Development and Demonstration of Medium-Heavy Duty PHEV Work Trucks

EERE Award DE-EE0007994
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Final Report

Executive Summary:

The heavy-duty vehicle market (Class 6-8) has been a difficult segment for the introduction of plug-in vehicles due to the large energy storage requirement (with corresponding cost), challenging duty cycles, and the diversity of vehicle configurations. The Work Truck market represents a significant opportunity for Heavy-Duty PHEV adoption.

- The usage cycle includes driving and stationary/worksite power requirements, ensuring full daily usage of the grid-charged battery (battery size: 15-30kWhr). Though daily driving can often be short (an average of 26 miles per day), worksite power includes substantial demand (hydraulics, exportable 110/220V power, 12V support, HVAC).
- Worksite power demands for conventional vehicles require continuous loaded engine operation, resulting in significant emissions, fuel consumption and noise impacts.
- These trucks serve an industry that is highly diverse in final vehicle duty cycle, configuration, and jobsite power demands resulting in the need for a modular, configurable hybrid solution.

Through this program, Odyne has developed and demonstrated a medium/heavy duty plug-in hybrid solution capable of meeting the needs of the work truck market while delivering fuel and emissions reductions of 50% or greater when evaluated against the full-day work truck duty cycle. The Odyne system developed in this project was released for commercial sale as the G2V7 Odyne Plug-in Hybrid and ePTO systems. The testing and field demonstration proved that the Odyne hybrid system is capable of reducing work truck fuel use and emissions by over 50% while subsequent commercial sales demonstrate the flexibility of the modular design and the capability to support electric systems of 12 – 30 kW and hydraulic based systems of 60 kW (80 HP) or greater. Odyne is continuing to work with suppliers on reducing component costs and working with supporting agencies to initiate projects to increase the driving and full day fuel and emissions savings in order to continue to improve the customer value and return on investment.

Project Objectives/Actual Accomplishments:

The project goal was to design, develop, and demonstrate a new generation of medium/heavy-duty plug-in hybrid electric work truck that achieves a 50% reduction in fuel consumption versus a conventional vehicle baseline when evaluated across a full day work cycle representative of the vocational work truck. The primary objectives are:

- To simulate, design and develop unique and innovative integrated powertrain, software, and calibrations which will optimize the complete diesel/transmission/hybrid powertrain and demonstrate the potential for driving fuel efficiency improvements greater than 40% with commensurate reductions in GHG emissions.
  - Odyne demonstrated the capability of fuel efficiency improvements of up to 75%, depending on duty cycle and battery energy utilization/
- To develop and validate a modular Lithium-Ion battery system based on high volume lower cost cells and modules that are utilized in the light-duty sector which will meet the power, energy, and duty cycle requirements of the MD-HD vocational truck market at a cost approaching half that of currently available low volume solutions.
  - Odyne was not able to secure a supplier to meet the cost/kW targets. The low volumes of the current work truck market was the critical stopping point. Odyne was able to find a supplier with increased capacity, reduced space claim, and a slightly reduced cost per kWh which ended up being a major improvement in Odyne's improved modular packaging and which led to commercial expansion.
- To integrate fully electrified worksite functions and a daily duty cycle optimization function with the powertrain and battery solutions on an OEM class 6-7 chassis and demonstrate the capability of 50% reduction in total fuel used when measured against a full day duty cycles and real-world performance.
  - Odyne demonstrated, analytically, the capability of achieving greater than 50% reduction in work truck fuel use.

- To demonstrate ten optimized PHEV work trucks and validate the vehicle's operating performance, emissions, and full work cycle fuel reduction capability in excess of 50%.
    - Initial results from the test fleet only demonstrated a 33% reduction in fuel use (Still significant), but opportunities were identified to raise that improvement to 50% or higher. Odyne is continuing to work with all of its commercial fleets to maximize the real world fuel savings.

Summary of Activities:

Hybrid Powertrain Integration and Optimization:

Odyne provided telematics data to NREL from 119 vehicle ARRA fleet. NREL preprocessed the data into 26,539 vehicle days and completed duty cycle analysis. Driving data was divided into trips, with trips separated by at least 5 minutes when the vehicle was stopped. The trips were clustered using a k-medoids algorithm to identify groups of trips with similar driving average speed, kinetic intensity, stops/mile, speed standard deviation, aerodynamic speed, and characteristic acceleration. NREL researchers used the DRIVE tool to generate representative drive cycles for each cluster. The custom cycles are referred to as Odyne Low, Mid, and Hi. UDDS and HHDDT drive cycles were also evaluated. The Drive Cycles developed by NREL utilized in baseline testing are shown in Figures 1-3. After review, it was decided to utilize the UDDS cycle in place of the Odyne Hi cycle due to the similarity of their duty cycle metrics and the wider range of comparative data available for UDDS. The HHDDT cycle was utilized intermittently for further reference.

