VS133

Cummins MD & HD Accessory Hybridization CRADA

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OAK RIDGE National Laboratory

OVERVIEW

Timeline	Barriers*
• Project start date: July 2013 • Project end date: Oct 2015 • 100% Complete	• Cost • Constant advances in technology • Computational models, design, and simulation methodologies **from 2011-2015 VTP MYPP*
Budget	**Partners**

• DOE Share (50%)
  • FY14 funding: $150k
  • FY15 funding: $500k
	• Oak Ridge National Laboratory
	• Cummins Inc.

RELEVANCE* – VSST and DOE Goals and Barriers

- **21st Century Truck Partnership Goals:**
  - Develop advanced heavy duty vehicle systems models.
  - Create methods to predict and measure the effects of idle reduction technologies.
  - Reduce engine parasitic energy losses.
- **Directly supports 3 VSST cross-cutting activities:**
  - Modeling and simulation, component & systems evaluations, and vehicle systems optimization.
- **VSST Barriers:**
  - **Cost**: Using ORNL's VSI Laboratory, testing prototypes at a component instead of using a test vehicle allows for development and validation to be, quicker, safer, and more cost effective.
  - **Constant advances in technology**: No other fully hybridized/electrified accessory systems on are available to compare current modeling to, this reveals the need for additional development and constant validation these types of baseline models to keep up with current technology for comparison.
  - **Computational models, design, and simulation methodologies:** Currently, medium and heavy duty physics or performance based dynamic accessories models are not available, typically all accessories are "lumped" into one lookup table that is purely speed based.

*Reference: Vehicle Technologies Multi-Year Program Plan 2011-2015:
http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf

OBJECTIVE: Analytically verify heavy duty (HD) line haul accessory hybridization approaches and experimentally validate prototype hardware

"WHY"

- HD line haul trucks often idle for long periods in traffic and overnight for hotel loads. This typically requires the engine to idle for little reason other than driver comfort and system readiness which uses excessive fuel and causes more emissions.
- Accessories have an optimal running condition based on load requirement. The ability to separate accessories from the engine speed allows the opportunity to run at ideal conditions without engine speed dependencies.

"HOW"

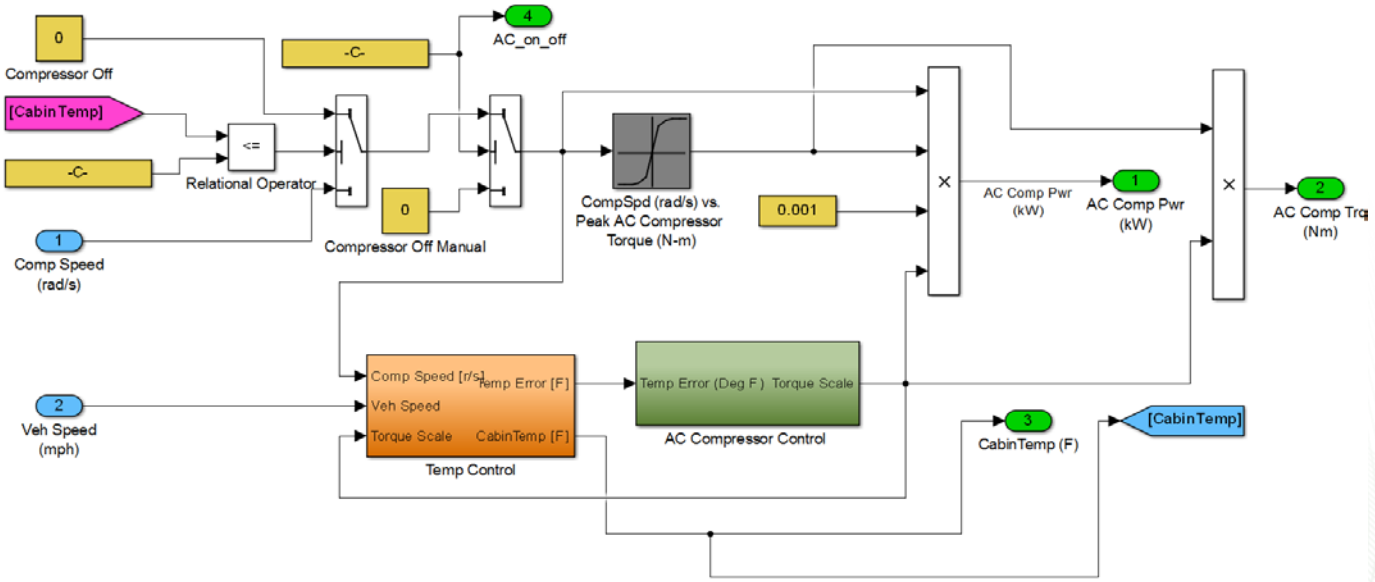
- Develop and validate accurate component models for simulating integrated conventional accessories.
- Evaluate different applications of hybridized accessories to identify which components have the most potential for reduced fuel consumption.
- Identify the system architecture that has the most promising returns on fuel economy, emissions, and investment. In addition, differentiating which technologies will be accepted by fleet owners and industry.
- Build prototype accessories and develop hybrid control strategies using the ORNL Vehicle Systems Integration (VSI) Laboratory Component Test Cell.
- Test the new prototype system in a real world setting on a test vehicle using one of Cummins test trucks.

