Hybridization of Class 8 Line Haul and Regional Refrigeration Trucks CRADA

Dean Deter
Email: DeterDD@ornl.gov
Phone: 865-946-1580

Oak Ridge National Laboratory
National Transportation Research Center

2017 U.S. DOE Vehicle Technologies Office Annual Merit Review

June 6, 2017 **Project ID: GI192**

This presentation does not contain any proprietary, confidential, or otherwise restricted information

ORNL is managed by UT-Battelle
for the US Department of Energy

Overview

Timeline	**Barriers***
• Project start date: April 2016 • Project end date: January 2019 • 20% Complete	• Cost • Infrastructure • Risk Aversion **from 2011-2015 VTP MYPP*
Budget	**Partners**

• Cummins Share (50%)
• DOE Share (50%)
    • FY16 funding: $50
    • FY17 funding: $350
    • FY18 funding: $100
	• Oak Ridge National Laboratory
	• Cummins Inc.

Relevance

- **Objective:**
  - Analytically verify a novel approach for the electrification of refrigeration trailers connected to Class 8 HD trucks.
- **How:**
  - Develop system control strategies that correspond to prototype hardware to hybridize the operation of heavy duty (HD) refrigeration trucks and trailers.
  - The proposed effort includes experimental validation and verification of functionality and petroleum consumption reduction as a result of the proposed technologies.
- **Why:**
  - The benefits from the hybridization of refrigeration trailers can provide significant reductions in fuel consumption, criteria pollutants, and greenhouse gas emissions.
  - The proposed hybrid system would provide these benefits by meeting power requirements of the refrigeration trailers in a more optimal way versus the current standard diesel genset approach.

OAK RIDGE National Laboratory | NATIONAL TRANSPORTATION RESEARCH CENTER

Milestones FY16 – FY18

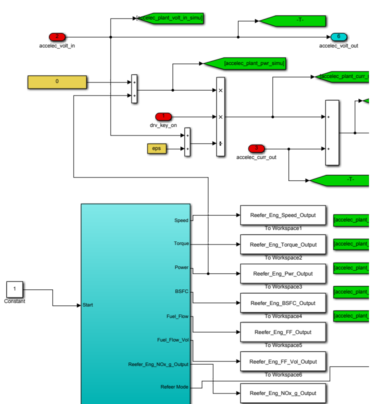
Month/ Year	Milestone or Go/No-Go Decision	Description	Status
Aug 2016	Milestone	Collect data, system specifications, available models, and various duty and drive cycle information.	COMPLETE
March 2017	Milestone	Validate conventional, diesel electric, and prototype refrigeration trailer models using the CTI fleet data, provided manufacture data, and possible Cummins test vehicle.	COMPLETE
Sept 2017	Milestone	Design and build a prototype hybrid system utilizing findings from the modeling portion of the project.	ON SCHEDULE
March 2018	Milestone	Integrate and test full prototype system in ORNL VSI laboratory. Develop full systems controls for vehicle integration and system optimization.	ON SCHEDULE
Dec 2018	Milestone	Integrate full system into Cummins test vehicle for on road and possible fleet testing as well as system validation.	ON SCHEDULE

OAK RIDGE National Laboratory | NATIONAL TRANSPORTATION RESEARCH CENTER

Approach/Strategy

	2016			2017				2018				2019
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Requirements, data and model gathering	■											
System architecture selection	■	■										
ORNL modeling and analysis		■	■	■								
Component procurement				■	■							
Component testing				■	■	■						
Mechanical design for powertrain test cell and vehicle test				■	■	■						
Control support for powertrain test cell						■	■	■				
Cummins Power Elec. Component Development			■	■	■							
ORNL Powertrain Test Cell Demo					■	■	■					
Cummins/CTI Field demo									■	■	■	
Field data analysis											■	■

Modeling an Simulation



Hardware in the Loop (HIL)

Vehicle Testing and Validation

Image courtesy of Carrier

Accomplishment: Current Industry Standards for Trailer Refrigeration Units (TRUs)

- Majority of current fleets:
  - Conventional units completely driven by small diesel engine.
    - Typically 18.5kW, 2.2L non-turbocharged diesel engine.
    - Engine drives everything compressor, alternator, condenser fan, and evaporator fan.
  - Industry "rule of thumb" is 0.6-1 gallon per hour depending on weather.
  - Runs continuously on diesel, even over multiple days.