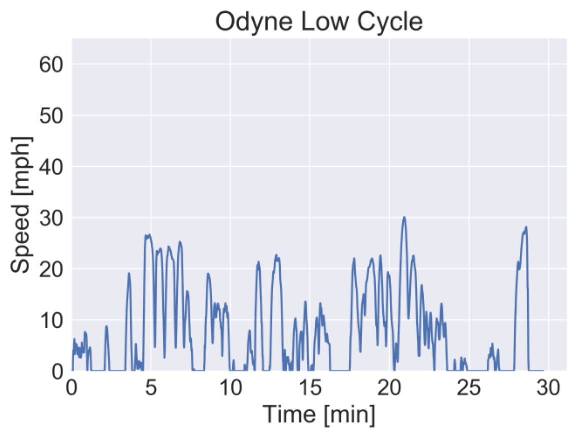

Figure 1: Odyne "Low" Cycle

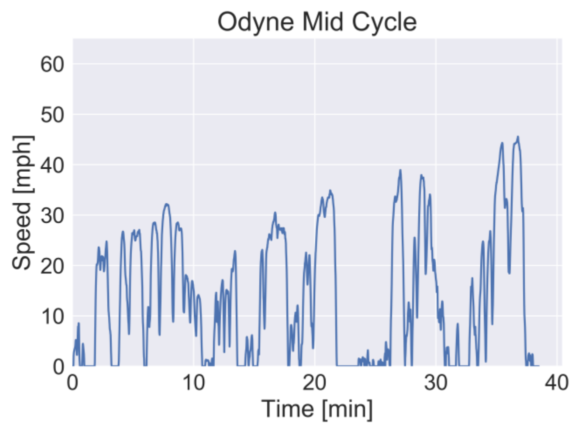

Figure 2: Odyne "Mid" Cycle

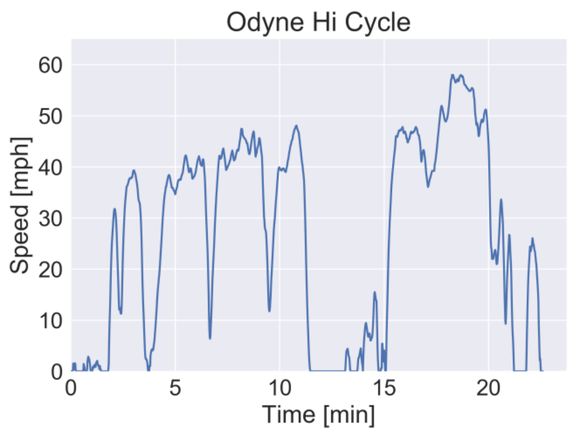

Figure 3: Odyne "Hi" Cycle

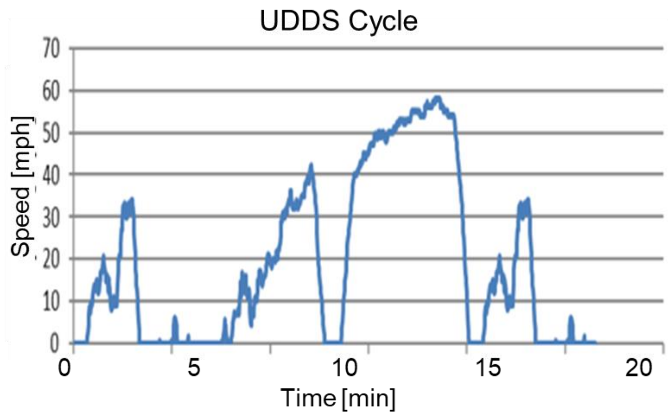

Figure 4: UDDS Cycle

NREL adapted methods utilized in creating drive cycles to develop a stationary duty-cycle. A transient PTO Stationary duty cycle was created for dynamometer testing and vehicle full-day simulation (Figure 5)

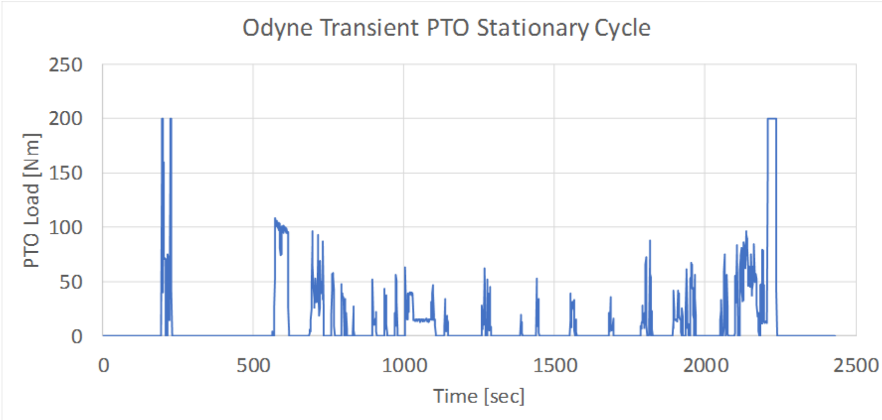

Figure 5: NREL PTO Stationary Duty Cycle

Odyne worked with Oak Ridge National Laboratory (ORNL) to analyze hybrid strategies against the NREL duty cycles to assess best possible means of employing hybrid driving strategy with an aim towards maximizing fuel economy benefits with efficient use of available plug-in battery energy utilization. After iterative development, 2 primary strategies were chosen to move to Hardware-in-Loop (HIL) powertrain dynamometer development: A Charge Depleting (CD) strategy which, when combined with Neutral Idle (NI), provided 29 – 57 % improvement in fuel economy. The second strategy was a Charge Sustaining (CS) strategy which, when combined with NI provided 8 – 17% improvement in fuel economy with no net use of battery energy. The results of the analysis are summarized in Table 1.

Table 1: Oak Ridge Driving Simulation Fuel Economy Improvement Summary

Cycle	CS	CS NI	CD	CD NI
UDDS	5%	8%	20%	29%
HHDDT	4%	6%	44%	48%
NREL Med	8%	11%	39%	39%
NREL Low	11%	17%	46%	57%

Odyne then worked with Oak Ridge National Laboratory (ORNL) to finalize the driving strategies utilizing the ORNL Hardware-in-Loop (HIL) powertrain dynamometer (Figure 6). The testing was based on strategies developed using full vehicle simulation. During dynamometer testing it was noted that the fuel economy improvements on the HIL did not achieve the levels of improvement predicted by the model (CD-Model) in three of four duty cycles (Table 2). After investigation, it was determined that there was significant interaction between the hybrid drive strategy and the powertrain SCR strategies. It was not known at the time of testing whether this interaction was a laboratory phenomenon or a real-world interaction. Although the HIL testing did not achieve the targeted 40% fuel economy improvement target, the 25 – 38% improvement was determined to be acceptable at this stage of development. The project team devised an "SCR mitigation" strategy to be available for evaluation during full vehicle testing at NREL.

