Low Carbon Transportation and Fuels Investment and Greenhouse Gas Reduction Fund Investments and the Air Quality Improvement Program Off-Road Advanced Technology Demonstration Project:

San Joaquin Valley Electric Tractor Development and Deployment

Final Report:

November 30, 2022

San Joaquin Valley Electric Tractor Development & Demonstration

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Acknowledgements

Project Clean Air (PCA), along with the Project Team expresses our appreciation to the California Air Resources Board (CARB) for the opportunity to apply to the Off-Road Advanced Technology Demonstration solicitation project in 2017. This project provided HummingbirdEV, PCA's technology partner, the opportunity to design/develop, manufacture, and demonstrate four 50 horsepower all-electric tractors and a Class 6 electric truck with Vehicle-to-Vehicle charging technology in San Joaquin Valley farms. Through this project, the project partners were able to prove that electric off-road vehicles, specifically electric tractors, can perform equally with conventionally fueled vehicles. This project has garnered excitement about electrical farming equipment, reduced harmful greenhouse gas emissions in a disadvantaged community, and educated users and large machine mechanics about the opportunities for electric vehicles and equipment in the agriculture industry sector. PCA and all project partners are sincerely appreciative of CARB's selection of the SJV Electric Tractor Development and Demonstration; without CARB funding this demonstration project would not have been possible.

Additionally, this project would not have been successful without the project partners, and more specifically, the individuals named here who worked directly over the course of this project:

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These organizations – non-profit, private businesses, and public university – with an array of specialties and expertise joined together based on their interest to demonstrate the advancement of this technology to reduce transportation and equipment emissions. In special acknowledgement, Ty Tavlan and Moonlight Companies dedicated an extraordinary amount of effort, through personal attention, and business resources, to see this project through. As the part-owner of Moonlight Companies, the primary demonstration site (see Figure 1), Ty made himself available for monthly calls and his employees available for deliveries, education, testing, maintenance, and minor repairs as well as the commitment to the installation of a transformer and solar field to provide capacity for the project. Ty and the Moonlight team were patient with the entire process and proved to be an invaluable partner in this project. Project Clean Air and HummingbirdEV are grateful to Ty Tavlan.

Figure 1: Two HummingbirdEV eTractors and eTruck parked at the demonstration site, Moonlight Farms, in Reedley, CA.

Preface

In 2007, the California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (AB 118, Statutes of 2007, Chapter 750) was signed into law. AB 118 created the Air Quality Improvement Plan (AQIP), a voluntary incentive program administered by the California Air Resources Board (CARB), to fund clean vehicle and equipment projects, air quality research, and workforce training. As required in Health and Safety Code (HSC) Section 44274(a), the Board adopted regulatory guidelines in 2009 for AQIP. The Guidelines for the AB 118 Air Quality Improvement Program (Guidelines) define the overall administrative requirements and policies and procedures for program implementation based on the framework established in statute. Central to the Guidelines is the requirement for a Board-approved annual funding plan developed with public input. The funding plan is each year's blueprint for expending AQIP funds appropriated to CARB in the annual State Budget. The funding plan focuses AQIP on supporting the development and deployment of the advanced technologies needed to meet California's longer-term, post-2020 air quality goals.

In 2012, the Legislature passed and Governor Brown signed into law three bills –AB 1532 (Pérez, Chapter 807), SB 535 (De León, Chapter 830), and SB 1018 (Budget and Fiscal Review Committee, Chapter 39) that established Green Gas Reduction Fund (GGRF) to receive Cap-and-Trade auction proceeds and to provide the framework for how the auction proceeds will be administered in furtherance of the purposes of AB 32, including supporting long-term, transformative efforts to improve public health and develop a clean energy economy. The suite of implementing legislation offers strong direction for investing a portion of the auction proceeds to benefit disadvantaged communities, including specific allocation requirements in SB 535.

In 2014, the Legislature appropriated $200 million in GGRF monies to establish a Low Carbon Transportation GGRF program that CARB is implementing in coordination with the AQIP AB 118 programs. In May of 2016, Governor Brown's proposed budget included $500 million in GGRF monies toward the Low Carbon Transportation program. Projects funded by the Low Carbon Transportation GGRF program must reduce GHG emissions and further the purposes of AB 32, with a strong emphasis on benefiting disadvantaged communities.

California Climate Investments began in 2013 and received guidance specifically for disadvantaged communities from the Legislature through Senate Bill (SB) 535 (2012). It set minimum investments for projects that benefit disadvantaged and low-income communities and projects that are located within disadvantaged communities.

In 2016, AB 1550 (2016) amended the investment minimums for disadvantaged communities created by SB 535 to require that a minimum percentage of projects be located within and provide a benefit to disadvantaged communities. AB 1550 also established new investment minimums for low-income communities and low-income households. To date, California

Climate Investments is meeting and exceeding these minimum levels while providing more than a half-million projects in communities statewide. CARB's April 2015 Sustainable Freight: Pathways to Zero and Near Zero Emissions discussion draft document details a long-term vision for transitioning the freight sector to near-zero and zero-emission and lists strategies for overcoming barriers to commercialization. The truck and bus commercial pilot projects funded under this Solicitation will support the Sustainable Freight document vision to overcome the technical and economic challenges with zero-emission technology advancement.

The Off-Road Advanced Technology Demonstration solicitation was funded through the Low Carbon Transportation Investments and the Air Quality Improvement Program. This program provided mobile source incentives to reduce greenhouse gas, criteria pollutant, and toxic air contaminant emissions through the deployment of advanced technology and clean transportation in the light-duty and heavy-duty sectors. Low Carbon Transportation Investments were supported by Cap-and-Trade Auction proceeds. The Air Quality Improvement Program (AQIP) was established by the California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (AB 118, Statutes of 2007, Chapter 750). Each year, the legislature appropriates funding to CARB for these incentives to reduce emissions and support advanced technology demonstrations and deployments.

The Advanced Technology Demonstration solicitation was posted in 2016 to fund pre-commercial demonstrations of advanced vehicles, engines, equipment, and transportation systems. These advanced technology projects are to demonstrate zero-emission or near zero-emission vehicles and equipment that use less petroleum and emit fewer GHG emissions. Project Clean Air was approached by HummingbirdEV and Moonlight Companies with an all-electric tractor and all-electric Class 6 truck concept. Project Clean Air, based in Bakersfield, and Moonlight Companies, based in Reedley – both in the central San Joaquin Valley – understand the amount of pollution that comes from the transportation cycle of the region’s largest economic driver: agriculture. Project Clean Air, and all project partners, were excited about the concept of designing an all-electric 50-horsepower tractor, which is a common tractor used for various tasks around a farm, to reduce emissions in the first 1-15 miles of the movement of agricultural products.

In response to our application submittal, CARB notified Project Clean Air the project was selected for funding on October 12, 2017. Project Clean Air and CARB executed the original grant agreement on April 30, 2018. The agreement was subsequently amended as follows:

Amendment #1 on February 27, 2020, and Amendment #2 on February 24, 2021.

Executive Summary

The intent of this project was for Project Clean Air, in partnership with HummingbirdEV as the technology provider, to develop, design, and deploy four 50 horsepower (HP) all-electric tractors. HummingbirdEV would deliver the first two eTractors to Moonlight Companies, with the remaining two delivered approximately six months later. HummingbirdEV would build an electric Class 6 truck for Moonlight Companies to replace the current diesel Class 6 truck. The diesel truck is used for operations, maintenance, and as a fueling truck. Moonlight has 35 different site operations that could be used as testing sites. Additionally, two other testing sites agreed to participate – Fresno State Ag Farm and Ranch Management. All 37 potential test sites are located within a disadvantaged community. Data collection would occur over a twelve-month period for the first pair of tractors and six months for the second pair. The Fresno State Transportation Institute would provide third-party data collection and analysis. A key component of this analysis would include the pairing of an electric tractor with a diesel tractor – the two would perform identical tasks to show true GHG and emission reductions (Table #1).

The original goals of the project included:

- Goal 1: Design, customize, develop, and test the first all-electric agriculture tractors with supporting electric Class 6 truck in California
- Goal 2: Demonstrate the functionality and GHG Emissions Reductions of the electric fleet (including eTractors and eTruck)
- Goal 3: Create a market for electric agriculture and freight equipment

Table #1: Emission Reductions Projected and Actual

Expected Emission Reductions	Actual Emission Reductions
NOx: 0.1344 tons/year (0.0336 per eTractor)	NOx: 0.09 tons/year (0.0225 per eTractor)
GHG: 24 Metric Tons/year (6.0 per eTractor)	GHG: 68 Metric Tons/year (17 per eTractor)
NOx: 0.151 tons/year (eTruck)	NOx: 0.05 tons/year (eTruck)
GHG: 21.1 Metric Tons/year (eTruck)	GHG: 53 Metric Tons/year (eTruck)

Funding:

Amount Requested: $1,500,000
Amount Awarded: $1,500,000
Awarded to HBEV: $1,340,000
Match Projected: $ 830,766
Match in Agreement: $ 792,054
Match Actual: $1,157,441

Project Outcomes:

All project deliverables – four eTractors and one Class 6 eTruck – were successfully delivered to Moonlight Companies. Additionally, the Procedural Manual and Marketing Materials were successfully delivered to Moonlight Companies and the California Air Resources Board. Project data was collected for a minimum of 12 months, and quarterly reports were provided to Project Clean Air. Project Clean Air hosted monthly meetings with the Project Team and the CARB Project Manager, and successfully submitted reports and invoices to CARB as well as prepared two contract amendments for time extensions in response to the COVID-19 Global Pandemic.

