

**An Investigation into Optimal Modes of Campus Food Delivery**  
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# **An Investigation into Optimal Modes of Campus Food Delivery**

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## Abstract

The construction of the new UBC Student Union Building (SUB), expected to be completed by 2015 offers an opportunity for AMS Food and Beverage to introduce changes to various aspects of food services offered to UBC students. One of these many changes has to do with the introduction of a campus-wide food delivery system. This research aims to investigate optimal modes of campus food delivery and offer recommendations.

Focusing mainly on a sustainable vehicle to use for delivery, a few requirements were made clear from the start. A suitable delivery vehicle should: have 100 cubic feet of cargo space, be able to withstand Vancouver's weather conditions and seasons, and have an operational range that can cover the whole of UBC's point grey campus. This research cites both primary and secondary sources for information on vehicles currently available in North America as well as existing research into the environmental and economic aspects of various vehicle types.

With the aim to evaluate the environmental, economic, and social implications of a potential delivery vehicle, this investigation begins by looking into existing research to compare the environmental impacts of vehicles that run on various fuels, full electric vehicles (EV), and hybrids. Following this, the search for a suitable vehicle can be narrowed down to just one class of vehicle – In this case, a full EV by Canadian Electric Vehicles Ltd – the Might-E Truck. The cost effectiveness of the candidate vehicle is then analyzed with initial costs, maintenance and energy costs among the parameters taken into account. A logistics analysis follows, making sure the vehicle fits the physical and range requirements followed finally by an investigation into the social implications of the chosen vehicle on members of the UBC campus community.

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## Glossary

**Adapted gear** - The natural gear on the vehicle for speed being tested.

**Inferior gear** - One gear lower than the natural gear on the vehicle for the speed being tested in order to induce higher motor speed and noise.

**Well-to-wheel energy efficiency** – The efficiency derived from comparing the energy content of the source fuel to the energy used to turn the wheels of the vehicle (hence the name). The energy content of the source fuel is tracked from: extraction from the ground, conversion into fuel type, energy lost from transportation of fuel, and advertised energy efficiency of the vehicle. This number is expressed in terms of kilometres driven for each megajoule (km/MJ) in this investigation.

**Well-to-wheel emissions** – The emission of the vehicle when the emissions from the source fuel to the energy used to turn the wheels of the vehicle are taken into account. The number is expressed in grams of carbon dioxide for each kilometer driven (g/km) in this investigation.

## List of Abbreviations

**CO<sub>2</sub>** – Carbon dioxide

**EV** – Electric vehicle

**g/km** – grams per kilometer. See glossary: well-to-wheel emissions.

**g/MJ** – grams per Mega joule

**km/MJ** – Kilometer per Mega joule. See glossary: well-to-wheel energy efficiency

**Mpg** – Miles per gallon

**SUB** – Student Union Building

**UBC** – University of British Columbia

**Wh/km** – Watt-hours per kilometer

## 1.0 Introduction

In this investigation we approach our recommendation by first analyzing the environmental impact of vehicles that run on various energy sources, citing mainly studies that compare these technologies to prove that full EVs should be the preferred choice when it comes to optimal energy efficiency for a campus food delivery setup. Here, comparisons are drawn between more regular automobiles as these are the focus of most existing research and we lean less towards the small utility vehicle class that is of interest.

Next, we explore the logistics and economic feasibility of EVs by studying the operational range that is expected of these vehicles as well as the number of hours in a day they will be expected to operate. This, together with a cost analysis of our main candidate – the Might-E Truck manufactured by Canadian Electric Vehicles Ltd. – in comparison to a similar solution – a John Deere Gator TH 6x4 Utility Vehicle will be used to draw conclusions on whether or not the Might-E truck fits the main requirements set by our stakeholders.

