VSS133

Cummins MD & HD Accessory Hybridization CRADA

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Presenter:

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OVERVIEW

Timeline	**Barriers***
• Project start date: July 2013 • Project end date: Oct 2015 • 70% 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.

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.

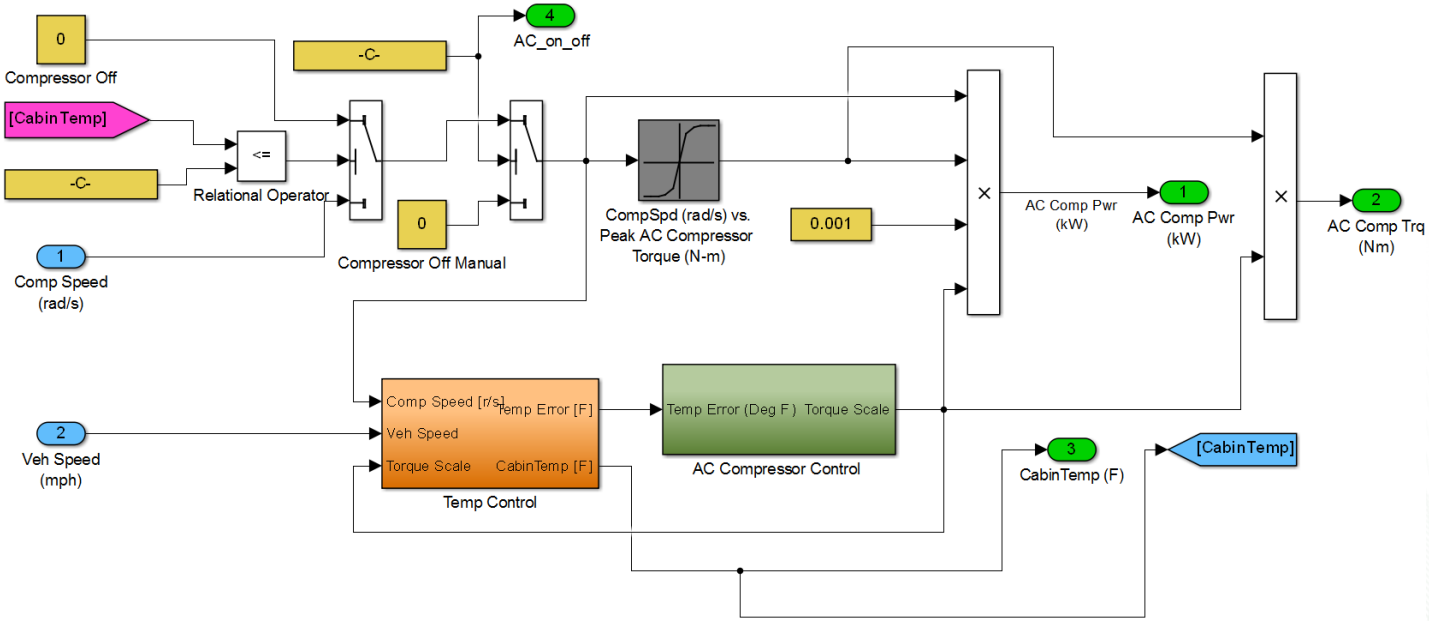
RELEVANCE* – VSST and DOE Goals and Barriers