All project goals and deliverables as stated in the original grant application were successfully delivered. The stated goals and objectives were as follows:

Goal 1: Design, customize, develop, and test the first all-electric agriculture tractors with supporting electric Class 6 truck in California

> Objective 1: Work with end-users to design an electric 50 HP tractor prototype to meet the needs of the growers
>
> Objective 2: Manufacture and deploy two eTractors by March 2019
>
> Objective 3: Design, manufacture and deploy one 97 kW electric Class 6 truck with vehicle-to-vehicle technology to be used with, and in support of, the eTractors
>
> Objective 4: Manufacture and deploy two eTractors by October 2019

Goal 2: Demonstrate the functionality and GHG Emissions Reductions of the electric fleet (including eTractors and eTruck)

> Objective 1: Test eTractors in multiple locations and for multiple applications; testing run-time and payload with varying temperatures, terrain, battery life, truck re-charging capabilities
>
> Objective 2: Create data log, with continuous observation, of eTractor and diesel tractor performing the same tasks
>
> Objective 3: Determine level of GHG reduction in the “First 5-15 miles” of freight movement

Goal 3: Create a market for electric agriculture and freight equipment

> Objective 1: Attend Ag shows with eTractor to garner interest, show usage and successes, and display viability to the industry
>
> Objective 2: Utilize resources, to the greatest extent possible, to reduce the cost of the eTractors

Objective 3: Work with US EPA and CARB to meet the standards for the eventual commercialization of the eTractors

HummingbirdEV (HBEV) did meet the goals and objectives during the development period, however, there were challenges during the demonstration period with the demonstration site and end-users. HummingbirdEV worked directly with Moonlight Companies to develop an eTractor that the end-user could use in conjunction with their existing diesel tractors. Q1-2019 HummingbirdEV received the first mule tractor Chassis from the OEM, however the engineers decided that there were issues with the mule tractor that required a near-complete redesign of the chassis. This issue, along with sourcing the components impacted the delivery of the first and second eTractor; which were deployed to Moonlight Companies in May 2020. Due to complications with the original chassis design, the China-United States Trade War, and the Coronavirus pandemic, eTractor #3 was deployed in July 2020 and eTractor #4 was deployed February 2021. The eTruck was deployed with vehicle-to-vehicle technology on-board.

Actual Emission Reductions:

The Fresno State Transportation Institute, the third-party data collector for this project, determined the optimal approach to provide emission results was through computing a neutral scenario, an optimistic scenario, and a pessimistic scenario for both state and national deployment. The annual emission reductions through this project are shown in Table 2.

Table 2: Estimated Well-to-Wheel (WTW) Annual Emissions Savings in Tons (assuming Conversion of All <40 HP Agricultural Tractors to Electric)

Scenario / Criteria	State			National		
	Pessimistic	Neutral	Optimistic	Pessimistic	Neutral	Optimistic
WTW GHG* savings (tons)	5219.3	6959.0	8698.8	156578.1	208770.8	260963.5
WTW PM2.5* savings (tons)	1.6	2.1	2.6	47.4	63.2	79.0
WTW PM10* savings (tons)	3.4	4.6	5.7	103.3	137.7	172.1
WTW NOx* savings (tons)	259.6	346.1	432.6	7786.6	10382.1	12977.6
WTW CO* savings (tons)	98.2	130.9	163.6	2945.4	3927.1	4908.9
WTW VOC* savings (tons)	33.0	44.0	55.0	990.3	1320.3	1650.4
WTW Sox* savings (tons)	-156.6	-208.8	-261.0	-4697.3	-6263.1	-7828.9

Please see *Appendix A* for a detailed description of the approach to this table and further explanation.

* Acronyms listed on Page 12 ,

When Fresno State Transportation Institute completed the Well-to-Wheel computations based on CARB's (Appendix E) Methodology, they found:

- eTractor GHG Emissions (over 2 year period): 17 metric tons CO2e/year
- eTractor Cost Effectiveness (over 10 year period): $490/metric ton reduced
- eTruck GHG Emissions (over 2 year period): 53 metric tons CO2e/year
- eTruck Cost Effectiveness (over 10 year period): $230/metric ton reduced

Full calculations can be found within *Appendix A.*

Project Timeline:

Throughout the life of this project, the Project Team faced two unprecedented hardships: the China-United States Trade War beginning in 2018 and the global Coronavirus (COVID-19) Pandemic and subsequent economic shutdown; which together, pushed this project back a full two years. The China-United States Trade War had a significant impact on this project because HummingbirdEV's chassis supplier is in China. The tariffs increased the cost of the chassis and delayed delivery. This caused a 12-month delay. As HummingbirdEV navigated through the supply-chain changes, the Coronavirus Pandemic hit and governments across the globe mandated lockdowns and quarantines, which impeded the movement of goods. This was followed by record-high unemployment, employees out due to exposure to – or illness from – COVID-19, and significant supply-chain issues on all goods. Supply-chain disruption on manufactured goods started during the China-United States Trade War and became worse through the Pandemic. Even the ability to test drive vehicles on local roads and acquiring vehicle registrations were affected. The mandates in California kept HummingbirdEV employees at home and away from the office and manufacturing plant. These two events caused a two-year delay in the project by impeding HummingbirdEV's ability to obtain the material required to build the eTractors. Additionally, the delayed project timeline led to staff turnover with the various partners.

Despite these setbacks, the Project Team attended events to showcase the eTractor and Vehicle-to-Vehicle technology. The project was highlighted by two publications: MotorWeek and Small Farms Canada. *(See Appendix C)*

Lessons Learned:

There were several "Lessons Learned" during this project including technical engineering lessons and end-user lessons. The technical engineering lessons were caused by using a standard-sized chassis. The electrical components would not fit properly, leading to a design change early in development, and the realization by the end of the project that the best solution in the future is to design and manufacture the chassis from the ground up. (See Figure 2) While the end-user was great to work with and extremely accommodating, it was a challenge to encourage the day-

to-day user to drive and use the equipment as it was designed and intended, which was also impacted by schedule delays. Due to the nature of farming, if work in the fields was not needed, the tractors were switched to alternate uses at the packing sheds, for instance, which places a different demand on the vehicle for towing weight at an incline. Electric farming - or agricultural - equipment will require identification of the full duty cycle and ample daily-user education before it will reach commercialization. Further, access to charging stations and infrastructure to charge the eTruck is a challenge that will be difficult to overcome.

Project Take-Aways:

1. Electric tractors can function in a similar and equal capacity as diesel tractors
2. Infrastructure is a challenge and expensive
3. Additional data collection, education, and incentives will be required to move this project to commercialization.

Figure #2: HummingbirdEV's eTruck and eTractor at the HummingbirdEV Facility in Livermore, CA.

Acronyms

2c	Twice as Fast
AQIP	Air Quality Improvement Program
AC	Alternate Current
BMS	Battery Management System
Cal/EPA	California Environmental Protection Agency
CARB	California Resources Air Board
CAN	Controller Air Network
CO2e	Carbon Dioxide equivalent
CORE	Clean Off-Road Equipment
CSUF	California State University, Fresno
DAC	Disadvantaged Community
DC	Direct Current
DVT	Design Validation Testing
ESS	Energy Storage System
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment (Chargers)
EVT	Engineering Validation Testing
FSTI	Fresno State Transit Institution
FTA	Federal Transit Authority
GGRF	Greenhouse Gas Reduction Fund
GHG	Greenhouse Gas
GVWR	Gross Vehicle Weight Rating
HBEV	Hummingbird EV
HP	Horsepower
kW	Kilowatt
kWh	Kilowatt Hour
Lbs.	Pounds
MPH	Miles Per Hours
m/sec^2	1 meter per second squared
MT	Metric Ton
Nm	Newton Meters
NOx	Nitric Oxide
OEM	Original Equipment Manufacturer
PBS	Public Broadcasting System

PCA	Project Clean Air
PG&E	Pacific Gas and Electric Company
PTO	Power Take-Off
PVT	Production Validation Testing
RPM	Revolutions Per Minute
SDP	Software Driven Powertrain
SOC	State of Charge
SOx	Sulfur Oxide
SJV	San Joaquin Valley
TTW	Tank-To-Wheel
V	Voltage
V2V	Vehicle-to-Vehicle
WTT	Well-to-Tank
WTW	Well-to-Wheel

Project Background

Project Clean Air, Inc. partnered with HummingbirdEV, Moonlight Companies, Fresno State Transportation Institute, Fresno State Ag Farm, Ranch Management, and Kings River Tractor to create the San Joaquin Valley Development and Demonstration project. During this project, four zero-emission, all-electric battery 50 HP tractors, and one zero-emission, all-electric battery Class 6 truck were delivered to the main demonstration site, Moonlight Companies in Reedley, California.

The Project Goals include:

1. Design, customize, develop, and test the first all-electric agriculture tractors with supporting electric Class 6 truck in California

2. Demonstrate the functionality and GHG Emissions Reductions of the electric fleet (including eTractors and eTruck)

3. Create a market for electric agriculture and freight equipment

The Demonstrated Technologies include the electrification of off-road agriculture equipment; specifically 50 HP eTractors (4 total) and a Class 6 medium-duty eTruck. The eTruck is a vital component of the project - the eTruck serves as a mobile recharge to the eTractors on location in the fields and can provide routine cargo service to Moonlight Company as needed and as availability allows.

The central San Joaquin Valley is a prime location for an eTractor deployment – fixed-route project, wide range socioeconomics, and the availability of, and access to, recharging/fueling stations for zero-emission vehicles. Further, the air quality across the project area is among the worse in the nation. Of the 277 metropolitan areas in the country, the American Lung Association's State of the Air 2012 ranked the Fresno-Madera Area in the top five most polluted cities for all three indicators of high ozone days, 24-hour particulate pollution, and annual particulate pollution. Fresno and Tulare Counties received a grade of "F" for air quality. (Article Appalachia West) Over the course of a year, these eTractors and eTruck will operate 100 percent of the time within a Disadvantaged Community based on CalEnviroScreen 2.0.

Implementation

Primary Technical Responsibilities:
As the technology partner on this project, HummingbirdEV performed the following tasks:

- Researched and developed an all-electric tractor that fits the needs and uses of Moonlight Companies and other demonstration sites.
- Manufactured and delivered four electric tractors and one all-electric Class 6 Truck (intended for freight transportation and charging tractors V2V).
- Provided technical consulting, training, and administrative services related to the acquisition and management of the electric tractor fleet; and
- Participate with the Applicant and other Project Partners in the application of zero-emission technology and commercialization of advanced alternative energy deployment.

Intended Vehicle Application
Moonlight Companies, based in Reedley, is a major Stone Fruit Grower in the United States with nearly 5,000 acres producing Peaches, Plums, Nectarines, and Cherries. They also produce oranges and pomegranates, making this a 12-month operation. Moonlight Companies has thirty-five properties, spanning three Counties – Fresno, Tulare, and Kings. They own forty-six, 30-50 HP range diesel tractors and rent an additional eighteen during peak season. Their fleet also includes eight, Class 5 – 8 trucks.

