CHBE 484: Term Report

Selection of UBC Campus Gators based on Life Cycle Analysis

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1.0 INTRODUCTION

UBC Plant Operation is considering replacing several of their utility vehicles, which are used for gardening and performing daily campus maintenance. The UBC SEEDS program has provided this project in-conjunction with UBC Plant Operations in order to choose which fuel alternative is most suitable. With the mindset of sustainability, UBC is considering utility vehicles that are safe for the environment and also within budget. Based on all of these considerations, our study will compare three types of fuels:

- Biodiesel (Section 3.0)
- Gasoline (Section 4.0)
- Electric (Section 5.0)

The comparison will be based on total emissions and energy use of the upstream processing and downstream vehicle operations. Furthermore, there are certain vehicle specifications that have to be followed in choosing a suitable utility vehicle, such as fuel economy and maximum load abilities. Based on this comparison, advantages and disadvantages from each type of fuel alternatives and total emission will be discussed in this report.

One of the purposes of this study is to assess the environmental impacts of electricity and biofuels such as biodiesel relative to conventional automotive fuels such as gasoline. The best environmental option is then identified by performing a *Life Cycle Analysis*, LCA, which takes into account the entire emissions generated during the life cycle of the fuel. The second purpose of this project is to help UBC Plant Operations make an “environmentally friendly” and “cost effective” decision on which John Deere Gator to choose.

2.0 BACKGROUND

To meet the requirements slated by UBC Plant Operations via the UBC SEEDS Program, the three fuels, biodiesel, gasoline and electricity must be compared. The most effective way of comparing fuels is known as a *Life Cycle Analysis* (LCA). The LCA incorporates all types of emission rates associated from producing the fuel to transporting the fuel to disposing the fuel or in other words, "Cradle-to-Grave" analysis. The types of emission rates associated with a LCA are air, water and soil. In more specific detail, these emission rates will include compounds such as CO_2, CO, NO_X, SO_X, and CFCs. When fuels are being compared, another more common phrase is "Well-to-wheel" analysis. LCA is a relatively recent method of environmental analysis for qualifying the environmental effect of any product, process or service over its entire life cycle.

2.1 Life Cycle Inventories

The first criterion for a LCA involves gathering or calculating all of the emission rates. A clearer picture of which emissions are associated with the life cycle of a fuel can be determined by developing the system boundary. Figure 2.1.1 shows the typical system boundary and life cycle of a fuel.

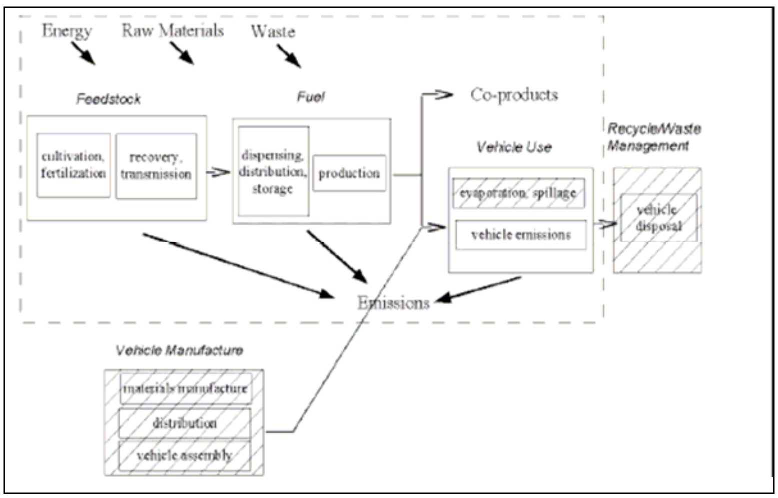

Figure 2.1.1: Process Flow of Fuel Life Cycle and Study Boundary.

In Figure 2.1.1, the production box indicates how the fuel produced. The emissions associated with the production of the fuel represent only a fraction of the overall emissions from its life cycle. These emission rates can be found in literature or from the US Environmental Protection Agency website. For our case, we were introduced to software known as GREET, which is developed by Argonne National Laboratory in Illinois, USA. The acronym GREET represents ***G***reenhouse Gases, ***R***egulated ***E***mission and ***E***nergy Use in ***T***ransportation. It is a user-friendly interface that provides simulation studies on energy efficiencies and emissions for different transportation fuels and vehicle technologies. The user will enter information regarding the production of the fuel by via fuel pathways and regarding the end-use of the fuel such as what type of vehicle will utilize the fuel.   Figure 2.1.2 shows the criteria considered by GREET in its evaluation of the fuel's life cycle and Figure 2.1.3 shows several fuel pathways incorporated into GREET's interface.