MILESTONES

Month /Year	Milestone or Go/No-Go Decision	Description	Status
Mar 2014	Milestone	Complete baseline reference simulation with integrated component accessory models for Cummins CRADA	**COMPLETE**
Sept 2014	Milestone	Complete hybridized accessory model architecture study with baseline supervisory control strategy implementation for Cummins CRADA	**COMPLETE**
Jan 2015	Milestone	Validate conventional and hybrid accessory models using the Cummins fleet test vehicle and ORNL's VSI component test cell	**COMPLETE**
April 2015	Milestone	Design and build a prototype hybrid accessory system utilizing findings from the modeling portion of the Cummins accessory hybridization project	**COMPLETE**
Oct 2015	Milestone	Finish testing and validation of prototype hybrid accessory system for both component HIL and vehicle testing.	**COMPLETE**

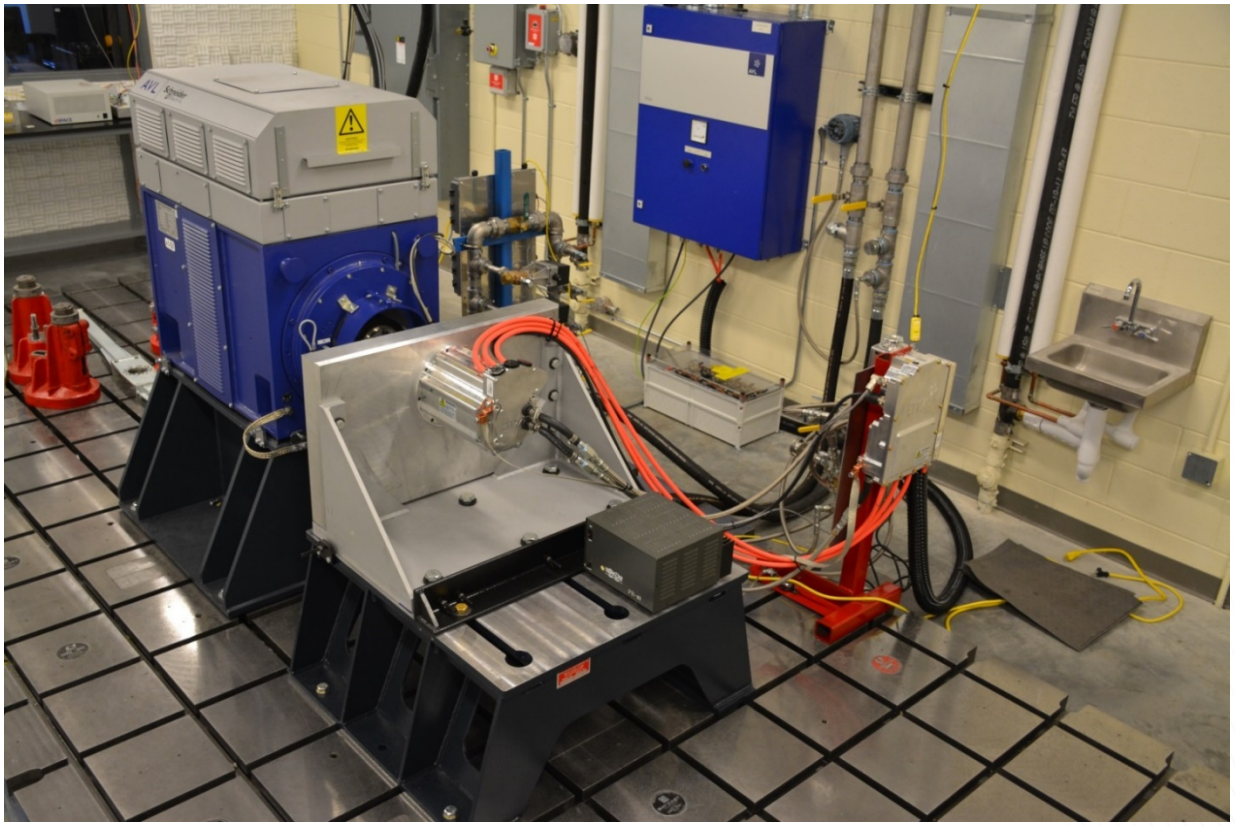
APPROACH (1): Modeling and Controls Development Phase

- Collect respective data for all accessories and develop new mechanical and electrical accessory models based on Cummins test vehicle and accessory specs.
- Integrate these new models into vehicle models with the same parameters as previously tested vehicles.
- Determine which accessories have the most potential for hybridization through vehicle simulation using Autonomie .
- Experimentally validate the chosen component models using Hardware-In-the-Loop (HIL) testing and data from a Cummins test vehicle.
- Develop hybridized accessory models and baseline controls for the prototype hybrid system.