Recognizing the potential to change their carbon footprint – Moonlight partnered with HummingbirdEV to test and demonstrate the first all-electric, zero-emission tractors and an advanced all-electric Class 6 transport truck with the capacity to charge the tractors in the field.

The diesel ag tractors are an integral part of the initial transfer of the fruit delivery. The tractors operate, on average, six days per week up to eight hours per day and work in the fields in start/stop operations. When tractors are used for harvesting – typically 4-6 months a year – it is estimated that the tractors are restarted as many as 50 times per day as they move through the field, producing additional criteria pollutant emissions every time the engine is restarted. Alternatively, when tractors are used for various applications throughout the year for tree staking, pruning, and weed spraying, the tractor continuously operates and moves at a slow pace (approximately five mph). These tractors run 300-400 hours annually.

Traditionally, tractors are delivered to orchards where they are left for weeks and fueled by a truck with a 100-gallon diesel tank attached to the truck bed. For this project, HummingbirdEV designed one 88 kWh electric truck with Vehicle-to-Vehicle (V2V) technology, equivalent to a Class 6/ 26,000 pound Gross Vehicle Weight Rating (GVWR) M2 Series with a Freightliner chassis, to directly support the four 50 HP eTractors. The primary purpose of the electric truck is

to recharge the electric tractors in the field, replacing the existing diesel fuel truck. The eTruck could also serve as a mobile service unit to transport eTractors, haul totes/bins, pull trailers or carry tires or compressors. This electric truck would replace a 2005 Class 6 diesel truck, which averages 20,000 miles annually along a fixed route at Moonlight Companies during the demonstration.

Electric Tractor Technical Baseline Comparison

The four baseline diesel tractors replaced by the eTractors were manufactured by New Holland between 2001 and 2007 (two in 2001 and one each in 2002 and 2007). They are powered by a 30 HP 3-cylinder diesel engine manufactured by Shibaura. Production of this tractor ceased in 2008. The next-generation replacement tractor (New Holland Workmaster 50) is very similar in all regards but with slightly more horsepower. The demonstration tractors are all-electric battery-operated built by HummingbirdEV and are similar in size and power to the baseline diesel tractors selected to work alongside the eTractor during the demonstration for comparison. Table 3 is a well-wheel comparison between the four baseline diesel tractors and the comparable sized eTractor. Table 4 (page 17) shows the eTractor Vehicle Specifications.

Table 3: Well-to-wheel (WTW) greenhouse gas (GHG) and air pollution emissions [7, 8]

Value	Diesel	BEV
WTT GHG emissions	27.8 gCO2/mile	186 gCO2-eq/mile
TTW GHG emissions	176.7 gCO2/mile	0 gCO2-eq/mile
WTW GHG emissions	**204.5 gCO2/mile**	**186.0 gCO2-eq/mile**
WTT PM2.5 emissions	0.0315 g/mile	0.0326 g/mile
TTW PM2.5 emissions	0.0068 g/mile	0 g/mile
WTW PM2.5 emissions	**0.0382 g/mile**	**0.0326 g/mile**
WTT PM10 emissions	0.0650 g/mile	0.0326 g/mile
TTW PM10 emissions	0.0087 g/mile	0 g/mile
WTW PM10 emissions	**0.0737 g/mile**	**0.0615 g/mile**
WTT NOx emissions	0.24 g/mile	0.26 g/mile
TTW NOx emissions	0.94 g/mile	0 g/mile
WTW NOx emissions	**1.18 g/mile**	**0.26 g/mile**
WTT CO emissions	0.116 g/mile	0.14 g/mile
TTW CO emissions	0.372 g/mile	0 g/mile
WTW CO emissions	**0.488 g/mile**	**0.14 g/mile**
WTT VOC emissions	0.069 g/mile	0.045 g/mile
TTW VOC emissions	0.093 g/mile	0 g/mile
WTW VOC emissions	**0.162 g/mile**	**0.045 g/mile**
WTT SOx emissions	0.095 g/mile	0.650 g/mile
TTW SOx emissions	0 g/mile	0 g/mile
WTW SOx emissions	**0.095 g/mile**	**0.650 g/mile**

Table 4: Specifications of HummingbirdEV's all-electric Tractor

eTractor Vehicle Specifications	
Key Specifications	
Type	Battery Electric
GVW	≈5400 lbs.
Chassis	2 Wheel Drive & 4 Wheel Drive
Wheelbase	72"
Trailer Towing Capacity	12,000 lbs.
Max Vehicle Speed	15 mph
Average run time	Up to 10 hrs. depending on use case
Rate RPM	2200
Acceleration (0-60 mph)	1.2 m/sec^2
Rated Mechanical Torque	200 Nm
Horsepower	50 HP
Low Voltage Battery	12V
Powertrain Cooling	Liquid (10lpm)
Dimensions	
Height	58" is high point to the steering (4.8 ft)
Width	62" tire to tire (5.16 ft)
Length	132" (11 ft)
Step Height	16"
Weight – To be confirmed -	5,600 lbs. approx. with batteries (5,400 lbs. without batteries)
Tires	Front 7.0-12 R-1 & Rear 11.2-20 R-1
Battery Specifications	
Type	Lithium-Ion Ferrous Phosphate
Battery Capacity/Usable	24.6KWh
Nominal Voltage	307V
Max Voltage	350V

Motor Specifications	
Motor Type	AC Permanent Magnet
Continuous Rated Power	40 KW
Peak Power	60 KW
Max Torque	200 Nm
Transmission Specifications	
Type	Manual Clutch; Shift at zero speed
PTO	2 speeds @ 540 & 1000 rpm
Number of Gears	12 gear combinations
Charger Specifications	
Type	12 KW Onboard Fast AC Charger
Configuration	208/480Vac, 3-phase US only
Charging Time	2 Hour on AC
Max Current	50 Arms

Electric Truck Technical Baseline Comparison:

This project included the deployment of an all-electric class 6 truck to provide service and recharging to the demonstration eTractors in the field and to deliver produce from the field to the packaging plant. This eTruck replaced a 2005 class 6 diesel truck (M2 Freightliner) that averages approximately 20,000 miles annually along a short, fixed route. The end-user, Moonlight Companies, installed additional charging infrastructure to charge the eTruck, and the onboard battery packs used to recharge the eTractors in the field. We believe this is the first fully integrated agricultural electrification demonstration that eliminates petroleum use from the field to the packaging plant.

Scope of Work:

In the alpha prototype phase, HummingbirdEV's engineering team was involved in the following high-level tasks:

- Custom design of HummingbirdEV's current battery pack and Battery Management System (BMS)
- Mechanical and Electrical redesign of application-specific High voltage power distribution unit

- Powertrain analysis based on chassis selection which depends on GVW
- Motor characterization using in-house dyno system and Inverter calibration
- Complete schematic build
- Design mountings for Mechanical integration of all powertrain components on the frame
- Software enhancements and updates to Inverter and vehicle integration logic

HummingbirdEV's proposed charging solution to facilitate the charging of the off-road electric agriculture tractors in any location and at any time, using a single source mobile mega-battery pack was incorporated into this project. As shown below in Figure #3, the battery pack is housed in a medium-duty truck to serve as a mobile charging station, driven to specific locations on the farm to allow for Vehicle-to-Vehicle charging of multiple electric tractors. This provided a unique opportunity for HummingbirdEV to charge multiple battery packs in tractors at different voltages from a single battery pack source in the medium-duty truck.

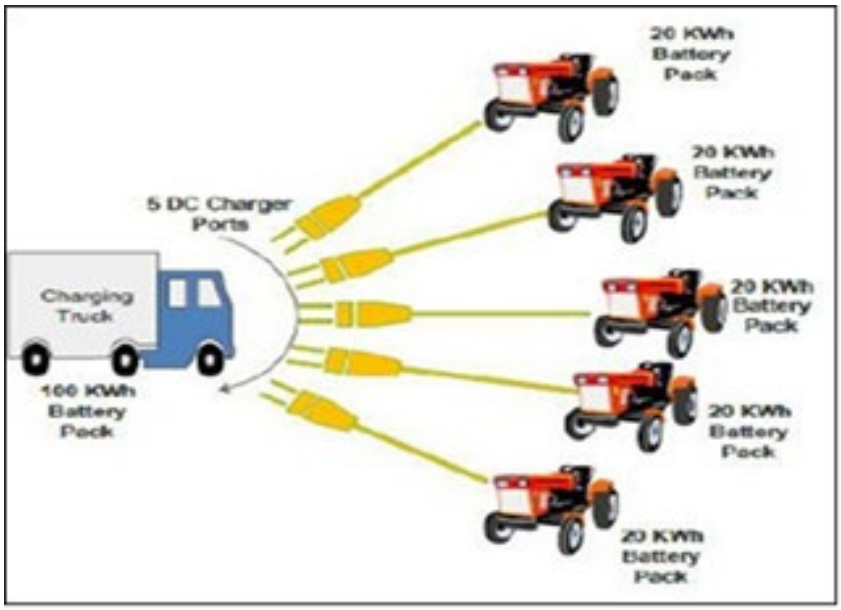


Figure #3: Graphic of concept HummingbirdEV all-electric class 6 truck with capability to charge multiple all-electric tractors simultaneously.

While the primary responsibility of the medium duty truck was to charge the tractors (Vehicle-to-Vehicle charging), it was also engineered for transportation as an on-road vehicle. Table 5 (page 20) details all specifications of the eTruck.

Table 5: Specifications of the HummingbirdEV all-electric class 6 truck

	DETAILS
GVWR	26,000 LBS
SPEED	MAX 60 MPH
RANGE	90 MILES
TRACTION POWER	200 kW PEAK AND 120 CONTINUOUS
BATTERY PACK CAPACITY	88 kWh
CHARGING POWER	UP TO 40 KW, LEVEL 2 AC CHARGING
MAX CHARGING TIME	2 HRS TO 80% SOC (DEPENDING ON GRID VOLTAGE & CURRENT)
V2V SYSTEM	UP TO 30 KW PER SIDE (2 SIDES) ABLE TO CHARGE ON BOTH SIDES AT THE SAME TIME
TRUCK WEIGHT – (For our reference)	Truck without bed – 10,980 lbs. Front axle: 6,020 lbs. Rear axle: 4,940 lbs.

Vehicle-to-Vehicle Charging:
The Vehicle-to-Vehicle (V2V) charging capabilities functioned as intended (see Table 6 below) as proven through multiple factory tests. The V2V technology was not used by the end-user during the demonstration period; this is discussed in greater detail on pages 24-25.

