VSS133

Cummins MD & HD Accessory Hybridization CRADA

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OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

OVERVIEW

Timeline	Barriers
• Project start date: July 2013 • Project end date: July 2015 • 15% Complete	• Cost • Constant advances in technology • Computational models, design, and simulation methodologies
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 and hybridized 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 on a powertrain in the VSI Powertrain Test Cell.

RELEVANCE – VSST and DOE Goals and Barriers

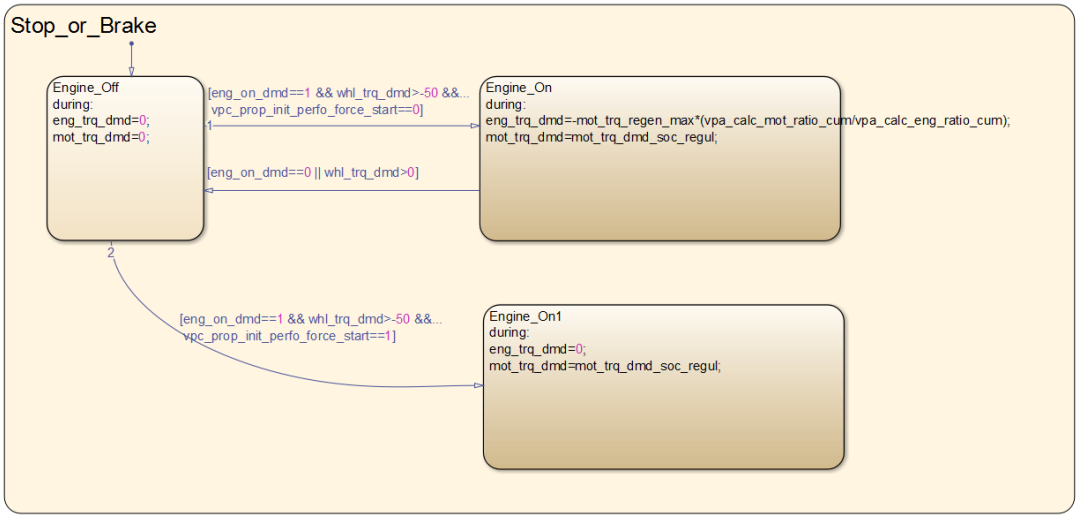
- **21st Century Truck Partnership Goals:**
  - Develop advanced heavy duty vehicle systems models.
  - Create methods to predict and measure the effects of idle reduction technologies.
  - Reduce engine parasitic energy losses.
- **VSST Program Activities:**
  - Modeling and simulation, component and systems evaluations, medium and heavy duty vehicle systems optimization.
- **VSST Barriers:**
  - **Cost**: Using ORNL's VSI Laboratory, testing prototypes at both a component and powertrain level 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 accessory systems on are available to compare current modeling, this reveals the need for additional development and validation these types of models.
  - **Computational models, design, and simulation methodologies:** Currently, medium and heavy duty physics based accessories models are not available, typically all accessories are "lumped" into one lookup table that is purely speed based.

