Conceptual Design for Converting a Vintage Tractor to a Safe and Functional Electric Tractor

UC Davis D-Lab 1
Final Report

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Report Index

EXECUTIVE SUMMARY

What is the UC Davis Student Experimental Farm?

The UC Davis Student Experimental Farm supports student exploration by creating a space and opportunity for students to learn about sustainable agriculture and food systems. Their team emphasizes in-field experiential learning through their volunteers, interns, and student workers. Tractor driving is one of the most popular opportunities the Student Farm offers. Students get to use the tractors to cultivate crops on the farm after undergoing a tractor training course.

James R. Muck, the Student Farm's Field Operations Coordinator, is in charge of training the students on the tractors. Currently, the farm uses internal combustion engine tractors that are loud and release emissions. The noisy tractors make communication during the training process difficult for students to learn properly. Fuel emissions also pose an occupational health problem for students working on the farm.

Internal Combustion Engine vs. Electric Motor

Internal combustion engine tractors use the chemical process of combustion to release energy from burning a mixture of fuel and air. This process occurs inside the engine, where the energy gets converted into work. Internal combustion engines are loud due to the force applied to the pistons and the vibrational movement. They can be powered by gasoline, diesel, or biofuels.

An electric motor consists of a battery connected to a motor. The battery supplies electrical energy to the stator, which is used to create a magnetic field. When the electrical energy from the battery is supplied to the motor, the magnetic field spins the rotor to produce mechanical energy. An electric motor tractor doesn't require any fuel and can be recharged. Therefore, it doesn't release any harmful emissions and makes little noise, unlike an internal combustion engine.

Our Project:

To improve the learning experience and occupational health of students working on the farm, the Student Experimental Farm would like to convert a gasoline tractor into an electric motor tractor. Our team of bio-based engineers is working with UC Davis Student Experimental Farm to convert a 1950's Allis Chalmers Model G gasoline tractor into a rechargeable electric tractor. The tractor will be used as a teaching tool for students and will require the following components: hydraulic system, three-point hitch, cultivator, and rollover protection system. The 15-20 hp tractor needs to last 4 hours per charge. The tractor also needs to meet OSHA (Occupational Safety & Health Administration) standards to ensure proper design and safety for the users.

Our Results:

1. Tractor conversion kit and project contact: Niekamp Tool Company, NY
2. Preliminary conceptual design with required components (SketchUp)
3. The Green Initiative Fund Grant Application

INTRODUCTION

Over ten weeks, we conducted intensive research, learned how to drive a tractor, performed SWOT analysis, and product analysis to come up with a conceptual design. As far as components are concerned, the Student Farm will provide a three-point hitch and cultivator for the tractor. However, the rollover protection system (ROPS), seats, headlights, and hydraulics will be outsourced by our team.

We came in contact with a company called Niekamp Tool Company, NY, who successfully converted the same Allis Chalmers Model G Cultivating Tractor (See Appendix A, Fig. 1) and built their conversion kit. With continuous contact and positive feedback from Herman Niekamp, President of the company, we decided to continue the project using the same kit with the addition of various components. The kit is $595 without shipping and includes 25 essential parts for the conversion, excluding the motor and battery for the tractor, allowing us flexibility while deciding the type of battery and motor to use for the tractor. We reached out to Mr. Niekamp who informed us regarding the success of the kit and said our main focus would be on batteries, especially their direct maintenance by farmers.

There are two types of batteries we're currently looking into (See Appendix F): the Lithium-Ion and the Lead-Acid battery. Both batteries have their pros and cons: however, based on life cycle analysis, the Lead Acid is a better option. We are currently in communication with Herman Niekamp to learn more about the different conversion processes people have done, and will decide on a battery based on documentation and feedback from the other farmers.

