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eTract: Same Tractor; Electrified

Bringing your Tractor into the 21st Century

Zackery Weitzman and Brandon Bonan
MCGILL UNIVERSITY – PRESENTED TO DR. CHANDRA MADRAMOOTOO FOR THE COURSE BREE495 – DESIGN III

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Table of Contents

Abstract

With the increase in electrification of cars and trucks, farmers want to take advantage of new technologies now available to them. While farmers are oftentimes reliant on hardware that has been in their family for generations, a large majority of farms are continually looking for ways to cut costs and increase profits. This report describes the steps required to upgrade a tractor from diesel power generation to rely solely on electricity for the entirety of its functions. The change has a goal of both decreasing the operating costs for a farmer, and lowering global greenhouse gas emissions from the transportation and agricultural sectors. With a relatively inexpensive and effective solution to convert pre-existing tractors, eTract is a fictional company positioning itself as a leader in tractor conversions. eTract's proprietary setup will allow for farmers to convert their current equipment to run on electricity. These modified electric tractors will charge on the charging grid currently developed for motor vehicles, making them practical for use in the coming years. The final solution is a simple, reliable, and cost-effective methodology geared toward a greenhouse gas-mitigating solution that tackles the triple bottom line, taking people, planet, and profits into account.

Introduction

Earth's resources, though abundant, are finite. A perpetual growth of any kind in demand for a resource that is not renewable is simply unsustainable. The anthropocentric burning of fossil fuels is the main cause of global climate change, and this combustion reaction occurs in millions of vehicles each day worldwide. Transportation in general is one of the largest contributors of greenhouse gas emissions both in Canada and abroad. While many assume the only problem with this industry lies in passenger vehicles, this could not be farther from the truth. For decades, farmers have been using diesel-powered mechanized machinery, including tractors and mowers, to produce crops and provide for the masses. While passenger vehicles are being improved in efficiency and technology each day, farming vehicles like tractors take a figurative backseat and continue to rely on ancient technologies that contribute to climate change. When it comes to the automobile, the word "innovative" does not begin to describe what has transpired since its inception. Today's cars are more fuel efficient, safer to operate, and visually appealing than ever. Furthermore, virtually all automakers both in Canada and abroad are looking into electrifying their fleets to some degree; a viewpoint that should carry over to manufacturers of agricultural, construction and forestry machinery. In Quebec, 99% of electricity is continually generated from renewable energy sources (National Energy Board, 2016). This provides an astonishing opportunity for the growth of vehicle electrification; one that should be exploited by manufacturers and the province's farmers.

Different farm types require different types of farm machinery. For reasons of excessive power requirements and output needs, farms with industrial-sized operations may have trouble electrifying the entirety of their equipment. Electric tractors are not as readily available and have their restrictions when it comes to runtime and power. For smaller farms, however, like many Canadian orchards, electric tractors are not only feasible replacements but worthwhile ones. The savings an orchard farmer could acquire are numerous, and coupled with Quebec's low electricity prices, changing to a tractor that relies solely on electricity for the sum of its functions is a sensible switch for many of the province's orchard farmers.

About eTract

eTract is a fictional company founded by two McGill Engineering students in 2017. eTract aims to be profitable by selling electric tractor conversions kits to farmers willing to commit to being more environmentally conscious about their business practices. Farmers will welcome this conversion, since a cost analysis shows that it will lead to added savings for then in the long-run.

Vision Statement

> *eTract aims to achieve a low-cost method for farmers to convert their current tractors into functioning, high-powered electric vehicles able to achieve strong autonomy without compromising on power. The design, large-scale, would have the ability to lower greenhouse gas emissions from the agricultural sector.*

Client and Initial Proposition

A Bioresource engineer and McGill alum, Mr. Hubert Philion owns and operates an orchard in Hemmingford, Quebec called *Vergers Écologiques Philion*. On the orchard's busiest days, Mr. Philion's main tractor burns through an entire tank of diesel per day, which is unmistakably not sustainable. This heavy diesel usage is an economic burden to the farmer himself, but an additional burden to the environment. Finding a team to design and build an electric tractor for his orchard has been an objective for Mr. Philion for over two years. In 2014, the client was approached by two pioneer companies in the electric car industry: Sun Country Highway and Tesla. These companies offered to provide the farm with gratis high-voltage high-amperage electric car chargers so long as the client took care of the accompanying installation costs.

Mr. Philion did not hesitate at this proposition. Not only was he attentive to the electrification of the automobile industry that is currently underway, but he saw this proposition as an opportunity to one day electrify his orchard's own fleet of machinery. Markedly, he recognized the numerous environmental impacts of his current diesel-powered tractor, and now his orchard was abundantly prepared for an electric replacement. Today, with two distinct charging stations that work with virtually any electric vehicle, this orchard has been ready to see its obsolete diesel-powered machinery undergo electrification for quite some time. The tractor to be designed must work ergonomically with at least one of the two chargers to make use of these valuable resources. Nevertheless, e-Tract's design will work with standard outlets as well so that farmers without level-2 chargers can similarly electrify.

Mentor Information

Dr. Valérie Orsat, like Mr. Philion, graduated from McGill in Bioresource engineering. Today, however, she continues her devotion to knowledge, and works at McGill University as a full professor and was department chair of Bioresource engineering, preparing young engineers for fruitful careers. This professor's knowledge was an asset to this project, since in addition to having contacts across the globe, she has overseen and supervised several projects in her profession related to energy, sustainability, and agriculture.

Partnerships

eTract partnered with *EcoTuned Automobile,* a private company specializing in electric conversions of Ford F-150 pick-up trucks and small buses. To date, *EcoTuned Automobile* has received funding from the province of Quebec along with other partners. They are currently contracted by the *city of Montreal, the Pierre-Elliott-Trudeau Airport* and the *city of Drummondville* for multiple projects.

Funding

This project is being fully funded and supported by Hubert Philion. *EcoTuned Automobile* has graciously offered any parts and/or pieces that may be required that they have on-site, at cost-price. Although multiple calls for funding were sent out, none of them materialized. eTract was in contact with various companies with regards to funding, including Kubota and Fendt, however while discussions ensued, it became evident that third parties wanted to limit the sharing of information, trade secrets, and intellectual property.

Literature Review

Why Electrify? A Lifecycle Analysis Approach

The term lifecycle analysis is defined by ISO as a compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system through its lifecycle (International Organization for Standardization, 2006). The LCA technique follows standard ISO 14040:2006, and involves phases of goal and scope definition, inventory analysis, impact assessment and interpretation (International Organization for Standardization, 2006). Since a tractor's life includes stages from raw material procurement to disposal, it is important to consider these stages when designing for electrification. Compared to diesel-powered tractors, electric tractors involve different precious metals in their raw materials. These metals can often be recycled at the end of their useful life, making this matter less of a concern. Throughout their life, electricity generation methods where the tractor will be used dictate the environmental advantages of electrification. It is known that Quebec's hydro power is a clean source, however this is not the case across the globe. Performing a lifecycle analysis incorporates factors as such, ensuring the implementation is indeed sustainable. eTract will not need to perform an LCA because of the extremely low environmental impacts of hydroelectricity in Quebec, however other farmers wishing to electrify should consider the sustainability of their electricity generation. *Figure 1* illustrates lifecycle analysis results from different electricity generation sources. These results can be used as a guide in assessing the value of electrification.

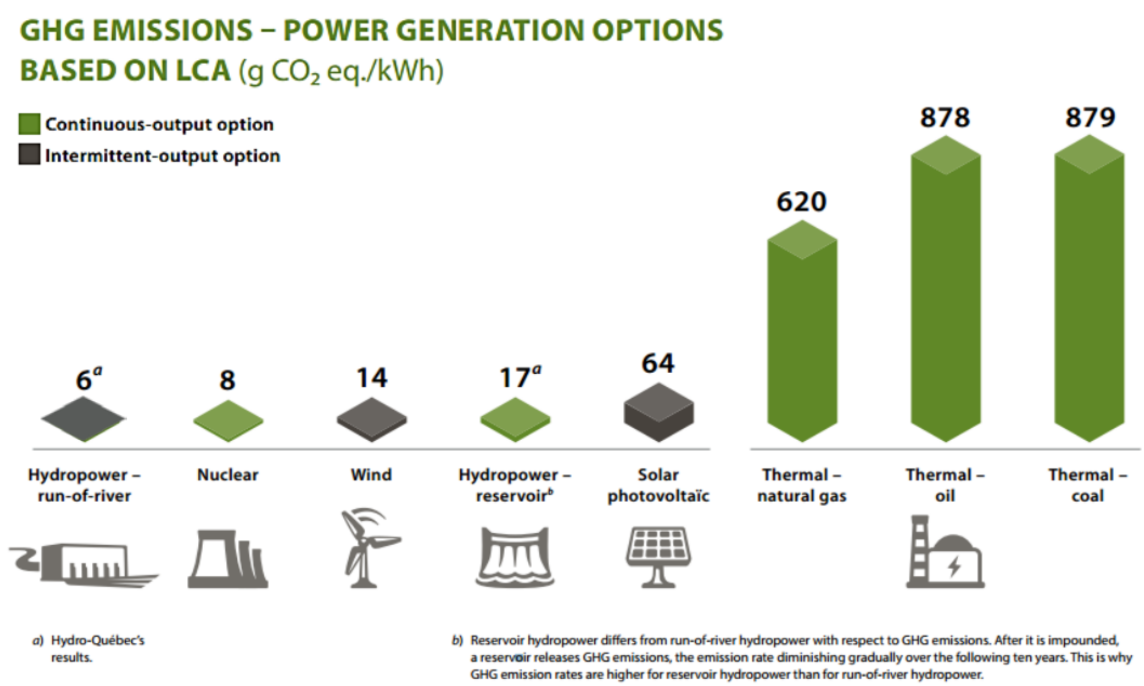

Figure 1: Greenhouse gas emissions from different sources of electricity

Biodiesel

Although many farmers are now choosing to run their tractors on biodiesel which they sometimes produce themselves, greenhouse gas emissions, albeit lower than regular diesel, still exist. The Canadian Society of Agricultural and Biological Engineers (CSBE) studied the effects of emissions of tractors running on different blends of biodiesel. The results found in the research conducted by Agri-Food Canada on behalf of CSBE determined that although there may be an emissions reduction in carbon dioxide, nitrous oxide emissions increases. (Li & McLaughlin, 2005). This is a troubling finding since one pound of NO_x is 300 times more powerful than one pound of carbon dioxide as a greenhouse gas (EPA, 2017).

Biofuels are produced using the same crops that feed the world. Although it might seem to some as though there is currently enough food and arable land to feed the entire population, that is certainly not the case. There is only a finite amount of arable land available on Earth. With an increase in biofuel production, due to supply and demand, the price of food will increase because more and more of the available crops will be used up for biofuels (Ajanovic, 2011). Since the population is increasing at an exponential rate and the amount of free arable land is decreasing, it would therefore be difficult to consider the use of biofuels as a means to power agricultural machinery since the current machines in use in industry are not efficient. Further, although the cost of biofuels is relatively cheap today, it is difficult to gauge what the cost of fuels will be in the years to come. It can therefore be inferred that due to the high emissions of biofuels, the low efficiency of farming equipment, and not knowing what the consequences of an increase in the demand for biofuels will bring, that the use of biofuel is not ideal for agricultural equipment.

Batteries

Multiple battery types exist which could be used to power an electric tractor. Beginning in the early 1900's, inventors such as Thomas Edison were inventing batteries to be used in electric cars. At the turn of the millennium, new technology allowed for advancements in battery technology. Cells are now able to be constructed out of materials which were never associated with batteries. Further, new technologies allowed more and more cells to be fitted into one battery, effectively increasing their power outputs. Battery life started seeing immense improvements with the aforementioned technological advancements. Today, new devices, including motor vehicles, can be fully battery-operated and attain performance benchmarks similar to their non-battery-powered counterparts.