Finally, we look into the UBC community. Given the current image of UBC as a campus with numerous initiatives towards social, economic and environmental sustainability, this investigation will explore how the introduction of one or more Might-E Trucks as campus food delivery vehicles will affect the community, and encourage further change within the students and staff.

## 2.0 Analysis of Environmental Impact

The environmental aspect of the investigation was a large factor in the final recommendation. Taking a general approach, a case-by-case analysis of different fuel sources was done involving: natural gas, hydrogen fuel cell, diesel, gasoline, hybrid, and electric, with the goal being to select the best fuel type. Specifically, the two most prominent indicators of environmental impact are: efficiency of the fuel type and emissions from the vehicle of the fuel type. Comparing these indicators across each of the different fuel types creates a well-defined picture of the environmental impact of fuel types.

### 2.1 *Efficiency*

With regards to efficiency, the idea of interest is the well-to-wheel efficiency of the vehicle. Computing the **well-to-wheel efficiency** of a fuel type is very difficult without some assumptions. Due to the general nature of the investigation, it is far simpler to use example vehicles for each fuel type and analyze their efficiencies. This will still be able to serve as a valuable basis for the investigation. The following is a snippet from an insightful case study done by Tesla:



Technology	Example Car	Source Fuel	Well-to-Station Efficiency	Vehicle Mileage	Vehicle Efficiency	Well-to-Wheel Efficiency
Natural Gas Engine	Honda CNG	Natural Gas	86.0%	35 mpg	0.37 km/MJ	0.318 km/MJ
Hydrogen Fuel Cell	Honda FCX	Natural Gas	61.0%	64 m/kg	0.57 km/MJ	0.348 km/MJ
Diesel Engine	VW Jetta Diesel	Crude Oil	90.1%	50 mpg	0.53 km/MJ	0.478 km/MJ
Gasoline Engine	Honda Civic VX	Crude Oil	81.7%	51 mpg	0.63 km/MJ	0.515 km/MJ
Hybrid (Gas/Electric)	Toyota Prius	Crude Oil	81.7%	55 mpg	0.68 km/MJ	0.556 km/MJ
Electric	Tesla Roadster	Natural Gas	52.5%	110 Wh/km	2.18 km/MJ	1.145 km/MJ

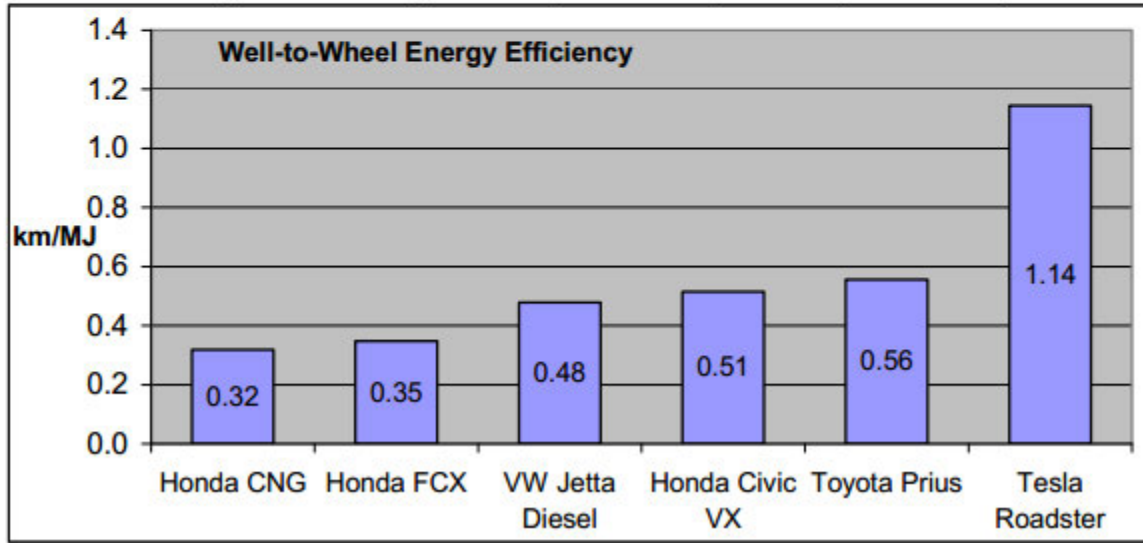


Figure 1: Comparison of well-to-wheel efficiencies.