- **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

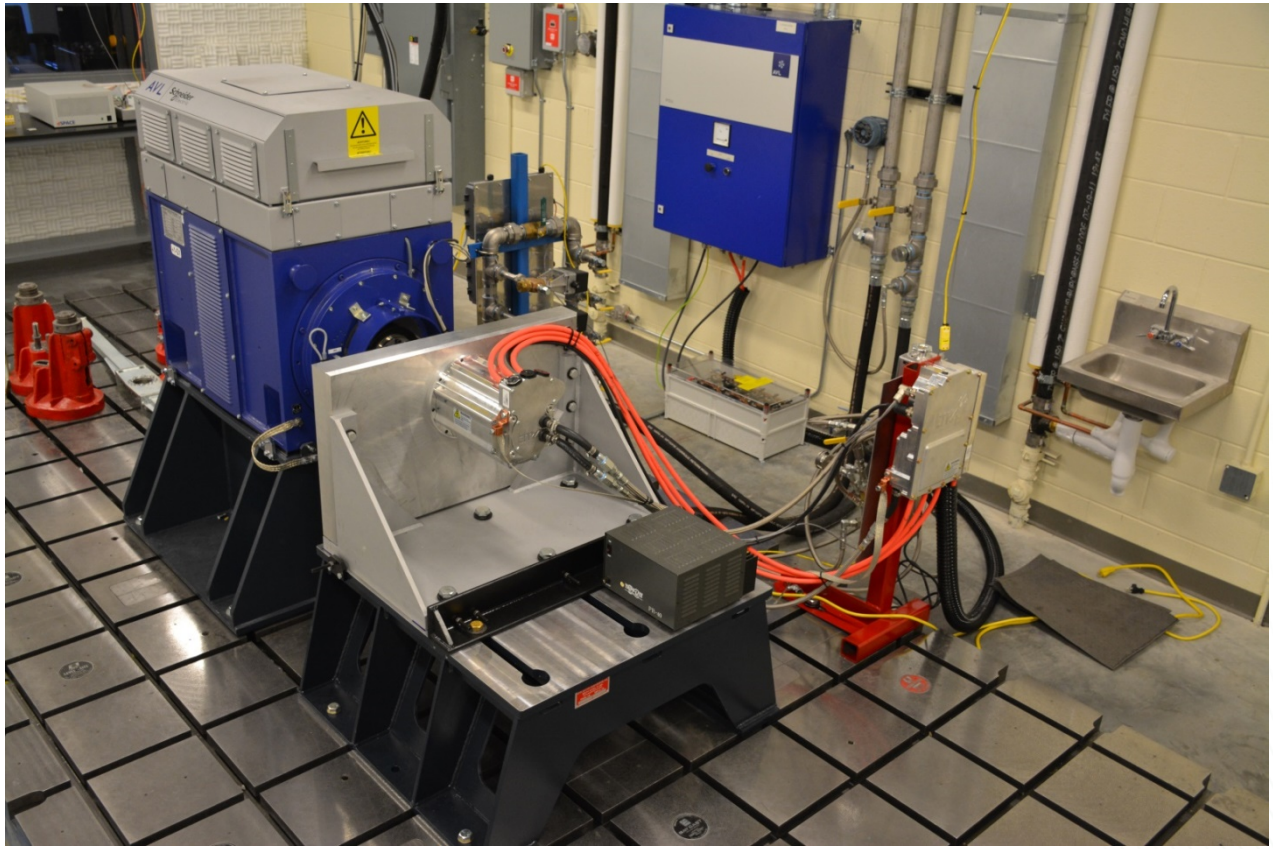
APPROACH (1): Modeling and Controls Development Phase

- 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.