Nickel-iron Battery

Thomas Edison invented a battery that could be used to power electric vehicles in 1901, the nickel-iron battery. At the beginning of the 20th century, electric cars accounted for roughly 50% of the car market in the United States (Westbrook, 2001). Edison's invention offered a better range than the lead-acid batteries which were being used in electric cars at the beginning of the last century. As the electric car saw its demise following the invention of the internal combustion petrol engine, the industries in which nickel-iron batteries were used changed. These batteries were installed in commercial machines as a secondary source of energy in stationary applications (Westbrook, 2001).

Although Nickel-iron batteries seemed at the time to be a breakthrough in battery technology, their uses today are limited. These batteries need to be properly managed since they require maintenance, unlike most other batteries. Nickel-iron batteries produce hydrogen and oxygen while they are being discharged. Further, at low temperatures, these batteries have a significantly reduced capacities (Westbrook, 2001).

Lead-acid Battery

The Lead-acid battery was invented by Gaston Planté, prior to the invention of Edison's Nickel-iron battery, in 1859. At the time of its invention, it was the first rechargeable battery able to be used for commercial purposes (Buchmann, 2017). Since pure lead is too soft and would not be able to support itself, these batteries are made from a lead alloy. Using an alloy allows the battery to increase its mechanical strength and improve its electrical properties. Calcium, tin, and selenium are often used to create the alloy (Buchmann, 2017). Lead-acid batteries can properly function for 200 to 300 charge/discharge cycles. This is considered today to be a short life cycle. The short life cycle is due to grid corrosion on the positive electrode, depletion of the active material and expansion of the positive plates (Buchmann, 2017). The amount of use one gets out of a lead-acid battery can be rapidly decreased when the battery is operating at high temperatures and when it is drawing a high current.

While lead-acid batteries can be charged in multiple ways, the one key factor is to maintain the correct voltage limits. There are two main ways of recharging a lead-acid battery: low-voltage charging and high-voltage charging. With low-voltage charging, sulfation occurs on the negative plate however, with high-voltage charging, the positive plate becomes corroded. Although sulfation can be clean whereas corrosion is permanent, high-voltage charging improves the performance of the battery (Buchmann, 2017).

Lithium-ion Battery

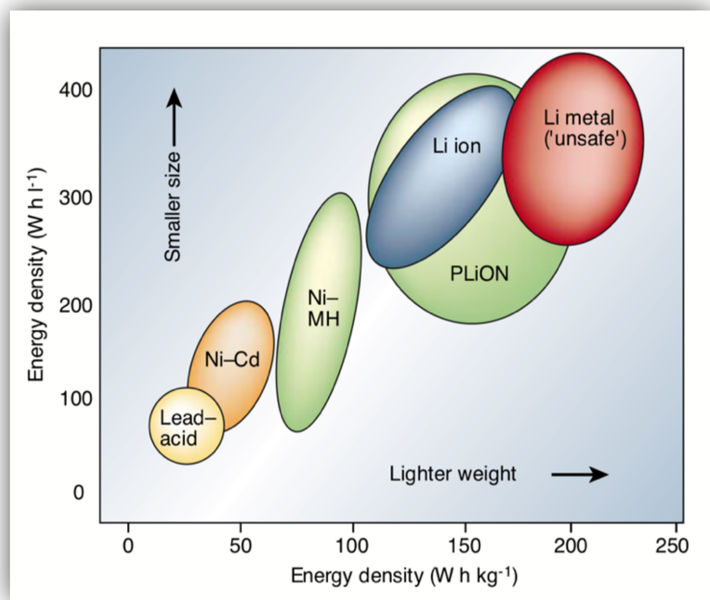

Figure 2: Comparison of Metals Used for Battery Production (Tarascon & Armand, 2001)

With an atomic mass of 6.941 g/mol, Lithium is the lightest metal found on the periodic table of the elements (Tro, Fridgen, & Shaw, 2016). Moreover, it is also the most electropositive metal, making it ideal for use in batteries. In any capacity, a battery is a device that is able to store electrical energy in the form of chemical energy and convert that energy into electricity (Bates, 2012). Scientists and engineers alike have exploited the metal's idyllic characteristics, designing storage systems with remarkable energy densities (Tarascon & Armand, 2001). In addition to energy density, Lithium-Ion batteries are excellent at retaining their cell capacities. Where aforementioned lead-acid batteries can properly function for 200-300 cycles, researchers show that after thousands of driving days' worth of use, lithium-ion batteries retain more than 95% of their original cell capacity (Peterson & Apt, 2010).

Motors

When designing and promoting vehicles with internal combustion engines, the actual engine is at the forefront of information available for the vehicle. This includes characteristics like engine displacement, horsepower, and torque. With electric vehicles, the electric motor is often not spoken about at all. To exemplify this, the "specifications" section for the Tesla Model 3, the Chevrolet Bolt, and the BMW i3 make no reference to the motor other than defining it as an 'electric drive unit' (Adams, 2018). In the future, motors will likely continue to grow in both performance and efficiency, however the lack of publicly available information makes it difficult to predict and analyze both what is available and what is to come. Most of the information eTract was able to obtain with regards to motors was provided by EcoTuned and by researching peer-reviewed articles on vehicle electrification. Since technology has changed rapidly over the last decade, many of the explored articles on motor selection had become relatively immaterial and obsolete. EcoTuned uses a BorgWarner motor that is capable of providing adequate power, in addition to functioning in Quebec's harsh winters. The company is well-known in industry and has over 100,000 motors in service (BorgWarner, 2016). Selecting a reputable company with several years of experience is of great important to eTract since the process is to be replicated by other farmers. Suggesting a motor that has not undergone rigorous testing could be detrimental, as failure or serious injury could occur.

There are two types of motors that can be used for the conversion, either A/C or D/C motors. Although the energy supplied by the batteries is in D/C, an inverter can be used with an A/C motor. In terms of the differences, A/C motors provide more power in a smaller footprint allowing for higher-powered machines with less weight and smaller volume requirements. A/C motors can also be configured in single-phase or three-phase. Similarly, power outputs differ between the two. Three-phase engine require "lower wire cost per watt delivered. At the same current/voltage, a three-phase system requires 50% more conductor area, yet delivers 73% more power" (Ferguson, 2017). Thus, three-phase A/C motors provide more power than single-phase A/C motors for a small space sacrifice.

Transmissions

Current mass-produced electric vehicles are offered with an automatic one-gear transmission only. This is due to many factors, but mainly because of the need to only have one gear in an electric vehicle. Since electric motors can deliver instantaneous torque, there is no need to build up enough energy to reach a desired engine rpm. Further, conventional manual and automatic transmissions and gearboxes significantly increase the weight of the vehicle. To allow for an electric vehicle to have an increased range without improving the battery would be to decrease the weight of the vehicle (United States of America Patent No. US 5419406 A, 1991).

In terms of the transmission options, the client was hesitant is switching to an automatic transmission and preferred the idea of staying with his current manual transmission. This presented additional challenges which are revealed throughout the report.

Québec Cost Comparison – Diesel vs. Electricity

Diesel Prices

In Quebec, the average diesel price in cents per litre for the period of June – October 2017 was 107.7c/L (Statistics Canada, 2017). Working with an average consumption of 200L/week in periods of increased usage (40 weeks per year), and 100L/week throughout less busy times (12 weeks per year), a very rough yearly consumption approximation is 8160L/year. Factoring in the average diesel cost, the client for this project is spending close to $10,000 per year on fuel alone. These numbers make it evident that diesel use does not only have environmental consequences, but also excessive economic ramifications.

Electricity Costs

In the 2017 report, a specific battery had not yet been determined, therefore an estimate of per-charge electricity costs was not yet possible. An estimation was done using information from the Nissan Leaf, a typical electric car with a 30kWh battery (Nissan, 2017). Estimating 30 charges per month, the projected electricity usage addition from eTract's electric tractor was 900 kWh. Using Hydro Québec's farming electricity rates of $0.0577/kWh for the first 1,200kWh and $0.0877/kWh for the remainder, and considering that Mr. Philion could fill the first 1,200 kWh with other electricity demands, the added cost of electricity was estimated to be approximately $78.93/month, and $947.16 per year (Hydro Quebec, 2017). Since the battery is now chosen, the estimation is far less than anticipated. With the 11.6-kW battery eTract now plans to implement, the added cost of electricity is estimated to be approximately $30.50/month, and $365.98 per year. To come close to his current expenditures on diesel, the client would have to recharge an electric car battery at least 20 times per day for an entire year incessantly. Even with variations in battery capacities and number of recharges per day, it is evident from the information that in Quebec, an electric tractor is more cost-efficient than a diesel-powered tractor.

Design

Adhering to the Engineering Design Process

Identifying a need or problem

The client, Mr. Hubert Philion, requested a fully electric tractor that relies solely on electricity for the entirety of its functions. Brief ideas of a diesel-powered electric generator were considered, however to comply with preliminary requirements, it was established that the tractor would be fully electric.

Researching Criteria and Constraints

Orchard tractors differ from conventional tractors mostly in shape and size. To be able to navigate through constricted orchards, the proposed design must have a narrow body. In addition, all components of the tractor must have recommended operating temperatures comparable to the Quebec's temperatures during all four seasons. Since the client uses his current tractor in both winter and summer months, the latter is a non-negotiable requirement. His current engine is a Perkins A4-236 and has a maximum horsepower of 70HP. To have comparable performance, the fully electric tractor will either have analogous or higher power ratings. In terms of costs, the process should be projected under $15 000, a condition that was modified in the early stages of the design solution. This price does not include the procurement of a tractor. Further, this price would allow the farmer to break even on the cost of the upgrade in a relatively short amount of time. A full cost analysis is found in a later section of the report.

Brainstorming Possible Solutions

Although many solutions were brainstormed, including the re-consideration of implementing a diesel generator with an electric powertrain, two leading possible solutions persisted until step three of the design process. The first heavily contemplated solution was to build an electric tractor from raw materials, using new constituents only. The second was to design a conversion system that would be used to convert an out-of-date or non-functional diesel-powered tractor into a fully electric tractor. During the brainstorming process, pros and cons for each possibility were considered, and their overall factors were tabulated.

Picking the Best Solution

In picking the best solution, a numerical evaluation matrix was used. A scale of 1 to 10 was implemented, with 10 being the highest possible attribute score. Moreover, each consideration was weighted between 1 and 5. The best solution is the solution with the highest weighted average among categories.

Table 1: Assessment of alternatives to determine which path to follow for the client using Pugh chart method.

Design constraints and objectives (Weight)	**Baseline**	**Conversion of Current Diesel Tractor**	**Electric Tractor Designed Using New Materials**
Aesthetics (2)	0	0	1
Cost to design (5)	0	1	-1
Ergonomics (5)	0	1	1
Environmental Impacts (5)	0	1	-1
Time to build (4)	0	-1	1
Cost to purchase for farmer (5)	0	1	-1
Adaptation and learning time for farmer (3)	0	0	0
Charging and usage time based on electrical uses of current mechanisms in old tractor vs. efficient mechanisms in new tractor (5)	0	-1	1
Total → Weighted average	**0**	**11**	**1**

For reasons of cost efficiency and from conclusions based on the above tabulation, it was established that the best solution for this project was to design and implement a process in which a diesel-powered tractor can be modified to be fully electric. In addition to being more cost effective, salvaging an old tractor involves less environmental consequences, less time to build, and less adaptation and learning time for the farmer.

Offsetting Possible Hesitations

With electric cars, a large fear is a term widely known as “range anxiety.” This is the apprehension many potential users have toward electric cars regarding battery drainage and the lack of a nearby charging station. Since eTract is making a tractor with a runtime of approximately one day, the issue will be more concentrated on power than on range. Farmers will worry about factors such as runtime at maximum power, in addition to what would occur should there be a major power outage.