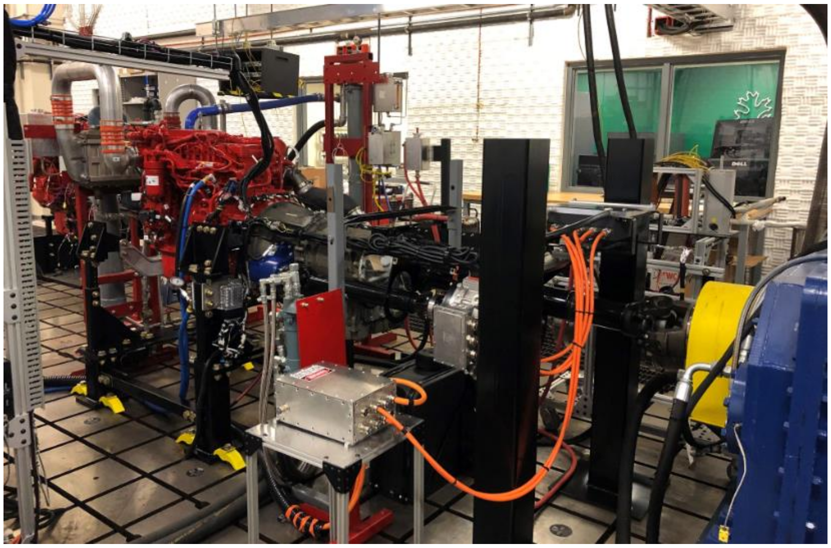

Figure 6: : Oak Ridge Hardware-in-Loop (HIL) powertrain dynamometer

Table 2: Oak Ridge Driving Simulation vs HIL Test Fuel Economy Improvement Summary

Cycle	CD – Model	CD – HIL
UDDS	29%	36%
HHDDT	48%	38%
NREL Med	44%	35%
NREL Low	57%	29%

The prototype hybrid drive software was installed in the project test vehicle (Figure 7) and the test vehicle was shipped to the NREL ReFuel chassis dynamometer in February 2020 (Figure 8). The scheduled testing was delayed due to the Covid related shutdown of the facility. Testing began in July 2020 and was completed in late August under a reduced number of duty cycles due to laboratory backlog. In this testing the project team tested both a low energy strategy (Mild) and the previously developed CD strategy, now termed "Aggressive" against three duty cycles, eliminating the HHDDT cycle which was considered to have similar characteristics to the NREL Med cycle developed for this project. During chassis testing, the impact of the SCR system did not appear to interact as significantly as on the ORNL testing. The SCR mitigation strategy was also utilized. Fuel economy improvement results for the Aggressive calibration ranged from 69 – 75%, far exceeding the project target of 40% improvement. Fuel economy improvement results for the Mild calibration ranged from 9 – 23%, (Table 3).

Figure 7: Odyne Project Test Vehicle

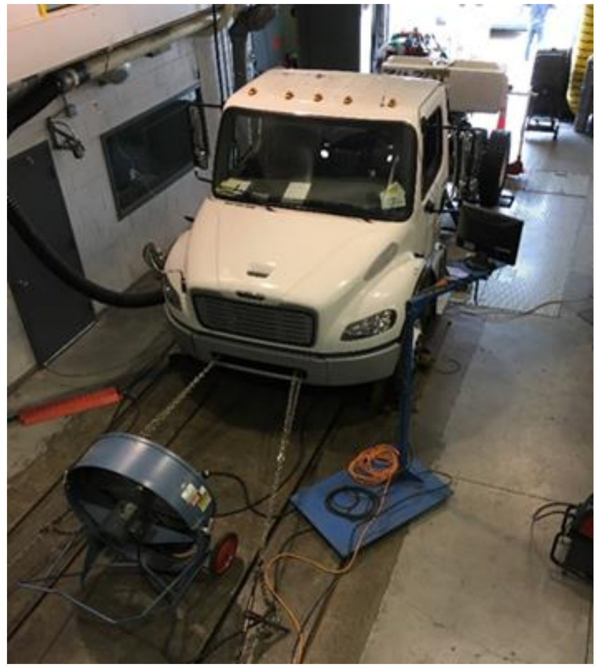

Figure 8: Test Vehicle at NREL ReFUEL Dynamometer

Table 3: NREL ReFUEL Chassis Dynamometer Fuel Economy Improvement

Strategy	Duty Cycle	Distance (mi)	Fuel Used (Gal)	MPG	MPG Improvement (%)	Energy Used per Mile (kWh)
Conventional	UDDS	5.503	0.892	6.174		0.000
Hybrid Mild	UDDS	5.498	0.813	6.762	9.5%	0.060
Aggressive	UDDS	5.514	0.528	10.456	69.4%	0.971
Conventional	Odyne Low	3.782	0.809	4.678		0.000
Hybrid Mild	Odyne Low	3.780	0.656	5.758	23.1%	0.508
Aggressive	Odyne Low	3.788	0.476	7.954	70.0%	1.675
Conventional	Odyne Med	8.911	1.431	6.226		0.000
Hybrid Mild	Odyne Med	8.907	1.226	7.266	16.7%	0.197
Aggressive	Odyne Med	8.897	0.815	10.918	75.4%	1.220

NREL also provided stationary test results from the Stationary duty cycle created during duty cycle analysis. The NREL calculation considers the energy utilized by electric PTO (ePTO) to be replenished by a field recharge (as opposed to Plug-in charge). This is a worst-case scenario; telematics data indicates 80-100% of ePTO energy is derived from Plug-in charge during a typical day. Under the NREL assumptions, the Odyne ePTO system utilized 80% less fuel and produced 98% less NOx when compared to a conventional Diesel PTO system . If the energy was derived from Plug-in charge, the reduction would be 100%. The field recharge comparison results are depicted in Table 4.