Table 6: HummingbirdEV V2V Charging Specifications

Specs	Tractor	Vehicle-To-Vehicle Charging Truck
Horsepower	65 HP	750 HP
Motor	120kw Peak/70kw Cont.	400KW
Battery Size	25 kwh	88 kwh
Charging Time (20% to 80%)	1 hour	90-120 minutes
Batteries	Lithium Ion	Lithium Ion
PTO	Included	Included
Designed and Assembled	USA	USA
Emissions	None	None

Deployment

eTractor#1

Once the design met end-user specifications, HummingbirdEV went into the development phase primarily focused on working with the Chassis Original Equipment Manufacturer (OEM).

- During Q1-2019 HummingbirdEV received the first mule tractor Chassis from the OEM
- Upon looking at the design and working with the end-user, the engineers decided that HummingbirdEV would need to a near-complete redesign on the chassis before implementing the Electric Power Train into the vehicle. Below are some high-level key reasons for the decision:
    1. To meet end-user specifications and needs.
    2. Chassis height turned out to be about 12" higher than expected because of the framework for the higher HP.
    3. Chassis width turned out to be about 4" wider than expected because of the framework for the higher HP.

Another major issue was sourcing the cell that fits the 2c (twice as fast) charging rating requirements for the eTractor to meet the expectations of the end-users. Based on lessons learned from the first mule tractor, HummingbirdEV engineers went back to the drawing board and worked with the OEM to resolve the identified issues. HummingbirdEV also had a new battery supplier in place able to handle up to 2c charge current.

HummingbirdEV received the redesigned chassis and completed the final modifications, which included the Powertrain and Battery packaging. eTractor#1 and #2 were intended to be the prototypes, and HummingbirdEV anticipated complications. What was not expected were the delays and constant interruptions due to the Coronavirus Pandemic. eTractor#1 was delivered to Moonlight Farms in May 2020.

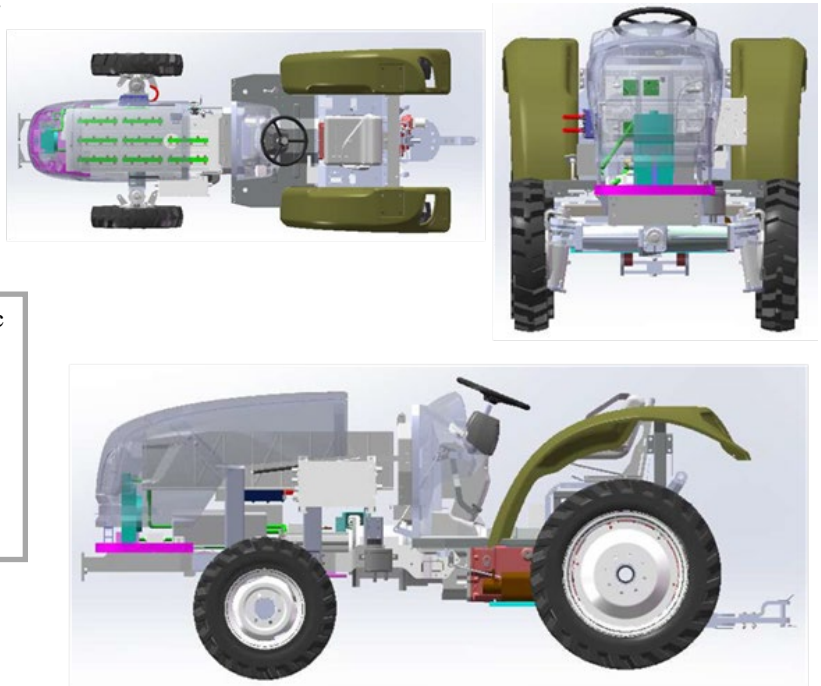


Figure #4: HummingbirdEV graphic design of eTractor#1. Top Left graphic is looking down into the eTractor. Top Right graphic is looking at the front of the eTractor. Bottom graphic is looking at the driver's side of the eTractor.

During Q1-2020 the eTractor#1 and eTruck were showcased for the first time at the World Ag Expo in Tulare, California.

eTractor#2

Before the delivery of eTractor#2, HummingbirdEV addressed and resolved the issues found in eTractor#1.

- CAN (Controller Area Network) communication faults were found to be caused by the tight space within the internal design of the unit. This was causing problems with the low voltage and high voltage wiring.
- Improper greasing from the chassis supplier resulted in damaged gearboxes coming from the chassis OEM
- Thermal had been poor, especially during charge sessions to enable fast charge

These issues were re-engineered and redesigned and adapted for eTractor#2 (see Figure #5) eTractor #1, eTractor #2, and two charging stations were delivered to Moonlight Farms in May 2020.

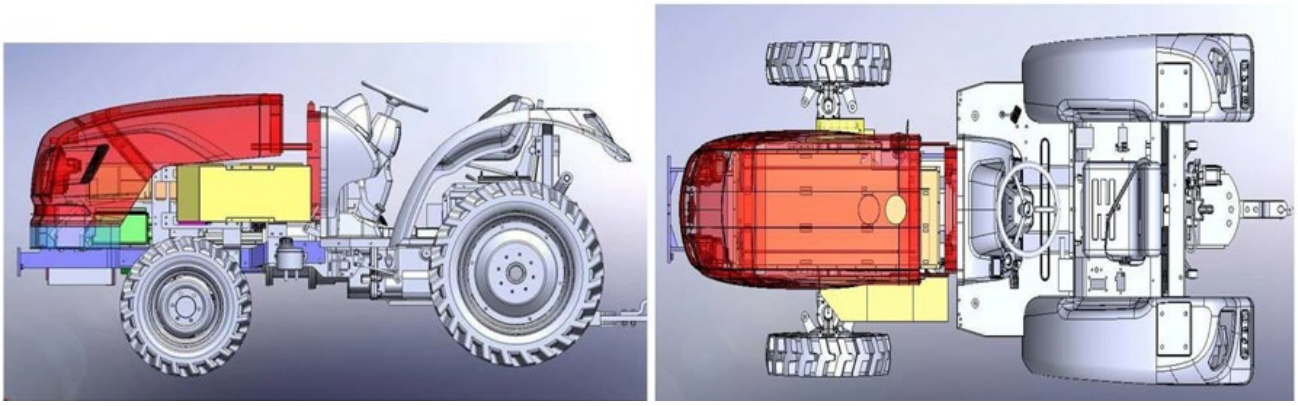


Figure #5: Graphic of HummingbirdEV redesigned eTractor. Left graphic is looking at driver's side of eTractor. Right Graphic is looking down into eTractor.

eTractors #3 & #4

With all engineering and design issues addressed, the production and deployment of eTractor#3 and eTractor#4 went smooth with minimal engineering involvement. eTractor#3 deployed to Moonlight Farms in July 2020, and eTractor#4 deployed in February 2021.

The eTractors were transported via flatbed truck between HummingbirdEV in Livermore, CA and Moonlight Farms in Reedley, CA. The same method was used to transport the eTractors to the World Ag Expo in Tulare, CA. (See Figure 6 below)

Figure #6: HummingbirdEV eTractors being delivered to demonstration site, Moonlight Farms, in Reedley, CA.

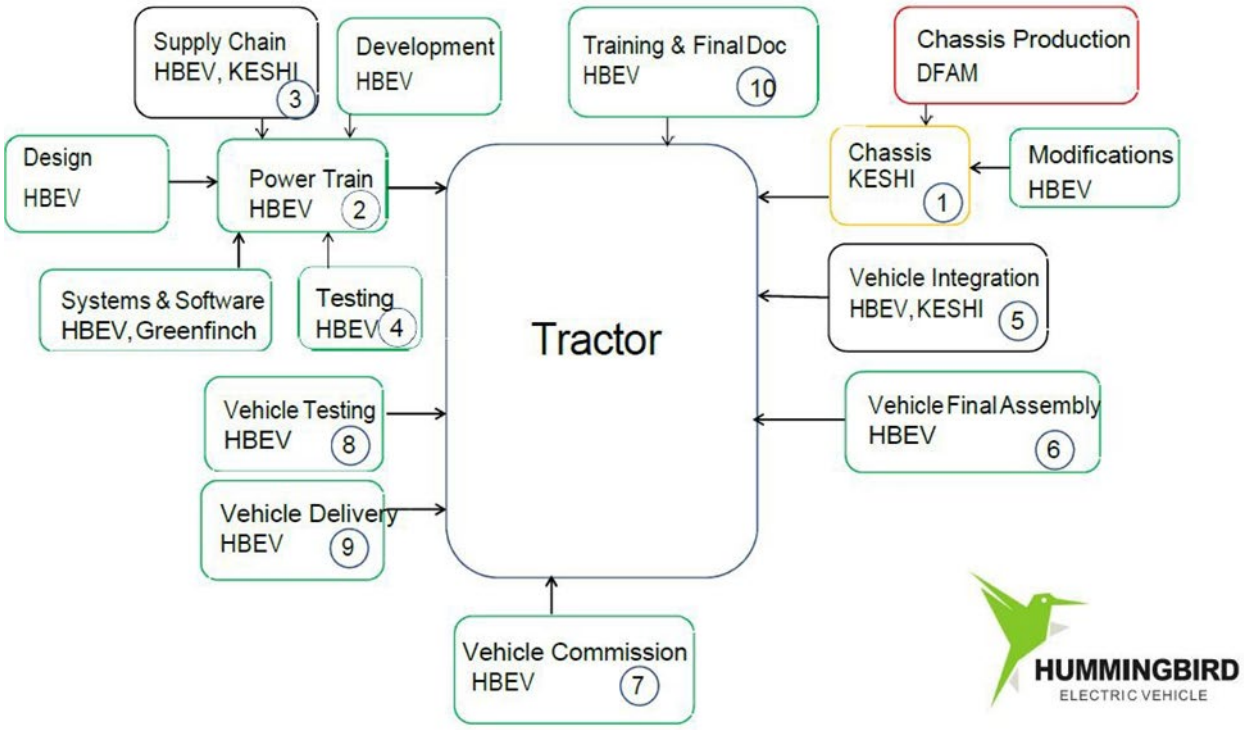
eTruck

The eTruck was built based on the specifications provided in Table 5 (page 20) and deployed to Moonlight Farms in February 2021. However, due to grid limitations at the demonstration site, the eTruck was not put into service until May 2021. The end-user installed a flatbed on the eTruck which was used to move fruit from the warehouse to the packaging centers (Figure 7).