The example vehicles used in the comparison are considered to have a very high efficiency for their fuel type. Despite this, it is still easy to see that the EV is the clear winner with regards to environmental impact with over twice the efficiency of the next best choice: the hybrid.

From the perspective of the investigation, it is reasonable to assume that EVs in general have an advantage over the other fuel types. Furthermore, due to the great environmental advantage, the EV is an excellent starting point for the rest of the investigation. It is also worth mentioning that the comparison shown previously was done with the assumption that the source fuel for the EV (that is, the fuel that is converted to electricity) is natural gas. Here in British Columbia, 90% of electricity is hydroelectricity which translates to an even higher efficiency than depicted in Tesla's investigation.

## 2.2 Emissions

Similar to well-to-wheel-efficiency, the **well-to-wheel emission** of vehicles is also explored. In the same case-study as above, emissions are computed with the same considerations in mind as the efficiency calculations. That is, the carbon content of the source fuel is compared to the carbon emissions required to reach the wheels of the vehicle. However, the assumption here is that each vehicle uses an ideal engine that emits only carbon dioxide and water. Of course, the CO<sub>2</sub> emissions are of particular concern. The following shows the data collected from the case study:

Technology	Example Car	Source Fuel		Well-to-Wheel	
			CO <sub>2</sub> Content	Efficiency	CO <sub>2</sub> Emissions
Natural Gas Engine	Honda CNG	Natural Gas	52.8 g/MJ	0.32 km/MJ	166.0 g/km
Hydrogen Fuel Cell	Honda FCX	Natural Gas	52.8 g/MJ	0.35 km/MJ	151.7 g/km
Diesel Engine	VW Jetta Diesel	Crude Oil	73.0 g/MJ	0.48 km/MJ	152.7 g/km
Gasoline Engine	Honda Civic VX	Crude Oil	73.0 g/MJ	0.52 km/MJ	141.7 g/km
Hybrid (Gas/Electric)	Toyota Prius	Crude Oil	73.0 g/MJ	0.56 km/MJ	130.4 g/km
Electric	Tesla Roadster	Natural Gas	52.8 g/MJ	1.15 km/MJ	46.1 g/km

