EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017

Creating a 12-Ton BEV Refrigerated Delivery Truck Capable of 200 Miles Range per Charge

Stephen Johnsen[1]

[1]*Stephen Johnsen, HPEV LLC, PO Box 302, Maple Valley, WA 98038 U.S.A. Hpev.llc@gmail.com*

Summary

This presentation will explain the designing and building of a 12-ton fully battery-electric powered refrigerated delivery truck capable of extended highway and city driving. As of this writing there is no commercially available fully electric refrigerated delivery truck with a 200 mile range per charge. This presentation details the creation of a very unique, massive electric vehicle created to provide years of clean, quiet service while demonstrating to the world that purely electric propulsion can be a viable choice for even very large, heavy commercial trucks. The project exemplifies sustainability as an old inefficient, polluting gasoline powered truck served as the base chassis and was transformed with a modern 100% electric powertrain. Furthermore, the project sourced as many US made parts as possible as well as used local labor for the design, fabrication and integration. In addition to serving the needs of the community by cleanly and quietly delivering its produce and other food items, the truck has the striking appearance of a classic 1954 GMC so that it attracts attention wherever it goes. The hope is that this iconic truck can serve as a proof-of-concept which will spur other companies to consider the many promising attributes of battery electric transportation.

Keywords: Truck, Heavy Duty, Special Vehicles, Fleet, BEV (Battery Electric Vehicle)

Figure 1: Front view of the donor truck body, a 1954 GMC 630

1 The Project Begins

1.1 Background

21 Acres is an organic farm and center for sustainable agriculture in Woodinville, Washington, USA. Their mission is "...to inspire action to solve climate challenges by learning as a community to grow, eat, and live sustainably." In addition to providing educational classes and hosting events, 21 Acres is also part of a larger co-operative of farmers which delivers local farm-fresh food to restaurants and other customers in the greater Seattle area. These deliveries had been made by trucks powered by bio-diesel but they were interested in an even cleaner and more sustainable delivery truck option which would not be reliant upon fossil fuels. They were disappointed to find that there was no suitable 100% electric vehicle which could satisfy their range and capacity requirements.

They initially approached HPEV LLC to find out if such a vehicle could be built to meet their needs. I told them yes, but for 200 mile range it would be quite expensive and require an enormous battery pack. After a preliminary feasibility study, the project was ultimately given the go-ahead.

1.2 Specific Project Objectives

At 5:30 in the morning the empty refrigerated truck would drive at highway speeds for over 60 miles up to the rural farmlands in northwestern Washington State where local farmers would load the truck with their food. It would then make the 60+ mile return trip back to the food hub where more food from other local farmers would be loaded up. Then in the afternoon, the truck would head out to make its deliveries throughout Seattle and the surrounding cities, adding about 60 more miles to the day's journey. The truck would return by 19:00 in the evening and it would need to be able to fully recharge overnight and be ready by 5:30am the next morning for another full day. The facility where the truck is based in Woodinville, WA has a LEED platinum certification and was designed with efficiency and sustainability in mind. The roof of the building has a massive solar array of over 25kW which feeds into the local power grid during the daytime and can produce more than enough energy to fully charge the truck. However by charging up at night, the electric truck can take advantage of off-peak electricity that would otherwise go to waste.

2 Project Planning

2.1 Special Operational Considerations

Not only would the truck need to be able to travel for extended periods at highway speeds, but it would also have to be able to handle being fully loaded and stopping and starting on steep Seattle hills. It would have to be able to fit through tight alleyways in the city yet might also be on uneven farmland terrain or gravel roads. The truck would need to keep the food it is carrying at safe cold storage temperatures and I wanted the refrigeration system to be 100 percent battery powered as well.

2.2 Weight and Aerodynamics

In order to be able to carry the desired amount of cargo and propulsion batteries, the truck would be heavy enough that it would have to stop at truck scale weigh stations along the highway. Yet we wanted the truck to stay below the gross vehicle weight rating that would require the driver to have a commercial driver's license. The refrigerated box would need to be able to accept heavy pallets being loaded by forklift as well as tall employees moving cargo in and out.