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	**ON SCHEDULE**

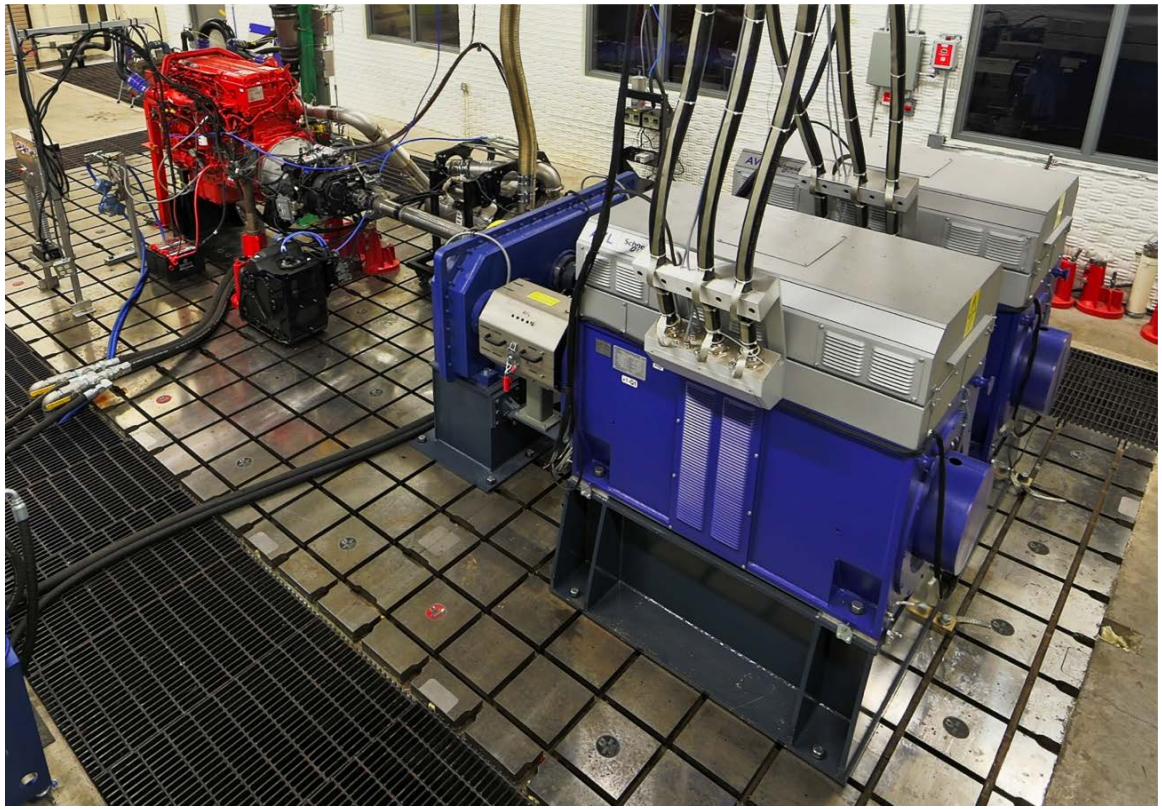
APPROACH(1): Modeling and Controls Development Phase

- **Collect respective data for all accessories and develop new mechanical and electrical accessory models.**
- **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 for three different vehicle types.**
  - HD Line Haul with Sleeper Cab
  - HD Transit Bus
  - MD Parcel and Delivery
- **Experimentally validate component models using Hardware-In-the-Loop (HIL) testing.**
- **Develop hybridized accessory models and controls.**