The leading cause of death on farms is tractor rollovers caused by driving too fast around a curve or a slope. The ROPS, located on the back of the tractor, prevents the tractor from crushing the operator during a rollover. A hood is typically installed for additional protection along with a seat belt to ensure the operator is securely fastened into the seat. ROPS are designed and engineered for specific tractor sizes and weights and are not recommended to be installed independently to ensure proper performance and safety.

Additionally, our team will need to refurbish and perform maintenance on the tractor before conversion. The tractor will require new tires and paint on the chassis after stripping the tractor of any unnecessary components. To cover the costs of the conversion and refurbishment of the vintage tractor, we'll be applying for The Green Initiative Fund grant, which awards up to $200,000 for enacting sustainable projects on campus.

The tractor will be an icon of sustainability on campus, so we will be hosting a design competition based on what sustainability means to students. The design that is most representative of how the tractor promotes sustainability will be the exterior design of the tractor. We will also showcase the tractor at the Winter Tractor Parade!

METHODOLOGY AND RESULTS

The steps followed in the methodology are outlined below:

1. Defining the Problem Statement and Scope of the Project
    a. Experiential Learning - "D-Lab team learns to drive a tractor"
    b. Identified timeline and Goals
2. Design Considerations**:** Occupational Health & Safety
3. Utilizing Analytical Tools to inform project design
    a. Established contact with key commercial stakeholder
    b. Evaluating options for conversion of the Gasoline tractor
    c. Constructed a Questionnaire
    d. Filled the TGIF grant application to secure funding

1. Defining the Problem Statement and Scope of the Project

Experiential Learning

The first phase of our project relied heavily on understanding the background of the tractor itself, and the client's motivations behind envisioning a conversion - as outlined in the *Introduction*. A majority of our work relied heavily on the literature and commercial work done by companies like Allis Chalmers, the manufacturer of our subject of conversion, and Massey Ferguson, a leading American agriculture company.

After gaining a primary understanding of the main components of a tractor, and different horsepower capabilities of tractors that have been in the market since the 1950s, we spent our second field trip on the Student Farm, getting our very first tractor driving lesson (See Appendix A, Fig. 2.) For our team, this was an experiential learning opportunity in that we got to train in the same manner as Student Farm Interns and survey the challenges they face. Major takeaways from this experience are as follows:

a. Gasoline tractors are too loud for instruction.
b. Student farm workers run a minimum of a 4-hour shift at the site

In the above cases, exposure of the student worker to the noise generated can be harmful to their overall health - thus, requiring the earplugs to block the sound.

Timeline and Goals

To efficiently come up with a deliverable for the Student Farm, we decided to focus our resources to create a conceptual design of the tractor's conversion from running on gasoline to being powered by electricity. To accomplish this, we also established a timeline, which included some of the following goals to be completed February and (early) March.

a. February:
    i. Research on Occupational Health and Electrical Design
    ii. Preliminary design and client approval
b. March:
    i. SketchUp prototype
    ii. The Green Initiative Fund grant application

2. Design Considerations: Occupational Health & Safety

Primarily guided by the OSHA policy governing the conditions of operation for *Youth in Agriculture,* looking at the health of student farm workers and interns while designing the revamped version of our vintage tractor. In the table below, we synthesize concerns outlined in the policy above and in the literature along with our recommendations in eliminating/evading the same:

Concern (as outlined by OSHA guidelines)	Effect of the concern	Recommendation?
Noise production as a hazard	Long-term physiological and psychological effects (Basner et al., 2014); should not exceed an average hearing threshold level (HTL) of 25dB (Prince et al., 1997, p.)	Use a system wherein the generator powers the motor to drive the hydraulic pump and reduce sound generated by gas flow and combustion.
Spinal Health & effects of Vibration exposure	Placement of the engine below the tractor seat while balancing can cause whole body vibrations - leading to deformation, lumbago or sciatica (See Appendix A, Fig. 3) and other conditions (Bogadi-Sare, 1993).	Driver seat dampening as seen in lighter caterpillar tractors (Lian et al., 2015).
Rolling over of unbalanced tractors and body injuries	⅔ farm fatalities in the US are caused by overturning tractor bodies, that lead to physical injury and head trauma (Walter, 2011).	Install a Roll Over Protection System - that adheres with the ISO certification and is approved by a safety engineer.