Figure #7: HummingbirdEV eTruck with End-User installed flatbed to move pallets of fruit at demonstration site, Moonlight Farms, in Reedley, CA.

Supply Chain:
The Supply Chain was developed and modified as the project progressed. This was also shared as part of Task deliverables as per Figure #8 below.

Figure #8: HummingbirdEV Supply Chain



Additional Demonstration Sites:
The intent of this project was for the eTractors to deploy to multiple sites owned by Moonlight Farms, the Fresno State Farm, and Ranch Management located in western Fresno County. The eTractors were not deployed to all of these locations during the demonstration phase because of the project delays, Coronavirus lockdowns did not allow for HummingbirdEV to transport and deliver the eTractors multiple locations, and the near-complete redesign of the equipment. HummingbirdEV has found other locations within California to test the eTractors with different implements and environments. As of October 2021, all four eTractors were returned to HummingbirdEV from Moonlight Farms for the eTractors to deploy and be demonstrated at locations post-grant period. These sites include:

1. Cheese and Vineyards in Farms, Modesto, CA
2. Ranch, Livingston, CA
3. Vineyards around East Bay area and Sonoma in California
4. Lavender Farm, near the California/Oregon border
5. Farm, Atwater, CA

Issues, Challenges & Lessons Learned:

Intended Vehicle Application:

Moonlight Companies, based in Reedley, is a major Stone Fruit Grower with nearly 5,000 acres producing peaches, plums, nectarines, cherries, oranges, and pomegranates, making this a 12-month operation. The majority of their properties are in a driving distance of about 10 miles from their base. They own 46, 30-50 HP range diesel tractors and rent an additional 18 during peak season not including their truck fleet.

Recognizing the potential to change their carbon footprint – Moonlight partnered with HummingbirdEV to test and demonstrate the first all-electric, zero-emission tractors and an advanced all-electric Class 6 transport truck with capacity to charge the tractors in the field.

The primary goal and intent of the project was to replace four diesel agriculture tractors with four electric agriculture tractors to showcase first mile fruit delivery (tree to warehouse). The diesel tractors operate, on average, six days per week up to eight hours per day and working in the fields in start/stop operations. When tractors are used for harvesting – typically 4-6 months a year – it was estimated that these tractors are restarted as many as 50 times per day as they move through the field, producing additional criteria pollutant emissions every time the engine is restarted.

Tractors are delivered to orchards, where they are left for weeks at a time and are fueled by a truck with a 100-gallon diesel tank attached to the truck bed. For this project, HummingbirdEV designed one 88 kWh electric truck with Vehicle-to-Vehicle (V2V) technology, equivalent to a Class 6/ 26,000 GVWR M2 Series with a Freightliner chassis, to directly support the four 50 HP eTractors and to carry on other operational work during the day.

Technical conclusions:
HummingbirdEV's proposed and approved application was set to design, build, test and deliver tractors that would:

a) Run up to 12 hours between charge sessions as per duty cycle requirements to carry fruit from the field using 25 Kwh battery pack
b) Work with an OEM to modify a conventional 50 HP chassis platform to accommodate the placement of the battery pack under the hood and to meet the lane width and step height requirements of Moonlight Farms for the vehicles to travel within tree lanes in the field
c) Provide the end-user with multiple and flexible charging solutions by helping them with conventional HummingbirdEV provided charging stations and a unique V2V charging truck which can drive to the eTractors and charge them

(Note: Detailed tractor specifications can be found on pages 16 and 17, eTruck specifications on page 19.)

Technical challenges:

HummingbirdEV originally proposed to develop a charging solution to facilitate the charging of the off-road electric agricultural tractors anywhere and at any time, using a single source mobile mega-battery pack. As shown in the graphic on page 18, the battery pack is housed in a medium-duty truck that can be driven to specific locations on the farm to allow for vehicle-to-vehicle (V2V) charging of multiple electric tractors. The V2V process involves a unique strategy by HummingbirdEV to charge multiple battery packs in electric tractors at different voltages from a single battery pack source in the medium-duty truck.

The prototype eTractor had unforeseen engineering complications. The Engineering Lessons Learned were recognized early in the deployment of the eTractors and were mainly due to using a standard chassis. The HummingbirdEV Engineering team now realizes they need to design, engineer, and build the entire tractor from the ground up to ensure the components fit property.

Technical Lessons Learned #1

The initial concept was to use a standard-size tractor chassis and adjust it to fit HummingbirdEV components. The standard chassis conventional gearbox has twenty-four gear mechanics, rather than four in an electric vehicle gearbox. The abundance of gears would essentially kill the efficiency of the eTractor. The system would overheat, and the battery would drain quickly. The HummingbirdEV team could not remove or adjust the gearbox because it was attached to the chassis.

Technical Lessons Learned #2

The chassis length was a hindrance. The HummingbirdEV team was not able to scale up the size of the battery packs because the chassis did not provide enough space.

Technical Lessons Learned #3

PTO motor is tied to the gearbox and is inefficient for an electric chassis.

HummingbirdEV learned the only way to scale the product to a commercialization level is to work on a chassis level-up design by building a skateboard architecture from the ground up thus limiting the use of conventional mechanical driven systems such as gearbox, thermal, and PTO units.

Users:
HummingbirdEV's main goal at the onset of the project was to provide eTractors and an eTruck that would meet the requirements of the end-user and learn from 12 months of data collection to help HummingbirdEV develop the next generation of production-ready and commercially viable tractors to market.

Meetings and discussions regarding the concept of the all-electric tractor started with Moonlight Companies long before the original grant application was submitted. Moonlight Companies was involved with the development of the grant application, and because of this, they were aware of the units that they would be receiving to demonstrate. They also understood the expectations during the demonstration period. Once awarded, the discussion started again, and design development began with Moonlight Companies input.

However, like any new technology, the project was caught in a familiar situation: management is receptive to changes and ready to take chance whereas drivers, operators and daily users are not.

During the demonstration period there were significant complications due to the operators. The ownership and management wanted to try something new – the day-to-day operators did not. There was disconnect, communication gap, and language barriers among all parties involved. The purpose of the eTractors and the project purpose was not communicated to the day-to-day operators. Once eTractor#1 was deployed to the demonstration site, HummingbirdEV worked closely with Moonlight Companies to provide end-user and operator training. The engineers spent countless days with the field manager and operators showing how the eTractors work – beyond "training" – they even spent time at the farm toward the end of the demonstration period using the eTractor to prove function and provide data for the project. Once the HummingbirdEV engineers and employees left, the eTractors were parked again for days at a time. When the end-user would try the eTractor again, they would be frustrated because the battery would be dead. There were countless conversations about using the eTractors daily – but there was little execution. As you can see in the service reports (*Appendix C*) many service issues were repeat customer error and misuse.

The eTractor, was designed to meet the needs of Moonlight Companies for this demonstration. Early in the project, Moonlight Companies and HummingbirdEV determined it would be best to demonstrate a 50 HP eTractor because this is a common tractor on farms and ranches. The eTractor was designed to transport fruit bins from the orchard to the warehouse – replacing 40 HP diesel tractors. Some of the failures during the demonstration were due to misuse of the eTractors; oftentimes they were used to pull weight heavier than designed to handle. The eTractors were not used by the end-user as they were designed and intended. During the demonstration, the eTractors were expected to function in applications that similar-sized diesel tractors are not typically used. The end-user expected the 50 HP eTractors to perform similar duties as the much larger diesel 125 HP tractors. This misuse compromised the reliability and efficiency of the technology.

Table #7 below is a brief tabular summary of use cases to help explain the intended use and the actual use of the eTractors. Figures 9 and 10 on page 31 also show the tractors in use.

Table #7: Use Cases – Intended and Actual

Description	Intended Use	End Use
Primary Application	Fruit picking	Used as a tow truck
Usage frequency	During harvest	Minimal and to not intended use case
Drive	Stop and go	Continuous
Hp	30-50 HP	75-125 HP
Towing	5,000 lbs. payload	18-24,000 lbs.
Grade	Mostly flat	8% grade

When the eTractors were used by the end-user as designed and intended, they performed appropriately and were highly successful. After the eTractors were delivered, Moonlight Companies' ownership reported that they would have liked the eTractor and eTruck to be more versatile.

In working with the end-user during project duration there were several reasons why the result was not what we had hoped for as detailed below:

1. Unrealistic expectations

   The eTractor is a new technology and in infancy/prototype stages. Demonstration projects help to build a robust, reliable, and cost-effective product. Openness towards trying new things by end-users and pushing that effort down to the operational day-to-day user is critical for the success of a project like this.

   A few of the main barriers in using eTractors are:

   a) The eTractor is not able to do what a diesel tractor can do by comparing the 50 HP eTractor to a much bigger class of diesel tractors and not intended duty cycle. Must be the same, or close to, HP for a true comparison.

   b) The eTractor breaks down more frequently. This can be true, and did happen, because of wrong usage.

   c) The eTractor batteries need frequent charge. When the eTractors were used in their intended use case, the eTractors did hold charge as per proposal.

2. Security and high-cost liabilities

   Moonlight Companies was not comfortable leaving the eTractor in the field, as per the original proposal. They felt the high vehicle cost associated with the eTractor increased

the likelihood of theft and liability on their end; which they could not bear. All risks and costs should not have been a surprise, given the costs of project units was well laid out during the proposal stage. Moonlight Companies was not convinced to use the eTractor in the field, irrespective of our continuous effort.

To collect certain data, the Fresno State Transportation Institute (third party data collector) had to use fields closer to the base where they were able to get back to a charging station, but even that effort was a minimal use case.

3. Drought and reduced cultivation

   During our monthly calls and interactions with the end-user one of the reasons for minimal use case was due to reduced cultivation in the field due to ongoing drought conditions.

4. Hesitancy and willingness to change and make it successful

   Hesitancy and willingness to try new technology for the day-to-day user; it was a constant struggle for HummingbirdEV to convince the daily operators to use the eTractor and eTruck during the demonstration period. Workforce Training was provided to Moonlight employees, including operators, drivers, farm managers, and mechanics. Unfortunately, the equipment was often left to sit, causing the batteries to die and the eTractors would not be charged at the start of the day. Moonlight Companies' ownership was very supportive during every phase, but it was challenging to get the day-to-day users to be supportive. New technology will be a challenge regardless of the end-user, particularly for end-users accustomed to using equipment they can fix themselves. Ongoing education and workforce development will be critical to the future success of electric ag equipment.