Image courtesy of Carrier

Accomplishment: Fleet Partner CTI

- Fleet Statistics:
  - Entire Fleet is Refrigeration Trailers
  - 204 Trucks, 250 Trailers
    - All trailers have the same model of TRU
    - All trucks are Cummins engines with Eaton AMTs
  - Entire Fleet is outfitted with telematics
  - Uses node or hub model to avoid trailer downtime.
    - This allows trailers on road about 16 hours a day where drivers can only do 8-10 hour stints.

Accomplishment: Identified Current Under-Utilized Models for Use in Project.

Carrier	ThermoKing
• Vector™ 8500 – Hybrid Model (Capable of being driven by a 2.2L Diesel or 460V AC) • Vector™ 8100 – All-Electric (460V AC)	• S-600, S-700, C-600 – Conventional ("Hybrid") models with Electric Standby Option. Most models capable of near full cooling capacity on 460V AC.

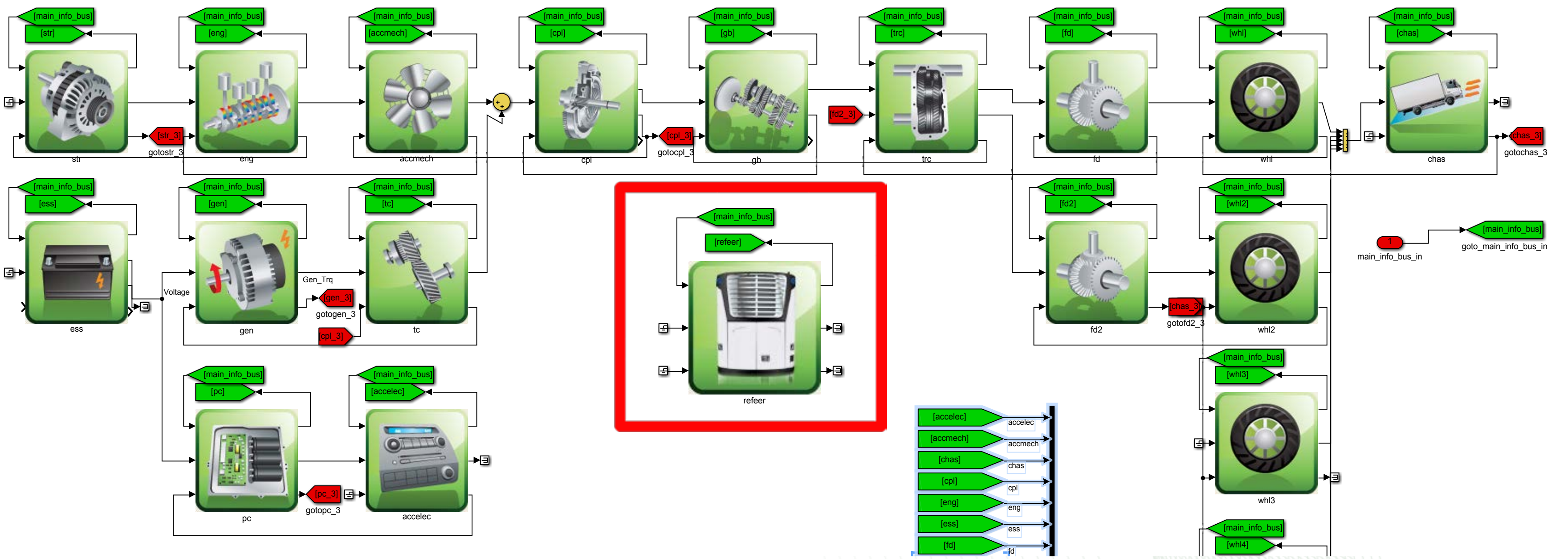
Why lack of market acceptance and penetration?