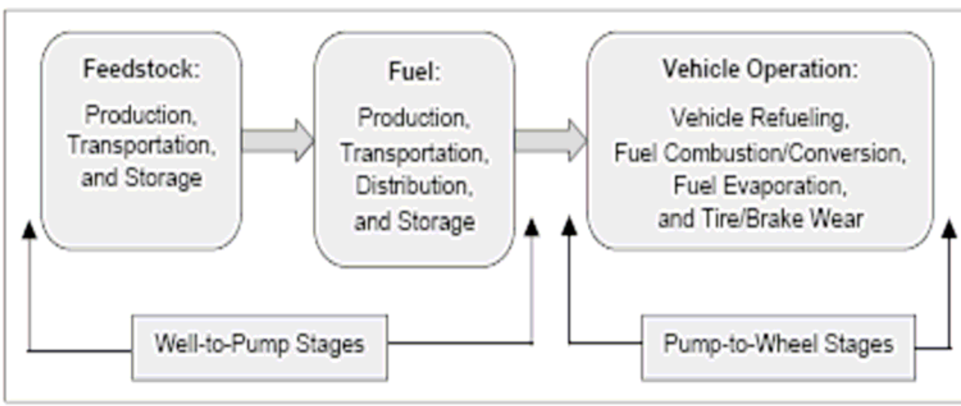

Figure 2.1.2: Stages covered in GREET Fuel-Cycle Analysis

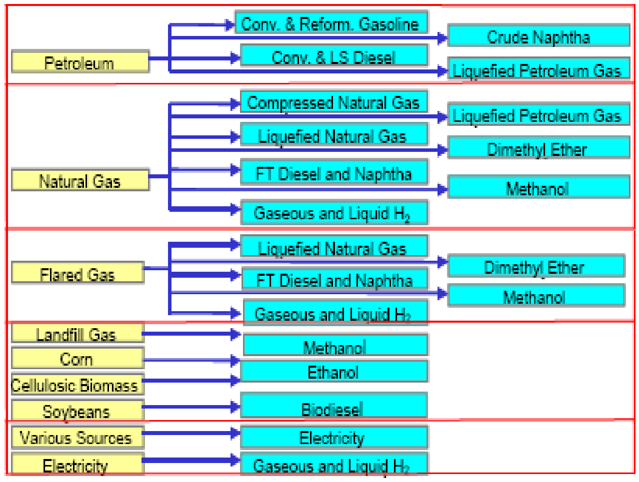

Figure 2.1.3: Fuel Pathways included in GREET

2.2 Environmental and Health Impact Assessment

The environmental impact of chemicals can be local, regional and global environmental issues. Global warming is a problem with potential global implications whereas smog formation and acid rain are problems with potential regional implications. In this report, three particular environmental impact indices will be evaluated, global warming, smog formation and acid rain. These three categories have been chosen for this study because all of them have been identified as the major environmental concern in North America. There are two toxicity indices used in this report to discuss health issue in workplace. The first one is TLV (Threshold Limit Value) method, which is set by The American Conference of Governmental Industrial Hygienists (ACGIH) to address airborne exposure concentration limit at workplace. The second one is PEL (Permissible Exposure Limit) method, which is set by Occupational Safety and Health Administration (OSHA) for workplace exposure.

After the emission rates have been determined, the second criterion is to determine the environmental and health impact values. The following equations are used to determine the overall impact indices for each GWP, ARP and MIR:

$$EI(GWP) = \sum (GWPi \; x \; Ei) \tag{2.2.1}$$

$$EI(ARP) = \sum (ARPi \; x \; Ei) \tag{2.2.2}$$

$$EI(MIR) = \sum (MIRi \; x \; Ei) \tag{2.2.3}$$

where i is the chemical compound

The following equation is used to determine the total health impact:

$$Total\ health\ impact = \sum (Ei / TLVi\ or\ PELi) \tag{2.2.4}$$

2.3 Total Cost Analysis

The final criterion is to determine the costs associated with the fuels. This will include raw material acquisitions costs, production costs, transporting costs, end-use costs and disposal costs. However it can be difficult to obtain information about these costs. Therefore in our assessment, we looked at the end-use costs of the fuels, more specifically the purchasing costs and operating costs of the John Deere Gators.

2.4 Evaluation and Ranking of Fuels

The final step in the comparison of the fuels is to determine which one meets the required criteria, based on the findings from the LCA, environmental and health impact indices and the total cost analysis. It is difficult to rank each criterion since they are determined in different units. Therefore each criterion is non-dimensionalized and then specific weighting factors are given to each criterion in order to determine the overall score. In our case, we chose to analyze several weighting factors such that we could compare how sensitive the criterions are to changes in weight. . The completion of this step will allow the most thorough comparison between a product, process or service. However there are uncertainties associated with the LCA such as being able to determine a complete life cycle inventory. The uncertainties associated with our analysis will be discussed in the conclusion.

3.0 BIODIESEL

The first type of fuel analyzed is biodiesel, a clean burning alternative fuel, produced from domestic, renewable resources. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. It can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel is simple to use, biodegradable, non-toxic, and essentially free of sulphur and aromatics. Currently the UBC Biodiesel Project, led by Professor Naoko Ellis, proposes to supply UBC Plant Operations with approximately 1000 litres of biodiesel per week. The UBC Plant Operations are also looking at off-campus biodiesel suppliers. Therefore biodiesel is ranked high for UBC Plant Operations when it comes to their preference of fuel type. However it is not enough just to base the decision just on simple knowledge or facts about biodiesel. The more effective way is to perform the LCA.

3.1 Life Cycle Analysis of Biodiesel

The first step in order to determine the LCA of biodiesel is to determine the system boundaries associated with life cycle of biodiesel. Figure 3.1.1 shows the typical life cycle of biodiesel based on a soybean production.