Recommending a Home Battery

As stated in the vision statement, eTract aims to achieve strong autonomy without compromising on power. Since autonomy is based on the ability to recharge when needed, electricity availability remains an important and deciding factor. While the client for this project, Mr. Hubert Philion, is not interested in investing in a stationary energy storage device, eTract recommends it for those that live in regions where major power outages are not a rare occurrence. The suggested home battery is a Tesla Powerwall. Not only does the Powerwall offer 14 kWh and an integrated inverter, but it can be connected to solar panels to provide autonomous electricity (Tesla Energy, 2018). Having this sort of storage system would allow farmers to pay less in electricity, be better off in the event of a power outage, and avoid using greenhouse gas-emitting electricity.

Constructing Prototype

eTract’s prototype was first constructed using Autodesk Inventor, and in the coming semesters, the design will be modified and brought to fruition by the incoming design team and fully incorporated into a Landini 85F tractor. This unit was acquired through auction by the project’s client, Mr. Hubert Philion, and is not operational as of yet because the motor is not attached, and other components essential to running a diesel-powered engine are missing. *Figure 3* shows the original tractor.

Figure 3: The original Landini 85F tractor purchased at auction by Hubert Philion

Tractor Requirements

In Fall 2018, the project acquired a Landini 85F tractor and cab, the final device to be converted to electric power. The decision to purchase this specific tractor presented additional challenges, since the original estimations in BREE490 were made using requirements of a smaller tractor. The 85F originally contained a 4-cylinder diesel Perkins A4.248 engine with a power output of 80 HP, 309 Nm of torque and a torque rpm of 1400 rpm. The original tractor is registered at Quebec's Ministry of Transportation at 2540 kg and has a wheelbase of 231 cm. The brakes are wet disc and steering is provided using hydraulic power (TractorData, 2018). The client would like to maintain the same torque and power output of the original tractor as to not have to make additional modifications to the tractor's frame. Further, weight must be properly monitored as an increase in weight will change the ergonomics of the tractor and possibly jeopardize the tractor's frame and body.

Motor Selection

In terms of selecting the new electric motor, a research process was undertaken as described in a previous section. As many of the motors found were not tested in the real world, i.e. in electric cars or trucks, but rather to power appliances or other equipment, it was difficult to decide which motor to use. The chosen motor, a BorgWarner HVH250-115-DOM, was chosen since it not only has ample power that, if necessary, can be toned down using software, but also has a proven performance record with *EcoTuned Automobile*. This is the engine that the corporation is using in the modified Ford F-150 pickup trucks and bus remodels. The motor is an AC permanent magnet synchronous motor with a 700 V-DC rated bus voltage and available torque of 400 Nm (BorgWarner, 2016). The power and torque curve can be seen in *figure 4*. It also has an available working temperature range from -40 degrees Celsius to 140 degrees Celsius, which meets the design requirements of the client. Deciding on a motor is extremely important to the design of an electric tractor because the component converts electric energy into mechanical energy. In a vehicle, including both automobiles and tractors, the mechanical energy is in the form of a rotational force. The way in which power is delivered from the batteries to the motor is via a controller. On eTract's tractor, the accelerator pedal will hook up to a pair of potentiometers which provide a signal that tells the controller how much power the engine should deliver.

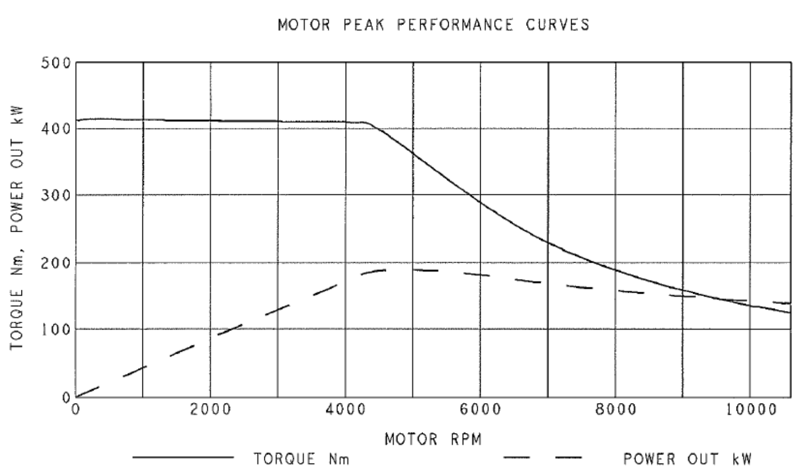

Figure 4: Motor peak performance curves of the BorgWarner HVH250-115-DOM

The original Landini 85F tractor, with an output of 80 HP (60 kW), has a rated torque of 309 Nm. A torque rpm of 1400 will need to be maintained to accomplish the orchard farmer's requirements. Using *figure 4* to determine the rotation of the new electric motor, a motor rpm of

1400 rpm is attainable. Moreover, the new configuration will have a higher available torque, at slightly over 400 Nm, while maintaining an output power of 80 HP (60 kW).

To allow for the A/C motor to properly function, an A/C power source must be available. As batteries feature D/C current, the electricity stored inside the batteries must be converted to A/C before reaching the motor. This conversion can occur using an inverter. An inverter is a device which changes D/C current into A/C current (IEEE Press, 2000). Inverters also amplify the D/C current and Voltage to be changed when inverted into A/C current and Voltage. In many cases, 12V D/C will be inverted to 220V A/C. This will allow the A/C to properly function as well maintain a low current throughout the system and therefore use higher gauge wires. The frequency of each system much match. As the frequency in Europe and Africa is 50 Hz and in North America is 60 Hz, this must be taken into consideration when purchasing electrical parts and systems. Although this would be necessary for most D/C to A/C connections, the BorgWarner HVH250-115-DOM was built with this flow of energy in mind since it was conceived to be used in electric vehicles. Thus, there is a built-in inverter which allows the change of voltage from D/C to A/C. Moreover, a wye (Y) connection is specified for this motor between the batteries and the motor. A wye connection is used to allow for the phase current and line current to be equal, reducing losses in the system.

Battery Selection

As with any piece of technology that runs on battery power, the tractor will only be as useful as its operation time. In terms of the eTract electric tractor, various environmental and ergonomic conditions must be met as per the request of the client. The tractor not only has to have a high enough runtime to allow a farmer to perform tasks for an entire day, but also needs to be able to operate in Quebec's frigid winters for snow removal operations. As previously determined, a lithium-ion battery not only ensures a long running time but can function relatively well in cold temperatures. Additionally, as the battery banks will be the heaviest component and will be the biggest modification made to the tractor, calculations will be made so to not overtax the tractor when the full battery packs are assembled and installed.

The chosen battery cell is a SEPNi8688190P with a cell capacity of 17 Ah. The cells will be used in a 4-cell (4PIS) configuration. These cells are not only small and lightweight, but moreover have ample capacities in linking together to build battery packs. These batteries have been proven to withstand Quebec winters, as the cells are the basis of EcoTuned's battery banks. Calculations for the battery are found in the *Battery Calculations* section of this report.

Type	NMC Module			
Battery cell MODE	SEPNi8688190P		SEPNi8688190P	
Single Battery module capacity Ah	15AH		17AH (Available in October 2017)	
Configuration	4P1S	5P1S	4P1S	5P1S
Dimension mm (H*W*T)	232.5*97*37.2	232.5*97*45.3	232.5*97*37.2	232.5*97*45.3
Module Rated Capacity Ah/Wh	60AH	75AH	68AH	85AH
Module Rated Voltage V	3.6V	3.6V	3.6V	3.6V
Module Weight Kg	1.235	1.515	1.35	1.65
Module Weight Wh/Kg	174.8	178.2	181.3	185.4
Photo				

Figure 5:The chosen battery cell is the SEPNi8688190P from 2017 with a 4PIS configuration

Fuel Tank

The present fuel tank in the Landini 85F tractor measures 21 inches wide with a height of 12 inches and a length of 10 inches, giving a volume of approximately 40 L (2520 in^3). The fuel tank is located under the driver's seat and extends backward. It was determined in a design meeting with the project's client that the heater in the tractor cab will be diesel-generated. This will necessitate a small diesel tank to be attached to the tractor. Thus, a 20 L tank will be installed in its place. The remaining space will be used to house a 12 V car battery to power the windshield wipers, lights, and other possible accessories that the client would like to add.

Test

In industry, the method to measure the performance of agricultural tractors approved by OECD and ISO is to measure the drawbar power in a range of gears on a test track using an instrumented load car. The power take-off (PTO) power is measured on a dynamometer (Culshaw, 1988). A dynamometer places a load on the engine and measures the amount of power that the engine can produce against the load (Brain, Horsepower Analyses, 2000). It was eTract's initial plan to test the Landini tractor before and after electrification, however due to timing constraints and difficulty acquiring the dynamometer, this will wait until 2019. Battery life testing will be performed in real-time once the tractor is built. If estimations were not precise, more cells can be added as needed. Although the battery configurations are in a 4PIS configuration, more units can be added, so long as they conform to ergonomic requirements.

Testing will additionally be done with regards to heat dissipation from both the batteries and the motor once construction is complete. Extensive testing has been performed by BorgWarner, the engine's manufacturer, and the company that produces the selected battery. It was determined that no heat dissipation installations would be necessary for use in full-sized electric vehicles. As the eTract tractor is a much smaller machine, this will not be of major concern.

Solution

The solution is to employ a set of 36 inline batteries and 12 side-saddle batteries in the front of the tractor's nose, with the engine and transmission sitting behind. The current transmission which will be used is already mounted to the tractor's frame on the back of the nose. Using this design allows for the transmission to remain in place, and will require a simple mounting of the motor to the tractor with a sheet metal attachment. eTract has already been in contact with sheet metal manufacturers for the project's fruition in 2019.

The 48 batteries will be sitting in three lines of 12 and four lines of three. There will not be anything on top or beneath, facilitating maintenance should the tractor's frame need to be repaired or a battery replaced. The batteries will be connected using a wye connection to the motor. It will be seen later in the report that a system will be attached to the pedal of the tractor to regulate the speed of the motor. It will also be mentioned that an IP68 tablet will be mounted in the tractor cab to display battery percentages. This has the possibility of, in the future, connecting to a GIS system which can aid the operator in running their operation. The choice of tablet and speed regulation system will be made in 2019.

The brakes are an intricate part of any moving vehicle, including a tractor. Currently, the Landini 85F has a hydraulic braking system. The brakes will not be changed and therefore a system will need to be created to link the hydraulic power to the motor. A possibility of this is keeping the hydraulic motor and have it powered by the 12 V car battery under the driver's seat, the same battery that will fuel the windshield wiper. This will be developed in 2019.

Below is a 3-D rendering and a selection of CAD drawings including two blueprints and an orthogonal drawing of the batteries, motor and transmission all fitting in the nose of the Landini 85F tractor. The blueprints were drawn in a ¼ scale and are in centimeters.