Table 4: NREL ReFUEL Chassis Dynamometer Stationary Results

Strategy	Duty Cycle	Condition	Shaft Energy (kw-hr)	Fuel Used (Gal)	Efficiency (gal/kW-hr)	Gal/kW-hr Improvement (%)
Conventional PTO	NREL Stationary	Cold Start	1.450	0.6153	0.4243	
Hybrid ePTO Charge	Field Recharge	Cold Start	4.774	0.5328	0.0893	78.5%
Conventional PTO	NREL Stationary	Hot Start	1.451	0.6184	0.4261	
Hybrid ePTO Charge	Field Recharge	Hot Start	5.299	0.4580	0.0692	82.8%

Utilizing the full year duty cycles provided by NREL, along with the Drive and Stationary fuel savings results generated by the project test vehicle as tested on the NREL ReFUEL dynamometer. Odyne created a hybrid and stationery ePTO strategy which is predicted to reduce fuel consumption of a typical Hybrid ePTO utility vehicle by greater than 50%. Figure 9 illustrates the predicted fuel savings on a daily basis when analyzed across the 1-year utility vehicle duty cycle provided by NREL.

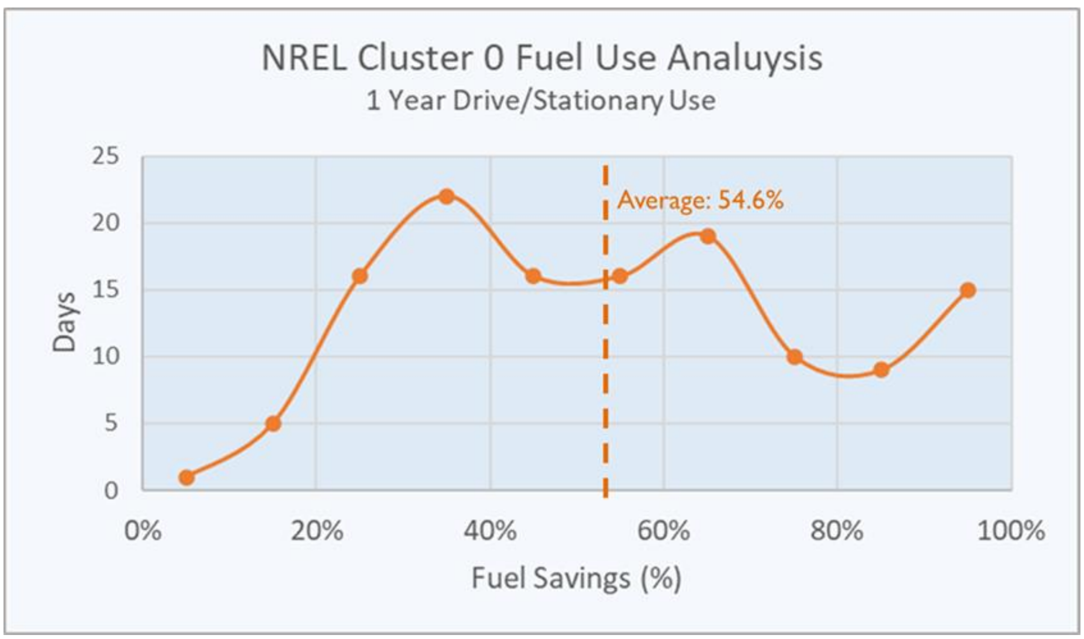

Figure 9: Daily and Average Fuel Savings – 1 year Utility Truck Duty Cycle

Summary: Hybrid Powertrain Integration and Optimization:

With the analytical development and test support of NREL and ORNL, Odyne was able to demonstrate that the driving duty cycle for the work truck spanned nearly the entire range of Medium/Heavy-Duty commercial vehicle cycles previously identified by NREL, that the driving portion of the work truck full-day duty cycle often accounted for less than 50% of the work truck fuel use, and that the Odyne Hybrid Drive system could be tuned to achieve from 10% to as much as 75% improvement in driving fuel economy, while electrifying the stationary ePTO work could provide 80 – 100% elimination of stationary fuel use and emissions. These results were utilized to develop a blended strategy for the demonstration vehicles when considering battery cost and size, stationary energy needs, and the real-world duty cycle of the Medium/Heavy Duty work truck.

- The improvements delivered by the Odyne System combine the fuel and emissions savings while driving with the Engine-Off benefits of hybrid jobsite operation.
- The benefits for All-electric Stationary work outweigh the driving benefits when looking at Gallons saved/kWh.
- The system was optimized for available Battery energy by utilizing a modified Mild driving strategy, thus reserving more energy for Stationary work.
- NREL Provided Full-year Drive/Stationary Duty Cycles for analysis.
- From the Drive and Stationary Dyno data, full year fuel use reduction could be calculated.
- **The Simulated Full Year Fuel Savings for the Odyne PHEV Work Truck was 54.6%**

Battery Systems:

Odyne began the project partnering with AVL, who had proposed that they could source a tier one battery pack utilized by a major OEM for integration into the Odyne system. At that time, Johnson Controls (JCI) was Odyne's production source, providing 14kWh battery packs at a cost of $704/kWh. The AVL proposal was to obtain and integrate the LG sourced battery pack or Modules at a cost of less than $400/kWh. Shortly after the initiation of the project, AVL encountered difficulties obtaining permission to utilize LG Chem / Chrysler packs or modules they had proposed during submission process and informed Odyne that they could not get Chrysler's permission to utilize pack or module and that LG Chem did not have enough interest to push the issue. AVL then proposed that they would assemble a supply evaluation matrix to identify key supply alternatives. The study identified no feasible solutions and AVL was removed from the project in late 2017.