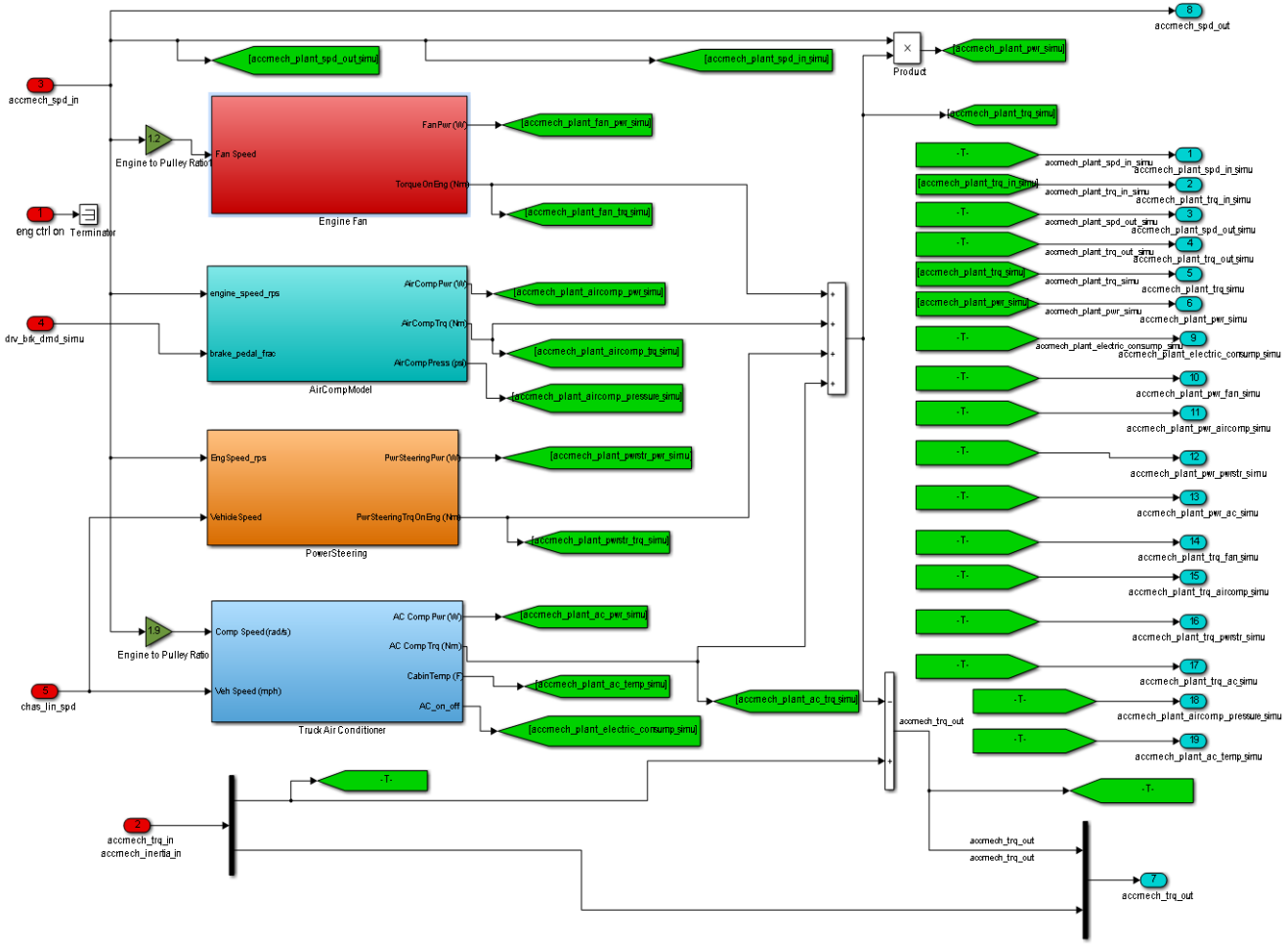
APPROACH(2): Testing and Validation Phase

- Acquire hybrid accessory prototypes designed from the modeling phase of the project.
- Test and further develop prototypes in the component test cell using HIL testing.
- Test and develop a hybrid accessory system as a whole on a powertrain using the VSI Powertrain Test Cell.
- Validate the component and vehicle models using experimental findings.