- Cost
  - The units use more advanced hardware when compared with conventional units, they do offer better efficiency however.
- Lack of Infrastructure
  - All electric operation is only useful if there is a 460V access plug available. The infrastructure to take full advantage of these units does not currently exist in the US.

OAK RIDGE National Laboratory | NATIONAL TRANSPORTATION RESEARCH CENTER

Accomplishment: Model Development Conventional (Baseline)

- Two Conventional Systems Developed for modeling:
  - Conventional Systems
  - Current Diesel (“Hybrid”) Systems with Electric Standby
- Developed Based on data and information from Carrier and CTI’s fleet.



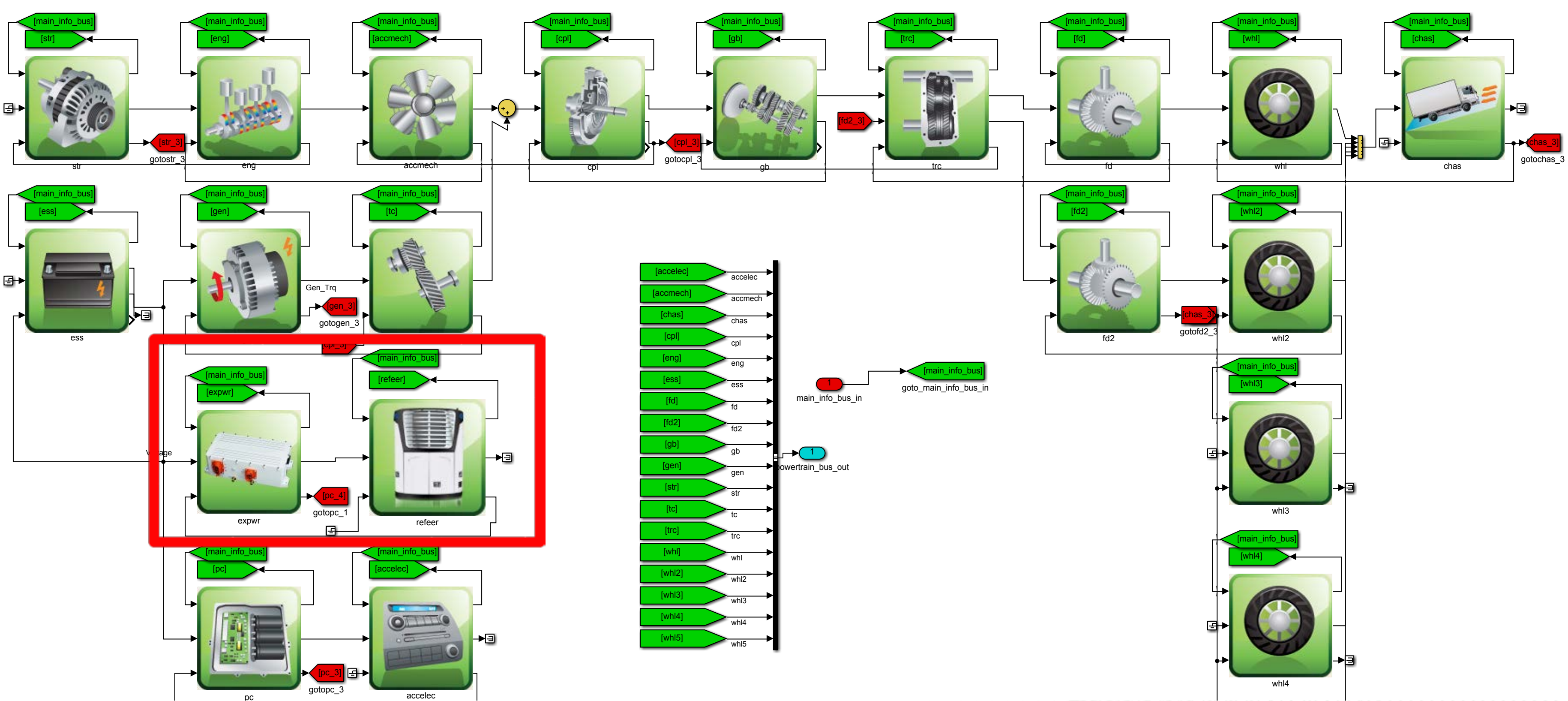
Accomplishment: Identified New System Requirements

- System Fully Capable of running the Hybrid TRU under any condition:
  - Idle
  - Cruise
  - Parked
  - Disconnected
- Capable of being powered all electrically either by the tractor or grid connection.
- Capable of full heating and cooling capacity as a conventional system.