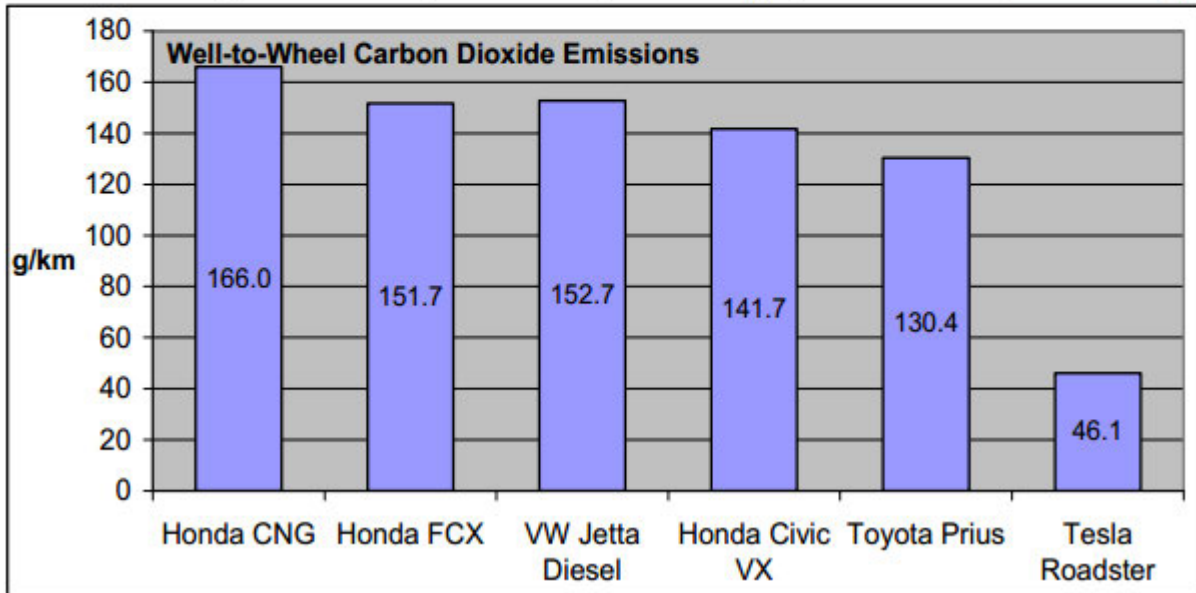


Figure 2: Comparison of well-to-wheel emissions.

It is evident again that the EV has the lowest environmental impact. The EV emits three times less than the prevalent gasoline engine, and still emits nearly three times less than the next closest competitor.

Once again, because of the magnitude of the advantage of EVs, it is not unreasonable to assume that EVs in general have an advantage with regards to CO<sub>2</sub> emissions. However, EV emissions vary in that they depend on the ease of the ability of the region to generate electricity. Since Tesla Motors is an American company, they have likely conducted their investigation with the US in mind. Thankfully, a study comparing EV emissions across different countries showed that for an EV with a well-to-wheel CO<sub>2</sub> emission of 75g/km in the US will only have a well-to-wheel emission of 31g/km in Canada. Since British Columbia has an especially large electricity sector, as mentioned above, there is a great comparative advantage in using EVs here.

### *2.3 Brief Summary*

The EV is the clear choice when considering the vehicle type with the best environmental impact. It has great advantages in the two areas that are salient indicators for environmental impact, namely efficiency and emission. Also, there is a regional advantage to using EVs in Canada and particularly in British Columbia due to the prominent electricity sector. As a result, the EV will serve as the focal point of the rest of the investigation: discussion of economic feasibility, social acceptability and final recommendations.

### 3.0 Economics and Logistics

In terms of the price and usability of an electric vehicle, there are several factors that come into play. First and foremost is the cost of the initial investment, then energy costs, then maintenance, and finally the range, charging and use of the vehicle. Through looking at these factors and comparing several vehicles, we come to the conclusion that the Might-E truck by Canadian Electric Vehicles is the best solution for a short-range food delivery application. For a comparison to a similar style of vehicle, but in a gasoline configuration, the specifications of a John Deere Gator TH 6x4 Utility Vehicle will be referenced.

#### 3.1 *Initial Investment*

The Might-E truck has an initial cost of \$34 000 when configured with a pickup box. The pickup box is important to the application of the vehicle because of the need to shelter food in transportation. The price of this vehicle is justified by its custom made parts specifically for this vehicle and because of the use of high quality, North American sourced parts. Compared to less expensive vehicles such as the Zaptruck XL, which is a repurposed truck made in China, the Might-E truck will be more reliable and have a higher grade build quality that will be essential for everyday use. The John Deere vehicle, as a comparison, costs approximately \$15 000.

#### 3.2 *Energy Costs*

In looking at similar vehicles only in terms of fuel costs and payload, a Might-E truck costs approximately 4 cents per mile, where a John Deere Gator gas powered vehicle costs approximately 18 cents per mile. Because the Gator vehicle has a relatively efficient estimated 25 mpg for our application, this figure would be the minimum cost of fuel for a gasoline powered car. In conclusion,

this means the Might-E truck will be approximately 4.5 times more cost efficient than its most similar competitor in a gas configuration.