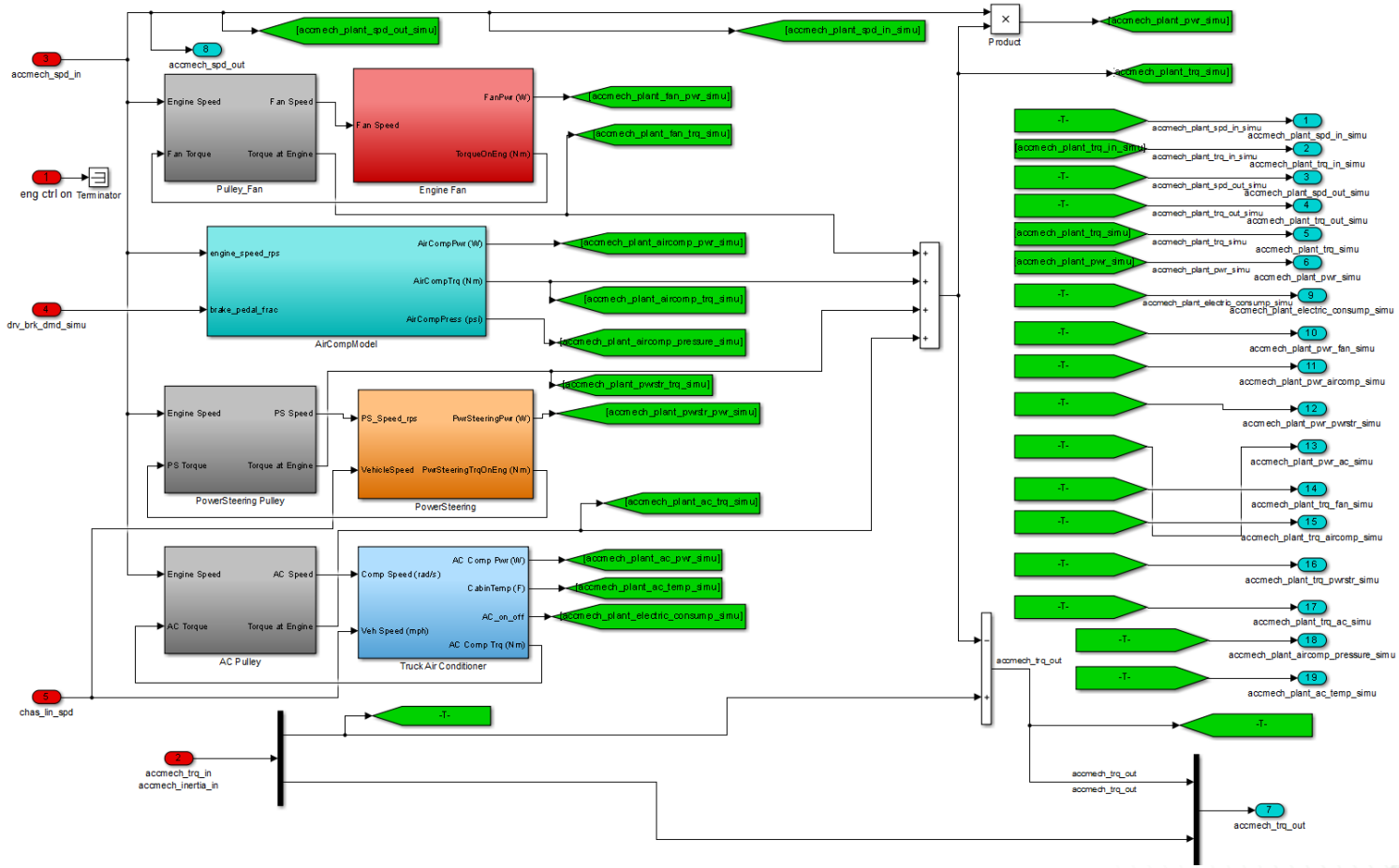
APPROACH (2): Testing and Validation Phase

- Acquire hybrid accessory prototypes designed from the modeling phase of the project.
- Test and develop a hybrid accessory system as a whole in the VSI Component Test Cell.
- Perform “real world” tests using the Component-In-the-Loop (CIL) to have realistic vehicle behaviors on the unit under test (UUT).
- Validate the component and vehicle models using experimental findings.
- Integrate finalized hybrid accessory prototype into a Cummins test vehicle.



ACCOMPLISHMENT (1): Changing Lumped Sum Lookup Tables to Higher Fidelity Physics and Performance Based Accessory Models.