3. Utilizing Analytical Tools to inform project design

<u>Established contact with key commercial stakeholder</u>

By performing a stakeholder analysis (See Appendix B), we mapped them out in different categories based on their interest and influence in the project. Since the **Student Farm** was our client, we worked closely with our primary contact, James R. Muck (FOC) at every step. Being a **UC Davis D-lab** team, we also had the analytical tools and access to the Engineering Student Design Center, the group art critique, and other novel ideas/spaces on campus. We also used Sketch-Up to create a preliminary design for our prototype. (See Appendix G)

A stakeholder that we did not actively engage with, but would like to see in the future, are the **small farm holders**, to give back to our community members involved in similar livelihoods. We could set up focus groups to understand their needs and challenges in working on these tractors for long hours to earn profit and grow enough to sell.

Evaluating options for conversion of the Gasoline tractor

To ensure this conversion of a gasoline tractor to a fully electric was the most beneficial option, we assessed internal combustion, electric, hybrid, and biofuel tractors through a Pugh chart (See Appendix C, Fig 1) based on their environmental, health, and economic impacts. Evidentially, electrical was the most attractive option. We also performed a SWOT analysis of the tractor conversion to analyze further the benefits of the conversion (See Appendix C, Fig 2).

Constructing a Questionnaire

Since our goal is to make tractor training more comfortable and efficient, while allowing students to gain transferable skills, we also created a feedback questionnaire that we could use to make improvements to the tractor design. (See Appendix H).

RECOMMENDATIONS AND NEXT STEPS

In D-Lab 2, we would work with the Student Farm Shop to strip the tractor completely of all components except the frame. We would then be able to create a thorough blueprint of the converted tractor. We would be adding extra safety measures like a rollover protection system as well as seatbelts. We would also place our engine in front for balance, and use two motors. One motor would function with the existing hydraulic system similar to a pump, with the other motor powering the tractor with higher energy supplied to power the tractor. The two motors would be connected to cut off power to both motors together when necessary safely. We would also focus on our battery selection based on the documentation from different conversion processes using the Niekamp conversion kit. The tractor will be an icon of sustainability on campus, so we will be hosting a design competition based on what sustainability means to students for the exterior design of the tractor. We also will showcase the tractor at the Winter Tractor Parade!

CONCLUSION

To summarize, our team has been working with the UC Davis Student Experimental Farm to improve the tractor training experience for students by converting a gasoline tractor into an electric motor tractor. Through research and analytical methodology, we have developed a conceptual design for the tractor, as well as a plan to use it to promote sustainability. Apart from this, we have included the safety measures in our design, and plan to use an electric motor for lower emissions as well as less noise for better audibility and communication during tractor training. TGIF Grant will cover costs of the kit, batteries, as well as other assembly items, including motors. The Niekamp Tool Company has also been an extremely valuable resource in providing us assembly guidelines and helping us obtain feedback on different conversions and their considerations.

