt/sand the walk paths early, and with electric vehicles this can be done, which will further improve the safety for people walking around campus before 9am. It will also allow for material transportation to occur at any time of the day, which will add benefits unknown at the current time. The big take away is that time is money, and with electric RTV vehicles the ability to perform task at any time opens the possibilities for operators to perform their functions when it is most needed without having to consider the variables of noise pollution. Furthermore, training the staff on the use of electric vehicles will be important to take into account because the longevity of the vehicle is highly correlated with how it is used. Starting and stopping, load carrying, choice of routes to and from places on campus, etc. Will have to be highly considered to optimize the vehicle. Additionally if an operator does not plug the vehicle in at the end of the day, then the vehicle will not be of any use the following day since re-charge times take about 10 hours for a full charge.

5 Conclusion

The analysis has reviewed a diesel all-terrain vehicle with an electric all-terrain vehicle for use on the UBC campus for building operations. The analysis reviewed the manufacturing of a diesel engine and the manufacturing and recycling of a lead-acid battery. The lead-acid battery will be replaced 3 times in the 7-year lifetime that UBC typically keeps their fleet for. The impacts of both vehicles have been analyzed, and the results show a marginal improvement in the reduction of GHG (greenhouse gas) emission (CO2-equivalent). Operating cost is lower with the electric vehicles, but the battery replacement cost of nearly $800 every 2.25-2.75 years creates a net zero operational cost savings. The purchase price is $8000 less per vehicle for the electric units, and potentially even less if other options are considered.

The environmental impacts, in particular GWP (global warming potential) are 2.09E6 kg of C02 equivalent for electric and 2.28E6 kg of C02 equivalent for diesel. There are 1000kg per tonne, therefore 190 tonnes will be reduced over the 7 years. This is equivalent 15% of the 2%. This 15% reduction considers the entire LCA. To further look at the reductions on campus based simply on operations, excluding any maintenance and end of life analysis. The results are much smaller; around 90 tonnes of C02-equivalent reduced which is 7% of the 2%, thus 0.14% of the entire campus emissions based on the 2012 number listed in the table below.