- **Typical vehicle level models use a "lumped" mechanical and electrical accessory models.**
- **Cummins and ORNL have created separated physics and performance based mechanical and electrical, dynamic accessory models.**



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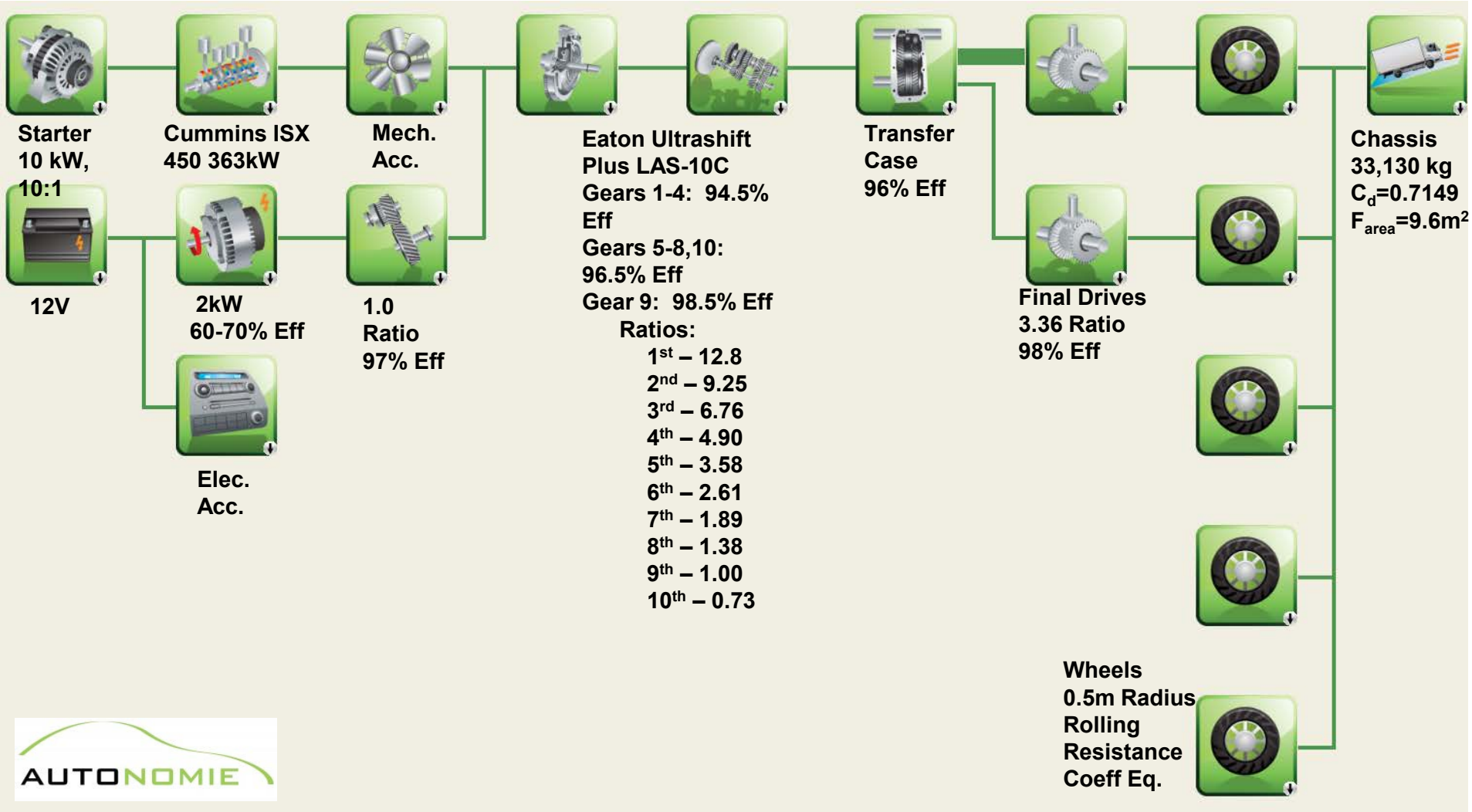
ACCOMPLISHMENT (2): Baseline Vehicle Model for Line Haul

- **Baseline vehicle for modeling was based upon Kenworth T700 .**



AUTONOMIE

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ACCOMPLISHMENT (3): Overnight Idle Mitigation Better Application than Hybrid or Electrified System for the Day's Cargo Haul

- **Baseline chassis vehicle results vs baseline model results.**

Chassis Vehicle vs. Simulation Fuel Economy						
Data	WHVC	Utility	CARB Transient	55mph Cruise	65mph Cruise	HHDDT65
Chassis Summery [mpg]	5.40	4.78	3.90	8.17	6.54	N/A
Model [mpg]	5.41	5.08	4.26	7.77	6.67	6.31
Percent Error	0.19	6.28	9.23	4.90	1.99	N/A
Percent Error Average	4.52					