5. Communication & Consistency

   Communication from drivers/supervisors was weak including providing teams with proper reports and feedback. At the end of day, the role of the end-user was to run their operations smoothly. It was easier to not use the eTractors than try something new.

   There was a constant change in operators and supervisors that HummingbirdEV had to work with, train and educate. Overcoming the language barriers was a constant challenge. This turned out to be a costly affair and resulted in several service and part replacements for HummingbirdEV; particularly because the eTractors were left unused for longer periods of time and not operated as intended, causing the systems/components to break.

6. eTruck

   The eTruck was built to perform as a vehicle and a V2V transfer unit. However, the eTruck was only used as a regular truck and was never used for V2V because:

   a) The charging infrastructure delay (PG&E) resulted in the charging station not being ready to support the eTruck upon deployment. Infrastructure was only functional at the tail end of the project.

   b) eTractors were used around the main operations facility so they would be close to the charging stations. The V2V was not used because the use case of eTractors did not demand need for V2V (not used in field).

Technology

There are many conversations in agriculture around advances in technology, mainly with the increase in onboard computers and software built into the equipment, including tractors and combines. Manufacturers must install sensors to regulate and test emissions, and manufacturers want to improve their equipment as traditional farming moves into "precision agriculture." Farmers are hesitant; in general, their comfort level with technology is low. Traditionally, farmers want two things: equipment that runs consistently and equipment they can fix themselves. With computers, software, and advancing technology, farmers do not trust the consistency and know they cannot fix it themselves. This is even truer when adapting off-road equipment from diesel to electric.

Others:

- Grid reliability and availability had been poor. Moonlight Companies struggled to get the charging stations setup for both the eTruck and the eTractors on time. This was delayed by 18 months. Grid instability and reliability of power was poor and caused further breakdown of the units while charging.
- Improper use of the eTractor resulted in reliability issues and was a financial burden for HummingbirdEV (such as draining low voltage batteries, not using tractors for long periods, using vehicles in applications they were not designed for, getting familiar with the proper functioning sequence of tractors, etc.)
- HummingbirdEV was expected to serve as the Project Manager and coordinator between Project Clean Air, Moonlight Farms and Fresno State Transportation Institute. Project Clean Air had multiple staff changes that caused ripples in their ability to manage the project.
- Timelines were impacted by COVID-19 lockdowns restricting the time of data collection and reduced usage of eTractors – including delivering eTractors – to other project sites.

Figure #9: HummingbirdEV eTractor mowing at Demonstration Site, Moonlight Farms in Reedley, CA.

Figure #10: HummingbirdEV eTractor pulling bins in orchard at Demonstration Site, Moonlight Farms in Reedley, CA

Third Party Data Collection

The Fresno State Transportation Institute at California State University, Fresno, is on the cutting-edge of multi-modal transit for Fresno County. The Institute – funded with a $3 million grant from the Fresno County Transportation Authority, Measure C funds – launched in September 2017. The vision and mission of the Institute coincide with the local, regional and national vision of sustainability and improve the quality of life for the residents of Fresno County by testing the capabilities of all transportation modes and various clean technologies within the County from an engineering, social science, and business perspective. Dr. Aly Tawfik is an Associate Professor in the Department of Civil and Geomatics Engineering and is heading the Institute. Dr. Tawfik earned his Ph.D. in Transportation Systems Engineering from Virginia Tech where his research focused on capturing and modeling human heterogeneity in route choice behavior. For this demonstration project, Dr. Tawfik and the graduate students working under the Fresno State Transportation Institute provided field studies and third-party data collection and analysis on the functionality and operation of the electric tractors and electric truck. All project partners provided information and data to Dr. Tawfik and the Institute as they processed and analyze the data. All data collected was provided to PCA and California Air Resources Board (CARB).

Data Collection:
CARB outlines data collection requirements for grant-funded off-road advanced technology demonstration projects in a document referred to as "Appendix F." All data collection items identified in "Appendix F" were collected in this project which are 42 data items under 12 data categories. Data collection tools (surveys and logs) were designed to ensure that all required data items were collected for the diesel vehicles currently in use and the novel electric vehicles used as part of this grant. To ensure the quality and comprehensiveness of the collected data, three different time horizon data collection phases were adopted: single-time data, representative-periods data, and continuous data.

Single-time data are the data items collected only once over the span of the project. For example, the "Vehicle / Equipment Specification" data items were recorded at the earlier stages of the project. Since the vehicle and equipment did not change for the duration, this information needed to be collected only once.

Representative period surveys and logs are the tools that will collect minute-by-minute data over four weeks of the project; one week during the fall, the winter, the spring, and the summer. This data will be collected simultaneously for every type of existing diesel vehicle and advanced electric vehicle. This ensures representativeness of the comparisons between the performance of the two-vehicle classes (conventional and advanced technology).

Continuous surveys are a tool that will collect data continuously over the project period for both existing diesel vehicles and new electric vehicles. Examples of these data items include those under "Maintenance," "Service Calls," and "Safety" data categories. A weekly phone call with

the onsite farm supervisor to discuss Maintenance, Service Calls, Safety, and Operations and Maintenance. The farm supervisors were asked to compare the eTractors to the conventionally fueled tractors.

Two Portable Emission Measurement Systems (PEMS) were procured and used for continuous real-time measurement and logging of tailpipe concentrations of gaseous and particulate pollutants of diesel tractors and trucks. For measurement of tailpipe emission concentrations of gaseous pollutants, such as carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbons (HCs), NOVA Plus portable emissions analyzer manufactured by MRU Instruments was used. The device is capable of the simultaneous measurement of the concentrations of CO2, CO, NO, NO2, and SO2 among other gases at high temperatures up to 2,012°F. Using lithium-ion batteries, the device can function continuously for up 20 hours. It can internally store up to 16,000 measurements, and additional memory can be added using SanDisk cards. Data can be transferred via an external drive interface to computers for processing and analysis.

Table #8: Operating costs for diesel and electric vehicles

Value	Diesel Tractor #1	Diesel Tractor #2	Diesel Tractor #3	Diesel Truck	eTractor #1	eTractor #2	eTractor #3	eTractor #4	eTruck
Accumulated hours of use	6000	6000	6000	6000	6000	6000	6000	6000	6000
Repair cost percentage	25%	25%	25%	25%	25%	25%	25%	25%	25%
Repair cost	$4,250	$4,250	$12,500	$13,750	$17,500	$17,500	$17,500	$17,500	$37,500
Repair cost / hr	$0.71	$0.71	$2.08	$0.06*	$2.92	$2.92	$2.92	$2.92	$0.15*
PTO horsepower	23	25.5	61	360	41.5	41.5	41.5	41.5	268
Avg. fuel consumption (gal/hr)	1.012	1.122	2.684	15.84	1.826	1.826	1.826	1.826	11.792
Equivalent electricity consumption (kWh/hr)	N/A	N/A	N/A	N/A	69.571	69.571	69.571	69.571	449.28
Avg energy cost / hr	$3.33	$3.69	$8.83	$1.25*	$7.37	$7.37	$7.37	$7.37	$1.14*
Lubrication cost / hr	$0.50	$0.55	$1.32	$0.19*	$0.90	$0.90	$0.90	$0.90	$0.14*
Labor cost / hr	$16.50	$16.50	$16.50	$0.40*	$16.50	$16.50	$16.50	$16.50	$0.40*
Operating Cost / hr	**$21.04**	**$21.45**	**$28.73**	**$1.90***	**$27.69**	**$27.69**	**$27.69**	**$27.69**	**$1.83***

* Per mile.

From the above Table 8, total costs for all diesel and electric vehicles can be calculated by summing the ownership and operating cost values. Table 9 on page 34 shows the total costs per hour for tractors and per mile for trucks.

Table #9: Total costs for diesel and electric vehicles

Value	Diesel Tractor #1	Diesel Tractor #2	Diesel Tractor #3	Diesel Truck	eTractor #1	eTractor #2	eTractor #3	eTractor #4	eTruck
Ownership cost / hr	$3.81	$3.81	$11.34	$0.30*	$15.88	$15.88	$15.88	$15.88	$0.83*
Operating Cost / hr	$21.04	$21.45	$28.73	$1.90*	$27.69	$27.69	$27.69	$27.69	$1.83*
Total cost / hr	**$24.85**	**$25.26**	**$40.07**	**$2.20***	**$43.57**	**$43.57**	**$43.57**	**$43.57**	**$2.66***

* Per mile.

Well-to-Wheel Footprint:

The well-to-wheel (WTW) energy consumption refers to the total indirect energy consumption of a vehicle that includes the energy needed for fuel extraction, refinery, transportation, and pumping. It can be broken down into well-to-tank (WTT) energy, referring to the energy needed to produce fuel and deliver it to a vehicle (or equivalently, deliver it to a power plant and produce electricity to power an electric vehicle), and tank-to-wheel (TTW) energy, which is the energy released from burning fuel in the tank, or its equivalent value for electric vehicles.

Overall WTW energy consumption data are provided in literature for various vehicle types based on the type of fuel used, including diesel vehicles and battery-electric vehicles (BEV). The reported WTW footprint of electric vehicles reflects the US average grid mix at the time of the literature study, where 52% of electricity was produced from coal, 20% from nuclear energy, 16% from natural gas, and 10% from renewables, and about 3% from petroleum.

The footprint would be much greater if a larger proportion of electricity is produced from coal, and vice versa. The study used a 127-hp diesel vehicle and a 114-hp electric vehicle. The conversion to a gallon of diesel equivalent per mile uses the diesel gallon equivalent (DGE) for electricity, which is 137 MJ/gal (38.1 kWh/gal). The results are shown in Table 10.

Table #10: Well-to-Wheel (WTW) Energy Consumption

Value	Diesel	BEV
WTT energy consumption	0.0023 gal/mile	0.0146 gal-eq/mile
TTW energy consumption	0.0169 gal/mile	0.0063 gal-eq/mile
WTW energy consumption	**0.0192 gal/mile**	**0.0209 gal-eq/mile**

Please see *Appendix A* for the full Fresno State Transportation Institute Data Report.