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APPENDICES

A - Figures

B - Stakeholder Analysis

C - Evaluation of Gasoline Tractor

D - Electric G Conversion Kit

E - Electric G Kit Assembly Suggestions

F - General Battery Comparison

G - Sketch Up

H - Student Training Survey

****Note:**

Appendices D and E are from: https://www.niekampinc.com/electric-g-tractor/

Appendix A - Figures

Fig. 1: *Allis Chalmer 1950 Model G*

Fig 2: *D-lab team goes Tractor Driving!*

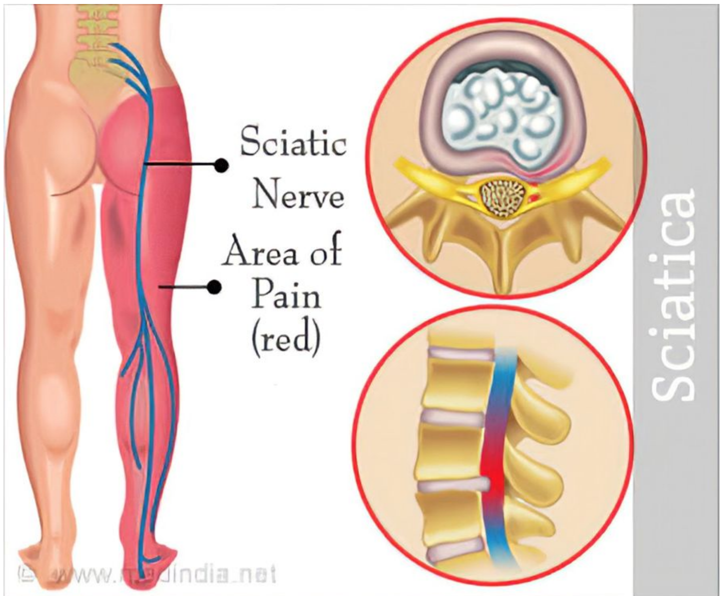
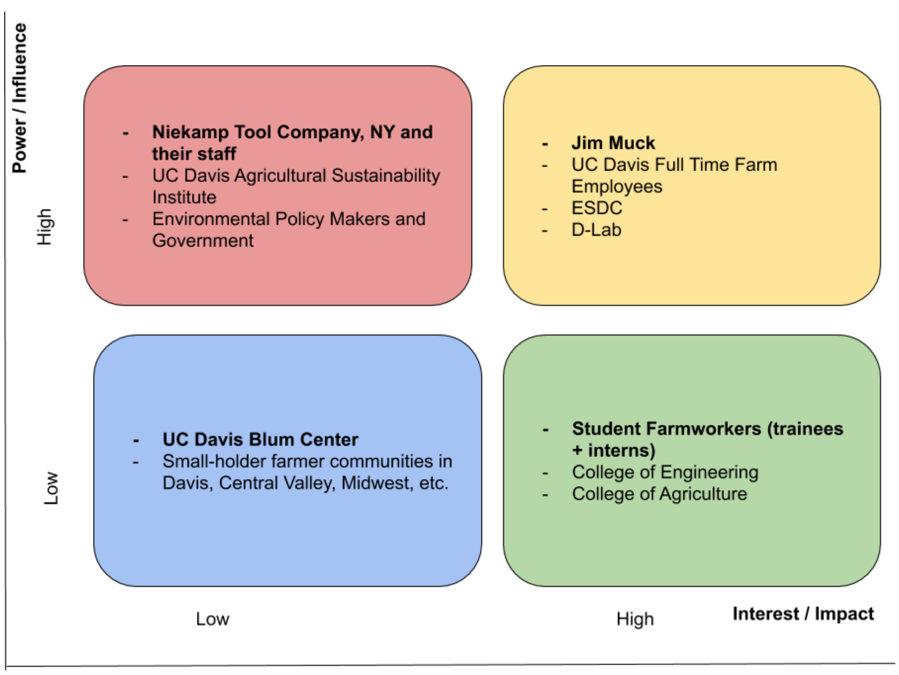


Fig 3: *Sciatica (compression of spinal nerves in lower back)*

Source: [*https://www.medindia.net/patients/patientinfo/sciatica.htm*](https://www.medindia.net/patients/patientinfo/sciatica.htm)