In the end, this meant the truck would have a tall and wide refrigerated box, a very large frontal area and it could have a gross weight of up to 26,000 pounds! None of these were traditionally desirable traits for an electric vehicle and initial calculations were done to estimate watt-hours per mile and it did not look good. We did not know many final details such as the coefficient of drag, the rolling resistance or even the frontal area but we did have an idea of the speeds it would travel at and the weight of the truck. Having built and tested various other electric vehicles in the past, we looked at the efficiency of them at various speeds and plotted the data on a graph. From that we could interpolate and we estimated that the electric delivery truck would likely average somewhere between 700 and 1,600 watt-hours per mile depending upon how it was loaded and what it was doing.

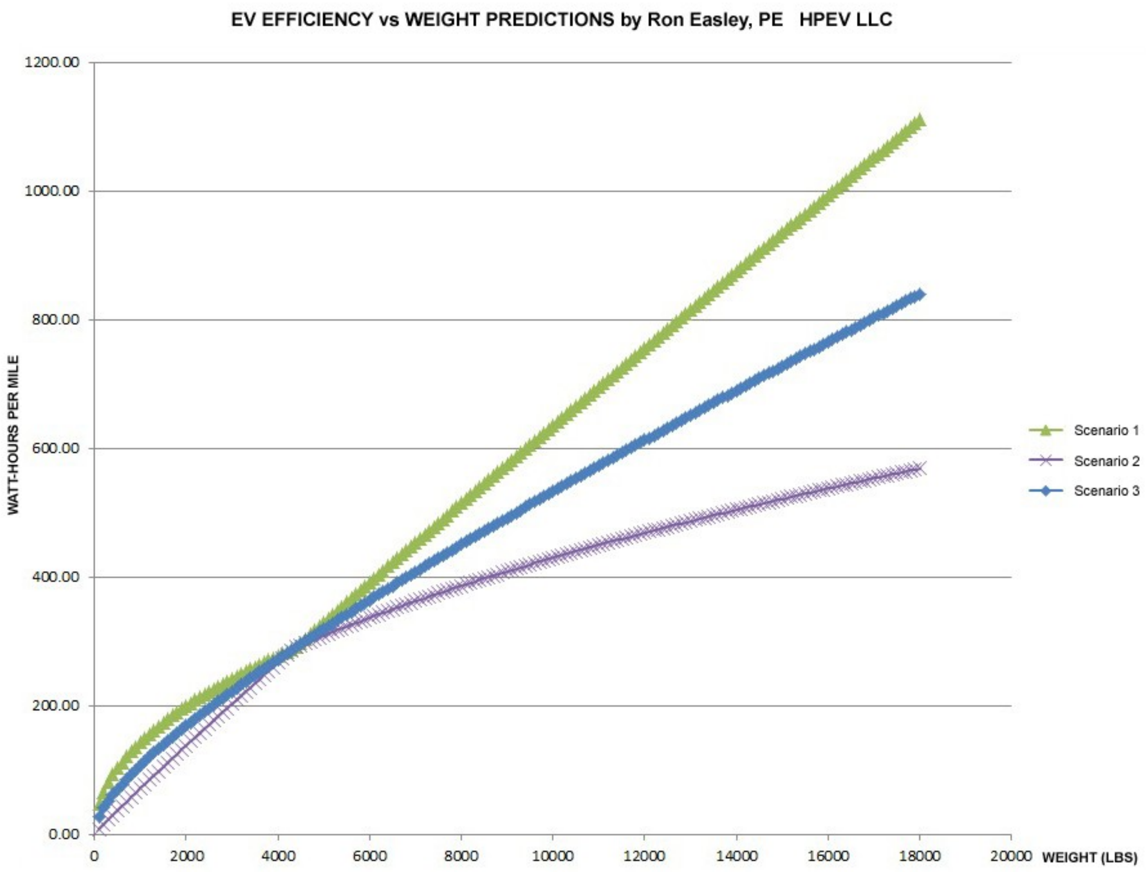

Figure 2: EV efficiency versus weight predictions

3 Putting the Pieces Together

3.1 Propulsion System

After looking into various motor and controller combinations, a single Remy HVH-250 internal permanent magnet motor was chosen. Remy is a US company that makes a very power-dense brushless motor with a proven track record and of course it is capable of regenerative braking. This motor would be coupled to a medium duty 5-speed manual Eaton-Fuller truck transmission which would turn traditional drive shafts ending at a single speed rear differential. Data from the department of transportation was obtained to determine the steepest grades in the Seattle area and engineer Ron Easley developed a spreadsheet which allowed us to test out various truck gross weights, wheel sizes, gear ratios and evaluate hill climbing abilities. We were keen to make the truck as efficient as we could while also keeping it as reliable and safe as possible. It looked like it *might* be possible for the truck to have a single speed gearbox but in the end the 5 speed truck transmission was chosen because it would give the truck greater flexibility while allowing it to easily meet all of its objectives under many conditions.