Public Engagement

While electric vehicles are not new, they do represent a new way of thinking for both public and private entities. Participation in public and private industry showcases is beneficial to demonstrate the benefits of electric vehicles to today's audiences. The eTractors and eTruck will continue to be made available for demonstrations during industry gatherings, and HummingbirdEV will continue to take these vehicles out to interested parties for inspection and short-term use. PCA and HummingbirdEV have participated in tutorials and online educational events. The team's marketing and educational efforts extend to all forms of media from traditional print and television to social media, such as Facebook, Twitter, and Instagram.

HummingbirdEV purchased booth space at the World Ag Expo to display the eTractor and the Class 6 eTruck in 2020, 2021 (virtually), and 2022. The World Ag Expo is a week-long, annual event held in Tulare, California. It is the largest annual outdoor agricultural exposition with over 1,450 exhibitors and an attendance of more than 100,000 each year. In the three years of participation, HummingbirdEV successfully delivered information to potential end-users. During the 2020 show, HummingbirdEV had approximately sixty truly interested visitors that left contact information. Some of the visitors were interested in receiving more information and others were interested in becoming a demonstration site. PG&E and San Joaquin Valley Air Pollution Control District representatives visited the booth and discussed potential funding and infrastructure opportunities. A Managing Editor for Diesel Progress Magazine also stopped by the booth; the magazine published an article about eTractors in July 2021. The events have been a success. A photo of the booth in 2020 is shown below (Figure #11).

Figure #11: HummingbirdEV all-electric tractor and all-electric Class 6 truck displaying the unique Vehicle-to-Vehicle charging capabilities at the 2020 World Ag Expo, held annually in Tulare, California.

The 2021 virtual booth was a challenge. Figures 12 and 13 below show the webpages for the virtual event. The overall Expo attendance was down by about seventy-five percent with only 24,600 visitors (this number was difficult to track and to know if these were unique visitors or the same person with multiple visits). Here is the link to the website: https://wae21.mapyourshow.com/8_0/exhibitor/exhibitor-details.cfm?exhid=17271

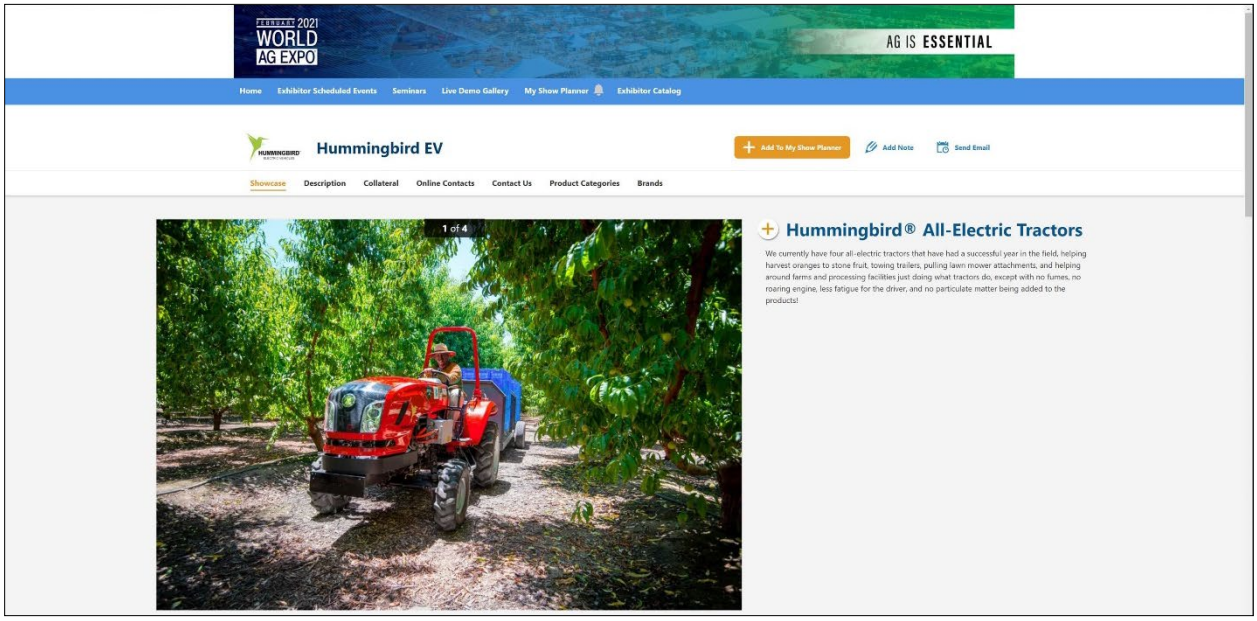


Figure #12: HummingbirdEV's website for the Virtual 2021 World Ag Expo

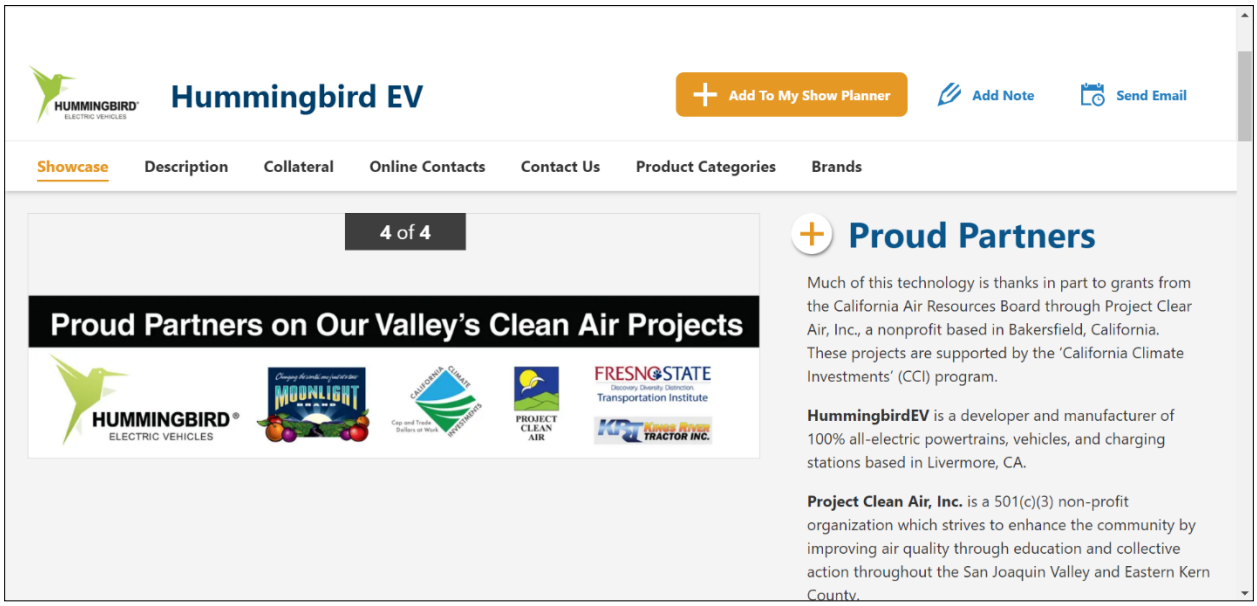


Figure #13: HummingbirdEV's website for the Virtual 2021 World Ag Expo.

The 2022 year was the most successful due to HummingbirdEV being named a "Top-10 New Product Winner"* and having the eTractor displayed in both the PG&E and the HummingbirdEV booths, as shown in Figure 14, the Exhibitor Map for the World Ag Expo.

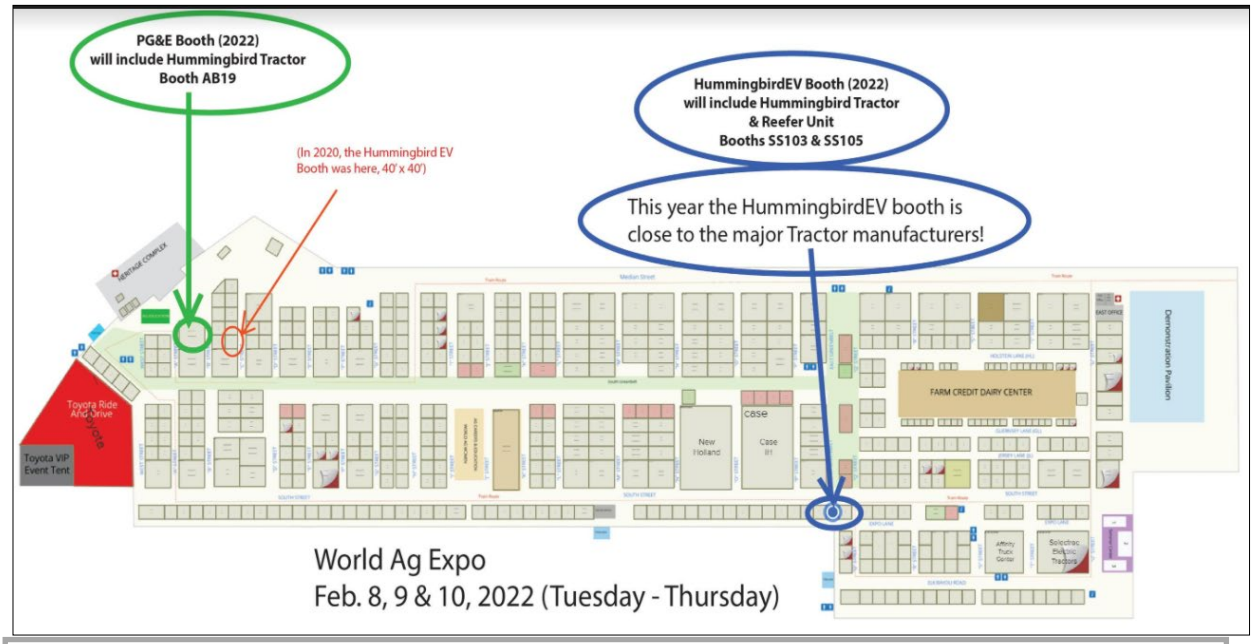


Figure #14: 2022 World Ag Expo Exhibitor Map Figure #13

Publicity

Diesel Progress Magazine is a digital and print magazine based in the UK, with locations in multiple countries. The company has over 26,000 subscribers to the published magazine, 20,250 unique digital visitors per month, and 23,162 weekly newsletter subscribers. HummingbirdEV met the Managing Editor at the 2020 World Ag Expo, and the Managing Editor visited the booth in 2021. In July 2021, Diesel Progress Magazine printed the article *HummingbirdEV develops a fast-charging system for electric tractors*. The printed article can be found in Appendix C. (https://www.dieselprogress.com/news/hummingbirdev-develops-fast-charging-system-for-electric-tractors/8013691.article)

Small Farm Canada Magazine contacted HummingbirdEV about writing an article. The article All-Electric Tractors and Charging Tender Trucks was published in February 2021. Small Farm Canada is a digital magazine largely funded by the Government of Canada and was recently purchased by farm.com. The website is updated regularly and is published six times per year with 40,800 subscribers. The printed article can be found in Appendix C.