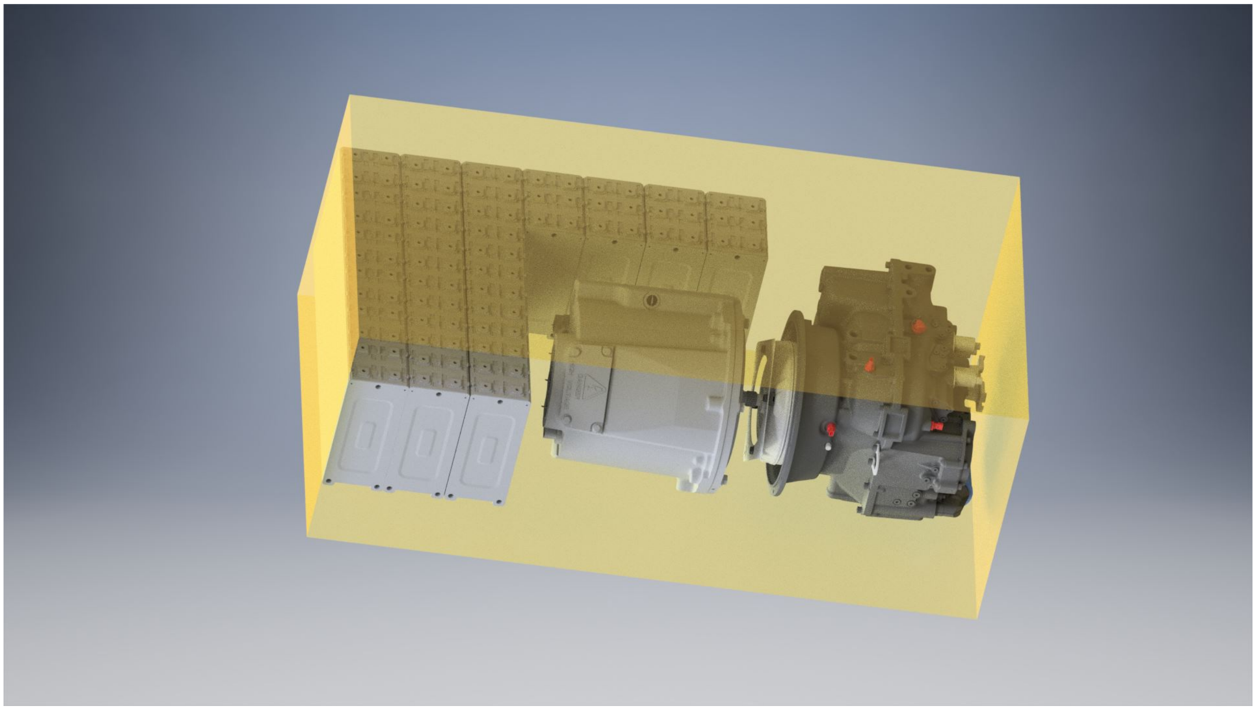

Figure 6: 3D-CAD drawing of the eTract tractor nose setup. The batteries are in the front of the nose followed by the motor and transmission at the back. The transmission position will be flush with the driver's cab. The hood (front nose enclosure) is shown here in yellow. This proves that the new configuration will fit within the current Landini 85F tractor.

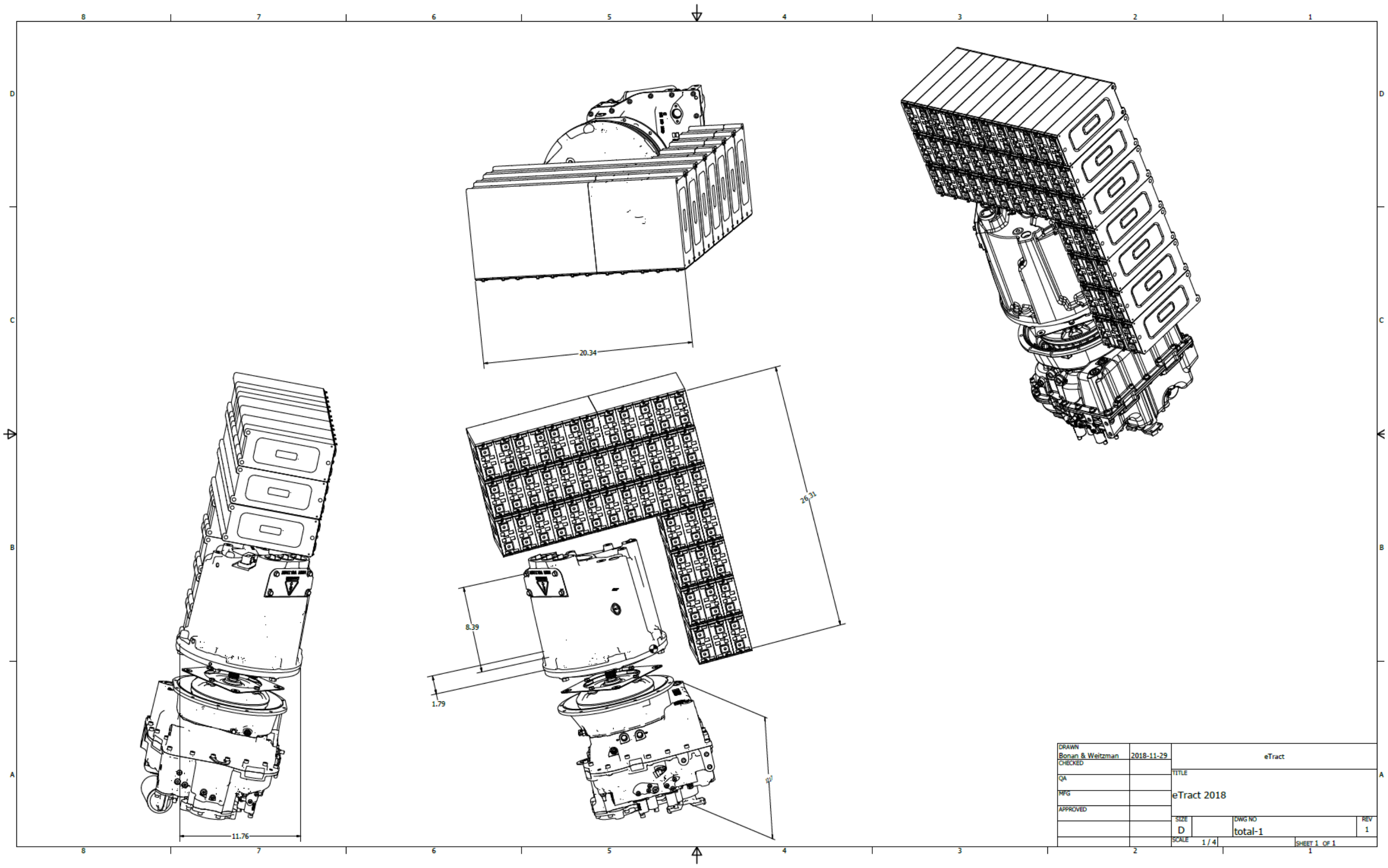

Figure 7: Multiple views of the setup of the new eTract tractor without rendered layers

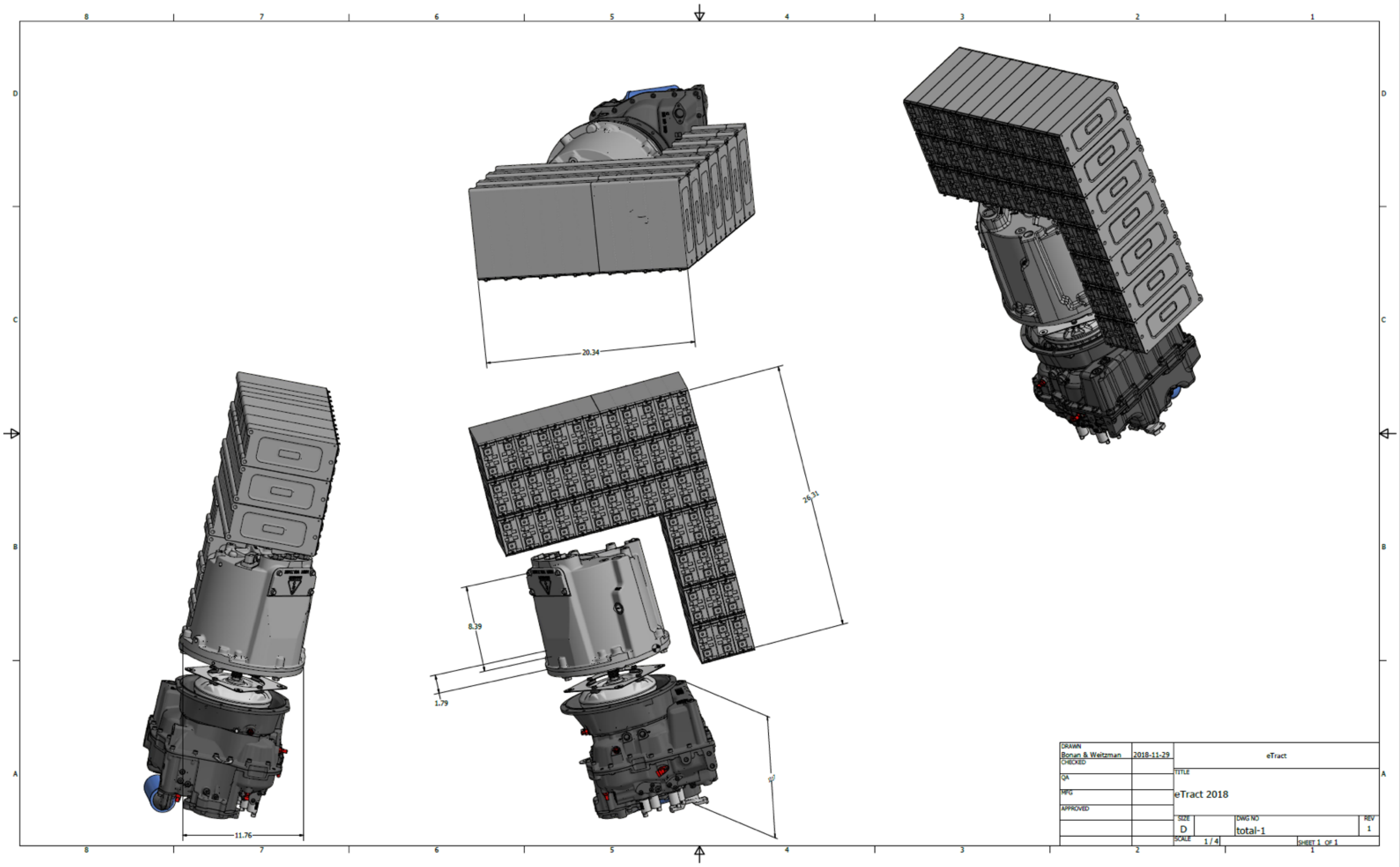

Figure 8: Multiple views of the setup of the new eTract tractor with rendered layers

The center of gravity of the new system comprising the battery, transmission and motor is essential to maintain the ergonomics of the tractor for the operator and to make sure that the tractor can continue proper daily operations. Due to the weight of the many components needed for the original diesel engine, including radiator, motor and oil tank, different fluids etc., it was estimated that the center of gravity of the nose of the tractor was in the center and closer to the front of the tractor because of implements being attached at the rear. The back of the tractor had the fuel tank and the cab along with the big rear wheels which evened out the weight distribution and center of gravity of the complete tractor. The center of gravity of the new eTract tractor was determined using Autodesk Inventor after completing the 3D-CAD drawing of the new assembly. It was determined that the center of gravity is a similar position to before, allowing for safe and proper handling of the tractor. A visual center of gravity result is seen below where the front of the nose is the area which comprises the batteries and the back is comprised of the transmission with the motor being in between both. As illustrated, additional batteries were added to the right-hand side of tractor's nose to balance out the offset of the engine's position.