Gas price per mile:

$$\frac{1 \text{ gallon}}{35 \text{ mile}} * \frac{3.78 \text{ litres}}{\text{gallon}} * \frac{\$1.40}{\text{litre}}$$

EV price per mile:

$$\frac{17.28 \text{ kWh}}{\text{charge}} * \frac{\$0.10}{\text{kWh}} * \frac{1 \text{ charge}}{40 \text{ miles}}$$

### 3.3 Maintenance

Including batteries and general maintenance, Ford estimates that the maintenance costs of an electric vehicle is said to be over 30 percent cheaper than a similarly equipped gasoline car. Many articles and applications of electric vehicles support these findings; Ingram, (2012) in an article on Green Car Reports cites a German study that estimates even further savings of up to 35 percent. In research done by the US Postal Service during their transition to electric vehicles, they calculated that they saved 46 percent in maintenance costs per mile. Because a consumer car and its components are much more complicated than either a Might-E truck or a John Deere Gator, it is assumed that the costs will scale the same in the case of both vehicles. It is estimated that the cost of maintenance of the electric vehicle will be \$1500 a year, and the cost of the John Deere will be about \$2300; this will be a savings of approximately 35 percent. Because the lead-acid batteries that are used in the Might-E truck have a life-cycle of approximately 5 years, the maintenance costs for years 1-4 will be less than \$1500 and year 5 will be slightly more.

### 3.4 *Range and Delivery*

When looking at distances on the UBC campus from the new Student Union building, the farthest buildings (not using pedestrian paths) are approximately 2 km. One of the buildings that are approximately 2 km away is the Totem Park residence. Using the approximate usable range of 72 km, it is estimated that the Might-E truck will be able to drive 18 trips to Totem Park on a single charge. Most residences are much closer than 2km, with the majority of them being about 1 km away, which means these residences could be delivered to approximately 36 times in one day. Using trip consolidation techniques, this figure could be increased even further.

Usable Range:

90km max – 10% safety – 10% load

### 3.5 *Charging, Usable Hours and Cost per Year*

It is estimated that, using the charging ports to be installed at the SUB loading bay, that the Might-E truck will take 6 hours to charge. It is assumed downtime needed to charge the vehicle will be available from approximately 2-8am. Compared to similar vehicles, such as the Zaptruck XL, with charging times of up to 12 hours, the Might-E truck is quite efficient.

Not including the initial costs, if the Might-E truck and the Gator were to drive 50 miles every day and maintenance estimates are included, the Might-E truck will cost less than half that of the Gator. It is estimated that it would take only 5 years to offset the cost of choosing the Might-E truck over a Gator. Every year after that it is estimated that it would save over \$3500 a year on fuel and maintenance costs.

## 4.0 Analysis of Social Impacts

The University of British Columbia is becoming a worldwide leader in developing an environmentally-friendly campus with initiatives such as the UBC Sustainability Initiative (USI), which sets sustainability goals and targets and how to achieve them. The scope of these goals range from what type of food is available on campus to what type of building materials the new SUB should use. As sustainability is deeply ingrained in UBC's culture, it is important to investigate how different options for vehicles for the new SUB's delivery network will affect this culture in the short and long term.

### *4.1 Noise Pollution*

The new SUB will offer a late-night delivery service to students in all of UBC's residences as well as all other accommodations across campus. The late-night nature of this service developed the need for investigation on how much noise these new campus vehicles would be emitting in order to ensure that UBC residents will not be disturbed by the operating noise of these vehicles. In general, electric vehicles generate much less vehicular noise than their diesel counterparts. Pallas et al. (2014) found that at low constant speeds, electric vehicles may have a noise benefit exceeding 8dBA when compared to their standard-engined counterparts; additionally, although smaller, the noise benefit during acceleration and braking is still prevalent. It can be seen that electric vehicles has the advantage when comparing noise that the vehicles produce.