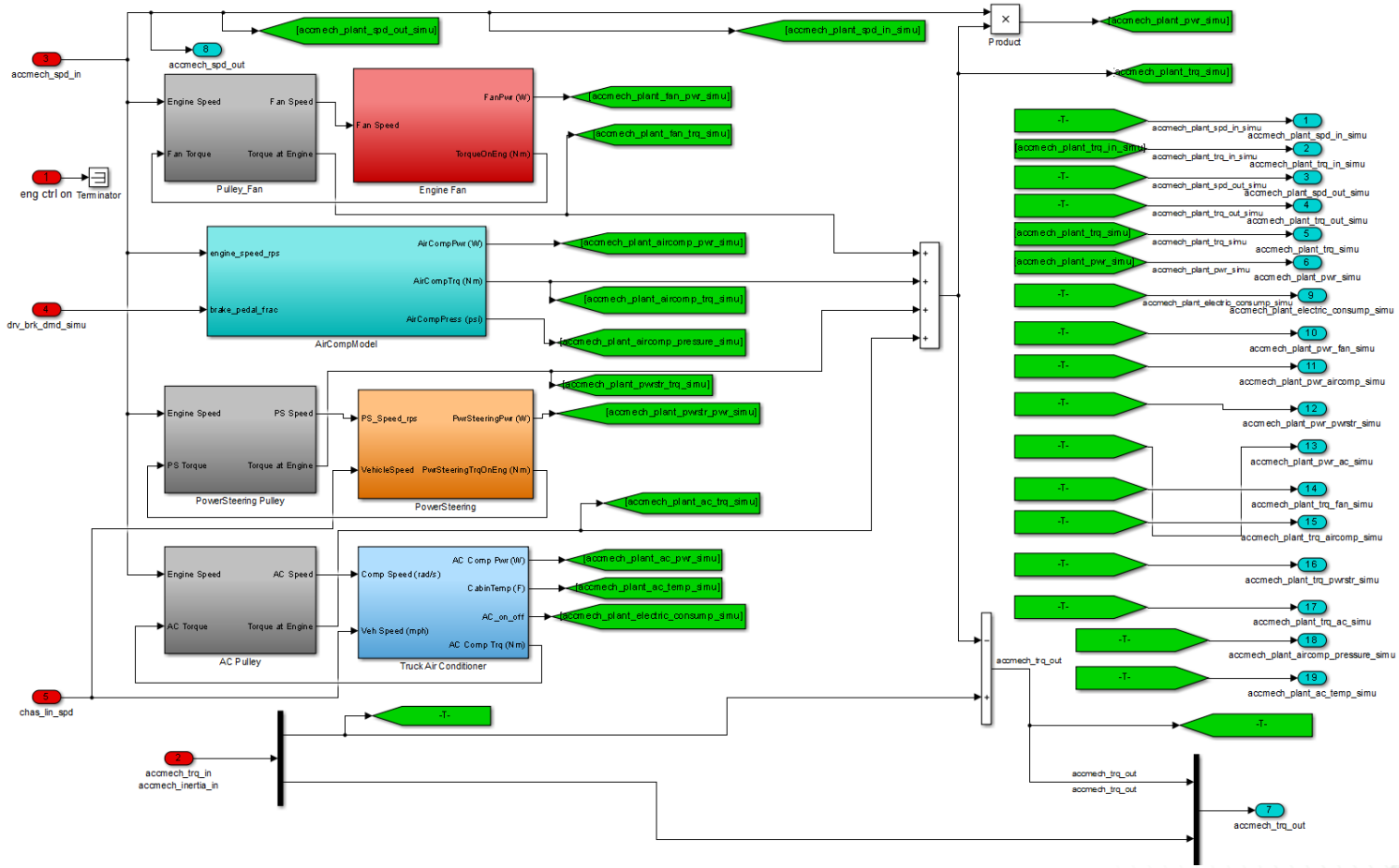


FY2014 MILESTONES

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	**In Progress**
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.	**On Schedule**