The motor controller chosen was a PM-250 from Rinehart Motion Systems. This controller is capable of 250+kW of power and is designed and built in nearby Oregon, USA. It is a good match for the Remy motor and it is very compact for its power capabilities. We had experience using the PM-250 in another very high performance racing application so we were confident in its abilities and figured it should work well at the lower power levels that would be required by the electric delivery truck.

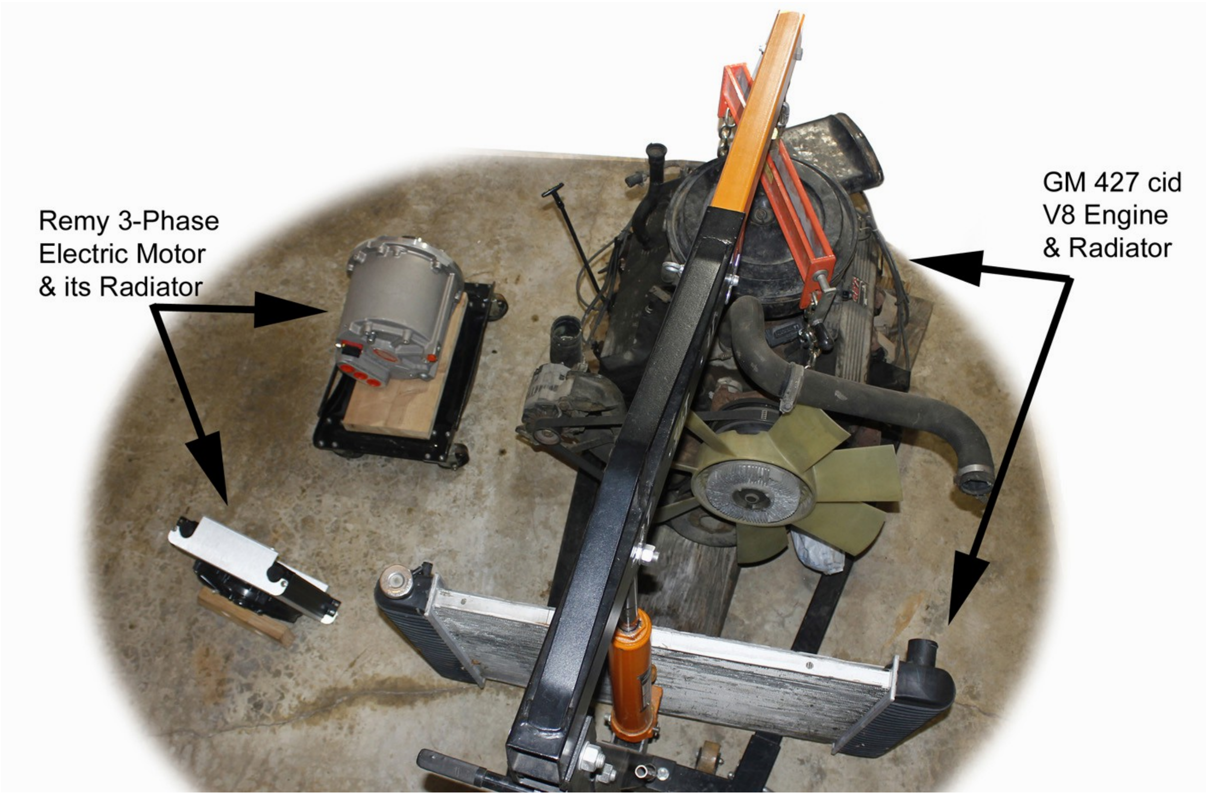

Figure 3: Remy electric motor next to the 7-liter V8 engine it replaced

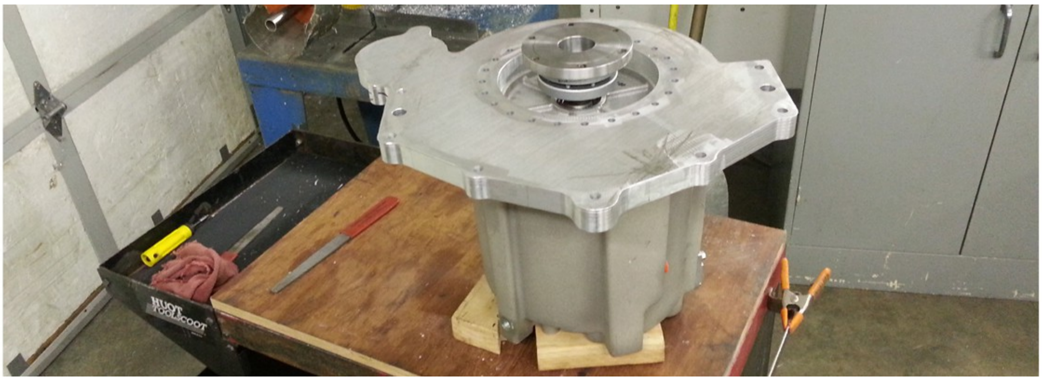
Figure 4: Remy HVH-250 motor with adapter for Eaton Transmission

3.2 Battery & Charging

The initial predictions had showed that the truck would likely get somewhere between 700 and 1,600 Wh/mile, so in order to come close to the goal of 200 miles per charge a 255kWh battery pack was chosen. After considering many options, the Lithium Nickel Cobalt Aluminum Oxide (NCA) chemistry was chosen due to its high energy density.

The final battery system in the truck is comprised of 3 separate physical packs which are isolated from each other and are charged by 3 separate chargers. The chargers were built locally by Manzanita Micro in

Kingston, Washington. The truck has three of the usual SAE J1772 type charge ports on the side and it can be fed by three separate EVSE stations. With this setup, a worst-case scenario would be about 10 hours for a full charge so it can be accomplished overnight.