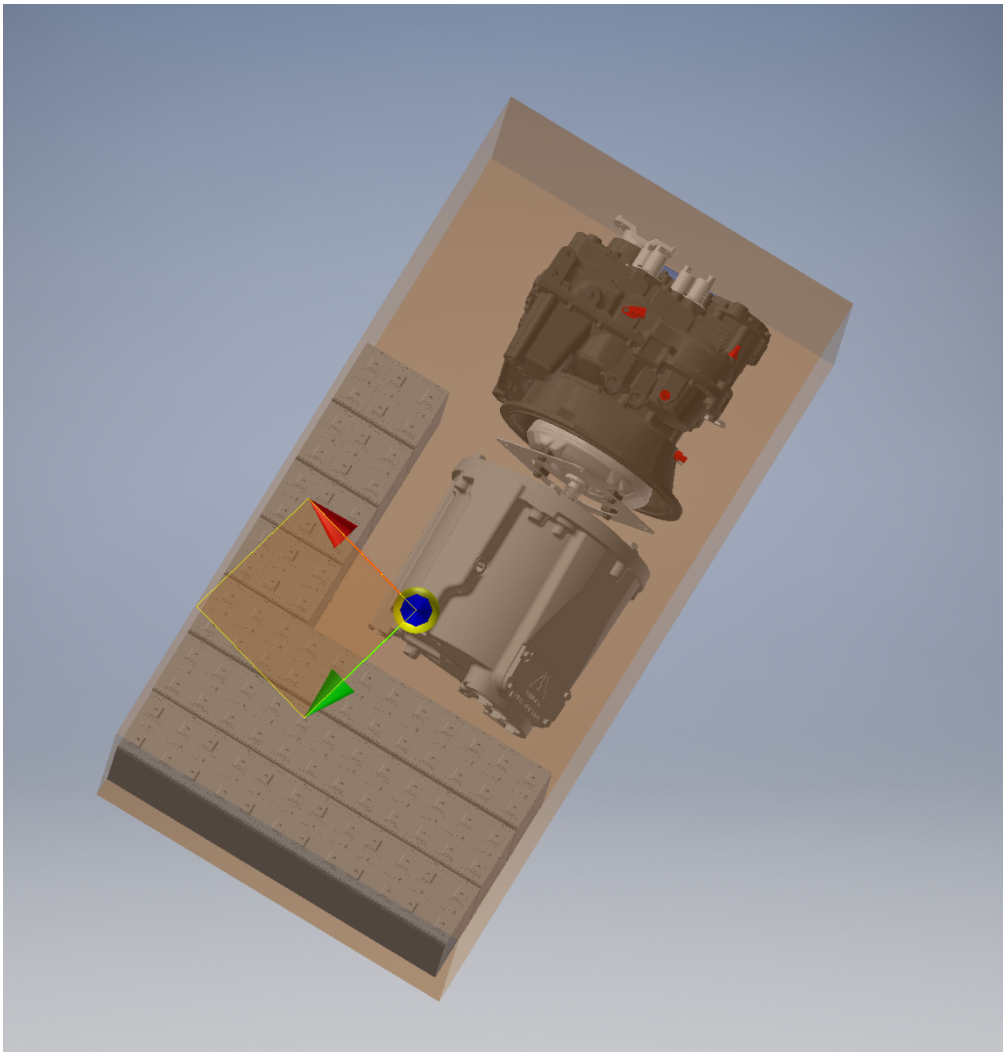

Figure 9: Visual representation of the center of gravity of the eTract tractor

Environmental, Social, Economic, Occupation Health & Safety and Ergonomic Factors

With all engineering designs, stakeholders must be considered at every step of the design process. These stakeholders can be taken into account using a multi-stakeholder process to engage different types of people involved, or by examining a project's various aspects separately and estimating their impacts. The latter method will be used, as investigating these factors involves good business management to create robust engineering solutions to any challenge.

Environmental Factors

The implementation of an electric tractor in Quebec involves mostly positive environmental factors. The electric tractor will have lower emissions short-term and long-term, as hydroelectricity in Quebec is an extremely sustainable way of producing electricity. This was seen previously when comparing generation mechanisms with a lifecycle assessment. The converted tractor will lead to a decreased carbon footprint for "Vergers Écologiques Philion", in addition to an improved living environment for surrounding flora and fauna. Negative environmental effects are extant when batteries are disposed of improperly after their cells have lost capacity, however eTract will recommend proper disposal, including taking advantage of the many recycling options available in Canada.

Social Factors

Diesel engines are extremely loud, therefore implementing an electric tractor will cause a major decrease in noise pollution. Although these lowered noise levels, coupled with cleaner air, prompt a better environment for employees and patrons, electrification brings along social ramifications. Farmers running electric tractors have less autonomy than those running diesel-powered machinery. While relatively fast charging is possible at Mr. Philion's orchard, recharge time will nevertheless be greater than the time it takes to fill a tank of diesel. eTract worked diligently to ensure runtime values are consistent with a full day's worth of mowing and blowing, however external factors such as drastic temperatures and extended power outages can abolish these estimates. For the client of this project, the aforementioned considerations are not of great concern. Since eTract aims to design a product that appeals to more farmers than just this client, a future section will explore the options of a battery-powered back-up charger.

Economic Factors

In the short-term, the conversion process itself is an economic burden to any farmer wishing to go electric. So long as prices of electricity in Quebec do not undergo a drastic increase, the up-front cost of replacement will be buffered by long-term fuel savings. Another factor considered was that today's diesel-powered tractors are most often used for several decades. While lithium-ion batteries can be recharged thousands of times before eventual depletion, they will inevitably need to be replaced after several years depending on usage. eTract's design will allow for an unproblematic and simple replacement process for these batteries, and cost-wise, the fuel savings will once again make up for the battery costs themselves. In addition, due to increased research and development into lithium-ion battery technologies, an eventual decrease in price is expected. *Figure 10* shows the cost of lithium-ion batteries from 2010-2016. The chart illustrates that the price of batteries is likely to come down in the future (Curry, 2017).

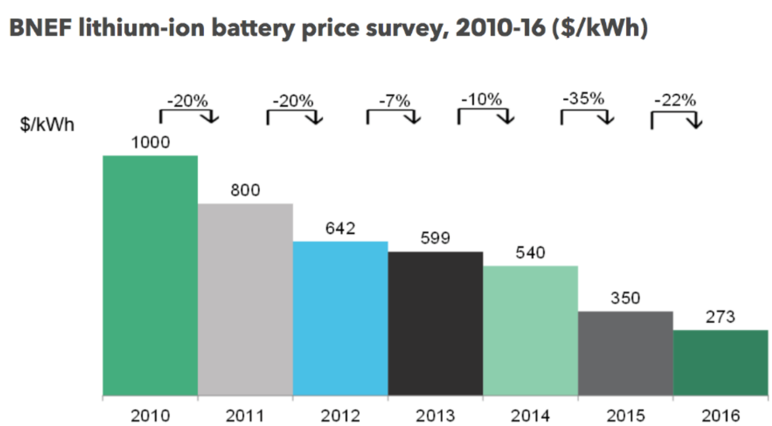

Figure 10: Prices of Lithium-ion batteries over the course of a six-year period

Occupational Health and Safety Factors

Issues relating to health and safety are paramount in any engineering project. For tractor electrification, these risks exist in the conversion stages, as well as during the tractor's usage. The transformation process involves working with electricity, and the threat of electrocution is imminent. Protective equipment will be worn to reduce dangers, including examples such as thick rubber gloves when working with electrical wires. Since high-voltage charging will be used at "Vergers Écologiques Philion," additional care must be taken to avoid shock. The Canadian Centre for Occupational Health and Safety offers fact sheets and how-to guides that explain the importance of working safely with or near electricity, in addition to providing general safety tips.

Furthermore, the centre has a safety checklist for basic electrical safety (Canadian Centre for Occupational Health and Safety, 2018). Conforming with the recommendations of the independent corporation is essential to safeguard human health and safety.

In terms of operation, there exist differences when comparing electric tractors to traditional tractors. The drivetrain and transmissions on electric tractors are different from their diesel-powered counterparts, as in the case of electric vehicles, 100% of their torque is available at 0 rpm. Individuals untrained and unfamiliar with the modified tractors pose a greater risk to themselves and anyone nearby. Additionally, as with any moving vehicle, operating a tractor involves physical hazards including possibility of injury or death to the operator or surrounding individuals. To protect against untrained drivers in their discovery of electrification, eTract will recommend inexpensive safety belts in case of accidental excessive speed.

Another consideration taken into account was the possibility of fire and electric problems. In many electric cars today, marks are identified on the lithium-ion battery for first responders in case of a fire. In Tesla vehicles, for example, there is a "first responder cup loop," which is a low voltage harness. Cutting the first responder loop shuts down the high voltage system outside of the high voltage battery and disables the SRS and airbag components (Tesla, 2016). A similar device will be implemented on eTract's tractor to protect occupants and first responders in the event of a fire or critical malfunction.

Ergonomic Factors

Throughout the entire design process, ergonomic factors were significantly considered. In the case of eTract, it was originally thought that the new battery pack, motor, and transmission had fit inside the current engine and transmission hold not to comprise the current ergonomics of the tractor. It was eventually learned that not all batteries had to be fitted in the front of the tractor; the fuel tank will be used to store an additional 12V battery for ancillary parts. The center of gravity was ensured and designed using Autodesk's Inventor software and specification sheets from the manufacturers of the respective pieces. Additionally, the lithium-ion batteries and motor cannot weigh considerably more than the current setup including a full fuel tank, so the tractor does not sink on wet ground. Further, the charging process must be easy, fast and efficient. It is also important to maintain the same driving dynamics of the diesel tractor. Should these change, the maneuverability of the tractor will be altered, and it may become too difficult to operate in the orchard. Further, the diesel motor along with the suspension of the tractor cause vibration which are felt by the driver while sitting on the tractor. These vibrations are standardized by an ASABE standard. The standard mentions that for a tractor up to 3600 kg, a frequency of vibration should not exceed 11.22 Hz (ASABE/ISO, 2006). The regular allowable vibrations should be maintained at 0.89 Hz (ASABE/ISO, 2006). However, with the removal of the diesel engine and keeping the same suspension, the vibrations should be greatly reduced as electric motors do not vibrate nearly as much as diesel engines if properly installed. eTract aims to reduce the vibration of the tractor to below the recommended standards which will allow for a smoother ride for the farmer.

Battery Calculations:

From previous calculations, the estimated battery capacity required to run for 9.44 hours (assuming 80% efficiency) is 2800 Ah. Implementing a safety factor of 1.15 for added power requirements from other components, the desired capacity for a built battery bank is 3,220 Ah.

$$\frac{68Ah}{configuration\ [pack]} * (x)packs = 3220\ Ah$$

$$x = 47.35\ Packs \rightarrow 48\ Packs$$

Charging time will affect the practicality of the tractor. If the charging time is too long and the usage time too low, the tractor will be deemed useless. In the case of the eTract tractor, assuming the use of the current Sun Country 240V charger (level 2 charging) already located at *Vergers Écologique Philion,* the following charging time has been calculated. In this case, the efficiency of charging is set to 60% (Electrical Technology Inc., 2013). In addition, the Sun Country level 2 charger installed, the Sun Country EV 40, has a power output of 7.7 kW (Sun Country Highway, 2017).

$$Calculating\ power\ of\ battery\ for\ charging\ time: P = VI = (3.6V)(3220Ah) \\ = 11.592\ kWh$$

$$Calculating\ charging\ time\ based\ on\ power\ and\ 60\%\ efficiency = \frac{kWh}{kW} = \frac{11.592}{7.7 * 0.6} \\ = 2.5\ hours$$

Tax Credits

Many federal and provincial/state governments across the world, including the Quebec Government, are adopting the idea of helping their populations make the transition to electric vehicles. Quebec has implemented a purchase/lease rebate of up to $8000 for the purchase or lease of an electric vehicle (Gouvernement du Quebec, 2017). This rebate varies on the type of vehicle purchased or leased. For example, a hybrid vehicle will receive up to $500 whereas a fully electric car, such as a Chevrolet Bolt, would receive the maximum amount of $8000 (Gouvernement du Quebec, 2017). Used vehicles are also eligible for up to 50% of this credit. As these rebates are regulated by provincial governments in Canada, the rebate varies by province. In Quebec, it is also possible to receive a charging station installation incentive. The maximum amount of this incentive is $600. This amount is broken up into two categories: purchase of the charging station and installation of the station. The incentives are $350 and $250 respectively, a total of $600 (Gouvernement du Quebec, 2017). Together, these two incentives ease the financial burden required to invest in an electric vehicle and charging station.