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

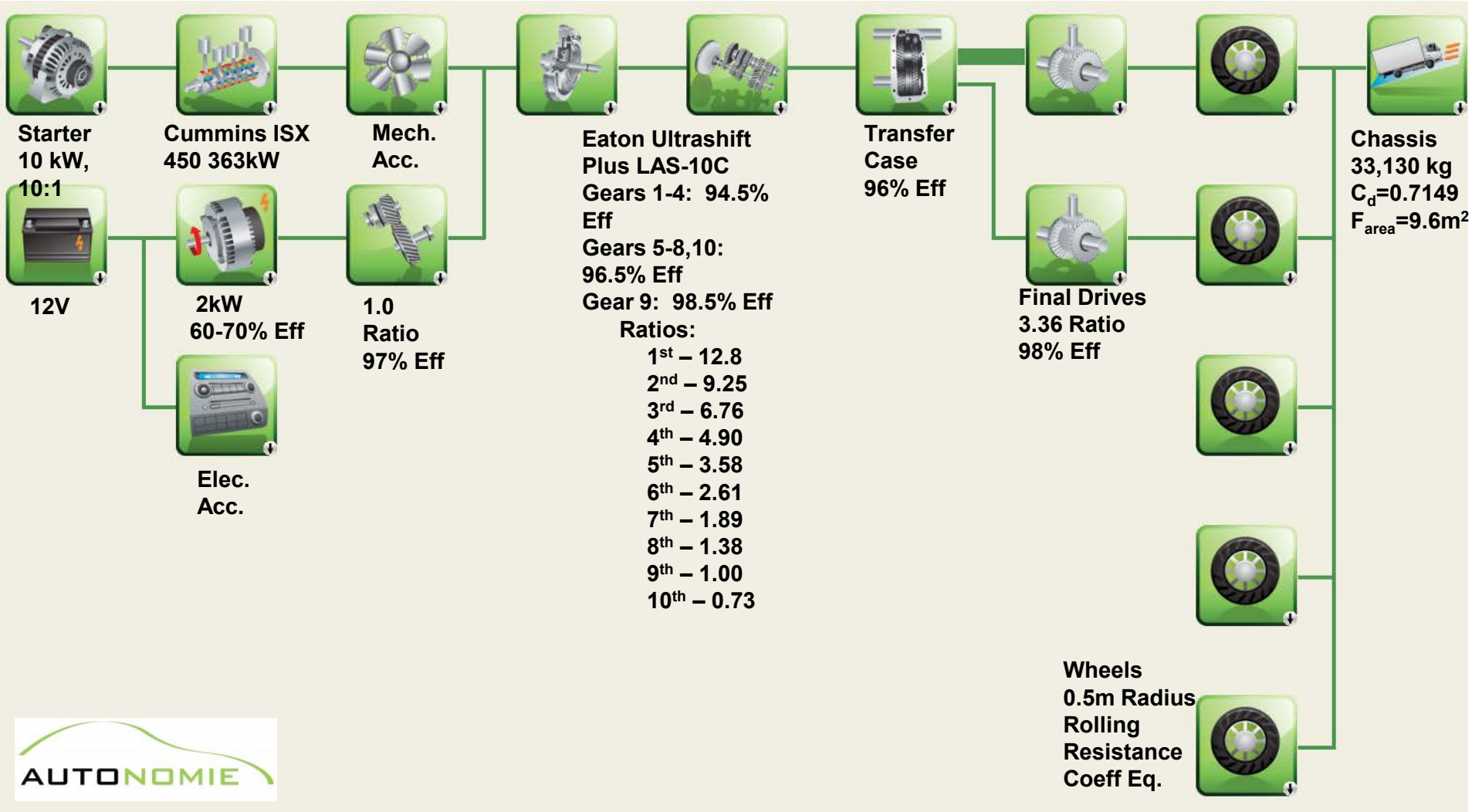
- **Typical vehicle level models use a "lumped" mechanical and electrical accessory models.**
- **Cummins and ORNL have created separated physics and performance based mechanical and electrical, dynamic accessory models.**



OAK RIDGE National Laboratory

ACCOMPLISHMENT (2): Baseline Vehicle Model for Line Haul

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



AUTONOMIE

OAK RIDGE National Laboratory

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:

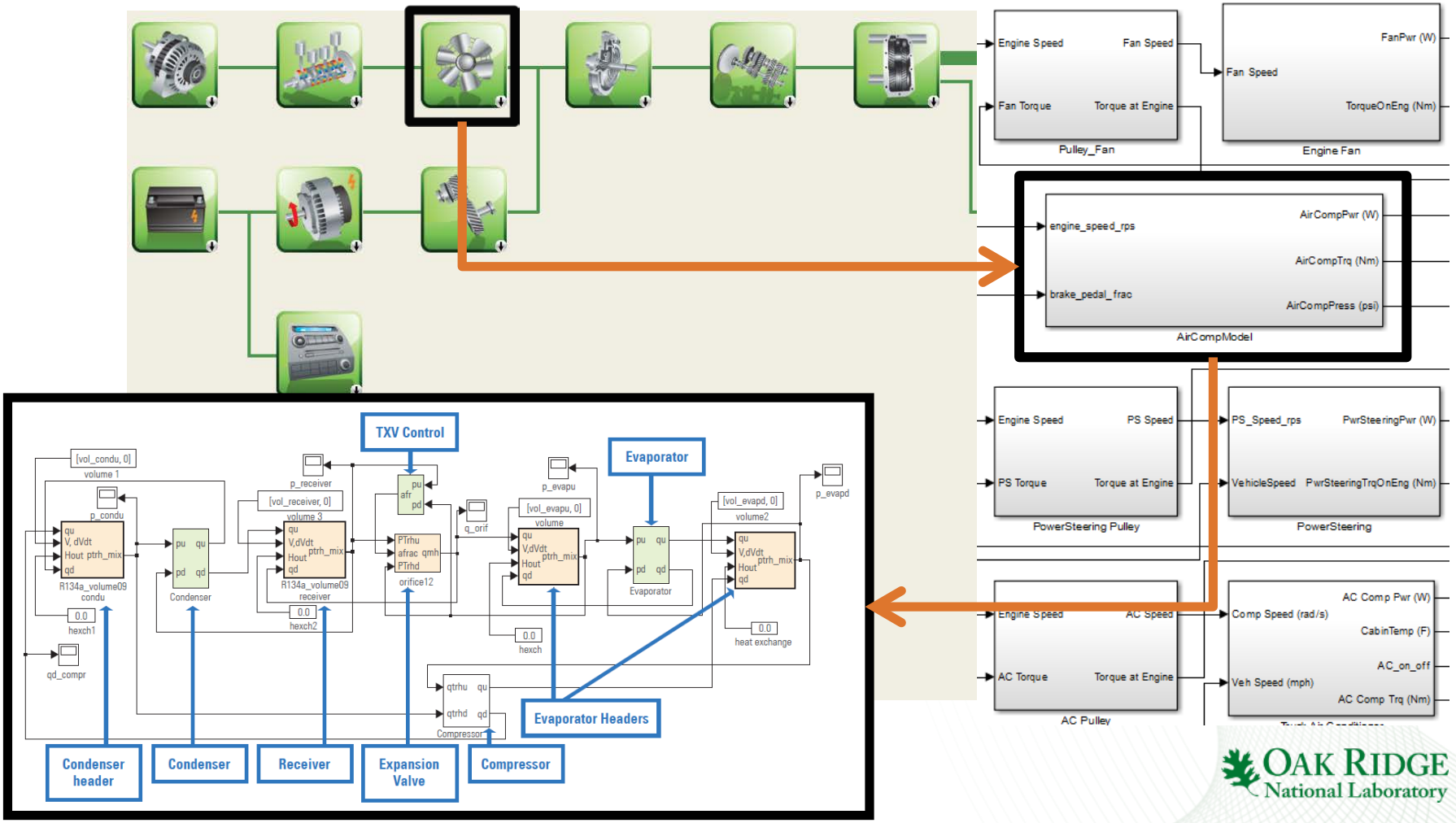
- **Auxiliary Power Units (APUs) are small generators used for hotel loads, but they are generally aftermarket units that are added rather than built into the original trucks systems. This results in several issues, including:**
  - Maintenance issues and service
  - Secondary HVAC loop
  - DPF or other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

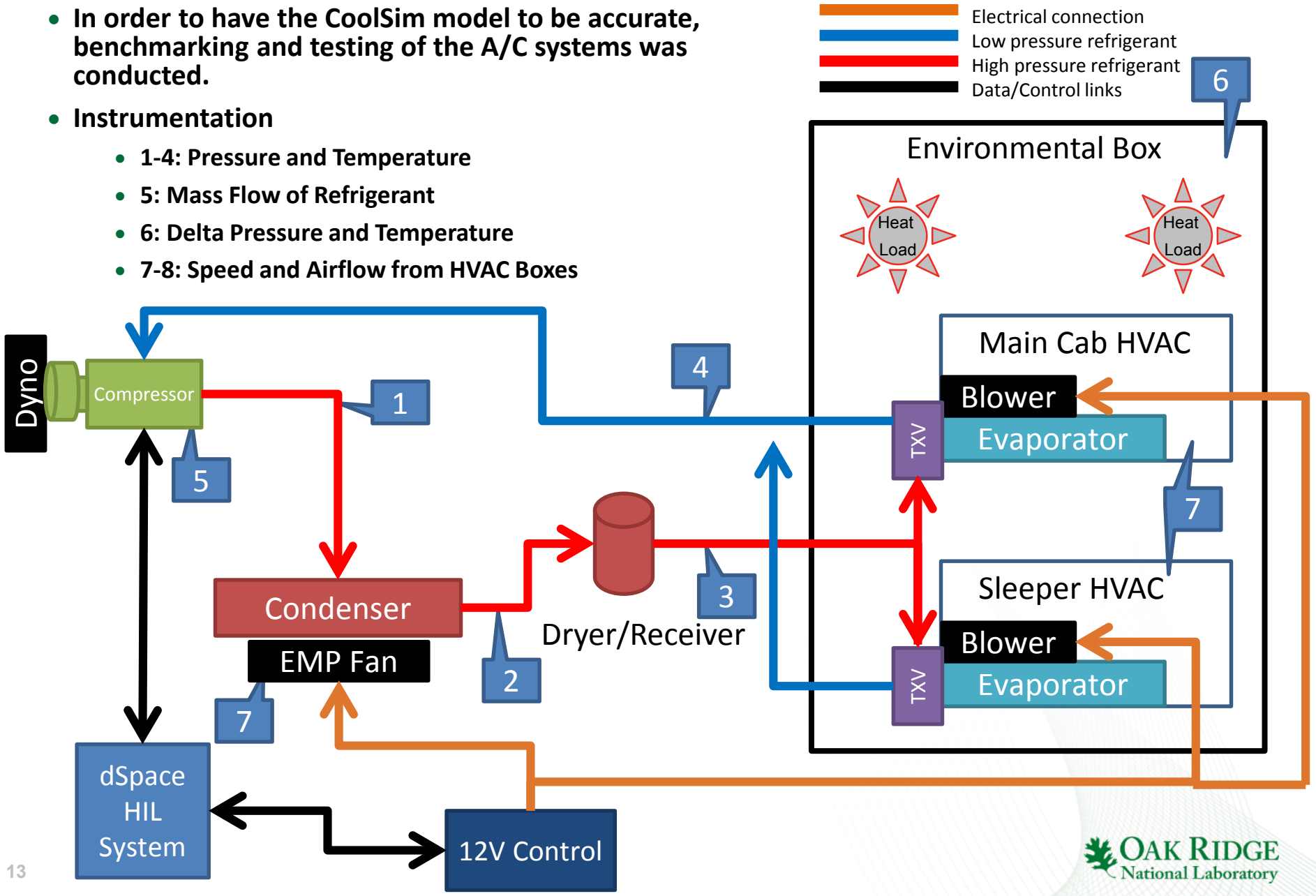
ACCOMPLISHMENT (5): Start of Data Collection for the Integration of NREL's CoolSim Model