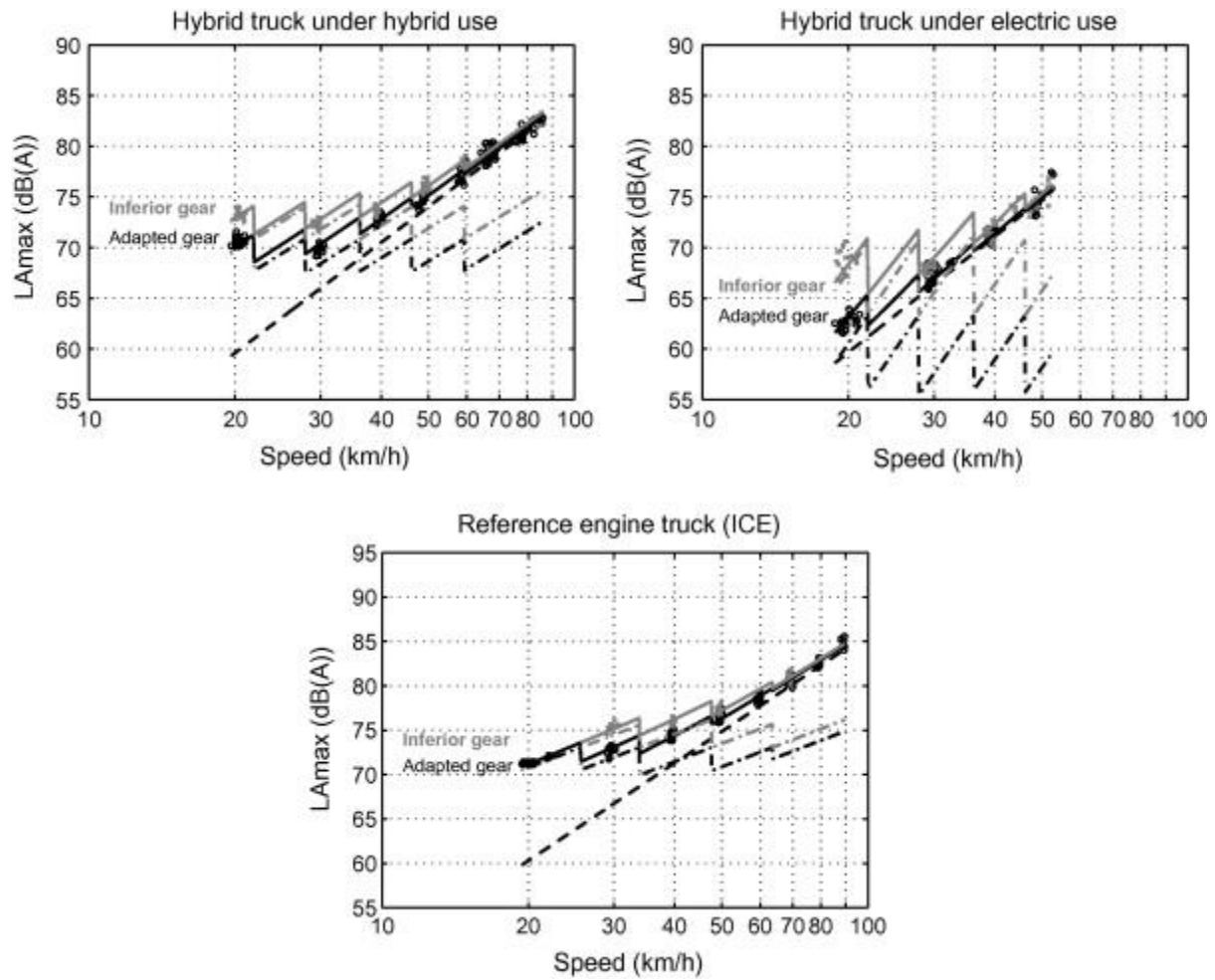


Figure 3: Comparison of Standard Internal Combustion Engine (ICE) and Electric at constant speed.