Appendix B - Stakeholder Analysis



Appendix C - Evaluation of Gasoline Tractor

Considerations/ Options	Noise (Wt - 3)	Emissions (Wt - 3)	Training Experience (Wt - 3)	Transferrable Skils (Wt - 2)	Ease of Maintenace (Wt - 2)	Waste Disposal (Wt - 2)	Start -Up Cost (Wt - 1)	Total
Solar and Rechargeability	3+	3+	0	0	1-	2-	1-	2+
Gasoline Tractor	3-	3-	3-	2+	2+	2-	0	7-
Hybrid Tractor: Gasoline and Electric	3+	0	3+	2+	3-	2-	2-	1+
Biofuel	3-	3-	3-	2+	2+	2-	1-	8-

Fig 1: *Comparative Pugh Chart*

	Electric Tractor	Gasoline Tractor
Strengths	❖ Has been converted before ❖ Access to D-lab	Students have already been trained to work on these
Weaknesses	If not built in line with other tractors on the farm, students might be limited to our electric tractor. For example, students must be well versed in shifting gears!	❖ Can impair hearing (during training, and in long term) ❖ Inhaling harmful particulate matter while working on the tractor

Fig 2: *Comparative SWOT Analysis Key Takeaways*

Appendix D - Electric G Conversion Kit

Electric G Conversion Kit

Parts List / Packing Slip

Item #	Part Name	Description	Part # for Vendor	Quantity
1	Bell Housing Plate	Adapter Plate to mount Motor and pulley assembly	BHP 0501	1
2*	Motor Plate	Plate to mount Motor and allow adjustment of belt.	MMP 0502	1
3	Motor Bolts	Special Undercut Head 3/8-16 x 3/4" Socket Head Cap Screws	91274A300	4
4	Motor Cover	Cover to protect Motor from weather and debris as well as backing into things.	BATT CVR	1
5*	Motor Cover Mount	Provides for Attachment of Motor Cover to Motor Plate	MCM 0503	2
6	Motor Pulley	16 Tooth 1.5 wide Pulley with 1008 taper lock bore	P16H150-1008	1
7	Motor Pulley Bushing	1008 taper lock bushing with 7/8 bore	TLB 1008 .875	1
8*	Ball Bearing	6007 Double Sealed Radial Ball Type	NAC 6007-2NSE	2
9*	Needle Bearing	Provides Support for Pilot Shaft	TOR JH-1112	1
10	Belt	240 Tooth H series Belt 1.50 Inch Wide	240H150	1
11*	Output Pulley	32 Tooth Pulley Custom Machined inside to fit Clutch Drive and Bearing Unit	P32H200-2517	1
12*	Bearing Unit Hub	Outer Bearing Mount and Clutch Drive mount	BUH 0504	1
13*	Bearing Unit Stub Shaft	Inner Bearing Mount and Pilot Bearing holder	BUS 0505	1
14*	Clutch Drive Clamp Ring	Attaches Clutch to Bearing Unit Hub	CDC 0506	1
15*	Bearing Unit Snap Ring	Keeper	5100-137 SZD	1
16*	Motor Plate Mounting Hex Nuts	3/8-16 SS NutWelded to Back of Bell Housing Plate	91845A031	4
17*	Grease Fitting	Pilot Bearing Grease	1095K41	
18*	Clutch Drive Clamp Bolts	5/16-18 x 1" Socket Head Cap Screws	91274A244	4
19	Motor Plate Fastening Bolts	3/8 - 16 x 1.25" Socket Head Cap Screws	91274A312	4
20	Motor Plate Fastening Washers	3/8 Heavy Flat Washers	98180A130	4
21*	1/4-20 x 7/8" Fastening Screws	4 for Controller, 4 for Stub Shaft, 4 for Motor Cover Mounts*	91274A168	12
22	Controller and Motor Cover Fastening Washers	1/4" SS Flat Washer	98019A355 or 98180A110	8
23	Motor Cover Bolts	1/4 - 20 x 1/2" SS Hex Head Bolts	92240A537	4
24	Contactor Mounting Screws	10-32 x 1/4" Pan Head Phillips Machine Screw	91772A825	2
25	Spacers for Controller	1/2" OD x .26" ID x .50 Long Steel/Alum/Brass	SPC 0507	4