- **A fuel consumption entitlements study was performed by removing all of the accessories one by one and calculated the percent difference in fuel consumption from the baseline vehicle.**

Fuel Consumption Entitlements	
Data	Fuel Consumption % Decrease
A/C	0.123
Power Steering	0.438
Brake Air Compressor	0.282
Cooling Fan	0.344

- **Based on our simulation results, during the days cargo haul HD Line Haul does not seem to be a good candidate for hybridized accessory for the following reasons;**
  - Line Haul trucks are built to cruise at steady speeds for long periods, so accessory OEMs have design accessories to run at efficient condition at these speeds.
  - Accessories at engine cruising speeds are less than 1.5% of the typical LH engine power.

ACCOMPLISHMENT (4): Hybridized Accessory Systems Make the Most Impact for Idle Reduction and Overnight Hotel Loads

Industry Importance and Fuel Consumption Impact:

- **Line Haul drivers are required to spend 10 hours of down time between each haul (typically overnight). If the driver needs air conditioning or power for phone chargers, a TV, radio, etc.. then the truck will be required to idle during the night's hotel (8-10 hrs.).**
  - This overnight idle period accounts for 4-7 gallons of diesel.
  - This does not account for time spent idling when trucks are preparing to load or unload cargo or sitting in traffic.

Current Sleeper Cab Idle Mitigation:

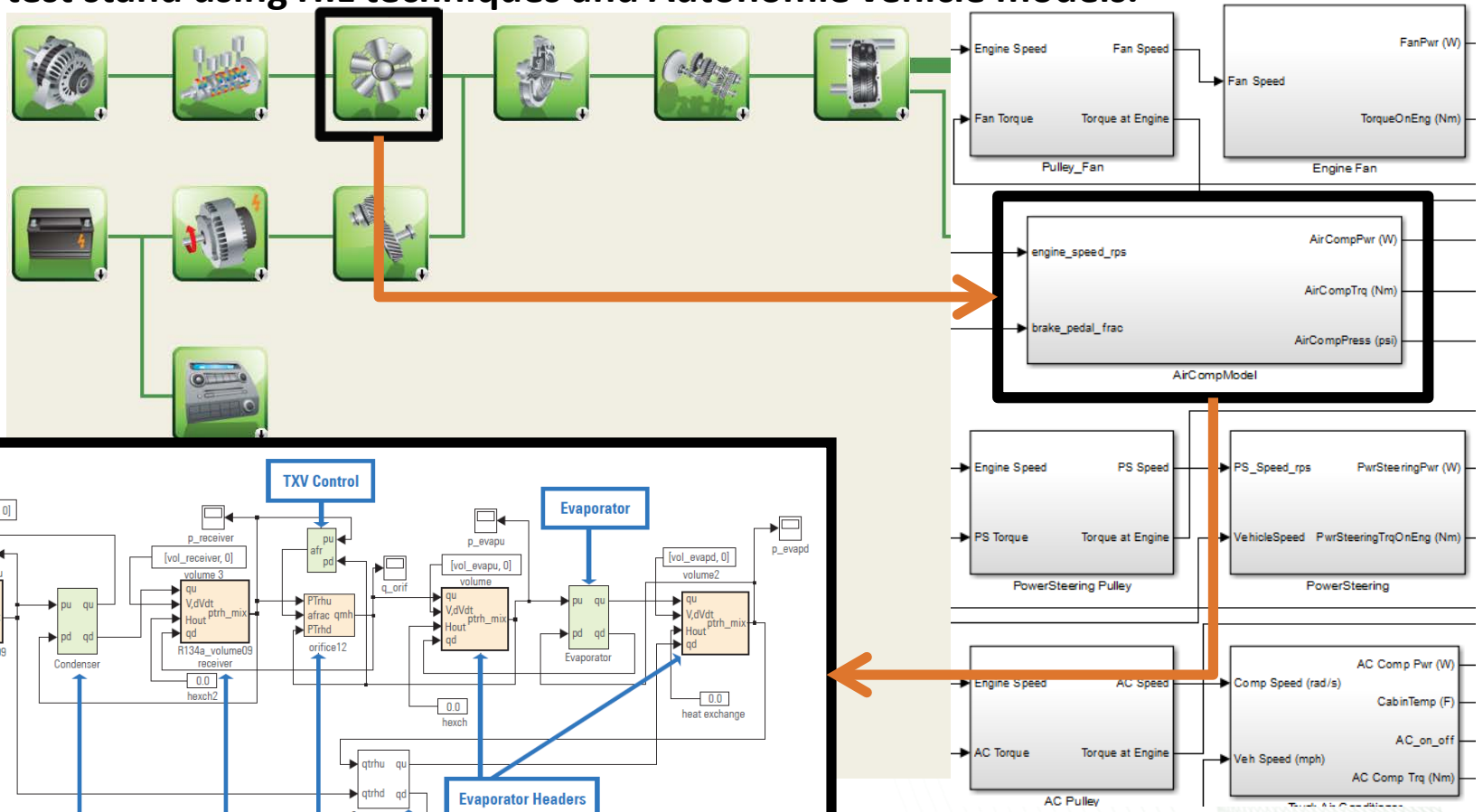
- **Auxiliary Power Units (APUs) are small generators used for hotel loads, but they are generally aftermarket units that are added rather than built into the original trucks systems. This results in several issues, including:**
  - Maintenance issues and service
  - Secondary HVAC loop
  - DPF or other emissions treatments
  - Units are only advantageous while the truck is off