The most exciting publicity the project received, was a showcase on MotorWeek (a television program highlighting automobiles, currently airing on PBS) in March 2021. Project Clean Air

* The "Top-10 New Product Winner" is based on HummingbirdEV's all-electric Class 8 Refrigerated Truck, which is CA. Air Resources Board grant funded project though the Zero- and Near Zero-Emission Freight Facilities Project 2017-2018. While the "Top-10" award was for a different project, HummingbirdEV gained the attention of attendees for both projects.

made the initial contact with MotorWeek, through the San Joaquin Valley Clean Cities Coalition managed by PCA. The five-minute video highlights the success of the advanced equipment, including the V2V technology, and was filmed on-sight at Moonlight. Rakesh Koneru, Director of Operations/Business Development for HummingbirdEV, and Ty Tavlan, Owner of Moonlight Companies, were interviewed and presented the eTractor and the eTruck. Figure #15 below shows some of the action at Moonlight Farms during the segment production. While the Fresno PBS station does not air MotorWeek, it was aired in other parts of California and parts of Oregon. This generated much attention and opened the door to new farms and ranches requesting to demonstrate the equipment during the grant period.
(https://www.youtube.com/watch?v=ox5GoCNsL4k)

Figure #15: MotorWeek Film Crew at demonstration site filming eTractor in use.

Marketing

A Marketing Plan was produced early on during the project period. Once the eTractor was designed a marketing brochure was created and distributed at the World Ag Expo. A press release was put together and emailed out nationally and internationally to magazines that cover electric vehicle news, tractor news, and agriculture news. The press release was sent out in February 2021 in conjunction with the 2021 World Ag Expo and served as an announcement of the delivery of the eTractor. The full Press Release can be found in Appendix D.

Commercialization

HummingbirdEV's approach to scale off-road agricultural vehicle platforms is to design all-electric vehicles to be modular while maintaining commonality of chassis and powertrain platforms using software driven systems to make one solution fit for a wide range of HP requirements.

New age farming is changing in terms of equipment used and cultivation methodologies partly due to global warming. HummingbirdEV's phased electrification approach is focused on reducing operational costs by going electric and reducing assets through our unique technology driven approach towards commercialization.

Commercialization is achieved in three phases working towards short-, mid-, and long-terms goals.

Phase 1: Engineering Validation Testing (EVT)

Number of tractors: 4

Through this project, HummingbirdEV was able to successfully complete the EVT phase by designing, developing, building and testing four engineering validation units which are still in fields – post grant period – collecting data for future eTractor generations.

Implemented as below:

- ***Re-power Chassis:*** During this phase, HummingbirdEV worked with a tractor OEM towards a re-power platform by selecting a conventional chassis and modifying the same to accommodate short, narrow, and low step height requirements at end-user sites.

- ***Modular Energy Storage Systems (ESS):*** HummingbirdEV worked with two different battery cell suppliers and built high voltage energy storage systems with a modular thought which allows future scale-up or scale-down on the battery capacity based on HP, duty cycle, and energy demands.

- ***Software Driven Powertrain (SDP):*** HummingbirdEV has built powertrain systems towards future proofing and using the same system to work between a range of vehicle requirements (30-65 HP). Software driven systems will enable HummingbirdEV to tune the vehicles on the production line based on user requirements while minimizing the need for an increase in production and vehicle costs with improved commonality between product lines.

- ***Power Take Off (PTO):*** As supplied by the OEM chassis varying the speeds from 0-2,000 rpm and rated power of up to 30 HP through our software driven powertrain directly connected to conventional gearbox.

- ***Charging:*** Using our unique and industry first Vehicle-to-Vehicle (V2V) charging protocol HummingbirdEV has built two different charging protocols to support overnight charging - Level2 AC EVSE and on-demand charging

Phase 2: Design Validation Testing (DVT)

Number of tractors: 25 (Current)

Over the next 18-24 months HummingbirdEV will work towards low volume production while implementing lessons learned from the EVT phase with a mix of re-power and ground-up tractor designs.

Some improvements from EVT include:

- Interchangeable and scalable battery packs with improved thermal systems to enable better performance while charging
- Efficient control mechanisms of PTO motor, rear wheel, and step height modifications
- Improved vehicle controls, integrated vehicle telematics and implemented diagnostics

During the DVT phase HummingbirdEV will also work on designing and building a skateboard allowing batteries to be packaged in between frame rails, uni-structure, lightweight and adjustable chassis platform. HummingbirdEV is also looking for partnerships to enable our long-term goals of building a modular frame that has low step height, is narrow in width, and can be scalable to accommodate different variants of battery sizes.

As of date HummingbirdEV has delivered three vehicles under the DVT phase and more are in progress across a wide range of customer profiles.

Phase 3: Production Validation Testing (PVT)

HummingbirdEV is working towards mid volume production while implementing lessons learnt from DVT phase over the next 36-48 months with a ground up tractor design.

Alongside DVT, HummingbirdEV is working on a skateboard chassis platform to further minimize the mechanical systems such:

- Direct drive versus traditional gearbox setup
- Modular batteries packaged in between the frame rails to provide improved safety, weight distribution and reduced costs as well as capabilities to increase (or decrease) the energy capacity based on applications

HummingbirdEV is working toward the design with a combination of both in-house engineering and partnership models (alongside traditional OEM's).

Manufacturing: Asset minimalist approach towards manufacturing using micro-factories (final assembly lines) and contract manufacturing primarily focused on localizing all supply chain related activities – including batteries manufactured in the U.S. The need for this is to decrease the time to market/product and reduce overhead costs to enable cheaper/modular/scalable product lines on the production line.

Sales & Service: As this technology is still in its nascent stage, taking long established traditional sales and service industry – especially in Agriculture industry – is equally important than direct sales and service distribution channels. Distribution channels will still be pursued to provide demonstration vehicles – but a larger focus will be on the direct and traditional sales model.

Agriculture communities are closely knit, and a vast majority of pre-sales and service models work hand-in-hand with communities today. HummingbirdEV believes in educating, training, and empowering the local channels to help achieve volumes and to create a closed loop localized economy.

Incentives

To push this technology into commercialization, there needs to be a large-scale comprehensive education, training, and marketing plan to provide information to farmers and mechanics. Up until recently, the off-road agricultural vehicle market has largely been left out of all statewide incentive programs. The statewide incentive programs for electric passenger vehicles and certain off-road vehicles (ATV/UTV and forklifts) have been critical in garnishing interests and encouraging buyers. Programs like CORE (Clean Off-Road Equipment) and the Funding Agricultural Replacement Measures for Emission Reductions (FARMER) need to be continuously promoted and used to educate end-users that the technology exists and is reliable.

Workforce Training

PCA and HummingbirdEV produced three supplementary training modules for on-site training: first responder training, driver training, and a technician training module. These modules were specifically tailored to the needs of each audience. CSU, Fresno provided training for the students working on the project. All training was meant to support the use of the vehicles in their agriculture vocation, to keep the equipment operational, to train individuals in the new technologies of electric vehicles and equipment, to reduce risks for operators, and to ensure the operation of the equipment on location.

Project Clean Air contracted with AVI On-Demand to offer an online training webinar during the COVID-19 Pandemic. The first responder training addressed light-duty, medium-duty, and heavy-duty vehicles as well as charging infrastructure scenarios. The first responder training included how to safely turn off the power or cut into an electric tractor in the case of an accident. Operator training included a system-level overview that included specifics such as how regenerative braking options will affect the starting/stopping, operator experience, Emergency Shut-Off of batteries, and effective range. The PowerPoint presentation can be found in Appendix F.

The technician training allowed the technicians to learn about the basic operations, maintenance needs, and how to troubleshoot the electric system as compared to a fossil fuel counterpart and high voltage dangers and precautionary safety-related issues related to component maintenance.

Driver training and technician training were conducted upon delivery of eTractor#1 and #2 in February 2021. PCA oversaw and collaborated with HummingbirdEV to provide direct, hands-on guided instruction for operator proficiency, preventative maintenance, repair, charging, and data collection – this included electric tractor familiarization and operation, operation of gauges, and controls, recharging procedures, and driving the vehicle.

Educational materials were provided to training participants from Moonlight Companies and Kings River Tractor. Guided instruction was provided by the design engineers to familiarize all operators and maintenance personnel with best management practices, proper protocols, and safety requirements. The technician training included an overview of maintenance protocols and troubleshooting techniques. In addition, preventative maintenance training that includes routine inspections of the eTractors has been provided.

CSUF provided hands-on training to four employees, including two students working with the Portable Emissions Measurement System (PEMS) equipment to collect data from the vehicles.

PCA conducted two First Responder Trainings: January 20, 2021, and November 2, 2021. The first training was conducted virtually, which allowed for greater participation. There were approximately 75 participants from 19 different agencies. The participants were from across the state – from UC Davis to the City of Long Beach, and included Fresno, Clovis, cities, counties, school districts, CalFire, and private companies. The downfall was the lack of hands-on training. Please see Appendix F for the list of participants.

The second training was held in person at Moonlight Farms in Reedley, California. Project Clean Air contracted with AFVEducate, as the lead instructor from the first workshop and became a partner in the new training company. AFV Educate (www.afveducate.com) is a training and curriculum development company focusing on alternative fuel vehicle training, including education for firefighters, law enforcement, EMS, tow operators, automotive salvage, automotive technicians, and collision repair specialists. This effort was developed by Chris Womack, Captain, and Indianapolis Fire Department, who has been teaching for Clean Cities for over eight years, and Michael Smyth, former Director of the National Alternative Fuels Training Consortium (NAFTC) at West Virginia University. Together, they have almost 20 years of service to the Clean Cities Coalitions in the United States. The curriculum meets the standards of the National Fire Academy. It was a great opportunity for hands-on training, asking questions, and proposing slight design changes to improve safety from the first responder's perspective. Suggestions and ideas were brought back to HummingbirdEV to include in an updated manual.