Notes:

* Item 5 shipped pre-attached to Item 2 using (4pcs.) Item 21
* Items 8, 9, 11, 12, 13, 15, and 17 are factory assembled and 14 and 18 are loosely in place.
* Item 16 nuts are factory welded onto Item 1

Appendix E - Electric G Kit Assembly Suggestions

Electric G Kit Assembly suggestions

Step 1- Using the Bolts pictured above from the Fastener Bag, attach the motor to the Motor Plate. Attempt to align the terminals on the motor so that they will be positioned at 10 and 2 O'clock with the plate's longest edge horizontal. This will make wiring easier and shorten the path making it slightly more direct.

Step 2- Attach the Stub Shaft and Larger Pulley Assembly to the Bell Housing Plate on the same side as the four welded on nuts using 4 of the ¼-20 x 7/8" Allen Screws (no washers). Tighten well.

Step 3- Remove the paper cover and Clamp Ring from the face of the Large Pulley Assembly and attach the OEM Clutch disk that previously was driven by the Gas engine. Again tighten well. You can use a bar between two bolts to give you extra leverage.

Step 4- Pre-grease the pilot bearing through the fitting to verify that grease has filled the passage up to the bearing hole. You will add two to three pumps more after mounting the plate to the bell housing so there is no need to over-do-it now but be sure to keep it clean in there.

Step 5- Loosely attach the Motor Plate to the Bell Housing Plate using the (4) 3/8-16 x 1 ¼ " Allen Bolts with Flat Washers from the Fastener Bag.

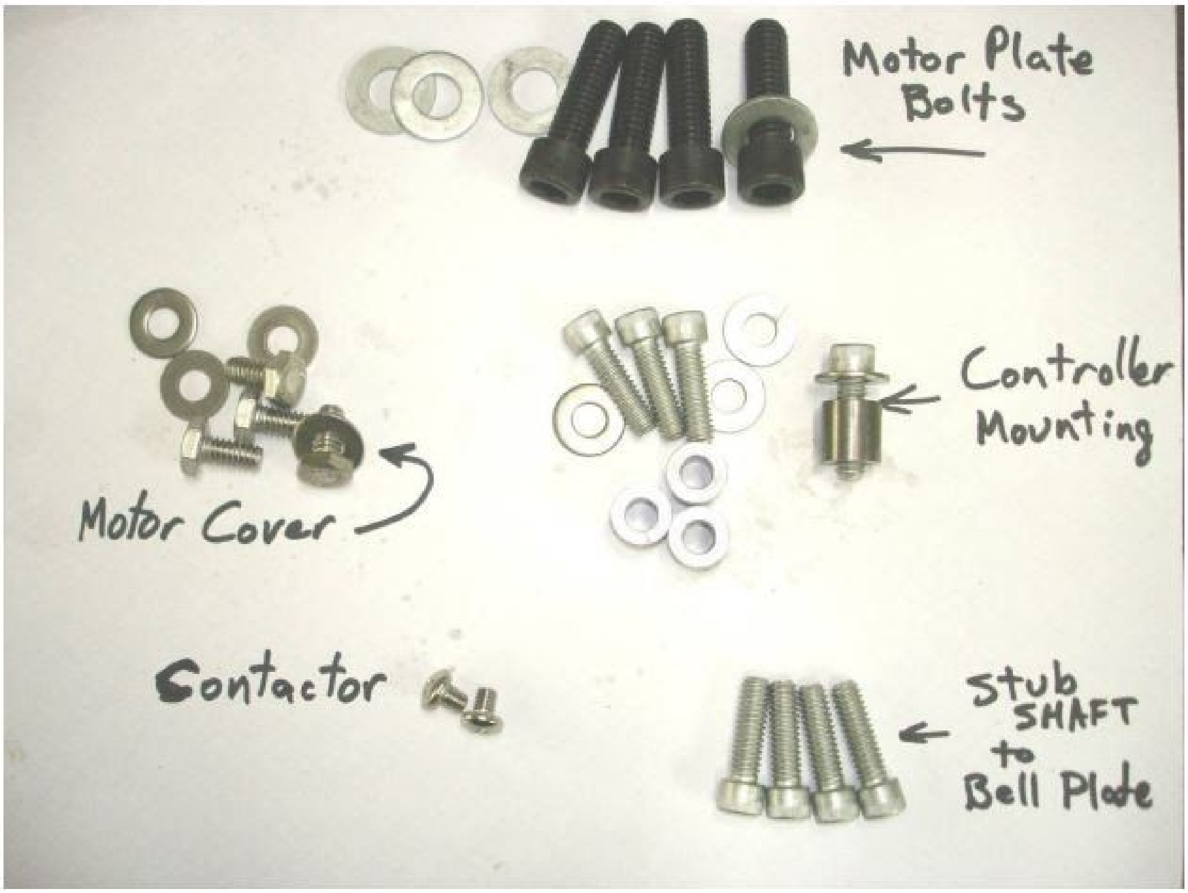
Step 6- Fit the key and Small Pulley with its Bushing onto the motor shaft and position the pulley so that the belt will clear the plate surface when tightened. Tighten the set screws together so the pulley stays straight and runs true.