Proposed Sleeper Cab Idle Mitigation:

- **ORNL and Cummins proposed solution will be an optimized system which will allow elimination or reduction of overnight idling, optimized cooling capacity via electric fans, and regenerative braking.**

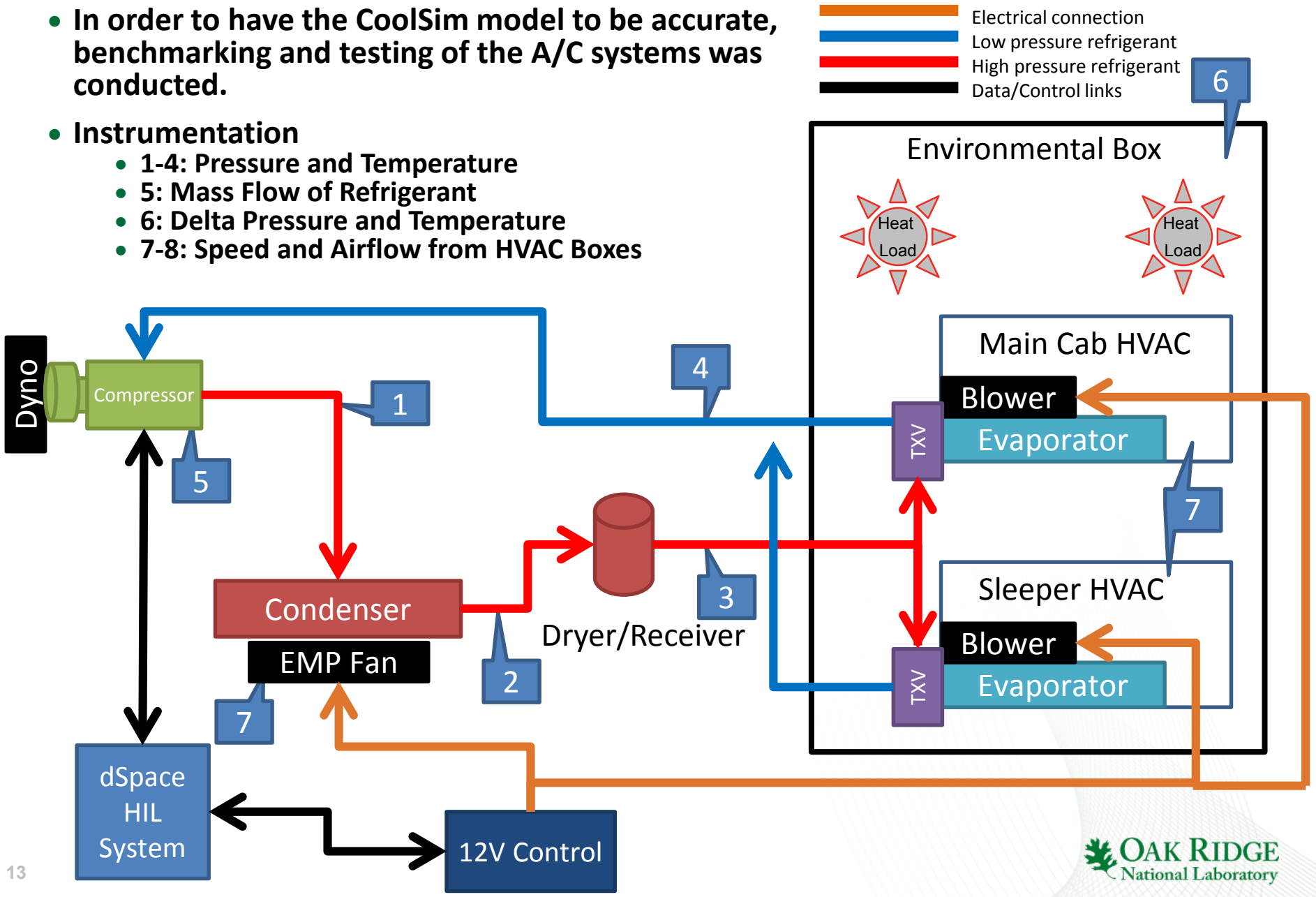
ACCOMPLISHMENT (5): Start of Data Collection for the Integration of NREL's CoolSim Model