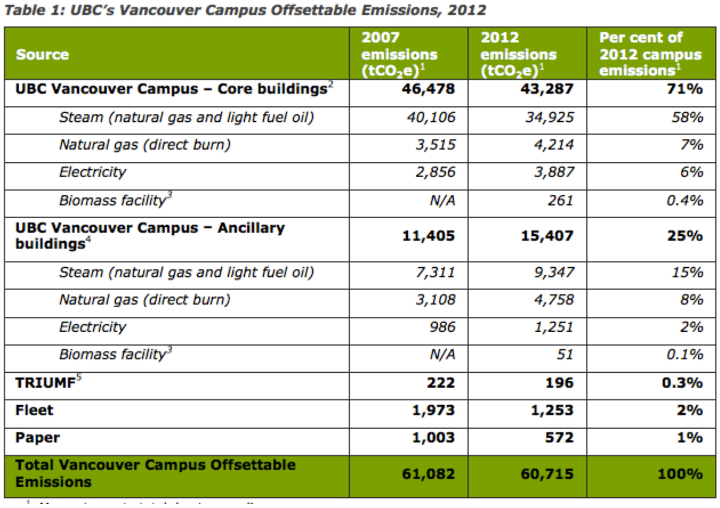


Table 1: UBC's Vancouver Campus Offsettable Emissions, 2012

Source	**2007 emissions (tCO_2e)[1]**	**2012 emissions (tCO_2e)[1]**	**Per cent of 2012 campus emissions[1]**
UBC Vancouver Campus – Core buildings[2]	**46,478**	**43,287**	**71%**
Steam (natural gas and light fuel oil)	*40,106*	*34,925*	*58%*
Natural gas (direct burn)	*3,515*	*4,214*	*7%*
Electricity	*2,856*	*3,887*	*6%*
Biomass facility[3]	*N/A*	*261*	*0.4%*
UBC Vancouver Campus – Ancillary buildings[4]	**11,405**	**15,407**	**25%**
Steam (natural gas and light fuel oil)	*7,311*	*9,347*	*15%*
Natural gas (direct burn)	*3,108*	*4,758*	*8%*
Electricity	*986*	*1,251*	*2%*
Biomass facility[3]	*N/A*	*51*	*0.1%*
TRIUMF[5]	**222**	**196**	**0.3%**
Fleet	**1,973**	**1,253**	**2%**
Paper	**1,003**	**572**	**1%**
Total Vancouver Campus Offsettable Emissions	**61,082**	**60,715**	**100%**

The electric vehicles also provide the opportunity to operate early in the mornings or late evening due to a reduction in noise while operating. This may provide options for the operators to complete various tasks early in the morning before the campus becomes busy with people. This is important to take into consideration because it may allow task to be completed more efficiently.
Additional factors that will need to be considered before the integration of electric vehicles will be finding developing charging stations, which has an upfront cost that has not been included. These charging stations will require space that is currently limited for parking the units. The photo below shows how the current units are parked.

Furthermore, training the staff on the use of electric vehicles will be important to take into account because the longevity of the vehicle is highly correlated with how it is used. Starting and stopping, load carrying, choice of routes to and from places on campus, ect. Will have to be highly considered to optimize the vehicle. Additionally if an operator does not plug the vehicle in at the end of the day, then the vehicle will not be of any use the following day since re-charge times take about 10 hours for a full charge.

6 Recommendations

To change the fleet from diesel powered to electric has advantages in terms of cost and reducing impacts on the environment. However, given the performance of electric vehicles, it would be best to maintain 2 or more diesel units. These diesel units will ensure the job duties and functions of long and hard periods of use, moving heavy loads over varying landscapes, or towing trailers. These duties may be time sensitive, and the completion of the job could still be completed in a timely manner with the diesel units. The electric counter-part should be assessed on site as a demo, and feedback from operators would provide further insight to the actual limits of the units. The electric all-terrain vehicle has the potential to be a useful tool and resource to the building operations.

7 Appendix

7.1 Methodology

The analysis in this report relied on previous LCA studies of diesel motors and lead-acid batteries. To utilize their work with the report, interpolations were done based the relationship between the functional units used in those LCA reports, and the functional unit chosen for this report.

7.2 Diesel Motor Methodology

The functional unit for the diesel motor LCA is 300,000 km (Li et al. 2013). For this report, it was assumed based on fuel efficiency and fuel consumption that the RTV units traveled an average of 20,470 km over the 7 years. This then was used to understand a percentage of relative use in comparison, and the data was entered into a spreadsheet and analyzed. Further research confirmed data from the LCA sources of (Li et al. 2013) and that was used. For a comprehensive understanding of those figures reference the original LCA. The usage and diesel fuel consumption and price was determined from data provided by UBC building operations. The cost of the vehicle was provided by UBC operations. The environmental impacts took the total kg and multiplied it by the factor and added the factors together.

7.3 Lead-Acid Battery Methodology

The functional unit for the lead acid battery was 1 kg of battery. Since the functional unit for this paper was 1 km, the battery weight is 60kg x 8 batteries for the unit, and the total distance the vehicle could travel on 1 charge was divided into the total kg of battery. Hence 480 kg of battery divided by 130 km of travel = 3.69 kg of battery per km traveled. This was then entered into a spreadsheet, and the Wh/kg was calculated as 38 based on the batteries used. This data was then integrated with the existing LCA study on lead-acid batteries. Then usage was assumed to brain the battery fully each day, thus requiring a full charge. Although distance could be determined based on the diesel units, the number of variables that could result in a reduced performance of the unit, it was more conservative to assume that the unit's battery was drained to 80% as suggested by manufacture. To see further about the previous LCA completed their analysis see the paper "A Review of Battery Life-Cycle Analysis: State of Knowledge and Critical Needs" by (Division n.d.).

8 References

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