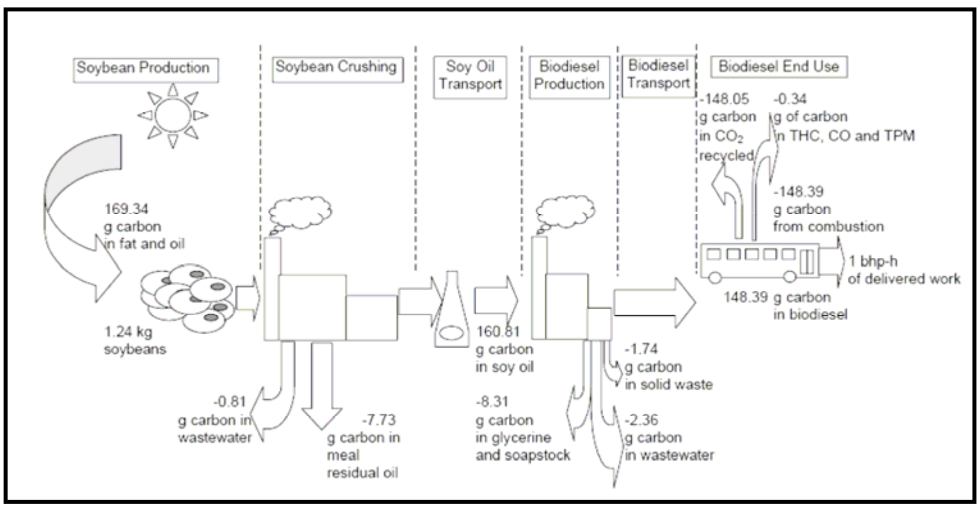

Figure 3.1.1: Biomass Carbon Balance for Biodiesel Life Cycle

The emission rates associated with the LCA of biodiesel were determined using GREET and scholarly journals. However, the specific blend of biodiesel that was analysed was 25% biodiesel and 75% conventional diesel. It is difficult to model such a specific type of fuel so we determined the emission rates for 100% conventional diesel using GREET. The biodiesel emission rates were determined from literature results, more specifically, GHGenius. Then 25% of the biodiesel emission rates were accounted for along with 75% of the conventional diesel emission rates. Table 3.1.1 summarizes the results obtained for a 25% biodiesel and 75% conventional diesel lend of fuel.

Table 3.1.1: Total Emission of Biodiesel Production and Transportation

Item	**Btu/mile or grams/mile**			
	Feedstock	**Fuel**	**Vehicle Operation**	**Total emission**
Total	186	614	4,209	
Fossil	186	614	4,209	
Petroleum	52	304	4,209	
GHGs	19.562	35.857	269.560	324.980
VOC:	0.012	0.019	0.073	0.104
CO: Total	0.029	0.020	0.919	0.968
NOx:	0.122	0.089	0.838	1.049
PM10:	0.004	0.012	0.178	0.193
SOx:	0.025	0.046	0.070	0.142

Note: Total energy, fossil fuels and petroleum values assumed from 100% Diesel

3.2 Environmental and Health Impact Assessment

Most of the emissions associated with the biodiesel life cycle occur during the operation of the vehicle. The largest environmental factor for biodiesel is the greenhouse gases, as indicated by the emission rate. However since the utility vehicles will only be used on campus under low mileage conditions, the net emission of greenhouse gases per year is considerably less then an automobile. Table 3.2.1 summarizes the environmental impacts and health impacts associated with the biodiesel. For the environmental impact of biodiesel, the total GWP is 368.232 equivalent kg CO_2, the MIR is 0.207 kg equivalent C_2H_4 and the ARP is 1.070 kg equivalent SO_2. For the health impact, there are two values determined, one using the TLV method and the other using the PEL method. Both methods are correct but there are discrepancies as can be seen from the biodiesel results. To improve the accuracy, we considered taking the average of both values during the evaluation and ranking of each fuel option.

Table 3.2.1: Summary of Environmental and Health Impacts

	ENVIRONMENTAL IMPACT						**HEALTH IMPACT**			
	GWP	**Global Warming**	**MIR**	**Smog Formation**	**ARP**	**Acid Rain**	**TLV**	**Total Impact based on TLV ([kg/hr]/[mg/m3])**	**PEL**	**Total Impact based on PEL ([kg/hr]/[mg/m3])**
GHGs	1	324.98	0	0	0	0	9000	0.036	18000	0.018
VOC: Total	0	0	2	0.207	0	0	188	0.001	375	0
CO: Total	1.34	1.297	0	0	0	0	29	0.033	40	0.024
NOx: Total	40	41.955	0	0	0.885	0.928	5.60	0.187	1.80	0.583
PM10: Total	0	0	0	0	0	0	2.137	0.090	2.055	0.094
SOx: Total	0	0	0	0	1	0.142	5.200	0.027	5	0.028
Total Impact		**368.232**		**0.207**		**1.070**		**0.375**		**0.748**