In the US, federal and state tax credits and incentives exist. These vary greatly by state. As is the case with many federal incentives in the United States, these credits are dependent on the governing political party. Electrification of the transportation network is highly partisan and can change with changing governments. To illustrate, the State of California offers an additional rebate on top of the USD 7500 federal tax credit. The state credits vary highly depending on the price of the vehicle and the income of the individual purchasing the vehicle. Further, California offers incentives for commercial electric vehicles. It was once the case that electric vehicle conversion kits would also receive a federal tax credit, however this program has since been discontinued.

While it is not yet known if the implementation of an electric tractor would qualify a farm owner for the incentives or tax credits mentioned above, there exist tax implications which a farmer can take advantage of. Although it would be difficult to qualify the purchase of the DIY kit as a capital expenditure, it could be declared as an operating expense by the farmer in their end-of-year tax returns. An advantage of mentioning this in the operating expenses of the business is to reduce the amount of taxes that the farm will pay for that year. As the conversion of the tractor will run in the thousands of dollars, it could represent a significant reduction in the taxes that would need to be paid by the business.

In terms of obtaining tax credits for eTract, Mr. Hubert Philion and his accountant have explored various options. The first option was simply using the expenditures on the tractor as expenses on the business, lowering business taxes overall. The second option was using a Quebec Government R&D grant that allows for 30% of expenses to be reimbursed. Since using the R&D grant would involve a lot of time and energy, and that the reimbursed expenditures could not be allocated to business expenses, it was established that the first option would be implemented.

Life-cycle Assessment of Project and Overall Sustainability

Lifecycle Assessment - Revisited

Lifecycle assessment, or LCA, determines environmental impact by looking at every single stage in a product's lifecycle. A holistic tool that is best used in comparing two or more products, LCA includes raw material extraction or sourcing, production, distribution, consumer use, and disposal or recycling (International Organization for Standardization, 2006). Once all stages are assessed, the results are compared and analyzed among different impact categories. For the scope of this design project, categories will include the effects of electric tractors versus conventional tractors on climate change, depletion of fossil fuels, and depletion of mineral resources. *Figures 11, 12, and 13* from previous research highlight findings related to the latter categories for electric cars. They offer insight as to where, geographically, electrification is worthwhile, and where it is not a climate-mitigating strategy. Lifecycle analyses are chosen for various reasons, and for this project, a strong influencer is the avoidance of environmental burden shifting. This sort of shifting often occurs when emissions are shifted from one lifecycle step to another and is the intention behind the brief analysis of energy generation that will be covered.

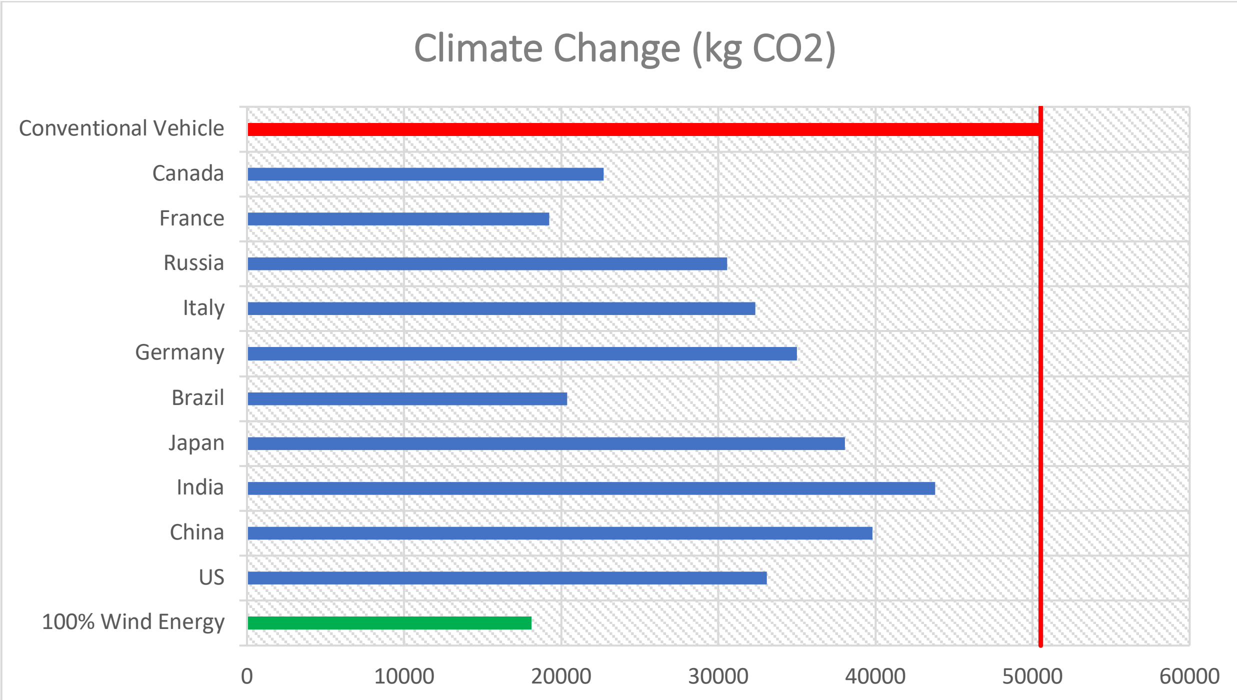

Figure 11: LCA Results for Electric Vehicles - Climate Change (Bonan, 2018)

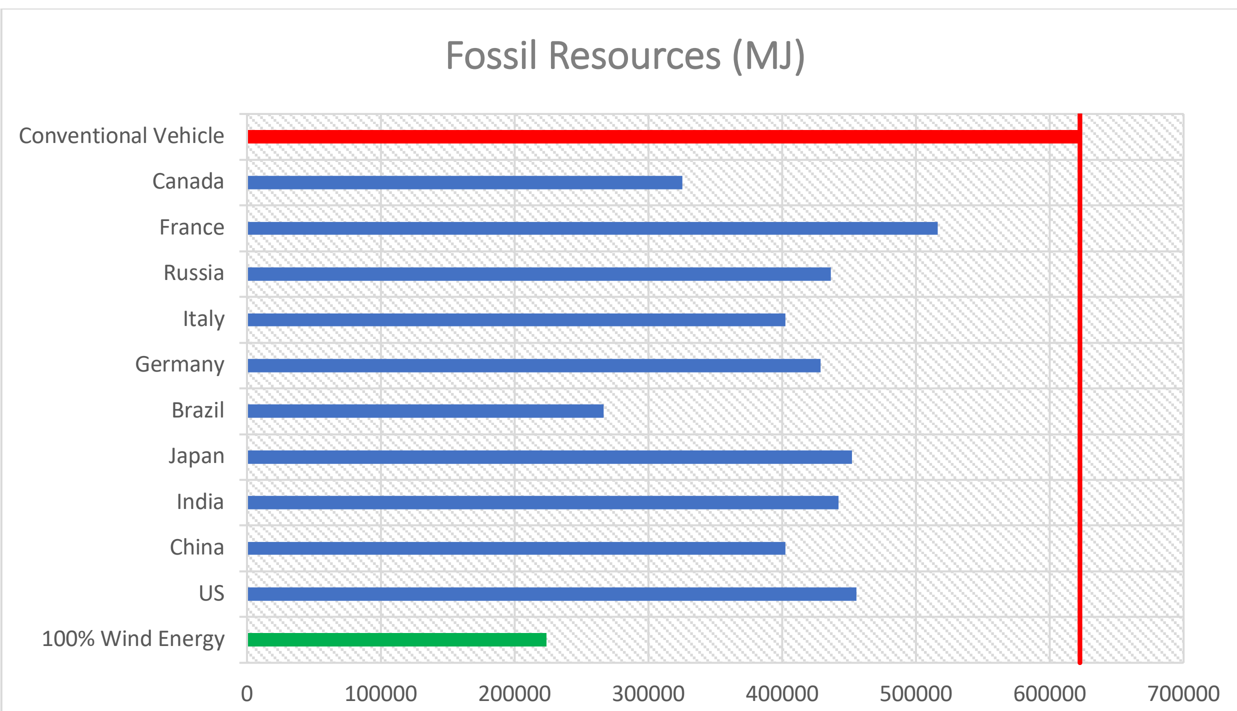

Figure 12: LCA Results for Electric Vehicles - Fossil Resources (Bonan, 2018)

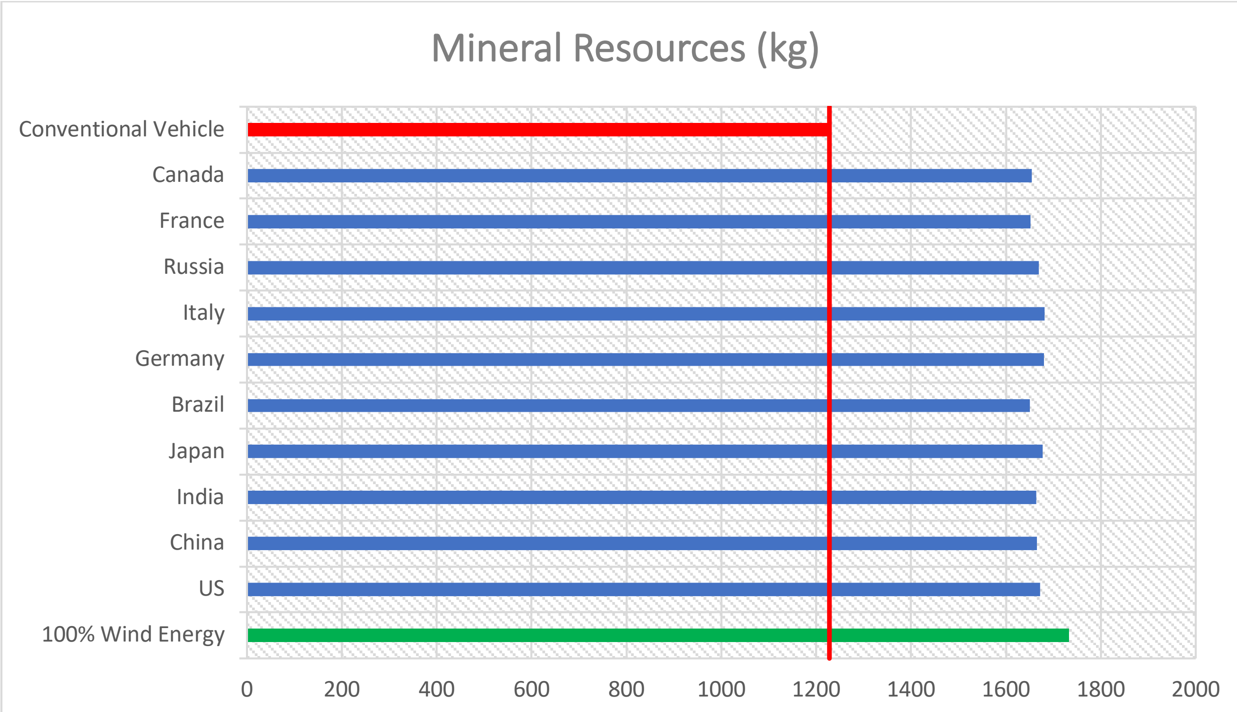

Figure 13: LCA Results for Electric Vehicles - Mineral Resources (Bonan, 2018)

Figures 11, 12, and 13 represent lifecycle analysis results for vehicle electrification in 10 countries. The red marker indicates where conventional cars fall in each impact category, whereas the blue lines are the implementation of electric cars in each country. The green line simulates a country whose electricity generation is entirely based on wind energy. It is observed that tractor electrification could have worthwhile benefits in many countries on the scopes of climate change and fossil resources, however mineral resources will be impacted regardless of the country because of the heavy use of lithium-ion.