#### 4.2 Electric Vehicle Infrastructure

We predict that the use of fully electric and partially electric vehicles will continue to increase and to increase dramatically over the next couple years. In the last year, UBC has installed more than eighteen charging stations across campus as well as plans to develop two more for the new SUB. These new power stations will provide increased exposure to the availability of power stations across



campus. With increased exposure to the availability of these charging stations, EV infrastructure is continue to increase. As a result, a social plan will need to be developed on a larger scale in order to accommodate more electric vehicles on campus and provide rules and regulations on the use of campus charging stations.

Overall, the increased use of electric vehicles on campus provides an educational opportunity to the students and staff on campus. It has been found that increasing the amount of charging stations (corrected for population) statistically predicted EV adoption rates in that area (Sierzchula, 2014). As the campus gets increased amounts of electric vehicle infrastructure, students and staff could be more educated into more environmentally efficient transport options for use in their daily commutes to school and work. With more infrastructure available, there will be less hassle in finding a charging station on campus, and therefore more people will be inclined to make the change over to either hybrid, or fully electric vehicles.

### *4.3 Health and Safety*

Emission reduction is one of the core areas that UBC has focused on in creating a more sustainable campus. In terms of health and safety of faculty and students at UBC, it is important to look at how these new campus vehicles will affect particle emissions across campus. In the driving process, standard vehicles emit organic and elemental carbon, ions, and a variety of particulate and semivolatile organic compounds that are not only an environmental concern, but are also a long-term health risk to humans (Zielinska, Sagebiel & McDonald, 2012). Comparatively, electric vehicles have little to no tailpipe emissions. With the aims of developing a more sustainable campus, it is in the best interest of UBC to limit emissions made on campus, and therefore a electric vehicle makes the most sense when increasing their vehicle fleet on across campus.

## 5.0 Conclusion and Recommendations

The aim of the investigation is to help the AMS food delivery system at UBC to find the best delivery vehicle for their intended service. Our investigation into the matter started with exploring different vehicle options that utilize different energy sources which include natural gas, hydrogen fuel cell, diesel, gasoline, electricity and hybrids. We then came to the conclusion that electric vehicles are the most suitable option for catering to the needs of AMS food delivery systems in the environmental, economic, and social aspects. Electric vehicles provide the highest efficiency among all fuel types, and with 90% of the electricity produced in British Columbia being Hydroelectricity, it translates into even higher well-to-wheel efficiency. Another study presented above illustrates that the carbon dioxide emission is the least for electric vehicles compared to vehicles utilizing other fuel sources. EVs have the least adverse environmental impact with low emissions and high efficiency, especially advantageous in BC. Then having decided EVs are the most promising vehicle type, we then investigated different EVs from various manufacturers and came to the recommendation of the Might-E Truck manufactured by Canadian Electric Vehicles Ltd. The initial cost of \$34,000 might seem high at first, however our detailed analysis and breaking down the operational cost it came to approximately 4 cents per mile, which is a great economic advantage in the long term. The range of one charge can cover multiple trips that are well beyond the needs of the delivery service. Rough estimates show potential savings up to \$3500 a year on fuel and maintenance costs. As the AMS at the new SUB is expected to implement night deliveries to residents on campus, noise pollution will also become a significant factor for choosing the right vehicle. As research shows, EVs produce the least amount of noise. As EV infrastructure is increasing dramatically, the use of EV vehicles for AMS will increase the exposure and awareness of power efficiency through new and efficient

technologies for services at UBC. Emission reduction through incorporation of EVs will provide a more healthy and sustainable campus. In conclusion, based on the full triple bottom line analysis proposed above we would like to make a recommendation to our client the AMS food delivery system to purchase the Might-E Truck manufactured by Canadian Electric Vehicles Ltd.

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