3.3 Effect of Biodiesel Blend Level on Emissions

The above results obtained for biodiesel were evaluated for the 25:75 biodiesel to conventional diesel blend. To understand the effect of different blends of biodiesel on emission rates, experiments or models must be conducted at different blend ratios. The following plots developed by the US Department of Agriculture and the US Department of Energy illustrate the effect of biodiesel blend level on emissions. Figure 3.3.1 shows the effect on CO_2 emissions, Figure 3.3.2 shows the effect on CH_4, SO_X, HF, PM and CO emissions. Figure 3.3.3 shows the effect on NO_X, HCl and HC emissions. As the blend ratio increases, the amount of CO2 release increases. This is evident from the fact as biodiesel is produced from oils containing chains of carbon molecules. The benefit of biodiesel is that as the blend ratio increases, less on CH_4, SO_X, HF, PM and CO emissions are released. The downside of biodiesel is that a higher ratio of biodiesel results in the increase of NO_X, HCl and HC emissions. Therefore an optimum level or range must be used to satisfy all emissions. In places such as southern United States, blend ratios of 100% biodiesel are being used. It would be recommended that UBC Plant Operation at least consider increasing the blend ratio to 40-50% biodiesel in order to reduce a certain degree of emissions.

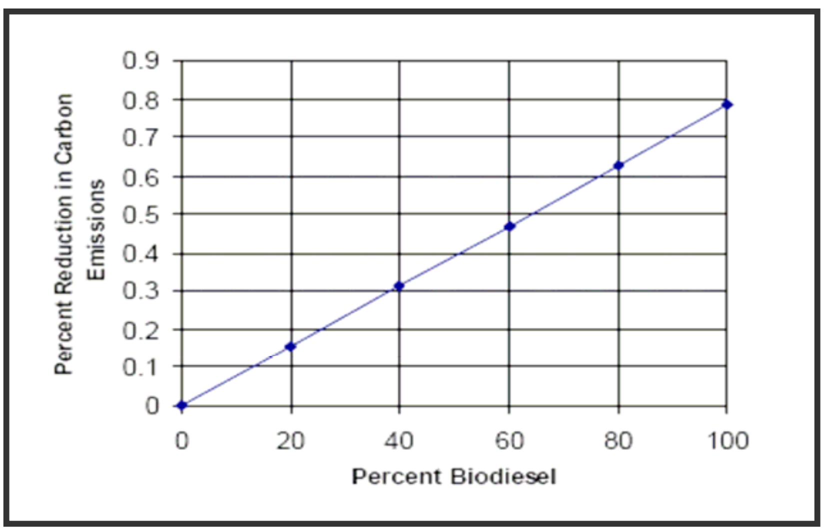

Figure 3.3.1: Effect of Biodiesel Blend Level on CO_2 Emissions

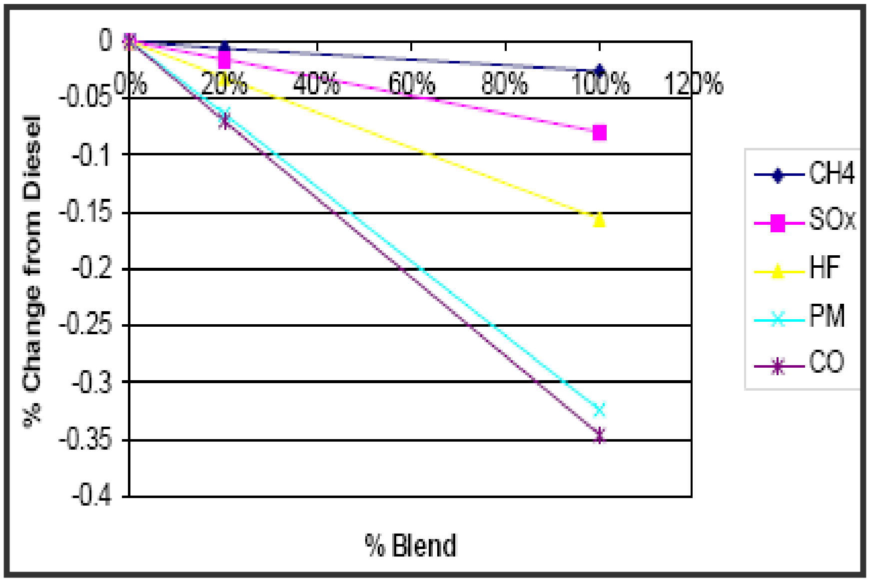

Figure 3.3.2: Effect of Biodiesel Blend Level on CH_4, SO_X, HF, PM and CO Emissions