- **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.**



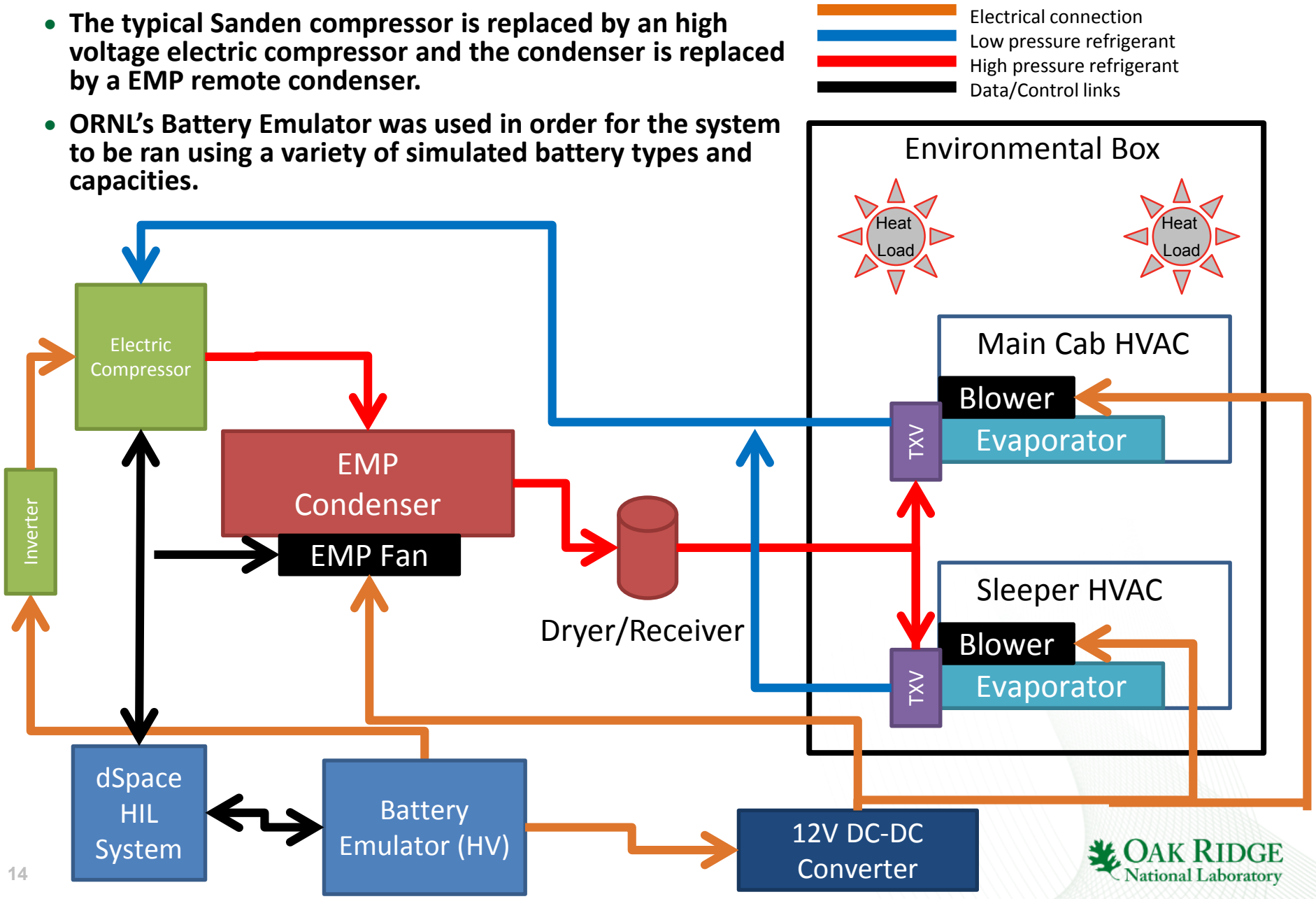
ACCOMPLISHMENT (6): Conventional Air Conditioning Testing