OAK RIDGE National Laboratory | NATIONAL TRANSPORTATION RESEARCH CENTER

Accomplishment: Model Development Hybrid with Cummins Power Electronics

- CMI/ORNL Architecture:
  - Includes models of all hardware acquired or currently in development for finalized prototype system.
  - Will be the platform used for developing first baseline runs.



Accomplishment: ORNL/CMI Hybrid Model Simulation Results

- $\% \, TRU \, Fuel \, Savings \, \frac{TRU \, Fuel \, Saved \, from \, new \, system}{TRU \, Fuel \, Used \, by \, conventional \, system}$
- $\% \, System \, Fuel \, Savings = \frac{Fuel \, Saved \, from \, new \, system \, (TRU+Tractor)}{Fuel \, Used \, by \, conventional \, system \, (TRU+Tractor)}$

Simulated Fuel Savings % over CMI Cycle	
Time Periods	**Total Saved**
TRU Savings	100.00%
Total System Savings -Truck	4.74%

Cycle Level Results (500mi and 8 hours)

24h Simulated Fuel Savings % Truck Only	
Time Periods	**Total Saved**
TRU Saving	69.43%
Total System Savings	1.80%

16 hr Drive Time and 8 Hours Stationary.
No Plug-In Infrastructure

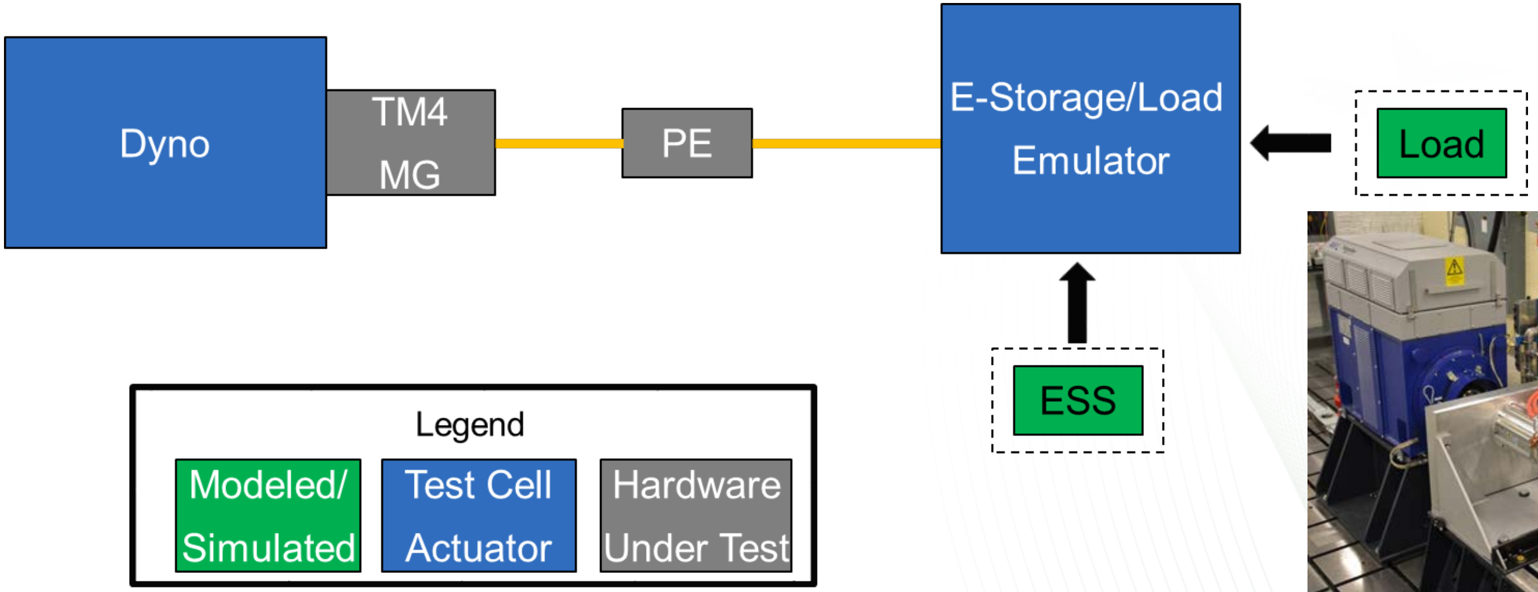
24h Simulated Fuel Savings % with Plug In	
Time Periods	**Total Saved**
TRU Saving	100.00%
Total System Savings	8.59%