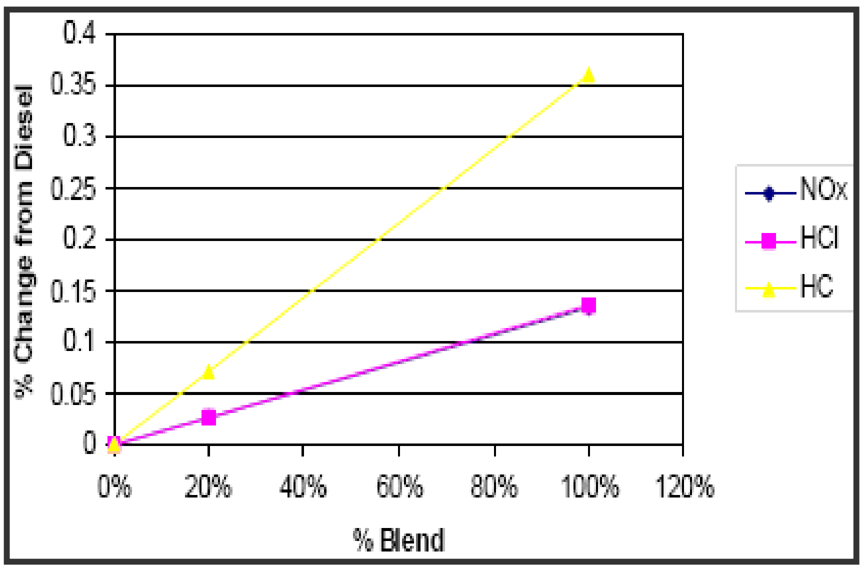

Figure 3.3.3: Effect of Biodiesel Blend Level on NO_X, HCl and HC Emissions

4.0 GASOLINE

The second type of fuel analyzed is gasoline, a petroleum-derived liquid mixture consisting primarily of hydrocarbons that is used as a fuel in internal combustion engines. Material that is separated from crude oil via distillation, called natural gasoline, does not meet the required specifications for modern engines. The bulk of typical gasoline consists of hydrocarbons with between 5 and 12 carbon atoms per molecule. There are various refinery streams blended together to make gasoline and each of those streams have different characteristics. Gasoline contains about 45 mega joules per kilogram.

4.1 Life Cycle Analysis of Gasoline

Assumptions have been made to the production and transportation of gasoline in order to complete the simulation. Figure 4.1.1 shows the simplified diagram of the fuel cycle.

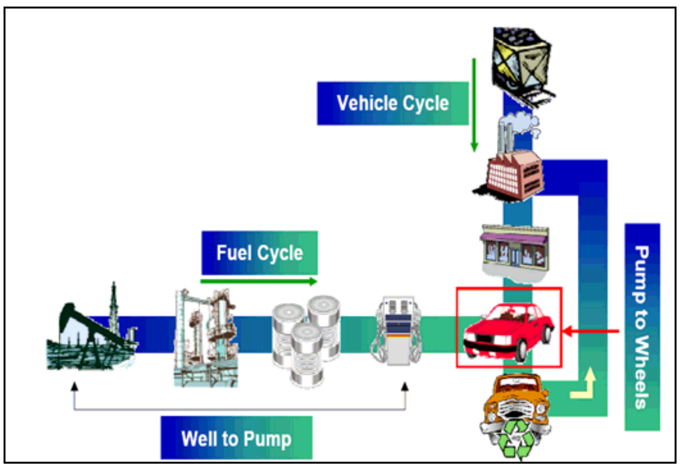

Figure 4.1.1: Life Cycle Diagram of Gasoline

In this simulation, oxygenate blending ads oxygen to the fuel in oxygen bearing compounds such as MTBE, and so reduces the amount of carbon monoxide and unburned fuel in the exhaust gas, thus reducing the smog. Assumptions associated with life cycle analysis of gasoline are shown in Tables 4.1.1, 4.1.2, 4.1.3 and 4.1.4 below.

Table 4.1.1: Pathway selections of gasoline production

Conventional Gasoline	
Vehicle Technology	
Spark Ignition Engine	
Pathway Options	
Conventional Gasoline O2 Content (%):	0.4
Conventional Gasoline Sulphur Level (ppm):	340
Conventional Gasoline Oxygenate:	Methyl Tertiary Butyl Ether

Table 4.1.2: Fuel Production Assumption

Petroleum	
Items	**Assumptions**
Crude Recovery Efficiency (%)	97.7%
CG Refining Efficiency (%)	85.5%
CD Refining Efficiency (%)	89.0%

Table 4.1.3: Gasoline Transportation Assumption

Feedstock and Fuel							
Transportation Mode		**Transport**	**Transport**	**Transport**	**Transport**	**Transport**	**Distribution**
		Ocean Tanker	**Barge**	**Pipeline**	**Rail**	**Truck**	**Truck**
Petroleum							
Crude for U.S. Average	Mode Share	57.0%	1.0%	100.0%	0.0%	0.0%	
	Distance	5,080	500	750	800	30	
CG	Mode Share	20.0%	4.0%	73.0%	7.0%		100.0%
	Distance	1,700	520	400	800		30

Table 4.1.4: Gasoline Tanker Size Assumption

Ocean Tanker	
Items	**Ocean Tanker Size (tons)**
Crude Oil	1,143,000
Gasoline	150,000

The GREET software was used to determine emission rates for the life cycle of gasoline based on the assumptions mentioned above. After all the assumptions have been made and the life cycle analysis is collected, the next step is to perform environmental impact, health impact and overall impact assessment based on the total emission summarized in Table 4.1.5 below.

Table 4.1.5: Total Emission of Gasoline Production and Transportation

Item	**Btu/mile or grams/mile**			
	Feedstock	**Fuel**	**Vehicle Operation**	**Total Emission**
Total Energy	228	1,046	5,156	
Fossil Fuels	228	1,046	5,156	
Petroleum	64	495	5,067	
CO2	21	74	390	
CH4	0.470	0.101	0.084	
N2O	0.000	0.001	0.028	
GHGs	31	76	401	507.623
VOC: Total	0.016	0.067	0.207	0.290
CO: Total	0.042	0.037	5.517	5.596
NOx: Total	0.108	0.097	0.275	0.479
PM10: Total	0.003	0.013	0.033	0.049
SOx: Total	0.033	0.079	0.085	0.197

Most of the emission that being released to the environment is coming during vehicle operation compare to feedstock and fuel as can be seen in Figure 4.1.2.