Concurrently, Odyne was informed by JCI, the current production source. that they were going end-of-life with high voltage battery packs within a year. Odyne launched its own sourcing investigation while also contracting Ricardo Strategic Consulting to perform a Supply chain sourcing exercise. Over 50 potential suppliers were contacted, over 50% of those returned no-quotes due to the lower volumes of the truck market. Of those returning quotes, most were above $800 per kilowatt-hour, 2 were between $600-$700 and one provided a quote of $352 per kilowatt-hour. Odyne selected 2 potential suppliers for battery systems, the low-cost bidder (Lishen America) and a low volume US source (Octillion). During late 2018, technical and commercial concerns caused the primary supplier, Lishen, to be dropped from consideration due to lack of corporate support and continuously changing designs. The second supplier, Octillion, missed several delivery milestones, at which point Odyne resumed the search for an alternate supplier of battery systems.

In January 2019, Torqeedo provided an 11.6 kWh battery pack based on a system used in light duty regular production (Figure 10). While not an optimal form factor for the work truck market and at a cost of $850/kWh, with the impending end-of-life of the current JCI production battery and no better solution available, for 2019 and early 2020, the Torqeedo pack was the primary project and production battery system, Odyne continued to search for alternative solutions.

Dimensions and preliminary specifications

	Torqeedo high-voltage battery
Nominal voltage	355 V
Max. continuous performance	55 kW
Capacity	10.0 kWh useable (11.6 kWh total)
Weight	98 kg
Dimensions	1460 x 305 (240) x 330 mm

Figure 10: Torqeedo 11.6 kWh battery pack

In early 2020, Odyne identified Enerdel as the next potential supplier. Compared to the Torqeedo 11.6kWh solution, the Enerdel 17.7 kWh pack was lower priced, at $594/kWh, higher capacity, more power dense, and provided better packaging (Figure 11), The design team developed the packaging, subsystem and component layouts and drawings to efficiently install the hybrid electrification system on a wide range of work trucks. In July 2020, The Enerdel 17.7 kWh pack was selected as the final primary path for the project and was concurrently put into production.   Figure 12 illustrates the Torqeedo design configuration with hybrid components represented in green, Figure 13 represents the final Enerdel configuration.

Enerdel 17.7 kWh system (Primary Path, July 2020)

- Compact design provides 70% more energy with good packaging capability
- 355v Nominal Voltage
- 150 kW Continuous Discharge
- Mass 152 kg
- Dimensions: 808 X 548 X 305 mm
- $594 per kWh
- Primary demonstration path
- Current Odyne Production

Enerdel 17kWh RESS

Figure 11: Enerdel 17.7 kW Battery

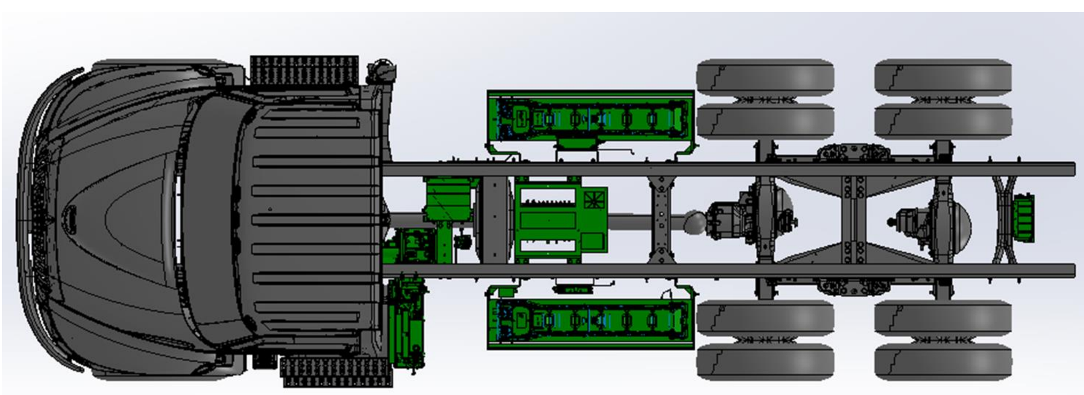

Figure 12: Torqeedo 2 X 11.6 kWh Configuration

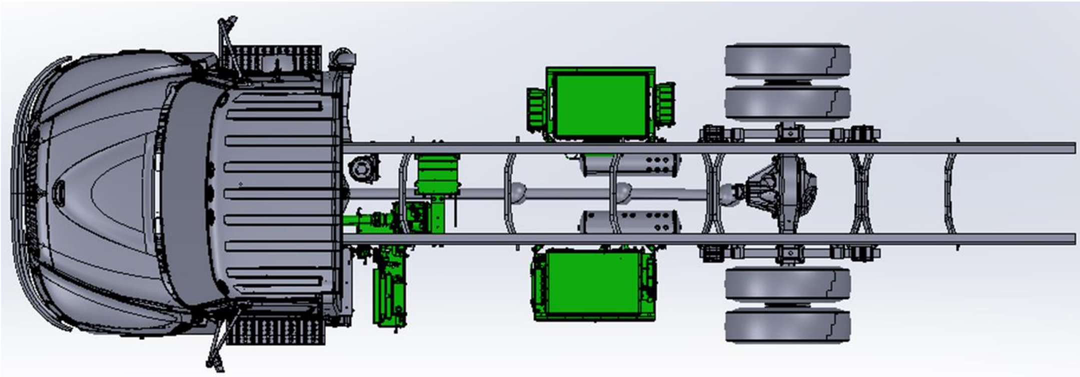

Figure 13: Enerdel 2 X 17.7kWh Configuration

Summary: Battery Systems:

Investigation into the RESS (Battery) supply base did not yield cost-effective alternatives in the targeted $400/kWh range It was found that few other suppliers have pre-packaged and validated systems in the 5-15kWh range. At the volumes that Odyne can reasonably predict, the engineering and validation costs of a custom module were cost prohibitive and production costs were quoted above the current JCI cost.