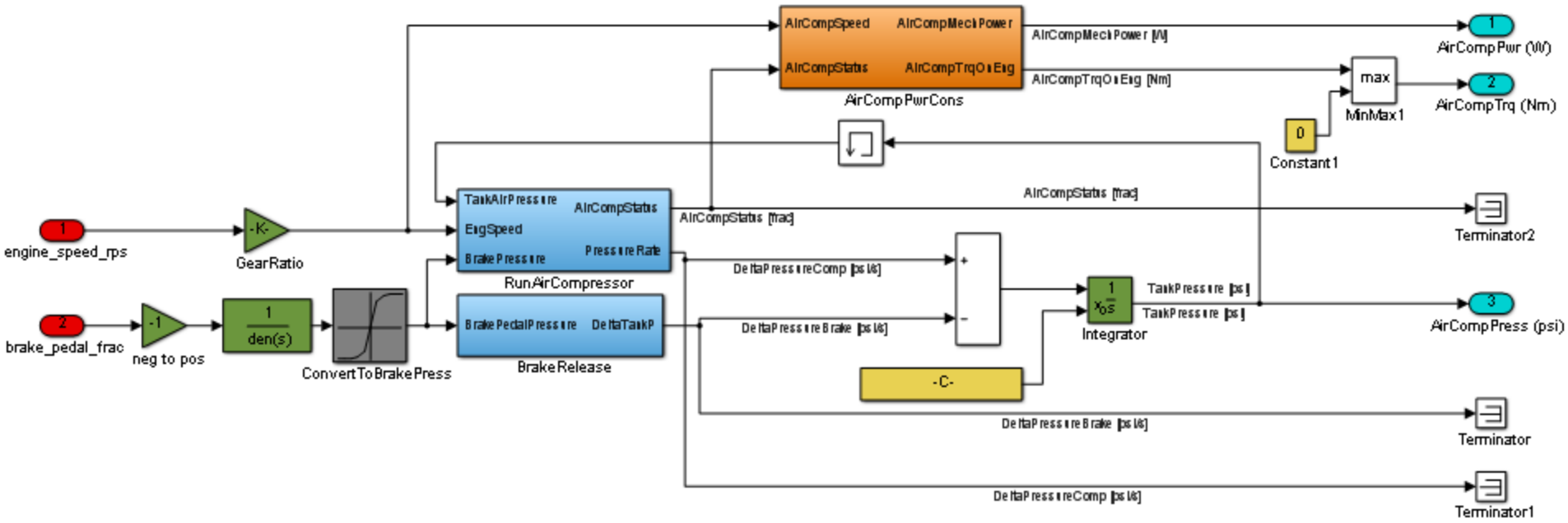
ACCOMPLISHMENT (3): Changing Lumped Sum Lookup Tables to Higher Fidelity Physics Based Accessory Models.

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



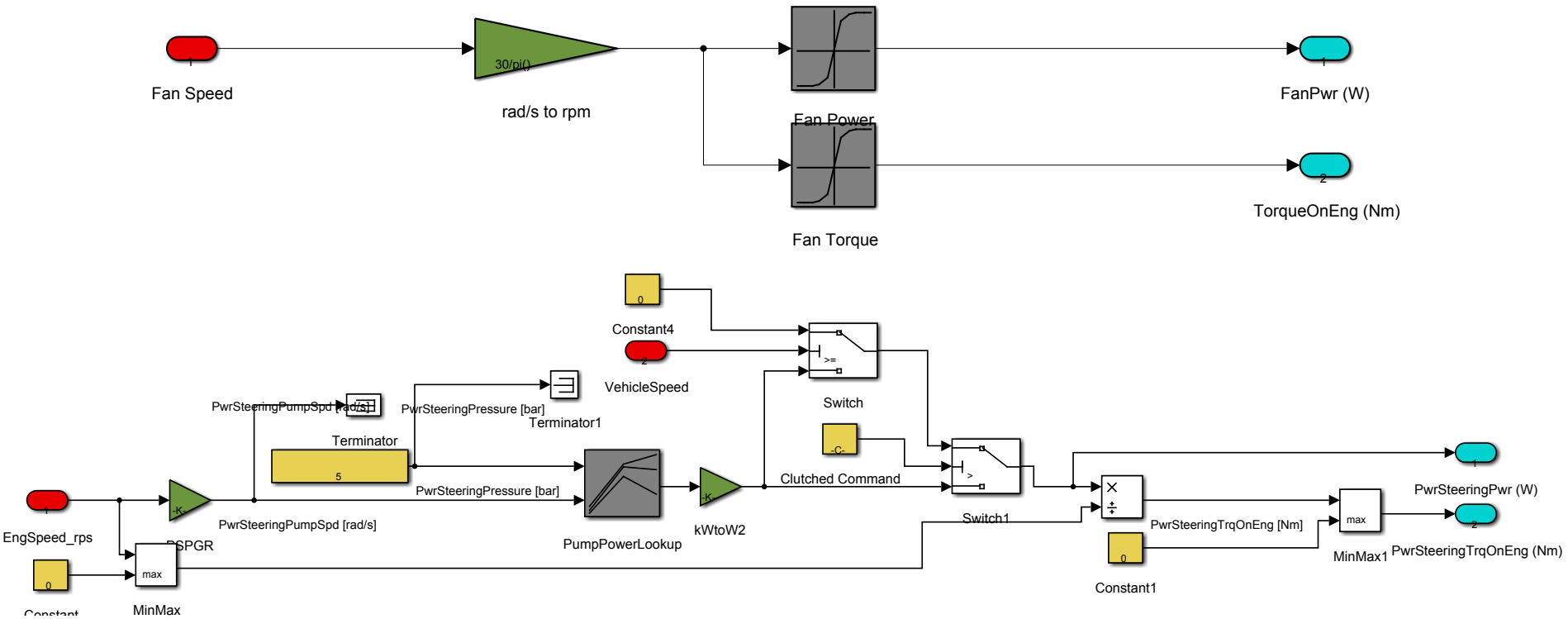
ACCOMPLISHMENT (4): Air Compressor Model