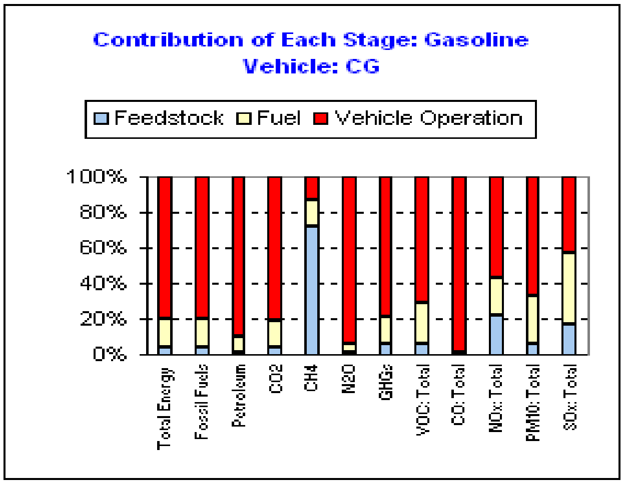

Figure 4.1.2: Contribution of Each Stage: Gasoline Vehicle

4.2 Environmental Impact Assessment

The environmental impact results are summarized on Table 4.2.1 below.

Table 4.2.1: Summary of Environmental Impact

	ENVIRONMENTAL IMPACT					
	GWP	**Global Warming**	**MIR**	**Smog Formation**	**ARP**	**Acid Rain**
GHGs	1	507.623	0	0	0	0
VOC: Total	0	0	2	0.580	0	0
CO: Total	1.340	7.499	0	0	0	0
NOx: Total	40	19.165	0	0	0.885	0.424
PM10: Total	0	0	0	0	0	0
SOx: Total	0	0	0	0	1.000	0.197
Total Impact		**534.287**		**0.580**		**0.621**

Based on the results, the overall environmental impacts on global warming, smog formation and acid rain are 507.623 equivalent kg CO_2, 0.580 kg equivalent C_2H_4 and 0.621 equivalent kg SO_2 respectively.

4.3 Health Impact Assessment

The health impact results are summarized in Table 4.3.1.

Table 4.3.1: Summary of Health Impact

	HEALTH IMPACT			
	TLV	**Total Impact based on TLV ([kg/hr]/[mg/m3])**	**PEL**	**Total Impact based on PEL ([kg/hr]/[mg/m3])**
GHGs	9000	0.056	18000	0.028
VOC: Total	188	0.002	375	0.001
CO: Total	29	0.193	40	0.140
NOx: Total	6	0.086	2	0.266
PM10: Total	2.137	0.023	2.055	0.024
SOx: Total	5.200	0.038	5.000	0.039
Total Impact		**0.397**		**0.498**

Based on the results, the overall health impacts based on TLV and PEL are 0397 and 0.498 ([kg/hr]/[mg/m3]) respectively.

5.0 ELECTRICITY

The third type of fuel that was studied is electricity. For this category, the same procedure was followed and a well-to-wheel analysis has been conducted. The environmental and health impact results are also obtained from the GREET software.

5.1 Life Cycle Analysis of Electricity

As it is widely known, there are numerous sources to produce electricity from such as fossil fuels, biomass, nuclear power, and renewable sources (solar, wind, hydro, geothermal). Fossil fuels are the most common sources used in electricity production in North America (70% of whole electricity production). Coal is the major fossil fuel used since there are many coal reserves available in North America. However, as these reserves are continued to deplete, in the following 50-60 years came the prominence of renewable sources.

Since this project is related to UBC Plant Operation's Gator utility vehicle selection, a more realistic combination of electricity production sources is used in our calculations. Since the water resources are abundant in British Columbia and a large amount of electricity is being produced from the motion of water, it is assumed that 90% electricity that will be used in the Gators are coming from that source. The remaining 10% is assumed to be coming from a natural gas plant and both environmental and health impacts are calculated based on these assumptions.

After entering the assumed data in the GREET software, the results in Table 5.1.1 are obtained.

Table 5.1.1: Total Emission of Electricity Production and Transportation

Item	Btu/mile or grams/mile			
	Feedstock	**Fuel**	**Vehicle Operation**	**Total emission**
Total Energy	301.872	4810.006	0.0	-
Fossil Fuels	30.187	481.001	0.0	-
Petroleum	1.721	0.000	0.0	-
CO2	2.251	29.814	0.0	-
CH4	0.083	0.001	0.0	-
N2O	0.0	0.001	0.0	-
GHGs	29.615	30.049	0.0	59.664
VOC: Total	0.031	0.001	0.0	0.032
CO: Total	0.022	0.011	0.0	0.033
NOx: Total	0.099	0.013	0.0	0.112
PM10: Total	0.018	0.002	0.002	0.022
SOx: Total	0.046	0.0	0.0	0.046

As it can be observed from the results in Table 5.1.1, most of the CO_2 is generated during the fuel production. A very small amount is produced in the extraction of the feedstock. There is no CO_2 generated during the vehicle operation, which is the most significant reason for electric vehicles to be considered as an alternative. The other greenhouse gas contributors, CH_4, N_2O, and CFCs' amounts are relatively very small. Again, generated volatile compounds, CO, NOx, large particulate matters (PM10), and SOx are nearly insignificant. None of these products are created during the vehicle operation. The generated small amounts are coming either from feedstock extraction or fuel production. The major contribution to the environmental and health impact comes from CO_2 generation.