16 hr Drive Time and 8 Hours Stationary.
With Plug-In Infrastructure

OAK RIDGE National Laboratory | NATIONAL TRANSPORTATION RESEARCH CENTER

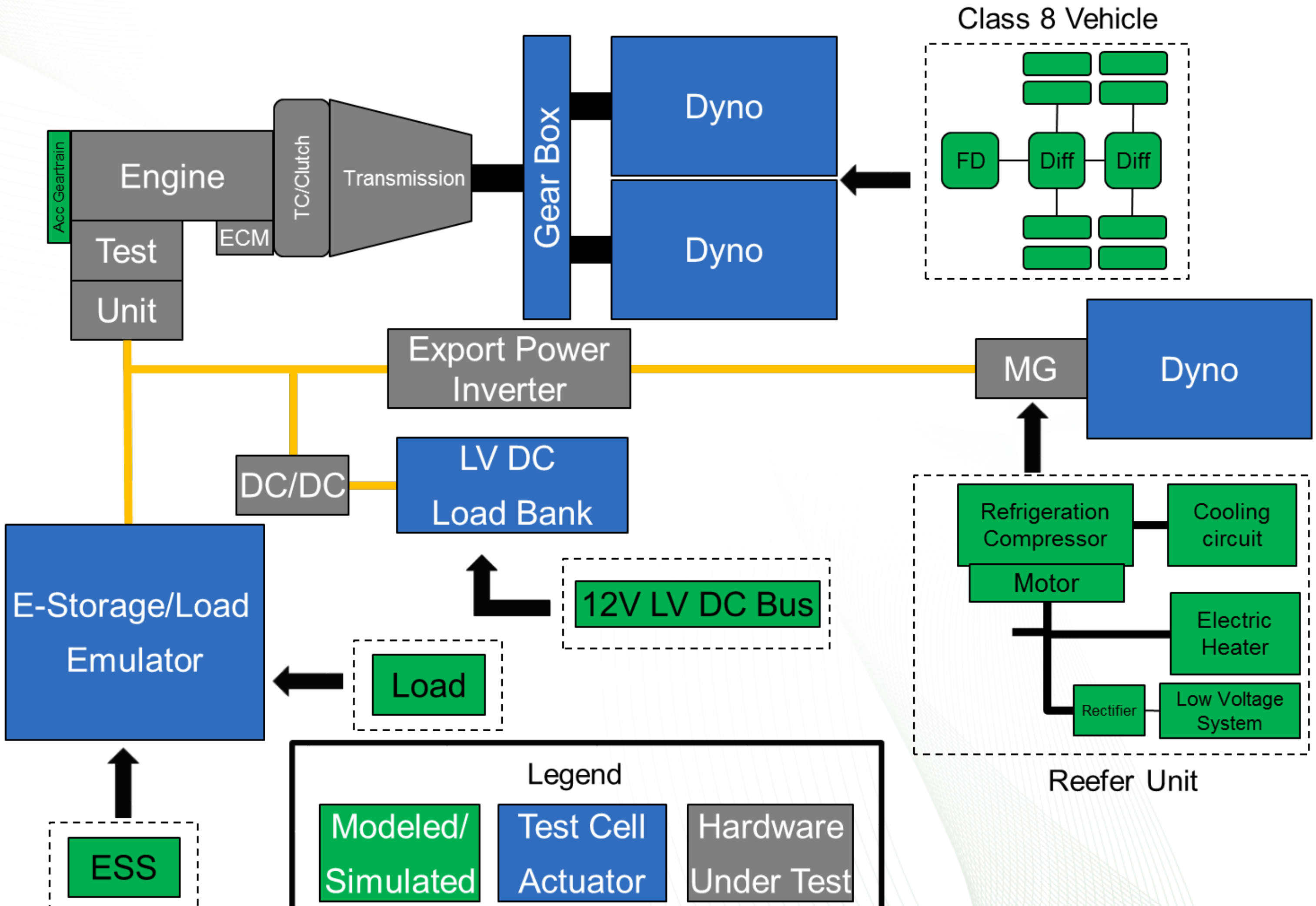
Accomplishment: Component-in-the-Loop Testing Setup.