Most Large OEM's and Tier 1's were not interested in Odyne due to low volume. Small, midrange, and specialty companies provided the most input with typical quoted cost is greater than $800 kWh and often could not meet promises. Although Odyne did end up with a cost per kWh decrease, the selected battery resulted in higher capacity and improved capability, not lower net system cost. While the Cost/kWh did go down, the results were nowhere near the industry projections at the onset of the project (Figure 14).

Project targets:
Target: <$400/kWh
Results: $594/kWh

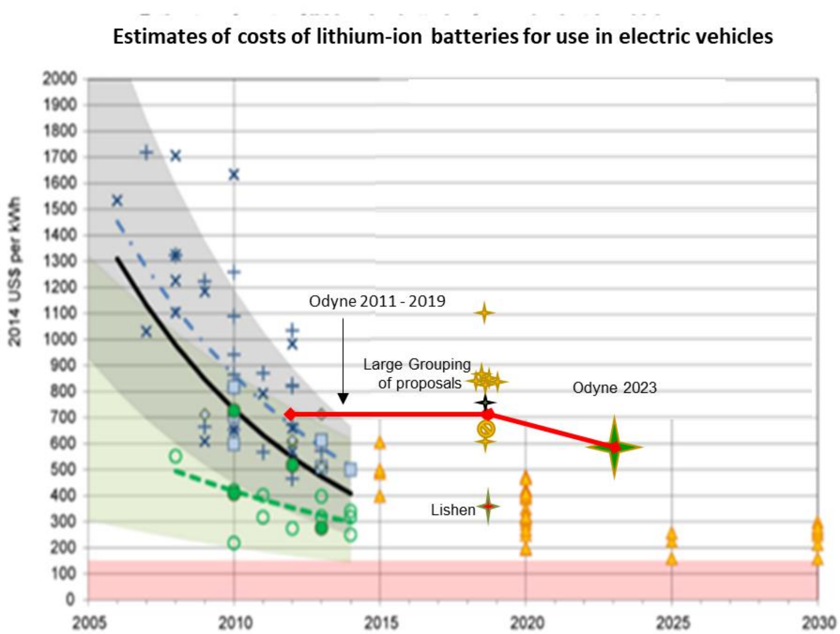

Figure 14: Results vs. Projected Trends ($/kWh)

Vehicle Development and Demonstration

The system solution incorporates a simple, parallel hybrid system that allows the torque of the electric motor to augment the torque output of the diesel engine, thus saving fuel. The motor speed is synchronized with the engine speed through the existing power take-off (PTO) unit. The traction motor drives the PTO, adding torque to the rear axle, or converts torque from the PTO into power to charge the PHEV batteries (Figure 15).

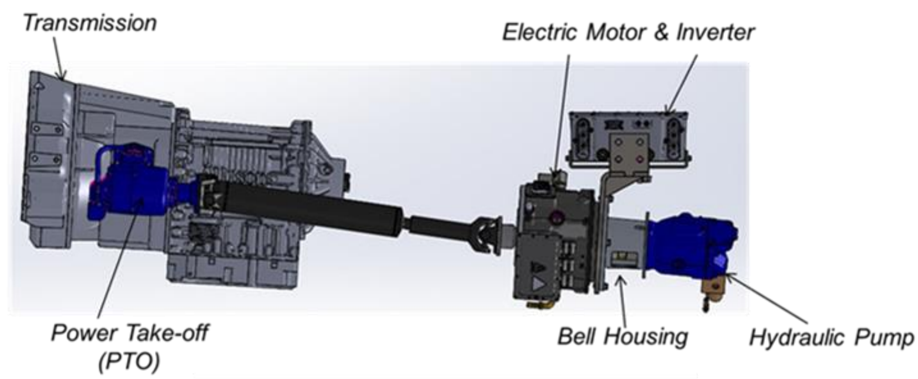

Figure 15: Odyne powertrain configuration

The system is also designed to provide full jobsite engine off electrification utilizing power from the lithium-ion battery system to provide 120/240 V exportable power, 12V chassis systems support, high efficiency electric heating and air conditioning along with the power to drive the primary work equipment (Figure 16).

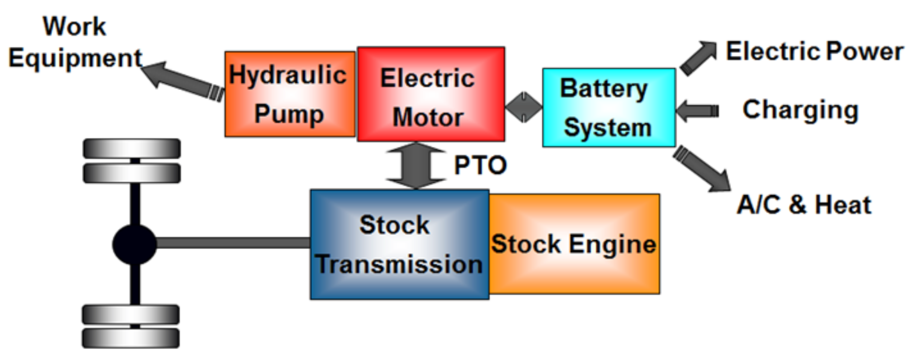

Figure 16: Odyne hybrid architecture

During FY21, the design team completed the packaging, subsystem and component layouts and drawings to efficiently install the hybrid electrification system on a wide range of work trucks and updated the test truck to the new configuration. Because of the compact size of the Enerdel battery, most of the freestanding power and control components were able to be attached within the footprint of the previous battery bracket, greatly reducing the system package space, number of sub-assemblies, and wiring complexity. Figure 17 represents the final configuration with the hybrid components identified and Figure 18 is the updated test vehicle.