- **Since the A/C system in sleeper cabs became the main focus of the project, NREL and their CoolSim model were brought into the project to provide a high fidelity model for model validation of the conventional and new prototype systems.**
- **NREL's CoolSim model is also a necessary component for realistically operating the A/C test stand using HIL techniques and Autonomie vehicle models.**



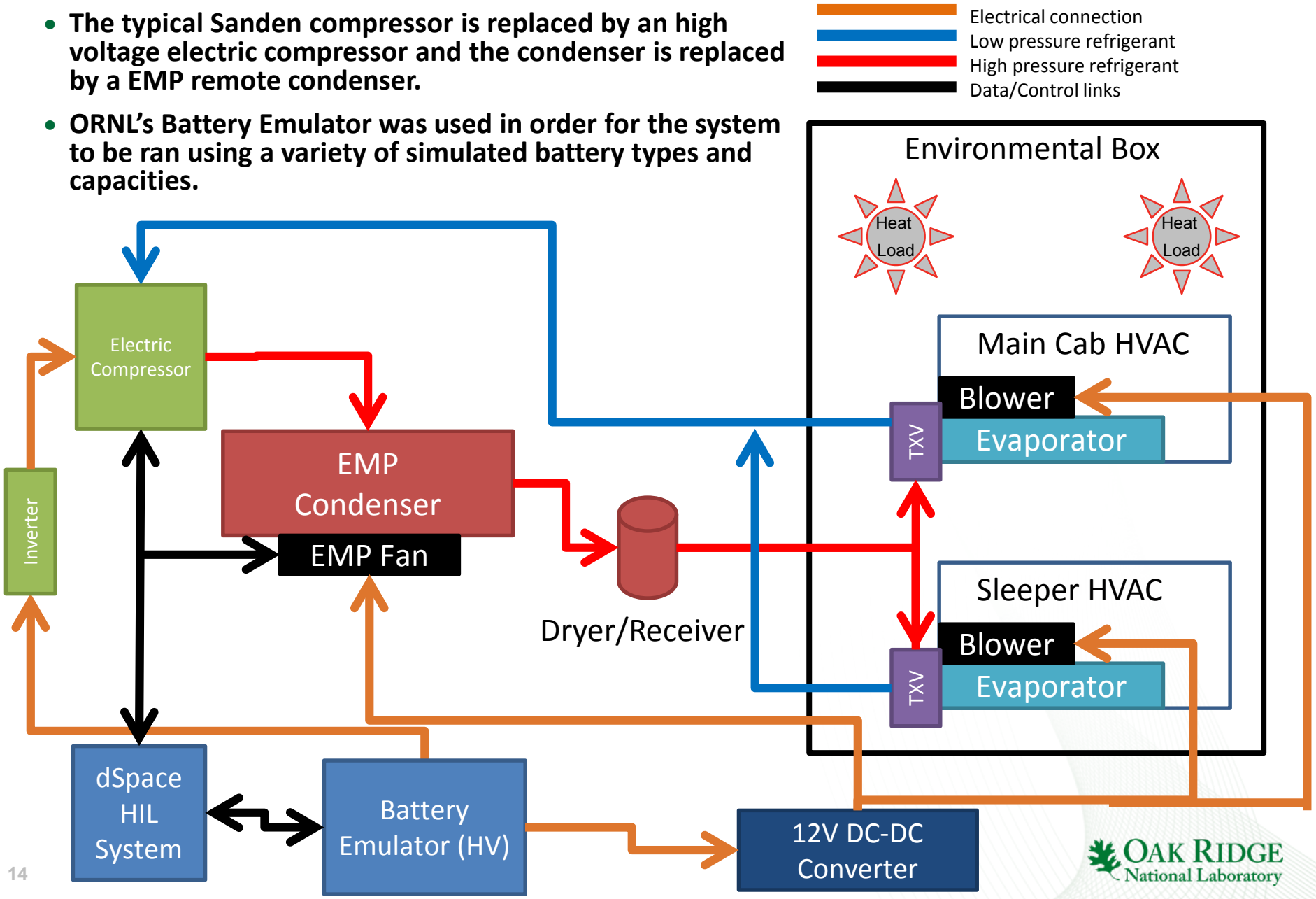
ACCOMPLISHMENT (6): Conventional Air Conditioning Testing

- **In order to have the CoolSim model to be accurate, benchmarking and testing of the A/C systems was conducted.**
- **Instrumentation**
  - **1-4: Pressure and Temperature**
  - **5: Mass Flow of Refrigerant**
  - **6: Delta Pressure and Temperature**
  - **7-8: Speed and Airflow from HVAC Boxes**