- Validate prototype hardware using ORNL's Component Test cell.
- Fully characterize operating behaviors and efficiencies.
- Test "Real World" operating conditions using HIL.



OAK RIDGE National Laboratory | NATIONAL TRANSPORTATION RESEARCH CENTER

Accomplishment: Powertrain-in-the-Loop Testing Concept



Partners/Collaborations

- Cummins, Inc – CRADA Partner
  - Responsible for hardware design and development, as well as identifying hardware procurement needs.
  - Vehicle level testing and validation.
- CTI – Fleet Partner
  - Provide on road and fleet data to establish system requirements and possible hurdles.
- Carrier – Engineering Support
  - Test unit is a Carrier TRU. Carrier provides integration requirements for power and estimated duty cycles.
- TM4 – Engineering Support
  - Supplier of prototype generator unit for testing as well as final working prototype.

Remaining Challenges and Barriers

- Hardware Development
  - With any prototype system hardware development time lines are difficult to maintain, and components often have to go through multiple iterations.
- On Road Testing Conditions
  - With the system targeting TRUs, on road testing becomes dependent on the weather. This makes testing and repeatability difficult.
- Fleet Testing
  - In order to be able to achieve fleet testing, the system must be robust. A test unit under fleet testing could be carrying perishable cargo. This makes fleet testing dependent on the prototype systems robustness.

Future Work/Upcoming Tasks

- FY17
  - ORNL:
    - Finish validation and testing of individual components in ORNL Component Test Cell.
    - Integrate entire system into VSI powertrain test cell and develop supervisory controls.
  - Cummins:
    - Finish mechanical design, and start on vehicle integration designs.
- FY18:
  - ORNL:
    - Controls support for vehicle testing.
  - Cummins:
    - Integrate finished system into test vehicle for system validation and possible fleet testing for demonstration.

Any proposed future work is subject to change based on funding levels

Summary

- **Relevance:**
  - The benefits from the **hybridization of refrigeration trailers** can provide significant **reductions in fuel consumption, criteria pollutants, and greenhouse gas emissions.**

- **Approach:**
  - **Model:** Based on data and information received from NREL, CTI, and Carrier develop baseline convention TRU models for baseline as well as use as a comparison with new prototype models.
  - **Hardware In The Loop:** Utilizing HIL leverage rapid prototyping capabilities to develop and optimize system controls in a controlled and repeatable environment.
  - **Vehicle Testing/Validation:** Validate controls and experimental data using a vehicle for validation of finalized prototypes and architecture.

- **Collaborations:**
  - **Partners:** Cummins, Inc. and ORNL
  - **Industry:** CTI, Carrier, TM4

- **Technical Accomplishments:**
  - **Completed** first round of foundational data based TRU models.
  - **Exercised** conventional and prototype vehicle models to determine which system application and architecture best benefits the project.
  - **Designed** a new prototype system that is being first assembled and tested in ORNL's HIL environment.

- **Future Work:**
  - **Complete testing** and benchmarking of the new prototype systems to validate the newly developed TRU model using **HIL Testing.**
  - **Finalize system controls development** and then **integrate the new system** and controls into the test vehicle for system validation.

Any proposed future work is subject to change based on funding levels