Step 7- Put belt over pulleys and slide Motor Plate back to tension belt, then tighten one of the bolts. The belt should not deflect more than 1/8" with finger pressure applied at middle of span. If tension looks right tighten remaining bolts.

Step 8- Mount the Bell Housing Plate to the tractor. Sometimes it is helpful to put the gearbox in high gear and move the tractor back and forth to help align the splines.

Step 9- Grease two or three pumps into the pilot bearing.

Step 10- Mount the Contactor and Controller using the provided hardware and fasteners from the Fastener Bag.



**The Motor Cover only allows the wires to escape over the Bell Housing plate so allow length enough to go that direction. The reason for this is to keep water and battery gunk off the motor and from running down the wires onto the motor also.

*** It is a good idea to wrap the motor terminals with tape a few layers thick to keep them from ever shorting against the Motor Cover (In case it gets backed into badly).

Appendix F - General Battery Comparison

	Lithium Ion	Lead Acid Battery
Cost	$5,000 - $15,000	**$500 - $3,000**
Capacity	**High energy density (discharge more energy)**	Low energy density
Depth of Discharge	**80%**	50%
Efficiency	**~95% efficient (charge faster/more solar power can be stored)**	~80-85%
Lifespan	**Several lifespans**	One lifespan
Maintenance	**Little to no maintenance**	Requires maintenance
weight	~400 lbs.	**~1,000 lbs.**
Charge Rate	**Fast**	Not so fast
LCA	75-80% of material recyclable Incineration of waste generates electricity and produces a lot of emissions	80% material is recycled for other batteries Easy to recycle Very toxic