- **Brake Air Compressor Model: High Fidelity**
  - Developed using experimental data from a Cummins test vehicle.
  - Tested and validated for accuracy by Cummins.



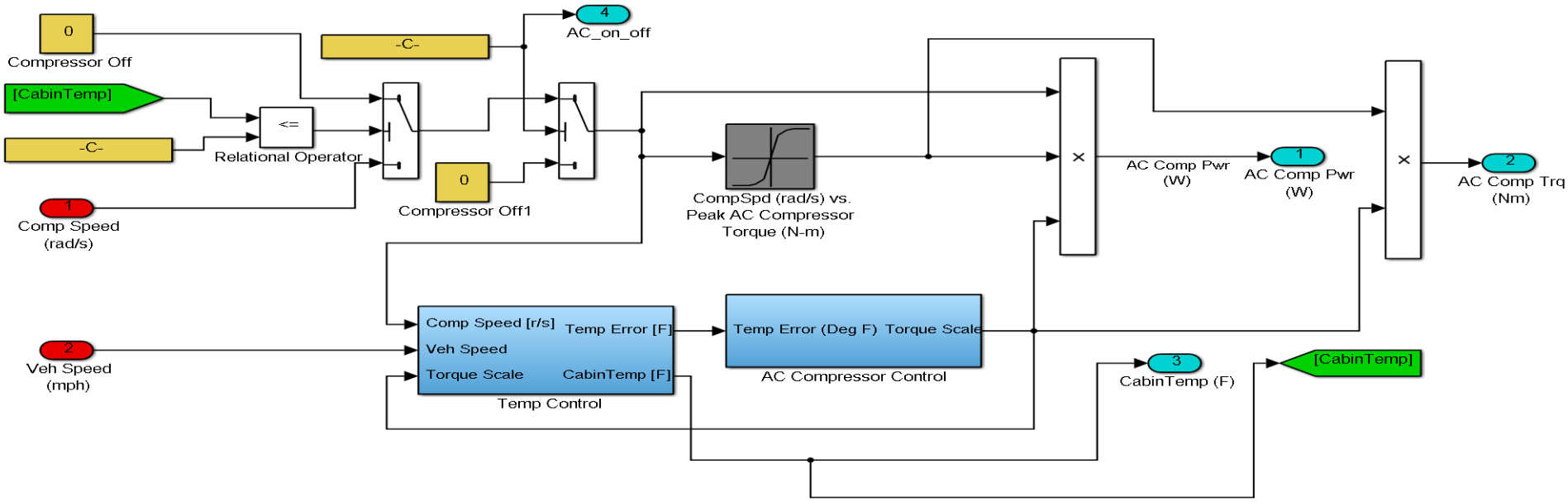
ACCOMPLISHMENT (5): Fan and Power Steering Models