ACCOMPLISHMENT (7): Electric Air Conditioning Testing

- **The typical Sanden compressor is replaced by an high voltage electric compressor and the condenser is replaced by a EMP remote condenser.**
- **ORNL's Battery Emulator was used in order for the system to be ran using a variety of simulated battery types and capacities.**



ACCOMPLISHMENT (8): Prototype Testing and Vehicle Integration

Prototype testing:

- **Using the data collected from the various modeling exercises and HIL testing the prototype was created and baseline controls done in the component test cell.**

Vehicle Integration:

- **Using the groundwork, troubleshooting, and data from the HIL testing a prototype system was installed in a test vehicle to validate the system in real world conditions.**

Responses to Previous Year Reviewer Comments

- **Reviewer Question 1 -** The reviewer commented that this project contributes to overcoming most barriers. The capability being developed can enable overcoming the barriers if used to identify cost effective alternative accessory drive system designs. The reviewer stated that it is not clear how this project overcomes the cost barrier, perhaps by avoiding new design solutions that do not provide adequate benefits.
  - ***ORNL Response: Since the finalized architecture is protected under the CRADA it is difficult to see how this barrier was tackled, but just like the reviewer mentioned, this project was determined how much of a current factory system could be adapted to work with the new system rather than designing the system from scratch. This would allow OEMs to adapt existing accessory systems utilizing the same install locations, thus saving production costs.***
- ***Reviewer Question 2 -*** The reviewer stated that the project team had added a productive collaboration with NREL since last year in response to a reviewer comment as well as collaborations with EMP and Masterflux. The reviewer asked if the collaboration with Meritor that was reported in 2014 has simply run its course, or did it fall apart.
  - ***ORNL Response: Meritor's collaboration was beneficial to developing the vehicle and validate the fuel economy results of the conventional vehicle as a baseline as it piggybacked on an old project. For FY 15 this was not a focus anymore and so the collaboration ended there.***
- **Reviewer Question 3 -** The reviewer pointed out that given the complexity of simulating many components and configurations, optimizing these configurations and then validating on an actual test vehicle, the funding seems to be modest.
  - ***ORNL Response: CMI and ORNL would agree. The focus on this project was to identify one or two accessories with the largest impact on fuel consumption. Because of this high level physical models were created to determine which accessory and application it would be. In order to create high detail models of accessory, a project solely focused on modeling would be necessary.***

COLLABORATION, COORDINATION, and SUPPORT

- **Cummins, Inc.**
  - Data collected and provided from instrumented fleet test vehicle to further develop and validate accessory models.
  - Supporting tasks for model development and validation.
  - Providing Engineering support for machine design and fabrication for testing setups and hybrid system.
  - Cummins Proprietary Drive Cycles
- **National Renewable Energy Laboratory**
  - Collaboration with and use of NREL's CoolSim model for HD sleeper trucks to develop a physics based air conditioning model.
- **EMP**
  - Providing technical support in selecting a new condenser system for the electrical A/C setup.
- **MasterFlux**
  - Providing engineering support in spec'ing and selecting the proper electric A/C compressor as well as guidance on materials compatibility.

PROPOSED FUTURE WORK

- **FY 2016**
  - **Using lab and vehicle data, validate and tune NREL's CoolSim model for use in future projects.**

SUMMARY:

- Relevance
  - Research is focused on advanced **heavy-duty line haul hybrid accessory systems** that will **reduce fuel consumption and criteria emissions**, especially when excessive **idling** is concerned.

- Approach
  - This project is a **two fold approach** that includes **modeling and controls development** to determine which system architecture provides the required benefits, and a **testing and validation phase** for the prototype hardware and system that was developed based on the modeling and simulation work.

- Technical accomplishments and progress
  - **Completed** first round of foundational performance and physics based accessory models.
  - **Exercised** different MD and HD vehicle models to determine which system application and architecture best benefits the project.
  - **Developed and designed** a new prototype system that was first assembled and is being tested in an HIL environment as well as installed in a test vehicle for system testing and validation.

- Collaborations:
  - **Industry**: Cummins and EMP
  - **Government**: NREL's CoolSim Model team, ORNL's Center for Transportation Analysis

- Proposed Future Work
  - **Validate** finalized NREL CoolSim model using data collected from the Cmponent test cell and Cummins test vehicle.

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Technical Back-Up Slides

Acronym Definitions

- MD- Medium Duty
- HD- Heavy Duty
- HIL – Hardware-In-the-Loop
- PIL – Powertrain-In-the-Loop
- VSI- Vehicle Systems Integration
- VSST- Vehicle and Systems Simulation and Testing
- VSS – Vehicle System and Simulation
- CILCC - Composite International Truck Local Cycle and Commuter
- HHDDT65- Heavy Heavy-Duty Diesel Truck Cycle
- WHVC - World Harmonized Vehicle Cycle
- ARB Transient – Air Resource Board
- ORNL- Oak Ridge National Laboratory
- A/C – Air Conditioning