REVIEW OF 9 POSSIBLE BATTERY PACKS FOR 21 ACRES CLASS 6 ELECTRIC DELIVERY TRUCK						Prepared by: Stephen Johnsen, HPEV LLC			REV: 1.1 3/31/2015
	Sinopoly 300AH	Sinopoly 200AH	CALB 400AH	CALB 180AH	Voltronix 260AH	CALB 400AH	Voltronix 700AH	LEAF Batteries	TESLA Batteries
Battery Pack Wh/lb (higher numbers = better)	45.7	50.0	42.7	45.7	41.8	42.7	48.4	54.3	70.8
Single Cell weight (lbs)	21	12.8	30	12.6	19.9	30	46.3	8.4	
Single Cell Amps Continuous	100	66	120	180	260	120	210	240	
Single Cell Amps Max (10sec)	300	600	800	720	780	800	700	540	
Single Cell Amps while charging	99	66	400	90	130	400	350	130	
Pack Cells in Parallel	2	3	-	3	2	2	-	11	
Pack Cells in Series	130	130	180	130	130	108	108	48	
Total # of cells in pack	260	390	180	390	260	216	108	528	21,312
Parallel Cells Module Weight (lbs)	42	38.4	30	37.8	39.8	60	46.3	92.4	
Parallel Cells AH Capacity	600	600	400	540	520	800	700	660	240
Pack Voltage Nom. (3.2V ea)	416	416	576	416	416	345.6	345.6	364.8	355.2
Pack Voltage Charged (3.5ea)	455	455	630	455	455	378	378	403.2	418
Pack Voltage empty (2.9ea)	377	377	522	377	377	313.2	313.2	288	
Total nominal pack Wh capacity (higher = better)	249600	249600	230400	224640	216320	276480	241920	240768	255000
Total battery pack cells weight (lbs)	5460	4992	5400	4914	5174	6480	5000.4	4435.2	3600
Total pack price (for in-vehicle cells)	$88,556	$88,530	$82,800	$80,730	$84,500	$99,360	$117,180	$71,500	~$90,000
Additional Tax	0	0	0	0	0	0	0	maybe...	
Additional shipping charges	0	0	1600	1500	1500	$1,700	2,000		5000
Number of extra cells	4	12	4	12	4	4	4	11	
Cost per cell for terminal fasteners	included	included	included	included		included		included	
Total # of terminal fasteners (less is better)	520	780	360	780	520	432	216	1584	
Total cost for terminal fasteners	0	0	0	0		0		0	0
Total bus bar cost (China)	792	1206	368	804		440		n/a	
Total bus bar cost (US made)	1584	2412	1104	2010	2500	2580	2500	4312	Included
Total braided strap cost (US made)	2904	3618	2024	3618	2904	2904		4851	
Cost for extra "replacement" cells	1362	2724	1840	2484	1300	1840	4340	1650	
TOTAL DELIVERED PACK COST w/US bars ($)	$92,822	$94,872	$88,264	$88,332	$90,204	$105,804	$126,020	$78,001	~$95,000
Lead-time for delivery of cells	8-16 weeks	8-16 weeks	3-10 days	3-10 days	likely 3-10 days	3-10 days	8-12 weeks	*Unavailable	(depends)
Cycle life expectancy per manf. data sheet	1500	2000	3000	2000		3000			600
Total pack Wh using 70%	174720	174720	161280	157248	151424	193536	169344	168537.6	178500
Total pack Wh using 80%	199680	199680	184320	179712	173056	221184	193536	192614.4	204000
Estimated range to 80% @ 775 Wh/mi (miles)	257.65	257.65	237.83	231.89	223.30	285.40	249.72	248.53	263.23