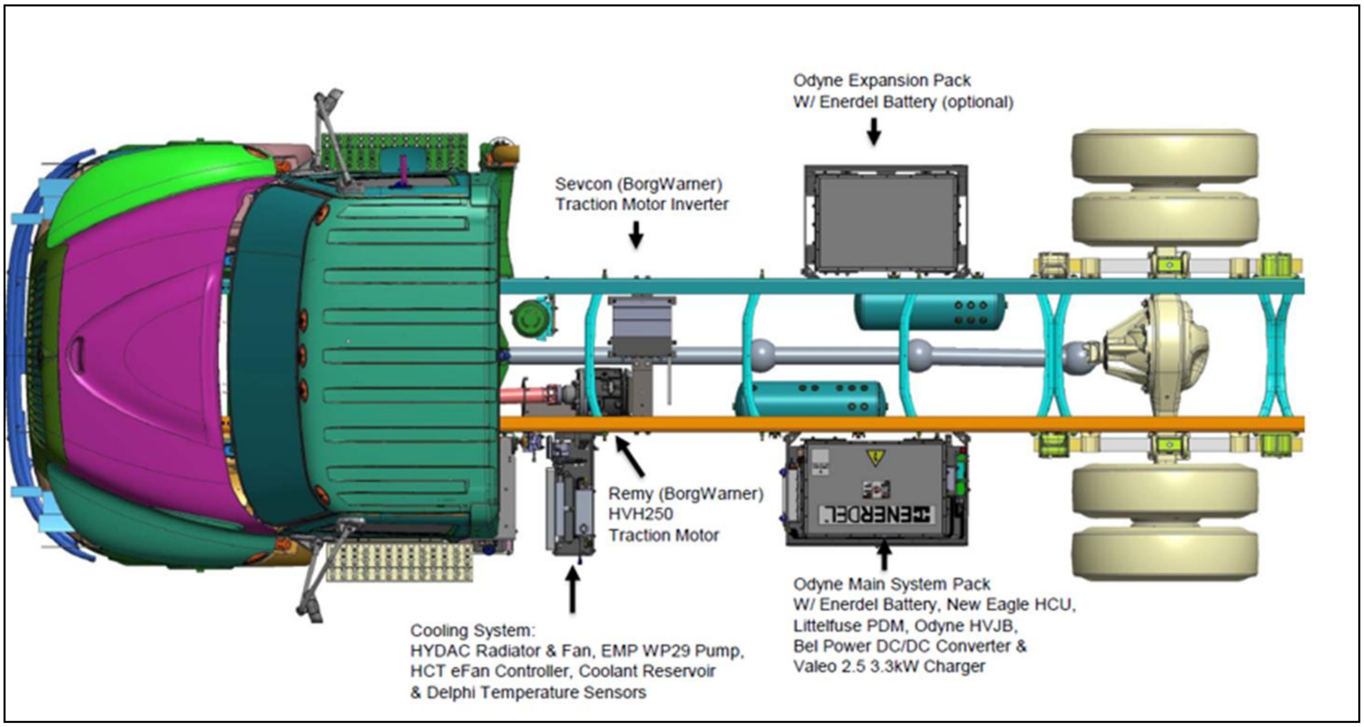

Figure 17: Odyne Final Design Configuration

Figure 18: Updated test vehicle

During FY22-23, Odyne completed delivery, training and vehicle support for the 15-unit demonstration fleet at Tacoma Public Utilities (TPU). Figure 19 is one of the first units delivered to TPU.

Figure 19: Tacoma Public Utilities Hybrid Step Van

Odyne installed telematics for use case analysis and visited Tacoma fleet and work sites to gather operator and fleet feedback. Fleet management reported all was going well and that their data on fuel savings appears about double that of the conventional step vans replaced by the Odyne Hybrid step vans (Combined driving and stationary fuel economy, reported in MPG - 50% reduction in fuel use). The operator crew leads also reported that they were very happy with the system. They all commented on the improvement improvements in driving on the hilly roads of Tacoma due to the improved acceleration of the Odyne Launch Assist and improved braking power due to regenerative braking. They also said they appreciated the silent work environment while keeping the vehicle cool utilizing the Odyne ePTO battery powered air conditioning system. Figure 20 contains images from operator visits.

Figure 20: Tacoma Site Visit

Odyne analyzed the usage patterns of the Tacoma fleet using data from the proprietary Odyne Telematics system. Of the 15 vehicles in the fleet, 11 vehicles provided consistent and usable data. Table 5 reflects the Duty-cycle statistics of the observed fleet.

Table 5: 4Q22 Tacoma Usage Summary

Total Usage Summary			
# Vehicles	11	# Driving Vehicle-Days	325
# Vehicle-Days	354	# ePTO Vehicle-Days	262
Net Distance (mi)	11,945	Net Plug-In Hours	4,325
Net Distance CS (mi)	0	Net Driving Hours	340
Net Distance CD (mi)	11,945	Net PTO Hours	1,094
Net Plug-In Energy (kWh)	2,028	Net Stationary Idle Hours	929
Net Eng. Charge Energy (kWh)	3	Net Drive Fuel (gal)	1,159
Net Drive Energy (kWh)	537	Net Eng. Charge Fuel (gal)	0
Net ePTO Energy (kWh)	1,014	Net Stationary Idle Fuel (gal)	852

Full Day Summary			
# Driving Vehicle-Days	325	# ePTO Vehicle-Days	262
Average Drive Hours	1.33	Average Distance (mi)	14.52
Average Idle Hours	2.9	Average Drive Fuel (gal)	3.1
Average PTO Hours	3.98	Average Idle Fuel (gal)	2.12
Average Plug-In Hours	13.03	Ave. Number of Engine Charges	0

Daily Driving Summary	
# Vehicle-Days Driving	325
Average Drive Hours	1.33
Average Drive Idle Time (min)	13.25
Average Distance (mi)	14.52
Average Speed (mph)	21.7
Average Kinetic Intensity (1/mi)	1.16
Average Drive Fuel (gal)	3.1
Average Drive Idle Fuel (gal)	0.27

Daily ePTO & Parked Idle Summary	
# of ePTO Days	262
Ave PTO Hours	3.98
Ave ePTO Energy (kWh)	3.99
Ave ePTO Power (kW)	0.97
Ave Parked Idle Hours	2.9
Ave Parked Idle Fuel (gal)	2.12
Weighted Ave Demand Ratio	0

Analysis

Individual vehicle records were analyzed for fuel used driving, idling, and, when the calculated effect of fuel savings due to ePTO were factored in, the conservative estimate for fleet fuel savings was a 33% reduction in fuel use.