Appendix G - Sketch Up

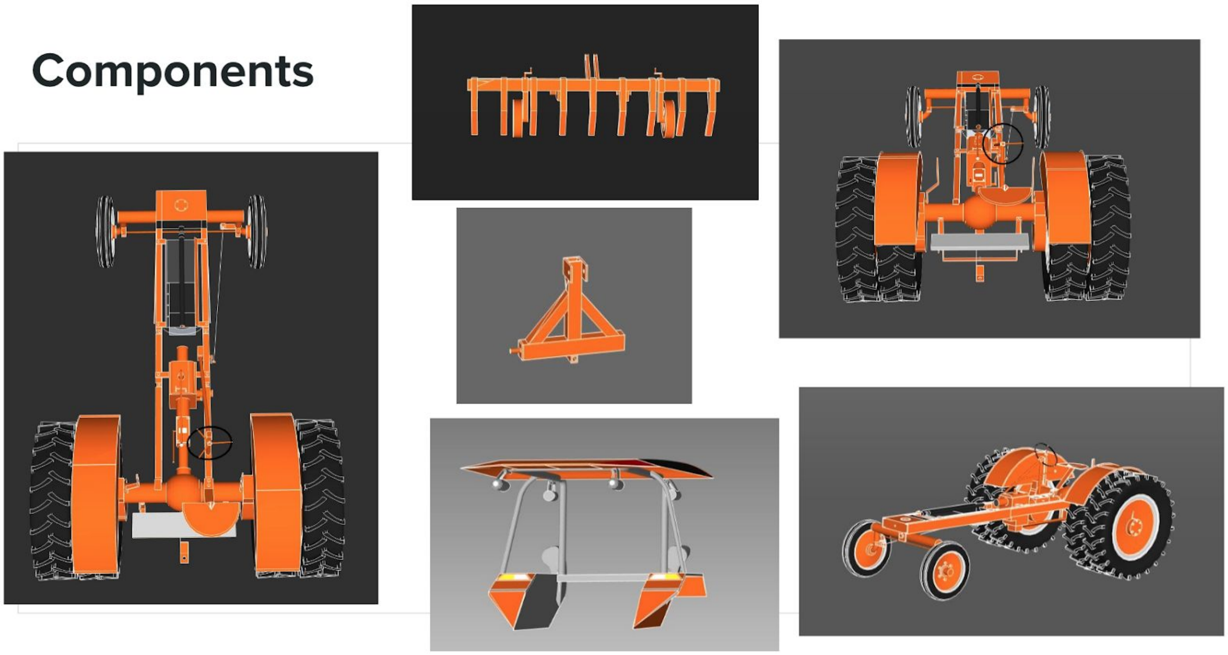


Fig 1: *Tractor components including a cultivator, three-point-hitch and a Roll Over Protection System and chassi*

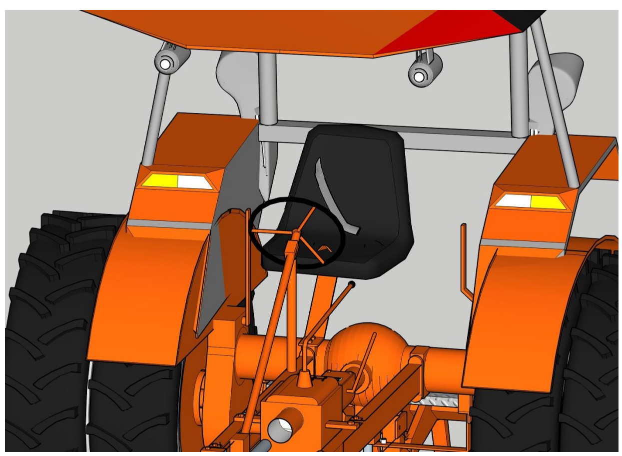


Fig 2: *Tractor seat - with seat belt for OSHA protection*

Appendix H - Student Training Survey

Electric Tractor Training Survey

Thank you for using the electric tractor to train today! We would love to learn about your experience on it as well as any feedback that could help us enhance the training!

Answer the following questions based on a scale of 1-10, with 1 being the least and 10 being the most suited to the question. Please feel free to add explanations as well.

1) How loud was the tractor, specifically how well were you able to hear your instructor?
2) How safe did you feel sitting in the tractor?
3) How comfortable do you feel riding other tractors on the farm?
4) Overall, how comfortable did you feel learning how to drive on this tractor?

Answer these questions based on your training experience!

1) Would you have chosen a different tractor to train on? Was this a good first tractor to drive?
2) Are there any additional elements you would like to have been trained on specific to other tractors on the farm?
3) What does sustainability mean to you? Do you feel that this tractor is an accurate representation of that definition?
4) Are there any changes you would make to the tractor or anything you would add to make it the ideal tractor to train students?