Estimated range to 80% @ 900 Wh/mi (miles)	221.87	221.87	204.80	199.68	192.28	245.76	215.04	214.02	226.67
Estimated range to 80% @ 1000 Wh/mi (miles)	199.68	199.68	184.32	179.71	173.06	221.18	193.54	192.61	204.00
Estimated range to 80% @ 1200 Wh/mi (miles)	166.40	166.40	153.60	149.76	144.21	184.32	161.28	160.51	170.00
Estimated range to 80% @ 1500 Wh/mi (miles)	133.12	133.12	122.88	119.81	115.37	147.46	129.02	128.41	136.00
Realistic "Safe Range" 1.1kW/mi & 80% (miles)	181.53	181.53	167.56	163.37	157.32	201.08	175.94	175.10	185.45
Best Case "Max Range"0.85kW/mi & 95% (miles	278.96	278.96	257.51	251.07	241.77	309.01	270.38	269.09	285.00
kWh Avail. after reefer use subtracted from line4	160080		144720	140112		181584			164400
Mileage after factoring pessimistic refrigeration	145.53		131.56	127.37		165.08			149.45
Best miles factoring pessimistic refrigeration	178.91		161.75	156.60		202.95			183.74

Figure 5: Many battery pack options were compared

3.3 The Chassis & Body

After comparing and considering many different truck chassis options, a GMC C6000 series Top Kick chassis was chosen to serve as the base frame and running gear. The front end, hood, fenders and cab were grafted onto it from a classic 1954 GMC Model 630. This solid 1950s American-built body came from a retired Washington State fire truck and it gives the truck a timeless retro-cool look that attracts lots of attention and will never go out of style.

Figure 6: The body from the 1954 GMC is placed onto the modern GMC chassis

Figure 7: One of the battery packs mounts below the driveshaft for a low CG and smooth underside

3.4 Cargo Box and Refrigeration

An 18ft long insulated box was chosen from Summit Body in Portland, Oregon. Summit builds some of the smoothest and most uniformly insulated refrigerated truck boxes locally, using high-efficiency insulation panels from Washington State. The refrigeration unit was selected from Thermo King Northwest and surprisingly requires only about 3kW of power. So with the highly insulated box the truck's refrigeration system should actually use fewer kW for cooling than a typical electric car's HVAC system!

3.5 Thermal Management

The motor, inverter and battery packs are all liquid-cooled. Three separate cooling systems were designed since each component had different requirements. The Remy motor is cooled with a Dexron oil system. The inverter and battery packs are cooled with a more traditional Glycol based coolant, but they have two separate systems since the inverter must always be kept cool whereas the battery pack must sometimes be kept cool and sometimes be heated.