ISO14040 – 2006

The International Organization for Standardization develops and publishes international standards. The ISO creates documents that provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose (International Organization for Standardization, 2006). In terms of lifecycle assessment, the international standard that exists is ISO 14040, titled “Environmental management – Life cycle assessment – Principles and framework.”

The LCA technique outlined in the standard involves four phases:

i. The goal and scope definition phase
ii. The inventory analysis phase
iii. The impact assessment phase
iv. The interpretation phase

These standard phases must be respected in the elaboration of a Life cycle assessment to be in line with ISO standards. With regards to the design of a life cycle assessment for converting a gas-powered tractor to electric, the goal and scope definition phase involves outlining the lack of current data related to the impact of tractor electrification on the environment. The "goal" for this design project is to convert a tractor from diesel power to electric, described above. The "scope" in this case includes all parts of the tractor other than the body itself. Since various pieces will be acquired, the environmental impact of each piece, as well as the lowered emissions due to lack of fuel also fall into the "scope" category. *Figures 11, 12, and 13* refer to three scope categories. The "inventory analysis" phase reviews current projects that involve vehicle electrification, and their impacts on the environment. It also identifies contradictions in existing research and emphasizes key findings. The "impact assessment" phase is the core of LCA data collection. It involves analyzing the impacts converting a tractor to electric will have on the various categories described in the "scope" section, in addition to the impacts associated with the manufacturing process of the acquired parts. In the "interpretation" phase, the data collected is compared and contrasted with conventional tractors to assess whether a true difference exists. Recommendations on the actual electrification of tractors are made based on these results.

End-of-life Strategies

From a mineral resources standpoint, it is evident that electrifying a gas-powered tractor has negative consequences. It is inferred, especially due to the positive lifecycle analysis results of Quebec's Hydroelectricity, that the environmental benefits will outweigh the consequences. Throughout the design plan, the end-of-life disposal of the tractor was considered. Firstly, it was ensured that the battery packs are both easily accessible, and that individual packs can be replaced, as well as the entire battery bank. This will ensure that once the batteries are depleted, the tractor will not have to be disposed of. When it does come to disposing of Lithium-Ion, research remains in progress. Recycling of automotive lithium-ion batteries is complicated and not yet established because few end-of-life batteries will need recycling for another decade (Gaines, 2014).

Additionally, this conversion process allows for the repurposing of tractors which would otherwise be sent to landfills. By removing the diesel engine and replacing it with a new electric one, the tractor will be revived, offsetting a significant amount of waste. Further, engines made of metal and other components of a tractor are recyclable. Taking apart an old tractor and converting it to electrical power allows for these pieces to be recycled rather than sent to landfill or scrapyard.

Additional Considerations

While removing the engine, gas tank, and exhaust system, and replacing them with electric counterparts is the largest part of eTract's design, it is not the entirety. For the final tractor to be functional, additional steps must be taken. Firstly, as discussed previously, a potentiometer must be installed to relay information from the gas pedal to the motor. This step is required with virtually all electric vehicles (Brain, Electric Vehicle Specifications, 2002). Second, the steering pump must be wired to the electric motor. In the case of Hubert Philion's tractor, the hydraulic pump will not be changed, however other farmers could intend on installing an electronic power steering system. Another deliberation was the air conditioner, since the Landini tractor is equipped. While this was a concern for eTract, many orchard tractors do not have air conditioning systems, and this step can be skipped. Like many other ancillary systems, the air conditioner compressor will be run by the electric motor. A final consideration is the brake system. Tractors and motorcars with internal combustion engines have brake boosters that connect directly to the vacuum of the engine. Since the engine is being replaced by an electric motor, there will be no vacuum for the brake system, therefore a vacuum pump must be installed.

In terms of ergonomics and ease of use, a tablet will be installed inside the tractor's cab to display information such as speed, battery pack charge, and potential motor problems. While EcoTuned uses a software to display the battery charge on the fuel gauge of their converted vehicles, this process involves in-depth knowledge of coding, in addition to a vehicle with software that can be changed. Since the Landini tractor is from 1994, it was decided that integrating an android tablet would be a better alternative. The tablet will be waterproof and dustproof, meeting IP68 requirements of "Protection from contact with harmful dust" and "Protected from immersion in water with a depth of more than 1 meter for up to 30 minutes" (Parker, 2018).

Cost Analysis

Cost of Conversion

As this design needs to be cost efficient to entice farmers to convert their current diesel-powered tractors to an eTract electric system, materials used in the conversion process must be kept relatively low-priced. Further, by keeping the price low, it will allow a faster payback time. A cost analysis, shown below in *Table 2*, was done if a used tractor would be acquired, as was the case with the project's client, Hubert Philion.

Table 2: Cost Analysis of Conversion including Tractor Acquisition (used tractor)

Ancillary Parts	Unit cost	Unit(s)	Total Cost	Tax (PST&GST)	Total Price
Tractor	$4,347.83	1	$4,347.83	$652.17	$5,000.00
Motor	$6,521.74	1	$6,521.74	$978.26	$7,500.00
Battery (including wiring)	$103.26	48	$4,956.34	$743.45	$5,699.79
Battery Assembly	$2,000.00	1	$2,000.00	$300.00	$2,300.00
Miscellaneous	$1,000.00	1	$1,000.00	$150.00	$1,150.00
	Total Price of Assembly excluding Tractor				**$16,649.79**
	Total Price of Assembly including Tractor				**$21,649.80**

Tax Implications and Depreciation

As this will be a business expense for a farmer, capital expenditure and depreciation can play a big part in reducing yearly taxes. Tax implications will change by region however for this report, due to the availability of information and ease of access to information, the Ontario tax code will be used below to determine payback period and depreciation.

Payback Period

As discussed, the client mentioned that during the busiest times of year, he uses one full tank of diesel per day. This was described as 40L. Assuming that peak business time equates to four months of the year, 16 weeks, and the rest of the year, half the amount of fuel is used, a total of 8160 L per year are used (Appendix). According to 2017 data, the average cost of diesel between June and October was 107.7c/L (Statistics Canada, 2017). Using this average cost and the average amount of litres used per year, a total of $8788 on average is spent on fuel for one orchard tractor.

The amount of energy required to charge the batteries to run the tractor will also play a role in determining the payback period for the conversion process, however for the purpose of this estimation, the cost of electricity will not be taken into account. In Quebec, a Hydro-Quebec incentive allows for free electric vehicle charging for the first two years following installation of the charger. Further, businesses can now receive a grant of up to $5000 for the installation of a charger (Gouvernement du Quebec, 2018).

Table 3: Annual Machinery Cost of Tractor if it was Diesel-powered as per the Ontario Ministry of Agriculture, Food and Rural Affairs (Ontario Ministry of Agriculture, Food, and Rural Affairs, 2016).

Type of Machine Operation: (eg combine)					
Machine Cost Calculator					
POWER UNIT (TRACTOR OR SELF-PROPELLED MACHINE)					
Life (years)	10	Purchase Price		$ 21,650	
Interest rate	5.00%	Trade in Value		$ -	
Acres/year	1600	Hours per year		200	
Acres/hr *(see table 5)*	8	Fuel Cost per litre		1.07	
Click To Go To Table 5		Fuel Used -litres/hr (see Table 5)	Click To Go To Table 5	5	
Annual Fixed Cost					
Depreciation =		purchase price – trade-in value	Click To Go To Table 3	2,165	
(see table 3)		life of machine (years)			
Interest* =		(purchase price + trade-in) x annual interest rate		541	
		2			
Insurance & housing =		purchase price x 1½ %		325	
Total Fixed Cost				**3,031**	(A)
Annual Operating Cost					
Fuel & lubricants *(Table 5)*		(litres/hour x hr/yr x fuel cost/L x 1.15)		1,231	
Repairs =		*estimate using Table 4*	Click To Go To Table 4	**2000**	
Total Operating Costs				**3,231**	(B)
Total Costs				**$ 6,261**	
MACHINE (TILLAGE IMPLEMENT, PTO MACHINE, OTHER)					
Life (years)	5	Purchase Price		$ -	
Interest rate	5.00%	Trade in Value		$ -	
Annual Fixed Cost					
Depreciation =		purchase price – trade-in value		0	
		life of machine (years)			
Interest* =		(purchase price + trade-in) x annual interest rate		0	
		2			
Insurance & housing =		purchase price x 1½%		0	
Total Fixed Cost				**0**	(C)
Annual Operating Cost					
Repairs =		*estimate using Table 4*	Click To Go To Table 4	**0**	
Total Operating Costs				**0**	(D)
Total Costs				**$ -**	
ANNUAL MACHINERY COSTS (A+B+C+D)				**$ 6,261**	**(E)**
Return to Management	15%	Operator Labour (self or hired) per Hour		$ 17.00	
		Labour Allowance for Machine travel, downtime		15%	
Profit Margin (return to management, admin. costs) (suggest 15% of machinery costs (E x 0.15)				$ 939	(F)
Operator Labour (self or hired) --- (suggest 15% over machine hr for travel, downtime) # of machinery hr x 1.15 x wage/h				$ 3,910	(G)
All Costs Including Management (E+F+G)				**$ 11,111**	(H)
** Interest — This interest calculation is the average annual interest cost of the investment (yours and/or the lender's) that is tied up in the machine*					

Table 4: Annual Machinery Cost of Tractor when Electrically-powered as per the Ontario Ministry of Agriculture, Food and Rural Affairs

Type of Machine Operation: (eg combine)				
Machine Cost Calculator				
POWER UNIT (TRACTOR OR SELF-PROPELLED MACHINE)				
Life (years)	10	Purchase Price	$ 21,650	
Interest rate	5.00%	Trade in Value	$ -	
Acres/year	1600	Hours per year	200	
Acres/hr *(see table 5)*	8	Fuel Cost per litre	0.00	
Click To Go To Table 5		Fuel Used -litres/hr (see Table 5) Click To Go To Table 5	0	
Annual Fixed Cost				
Depreciation =		purchase price – trade-in value Click To Go To Table 3	2,165	
(see table 3)		life of machine (years)		
Interest* =		(purchase price + trade-in) x annual interest rate	541	
		2		
Insurance & housing =		purchase price x 1½ %	325	
Total Fixed Cost			**3,031**	(A)
Annual Operating Cost				
Fuel & lubricants*(Table 5)*		(litres/hour x hr/yr x fuel cost/L x 1.15)	0	
Repairs =		*estimate using Table 4* Click To Go To Table 4	**500**	
Total Operating Costs			**500**	(B)
Total Costs			**$ 3,531**	
MACHINE (TILLAGE IMPLEMENT, PTO MACHINE, OTHER)				
Life (years)	5	Purchase Price	$ -	
Interest rate	5.00%	Trade in Value	$ -	
Annual Fixed Cost				
Depreciation =		purchase price – trade-in value	0	
		life of machine (years)		
Interest* =		(purchase price + trade-in) x annual interest rate	0	
		2		
Insurance & housing =		purchase price x 1½%	0	
Total Fixed Cost			**0**	(C)
Annual Operating Cost				
Repairs =		*estimate using Table 4* Click To Go To Table 4	**0**	
Total Operating Costs			**0**	(D)
Total Costs			**$ -**	
ANNUAL MACHINERY COSTS (A+B+C+D)			**$ 3,531**	**(E)**
Return to Management	15%	Operator Labour (self or hired) per Hour	$ 17.00	
		Labour Allowance for Machine travel, downtime	15%	
Profit Margin (return to management, admin. costs) (suggest 15% of machinery costs (E x 0.15)			$ 530	(F)
Operator Labour (self or hired) --- (suggest 15% over machine hr for travel, downtime) # of machinery hr x 1.15 x wage/h			$ 3,910	(G)
All Costs Including Management (E+F+G)			**$ 7,971**	(H)
** Interest — This interest calculation is the average annual interest cost of the investment (yours and/or the lender's) that is tied up in the machine*				

As observed, the difference in annual costs amid *table 3* and *table 4* is $3140. Using this difference and assuming the price of electricity to be negligible for the purpose of this calculation because of Hydro-Quebec's new benefit, the payback period was determined to be in the 9th year of operation. Using a discount rate of 5% equal to the rate used by the Ontario Ministry of Agriculture, Food and Rural Affairs, the following table was made to determine the payback period. In the case that a farmer converts their current tractor, which has already depreciated to $0, the payback period will, surprisingly, be much less at 5 years (See appendix). Conclusively, because of depreciation and tax rules, purchasing a used tractor and performing a conversion will have more of an economic burden than converting their own tractor. The tax situations in Quebec and Ontario are similar enough for agricultural producers that the payback period in Quebec will be relatively similar to Ontario.