5.2 Environmental and Health Impact Assessment

In the following table, the total emissions are multiplied with the corresponding potential factor and impacts of the emissions on global warming, smog formation, acid rain and health impact based on TLV and PEL values are calculated.

Table 5.2.1: Summary of Environmental and Health Impacts

	ENVIRONMENTAL IMPACT						**HEALTH IMPACT**			
	GWP	**Global Warming**	**MIR**	**Smog Formation**	**ARP**	**Acid Rain**	**TLV**	**Total Impact based on TLV ([kg/hr]/[mg/m3])**	**PEL**	**Total Impact based on PEL ([kg/hr]/[mg/m3])**
GHGs	1	59.664	0	0.000	0	0	9000	0.007	18000	0.003
VOC: Total	0	0	2	0.063	0	0	188	0	375	0
CO: Total	1.340	0.044	0	0	0	0	29	0.001	40	0.001
NOx: Total	40	4.484	0	0	0.885	0.099	5.60	0.020	1.80	0.062
PM10: Total	0	0	0	0	0	0.000	2.137	0.010	2.055	0.011
SOx: Total	0	0	0	0	1	0.046	5.20	0.009	5	0.009
Total Impact		**64.192**		**0.063**		**0.145**		**0.047**		**0.086**

The biggest impact of electrical vehicles is on global warming as it can be seen in Table 5.2.1. These types of vehicles do not contribute to smog formation and acid rain significantly. Furthermore, two types of health impact analysis are conducted; one based on TLV and the other one based on PEL factors. Consistent results are obtained from both analyses, which show that the biggest health impact was due to the generated NOx. However, in that case it is a very small impact indeed.

The following graph is a distribution of emission rates based on their sources. This graph is also produced by using Greet software and demonstrates the contribution of each stage on the generated emission rates.

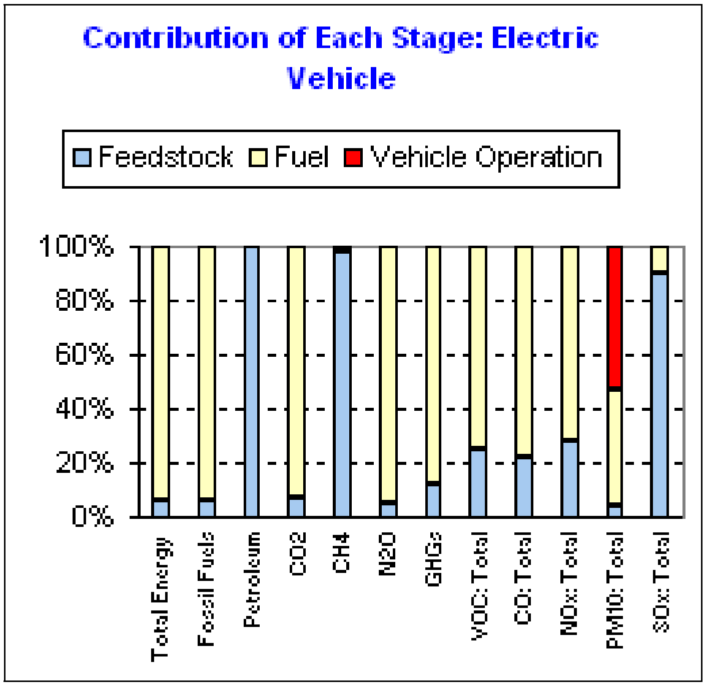

Figure 5.2.1: Contribution of Each Stage: Electric Vehicle

As it can be observed from Figure 5.2.1, only particulate matters are produced during the vehicle operation and none of the other gases are being generated. Only the majority of CH_4 and SOx are being generated during the fuel extraction from the feedstock and the rest of the gases are predominantly formed in the fuel production.

6.0 CONCLUSION

In this well-to-wheel life cycle analysis, three types of fuels are compared by using GREET, which is a rigorous software specialized on lifecycle analysis of transportation vehicles. The three types of fuels studied are bio-diesel (25% bio-diesel and 75% diesel mix), conventional gasoline, and electricity. The well-to-wheel analysis included the emission rates generated during the extraction, production, and use of the fuel in the utility vehicle. Furthermore, a cost analysis is also conducted for the specifications required by UBC Plant Operations. The costs are obtained for utility vehicles from John Deere, which is a very well known company.