- **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 is currently being installed in a test vehicle to validate the system in real world conditions.**

Responses to Previous Year Reviewer Comments

- **Reviewer Question 1 -** The reviewer remarked that validation is an important part of the project. The reviewer said that the better understanding of auxiliaries is the key. The reviewer added that NREL has done a high fidelity model for the HVAC system called COOLCAB. The reviewer suggested that this software should be included.
  - ***ORNL Response: Since the HVAC became the main focus of the project NREL has been asked to provide support in supplying a model of the A/C system using data collected from the project. They have agreed to the collaboration, and it will be used for both the modeling and the HIL portion of the project.***
- **Reviewer Question 2 -** The reviewer observed that a deeper study on the relevance should be completed on the component level.
  - ***ORNL Response: When we began to collect test vehicle data, it really did show how complex each of these systems really are to model. We were able to validate the Cummins power steering model and determine the air system model to have representative behaviors, but trying to make a more representative fan model was a larger undertaking than originally thought. So while we agree with the reviewer unfortunately we were only able to more deeply dive into the A/C system since overnight idle appeared to be the one system that would have the largest impact.***
- ***Reviewer Question 3 -*** The reviewer observed that it is important to do electric APU, or what we call battery HVAC along with diesel APU. The reviewer added that the project team had a strong approach for 2014/15 work and that the work was excellent.
  - ***ORNL Response: While we would have loved to do more laboratory testing with these units the best we could do was compare their specs vs the conventional cab HVAC system and contact fleets to get a feel for the general consensus of how well the battery powered HVACs work. In general we found that fleets did not like APUs, but not one fleet owner bought battery APUs after trying them out on a few test trucks.***

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 A/C hardware.
  - 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

- **FY2015**
  - **Continue development of the APU prototype and refine controls in the VSI Component Test Cell.**
  - **Integrate finished NREL CoolSim model into the Hardware-in-the-Loop (HIL) system.**
  - **Exercise new prototype system in real world drive cycles using Component-In-the-Loop (CIL) testing to validate the system and collect experimental results.**
  - **Outfit the Cummins test vehicle with the prototype system and controls for vehicle validation.**
  - **Final CRADA report.**

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 being prepped to be installed in a test vehicle.
- Collaborations:
  - **Industry**: Cummins and EMP
  - **Government**: NREL's CoolSim Model team, ORNL's Center for Transportation Analysis
- Proposed Future Work
  - Complete **testing and benchmarking** of both the conventional system and the new prototype system to **validate the newly developed accessory models .**
  - Finalize system **controls development** and then integrate the new system and controls into the test vehicle for **system validation.**

ACKOWLEDGEMENTS

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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