Table 5: Payback Period Estimator with a Discount Rate of 5%

Year n	Cash Flow CF	Present Value Factor	Discounted Cash Flow	Cumulative Discounted Cash Flow
0	-$21,649.80	1	-$21,649.80	-$21,649.80
1	$3,140.00	0.952380952	$2,990.48	-$18,659.32
2	$3,140.00	0.907029478	$2,848.07	-$15,811.25
3	$3,140.00	0.863837599	$2,712.45	-$13,098.80
4	$3,140.00	0.822702475	$2,583.29	-$10,515.52
5	$3,140.00	0.783526166	$2,460.27	-$8,055.24
6	$3,140.00	0.746215397	$2,343.12	-$5,712.13
7	$3,140.00	0.71068133	$2,231.54	-$3,480.59
8	$3,140.00	0.676839362	$2,125.28	-$1,355.31
9	$3,140.00	0.644608916	$2,024.07	$668.76

Conclusion

After a thorough literature review of vehicle electrification, various battery types, motors, and transmissions, a design process was initiated to convert a tractor from diesel power to electricity. eTract contemplated the options of building a new tractor or repurposing a used one, and it was established that the best solution for this project was to design and implement a process in which a diesel-powered tractor can be modified to become fully electric. In addition to being more cost effective, salvaging an old tractor involves less environmental consequences, less time to build, and less adaptation and learning time for the farmer. The client's needs remained at the forefront of all decisions, and the project incorporated hard work, dedication, working well with peers, and meeting with industry professionals. Since the original goal of constructing a prototype in 1 semester was deemed much too ambitious, designs and simulations using Autodesk Inventor ensued as a replacement. It was learned while discussing with industry professionals that these projects can take several years, as EcoTuned took over four years to develop their first prototype. Fortunately, a team of engineering students was keen on taking over the project and plans on bringing it to fruition in 2019. For a project to be sustainable and have reason for implementation, many argue it should benefit people, the planet, and involve some sort of profit. All three of the aforementioned characteristics were taken into account at various stages throughout this design project. For people, eTract's solution will lower long-term costs, in addition to reducing noise and air pollution. In terms of the planet, lower greenhouse gas emissions will be observed from a lifecycle analysis perspective, acting as a climate change mitigation strategy. Cost-wise, a full cost analysis was presented, with a payback period much smaller than the life of the tractor. While estimations put the project approximately $1500 over budget, it is possible that costs will change upon procurement, however the payback period nonetheless assumes these increased costs and deems the project worthwhile. To conclude, eTract's vision statement made reference to lowering greenhouse gases from the agricultural sector. The plan is to repurpose tractors that were once declared fully depreciated; turning possible wastes into resources without causing financial strain. The latter is inherent to pioneering a more sustainable future, one that safeguards the planet for future generations.

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Appendix

Battery Power Requirements:

If total capacity = 2800 Ah (assuming capacity increases proportionally to the number of cells)

Assuming runtime @ 70 HP,

$$\frac{2800\ Ah}{237.36\ A} = 11.8\ h$$

Assuming 80% efficiency (from literature), runtime for power of 70HP = 9.44 h

This estimation is based on optimal operating conditions and neglects factors such as temperature and rolling resistance.

Calculating rolling resistance:

Weight assumption of 1495 kg – after electrification this is the current weight of the tractor with motor and transmission and after removal of original engine, transmission, and exhaust system.

$$Rolling\ Resistance: Fr = c\ \times W$$

$$W\ = 1495\ kg\ \times 9.81\frac{m}{s^2} = 14665.95\ N\ \text{(Swaraj, 2015)}$$

$$c\ (resistance\ coefficient) = Assuming\ car\ tire\ on\ medium - hard\ soil$$

$$= range\ of\ 0.04 - 0.08, average\ of\ 0.06\ will\ be\ used\ \text{(Engineering Toolbox, 2017)}$$

$$Fr = 0.06\ \times 14665.95 = 879.957\ N$$

$$Using\ an\ estimated\ speed\ of\ 10\frac{km}{h}$$

$$(11\ \times 605\ m) + (55\ \times 470\ m) = 32\ 505\ m = 32.505\ km$$

$$\frac{32.505 km}{10\frac{km}{h}} = 3.2\ hours\ total\ to\ cover\ entire\ acreage$$

$$W\ = F\ \times D = 879.957N\ \times 32\ \ 505\ m = 286.0E5\ J$$

$$1\ kWh = 3.6E6\ J$$

$$286E5\ J = 7.944\ kWh$$

$$P = I \times V$$

$$7.944E3\ kWh = I\ \times 220V$$

$$I = 36.11\ Ah$$

With rolling resistance:

$$\left(\frac{2800Ah - 36.11Ah}{237.36}\right)(0.8) = 9.31\ hours$$

Fuel Use Estimation:

(16*40*6 days/week)+(52-16)*20*6 = 8160 L

Machine Cost Estimation:

Table 1: Cost of eTract using current tractor converted to electric

Type of Machine Operation: (eg combine)				
Machine Cost Calculator				
POWER UNIT (TRACTOR OR SELF-PROPELLED MACHINE)				
Life (years)	10	Purchase Price	$ 16,649	
Interest rate	5.00%	Trade in Value	$ -	
Acres/year	1600	Hours per year	200	
Acres/hr *(see table 5)*	8	Fuel Cost per litre	0.00	
Click To Go To Table 5		Fuel Used -litres/hr (see Table 5) Click To Go To Table 5	5	
Annual Fixed Cost				
Depreciation =		purchase price – trade-in value Click To Go To Table 3	1,665	
(see table 3)		life of machine (years)		
Interest* =		(purchase price + trade-in) x annual interest rate	416	
		2		
Insurance & housing =		purchase price x 1½ %	250	
Total Fixed Cost			**2,331**	(A)
Annual Operating Cost				
Fuel & lubricants*(Table 5)*		(litres/hour x hr/yr x fuel cost/L x 1.15)	0	
Repairs =		*estimate using Table 4* Click To Go To Table 4	**500**	
Total Operating Costs			**500**	(B)
Total Costs			**$ 2,831**	
MACHINE (TILLAGE IMPLEMENT, PTO MACHINE, OTHER)				
Life (years)	5	Purchase Price	$ -	
Interest rate	5.00%	Trade in Value	$ -	
Annual Fixed Cost				
Depreciation =		purchase price – trade-in value	0	
		life of machine (years)		
Interest* =		(purchase price + trade-in) x annual interest rate	0	
		2		
Insurance & housing =		purchase price x 1½%	0	
Total Fixed Cost			**0**	(C)
Annual Operating Cost				
Repairs =		*estimate using Table 4* Click To Go To Table 4	**0**	
Total Operating Costs			**0**	(D)
Total Costs			**$ -**	
ANNUAL MACHINERY COSTS (A+B+C+D)			**$ 2,831**	**(E)**
Return to Management	15%	Operator Labour (self or hired) per Hour	$ 17.00	
		Labour Allowance for Machine travel, downtime	15%	
Profit Margin (return to management, admin. costs) (suggest 15% of machinery costs (E x 0.15)			$ 425	(F)
Operator Labour (self or hired) --- (suggest 15% over machine hr for travel, downtime) # of machinery hr x 1.15 x wage/h			$ 3,910	(G)
All Costs Including Management (E+F+G)			**$ 7,165**	(H)
** Interest — This interest calculation is the average annual interest cost of the investment (yours and/or the lender's) that is tied up in the machine*				

Table 2: Cost of Tractor without electric conversion

Type of Machine Operation: (eg combine)				
Machine Cost Calculator				
POWER UNIT (TRACTOR OR SELF-PROPELLED MACHINE)				
Life (years)	10	Purchase Price	$ 16,649	
Interest rate	5.00%	Trade in Value	$ -	
Acres/year	1600	Hours per year	200	
Acres/hr *(see table 5)*	8	Fuel Cost per litre	1.07	
Click To Go To Table 5		Fuel Used -litres/hr (see Table 5) Click To Go To Table 5	5	
Annual Fixed Cost				
Depreciation =		purchase price – trade-in value Click To Go To Table 3	1,665	
(see table 3)		life of machine (years)		
Interest* =		(purchase price + trade-in) x annual interest rate	416	
		2		
Insurance & housing =		purchase price x 1½ %	250	
Total Fixed Cost			**2,331**	(A)
Annual Operating Cost				
Fuel & lubricants*(Table 5)*		(litres/hour x hr/yr x fuel cost/L x 1.15)	1,231	
Repairs =		*estimate using Table 4* Click To Go To Table 4	**500**	
Total Operating Costs			**1,731**	(B)
Total Costs			**$ 4,061**	
MACHINE (TILLAGE IMPLEMENT, PTO MACHINE, OTHER)				
Life (years)	5	Purchase Price	$ -	
Interest rate	5.00%	Trade in Value	$ -	
Annual Fixed Cost				
Depreciation =		purchase price – trade-in value	0	
		life of machine (years)		
Interest* =		(purchase price + trade-in) x annual interest rate	0	
		2		
Insurance & housing =		purchase price x 1½%	0	
Total Fixed Cost			**0**	(C)
Annual Operating Cost				
Repairs =		*estimate using Table 4* Click To Go To Table 4	**0**	
Total Operating Costs			**0**	(D)
Total Costs			**$ -**	
ANNUAL MACHINERY COSTS (A+B+C+D)			**$ 4,061**	**(E)**
Return to Management	15%	Operator Labour (self or hired) per Hour	$ 17.00	
		Labour Allowance for Machine travel, downtime	15%	
Profit Margin (return to management, admin. costs) (suggest 15% of machinery costs (E x 0.15)			$ 609	(F)
Operator Labour (self or hired) --- (suggest 15% over machine hr for travel, downtime) # of machinery hr x 1.15 x wage/h			$ 3,910	(G)
All Costs Including Management (E+F+G)			**$ 8,581**	(H)

Additional Cash Flow Calculations:

Table 3: Electric conversion of current tractor payback period

Year n	Cash Flow CF	Present Value Factor	Discounted Cash Flow	Cumulative Discounted Cash Flow
0	-16,649.00	1	-$16,649.00	-$16,649.00
1	4,096.00	0.952380952	$3,900.95	-$12,748.05
2	4,096.00	0.907029478	$3,715.19	-$9,032.85
3	4,096.00	0.863837599	$3,538.28	-$5,494.58
4	4,096.00	0.822702475	$3,369.79	-$2,124.79
5	4,096.00	0.783526166	$3,209.32	$1,084.54
6	4,096.00	0.746215397	$3,056.50	$4,141.03
7	4,096.00	0.71068133	$2,910.95	$7,051.99

8	4,096.00	0.676839362	$2,772.33	$9,824.32
9	4,096.00	0.644608916	$2,640.32	$12,464.64
10	4,096.00	0.613913254	$2,514.59	$14,979.23