It was noted that there was still an extremely high amount of fuel being utilized during stationary idle. Odyne offered to implement a 5-minute idle shut-down mode but the offer was turned down by Tacoma fleet management for the current time, instead opting for further operator training on effective use of the Odyne hybrid system. Odyne has calculated that with 5-minute idle-shutdown, the system should be capable of achieving over 60% reduction in fleet fuel use. Odyne will continue to work with Tacoma Fleet management to improve and optimize the systems and usages of the Odyne hybrid system beyond the conclusion of this project. The individual vehicle savings, fleet savings, and potential future savings calculations are illustrated in Table 6.

Table 6: 4Q22 Tacoma Usage Summary

Calculation of Driving Fuel Economy				Calculation of Stationary Idle Fuel Use Per Hour [gph]			Calculated Fuel Saved Using Odyne System [gal]		Calculated Percent Fuel Reduction [%] (from non-hybrid)	(if idle fuel is mitigated) Calculated Percent Fuel Reduction [%] (from non-hybrid)	
Odyne Truck	Distance Traveled [miles]	Fuel Consumed Driving [gal]	Miles Per Gallon [mpg]	Idle Hours [hrs]	Idle Fuel Consumed [gal]	Idle Fuel Used Per Hour [gph]	ePTO Hours [hrs]	Fuel Saved [gal]	Fuel Reduction [%]	% Statioary time idling	Fuel Reduction [%]
2540	355.07	32.04	11.08	5.52	8.05	1.46	55.55	81.04	67%	9%	74%
2543	1230.88	123.33	9.98	142.43	115.17	0.81	51.39	41.56	15%	73%	56%
2545	597.12	52.66	11.34	30.02	39.53	1.32	166.02	218.63	70%	15%	83%
2546	362.91	37.48	9.68	22.51	20.94	0.93	96.08	89.40	60%	19%	75%
2547	514.23	60.95	8.44	110.68	91.78	0.83	103.14	85.53	36%	52%	74%
2548	1045.92	88.26	11.85	117.20	126.21	1.08	74.82	80.57	27%	61%	70%
2549	1413.11	132.92	10.63	71.99	54.72	0.76	53.33	40.54	18%	57%	42%
2551	2327.23	263.28	8.84	198.35	171.90	0.87	126.82	109.91	20%	61%	52%
2552	1887.75	143.93	13.12	121.81	102.28	0.84	36.31	30.49	11%	77%	48%
2553	2115.78	212.40	9.96	95.32	100.24	1.05	305.32	321.09	51%	24%	66%
2554	95.75	12.00	7.98	13.19	22.04	1.67	26.19	43.75	56%	34%	85%
Fleet	11945.75	1159.26	10.30	929.01	852.88	0.92	1094.97	1005.23	33%	46%	62%

Products and Technology Transfer Activities:

The Odyne system developed in this project was released for commercial sale as the G2V7 Odyne Plug-in Hybrid and ePTO systems. As a result of the improvements generated within the project in the areas of duty cycle modelling, drive strategy tuning, Increased power and energy capacity, modular assembly, and reduced space-claim, Odyne has been able to expand the application of its hybrid systems into new vocations within the work truck market. Figures 21 – 24 illustrate the new markets Odyne is currently entering as a direct result of this project.

- Refuse: City of Cambridge:
  - Hybrid assist drive functions
    - Uses Modified Aggressive & Charge-while-drive strategy,
    - New Higher capacity batteries
  - **3 Units for daily fleet use - delivered**

Figure 21: City Refuse

- Wallboard/Large Crane – Interstate Crane
  - Higher motor power & duty cycle energy than existing systems
    - Uses modular Parker 210-300 – first application,
    - New, Higher Capacity Batteries
  - **9 units delivered – 18 in process**

Figure 22: Wallboard Crane

- Electrified Street Sweeper - Elgin Sweeper
  - Electrification of hydraulic sweep functions
    - Uses new Charge While Drive Strategy
  - **9 Units delivered**

Figure 23: Electrified Street Sweeper

- Rail Maintenance - SEPTA (Southeastern Pennsylvania Transportation Authority)
  - All Electric Creep
    - Developed in the course of project, Tested at NREL
  - **3 Units delivered**

Figure 24: Rail Maintenance

The project enabled Odyne to refine and validate its next generation product based on customer duty cycles, system optimization, and modularized assembly with reduced space-claim. . As a part of the project, Odyne worked extensively with the National Renewable Energy Lab to develop work truck duty cycle analytical capabilities and with Oak Ridge National Laboratory to refine and optimize its unique ePTO hybrid system. Through this work, Odyne remains the only proven provider of Hybrid Drive and ePTO systems for vocational vehicles capable of delivering fuel and emissions reductions of 50% or greater for the medium-heavy duty work truck market.

Odyne wishes to thank the supporting members of the Department of Energy Vehicle Technology Office, National Renewable Energies Laboratory and Oak Ridge National Laboratory for their considerable support in this project. Odyne is a registered small business operating out of Pewaukee, Wisconsin USA

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