Table 6.1: Emission Rate Comparison between Gasoline, Biodiesel and Electric Vehicles

Item	**Gasoline (gram/mile)**	**Bio-Diesel/Diesel Mix (gram/mile)**	**Electric (gram/mile)**
GHGs	507.623	324.980	59.664
VOC: Total	0.290	0.104	0.032
CO: Total	5.596	0.968	0.033
NOx: Total	0.479	1.049	0.112
PM10: Total	0.049	0.193	0.022
Sox: Total	0.197	0.142	0.046
Global Warming	534.287	368.232	64.192
Smog Formation	0.580	0.207	0.063
Acid Rain	0.621	1.070	0.145
Total Impact based on TLV	0.397	0.375	0.047
Total Impact based on PEL	0.498	0.748	0.086
Cost (based on John Deere)	**$9400**	**$10900**	**$12300**

Based on Table 6.1, electricity has the least emission rates and impact on the environment for each category studied in this analysis. Bio-diesel has lower greenhouse gases (GHGs), Volatile Organic Compounds (VOC), CO, and SO_X emission rates than conventional gasoline. However, bio-diesel generates more particulate matter (PM10) and NO_X than the gasoline vehicles. The contribution of these gases to the global warming favours the electric vehicle again, followed by bio-diesel and gasoline respectively. Smog formation has also the same trend. However, in the acid rain category, gasoline vehicles have less contribution than the bio-diesel vehicles.

Health impact is analyzed based on two different potential factors, TLV and PEL. In the analysis based on TLV factors, electric vehicles are found to be the least influential vehicles followed by bio-diesel and gasoline respectively; however, the difference between gasoline and bio-diesel is very little. Alternatively, the analysis based on PEL factors led to different results. Electric vehicles are again found to be the most favourable vehicle type followed by gasoline.

Different vehicles from different companies were considered but the vehicles from John Deere met the standards that the UBC Plant Operations required. Since John Deere is the only company providing all three types of engines for their utility vehicles, its prices are compared and unlike the environmental and health impact results, electric vehicles are found to be the most expensive choice among the three options. Bio-diesels are found to be $1500 more expensive than the currently cheapest vehicle type, which is gasoline. The high cost of electric vehicles is mainly due to frequent battery changes (1-2 per year) since they die very often. Another concern is about the charging system. The battery of an electric car is being charged in around 12 hours, which is a very problematic and inconvenient comparatively. The higher cost of the bio-diesel vehicles are due to the infrastructure of this relatively new technology.

Next, a sensitivity analysis is conducted for different scenarios, in which different weighting factors are assigned for each category. Basically, a score of 10 is given to the one that has the highest contribution to the related category and the ratio of the others to the highest one is multiplied by 10 to get the dimensionless scores. Then these weighting factors are multiplied with the impacts calculated and the sum of them gave the overall score for different weighting factor options. The lower the overall score is, the more preferable the fuel option is.

Table 6.2: Sensitivity Analysis for the Weighting Factors

	Weighting Factor 1	**Weighting Factor 2**	**Weighting Factor 3**	**Weighting Factor 4**	**Weighting Factor 5**
Global Warming	0.200	0.250	0.300	0.400	0.150
Smog Formation	0.150	0.150	0.100	0.250	0.100
Acid Rain	0.100	0.100	0.050	0.050	0.050
Total Impact based on TLV	0.050	0.100	0.050	0.100	0.050
Total Impact based on PEL	0.050	0.100	0.050	0.100	0.050
Cost (based on John Deere)	0.450	0.300	0.450	0.100	0.600
Overall Score Gasoline	**8.352**	**8.539**	**8.562**	**9.221**	**8.209**
Overall Score Bio-diesel	**7.874**	**7.861**	**7.884**	**6.980**	**8.180**
Overall Score Electric	**5.157**	**3.834**	**5.154**	**2.055**	**6.474**

Based on the sensitivity analysis conducted, electric vehicles have the lowest overall score in all cases and should be most preferable vehicle. Bio-diesel utility vehicles have the second lowest overall score. Therefore, they should be preferred rather than gasoline vehicles.

Based on the life cycle and cost analysis conducted, and the sensitivity analysis performed for different scenarios, the most preferable choice is the electric utility vehicles. However, after taking the cost of the maintenance (batteries and charging system) into considerations more, it is wiser to have a combination of two bio-diesel and two electric vehicles or even three bio-diesels and one electric vehicle since UBC Plant Operations is considering replacing four of their utility vehicles.

Another suggestion is to increase the blend ratio of bio-diesel and diesel mixture from 25% to 40-60%. By doing so, the environmental impacts would be lessened without affecting the performance of the vehicle. The blend ratio could be increased gradually to see the real impacts associated with the change and could be acted accordingly.

As mentioned before, the most uncertainties in a LCA arise under product or process comparison. Uncertainties are mainly related to the lack of emission data from other sources within the lifecycle such as incineration and landfills and the uncertainty associated with the recycling rate of used product. The uncertainties associated with the comparison of biodiesel, gasoline and electricity come from the difficulty in assessing the overall environmental impacts of the wastes and pollutants, the renewable versus non-renewable source, the biodegradable versus non-biodegradable product and as well as the overall emissions associated with the construction of the infrastructure that produces these fuels. The most uncontroversial use of a LCA is product or process improvement. From our individual analysis of each fuel, it can be concluded that majority of the emissions come during the operation of the vehicle. Therefore it would valuable to look at ways of improving the vehicle's daily operation.

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