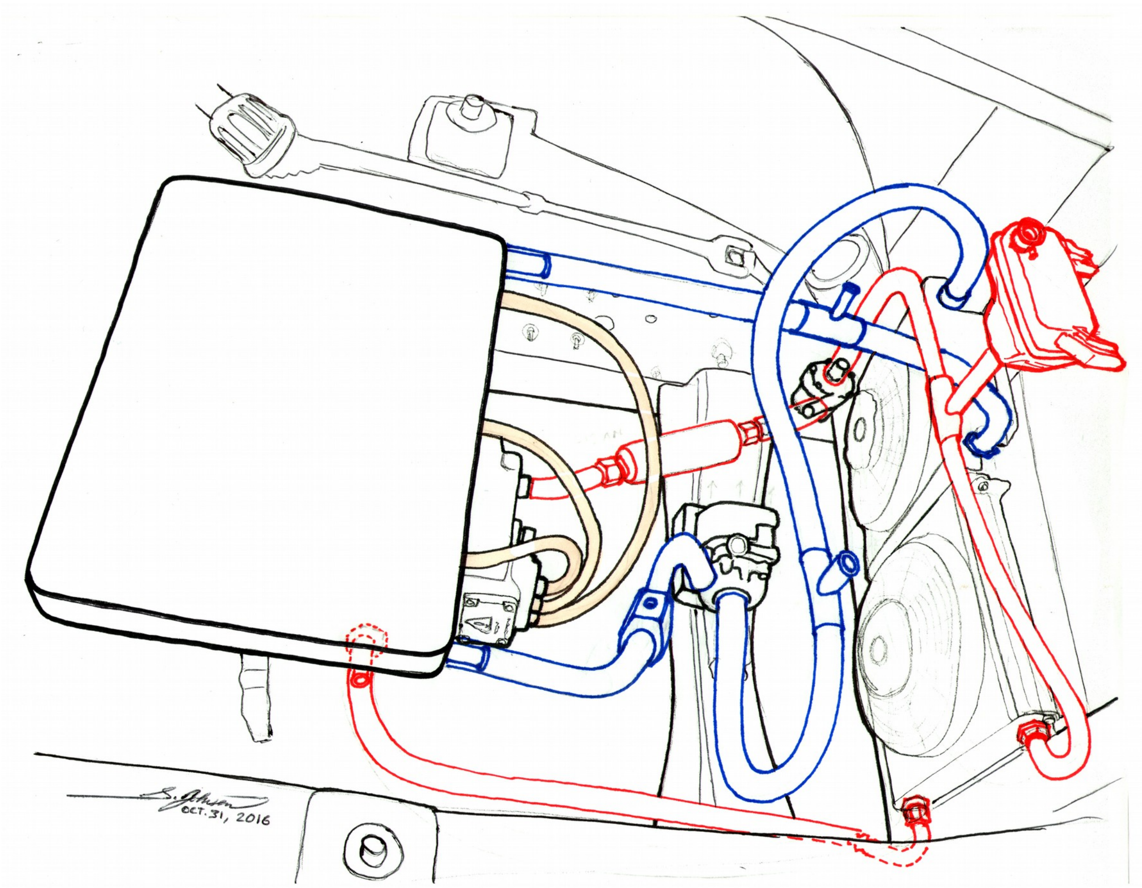

Figure 8: Motor and controller cooling systems

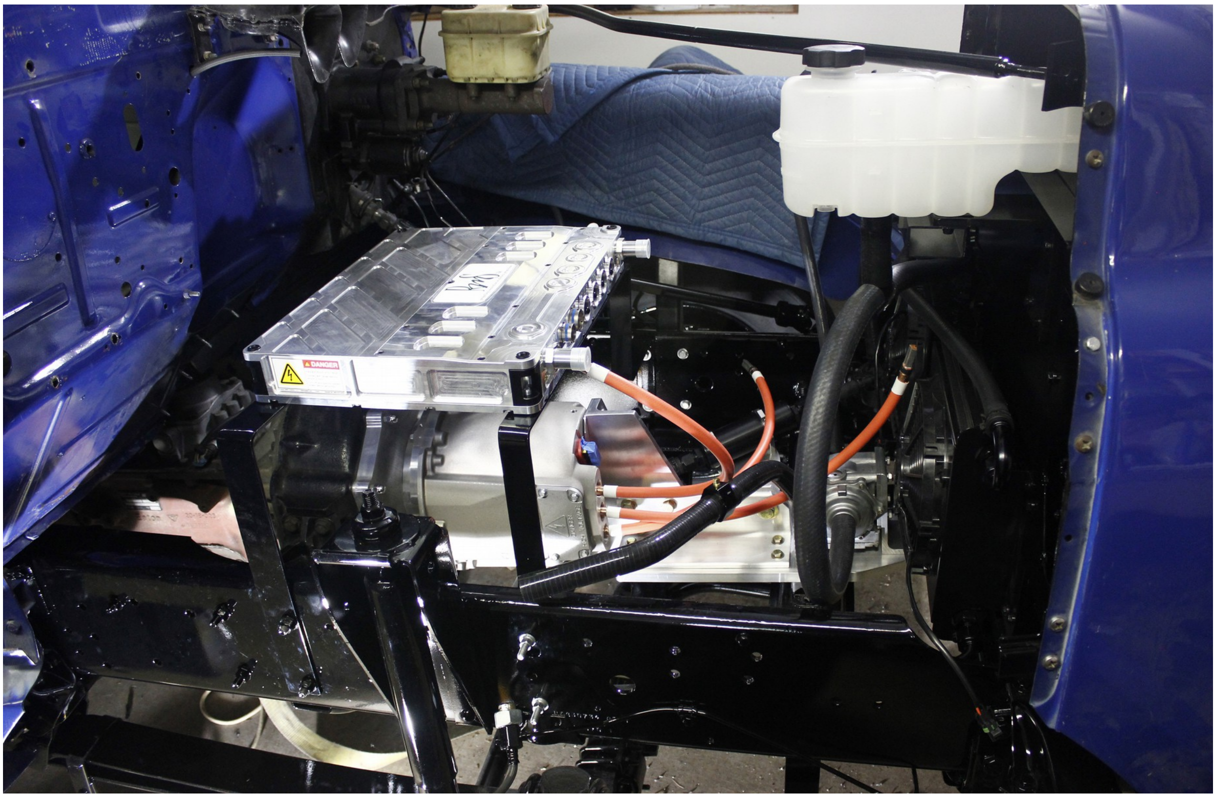

Figure 9: EV Components are being installed in the old engine bay

4 Conclusion

4.1 Going Forward

The project seeks to prove that the technology exists today to make even very heavy, un-aerodynamic refrigerated delivery trucks 100% electric. Large trucks are normally powered by fossil fuels which will eventually run out and their high maintenance combustion engines are loud and pollute the air. Furthermore, as internal combustion vehicles age, they tend to get dirtier, leak more fluids and pollute more. This project demonstrates that older vehicles, no matter their size or age can be upgraded and given new life with a much cleaner electric powertrain. Perhaps other companies and fleets will decide to re-cycle older vehicles by retrofitting them with electric drive systems. It is my hope that the industry will take notice and companies will begin to offer long-range, high performance fully electric trucks. At the time of this writing, the build phase of the electric delivery truck project is nearly completed and it is scheduled to hit the streets of Seattle for regular deliveries in the fall of 2017. If you are in the area you can come visit 21 Acres in Woodinville, WA and see this impressive truck in action.

Acknowledgments

I'd like to acknowledge Robin Crowder and the whole crew at 21 Acres for having the vision and determination to create a fully electric delivery truck when none was available that met their requirements. Also I would like to give a special thanks to Ron Easley, Cory Tsai, Charlie Tsai, Larry Rinehart, Chris Brune, Travis Travelstead, Ken Johnsen, Otmar Ebenhoech, Pat McCue, Jeff Rike, Larry Easley, Ken Young, Bill Kramer, Bob Stenerson, Brian Hughes, Craig Smith and Chad Hohn for their support. And thanks to the folks at Manzanita Micro and the crew at Top Secret Customs in Arlington, WA.

Authors

Stephen Johnsen graduated with a degree in industrial design from the University of Washington. He has taught many electric vehicle and battery courses at South Seattle College, worked with and tested many battery chemistries, designed battery packs, built and helped with a number of record setting electric racing vehicles. Mr. Johnsen started High Performance EV (HPEV LLC) in 2010 which provides consulting and R&D services. Stephen has served on numerous technical advisory committees advising policy makers on electric vehicle technology. He is also currently President of the Seattle Electric Vehicle Association, the second largest chapter of the EAA. In his leisure time, he is likely to be found hiking outdoors or racing an EV against petrol vehicles at the racetrack.