- **Cooling Fan: Low Fidelity**
  - Uses the power curve of the fan multiplied by application specific (i.e. bus, line haul, parcel and delivery, MD, HD, etc.) duty cycle from SAE J1343. This is still a lookup table model.
- **Power Steering: Medium Fidelity Model**
  - Uses OEM pump pressure and torque vs speed lookup tables.

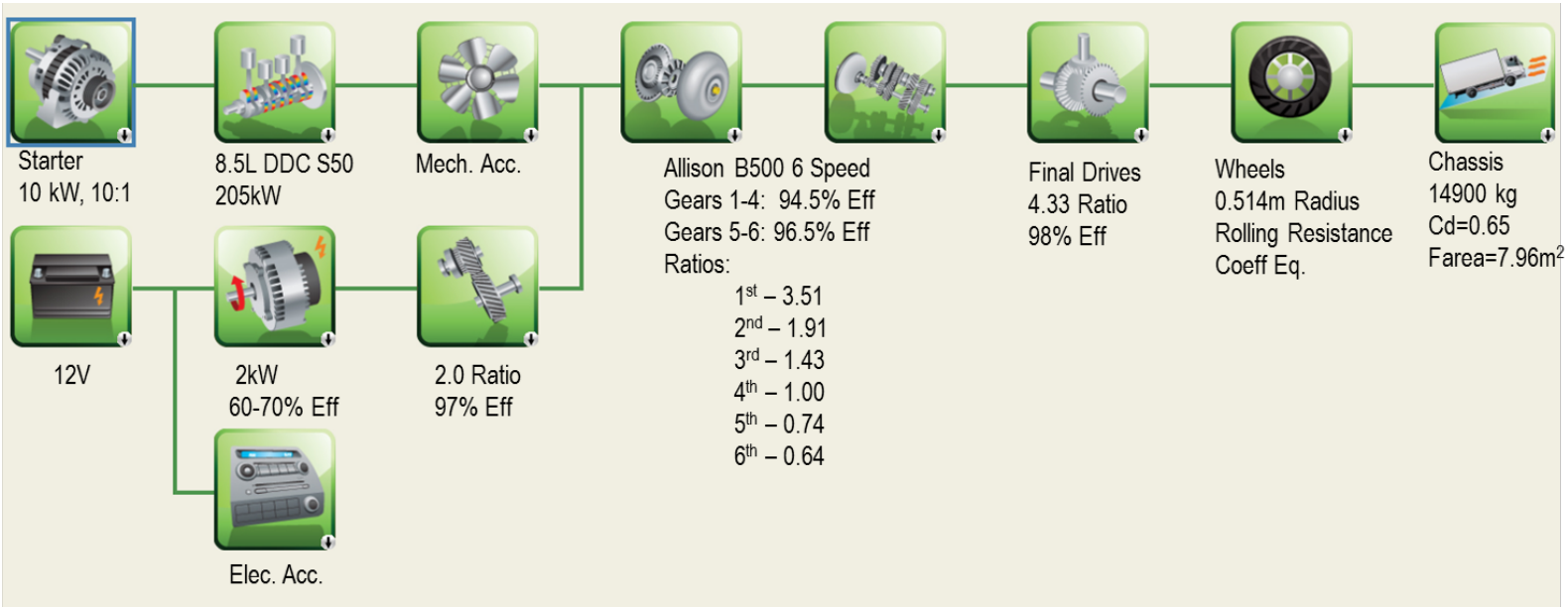


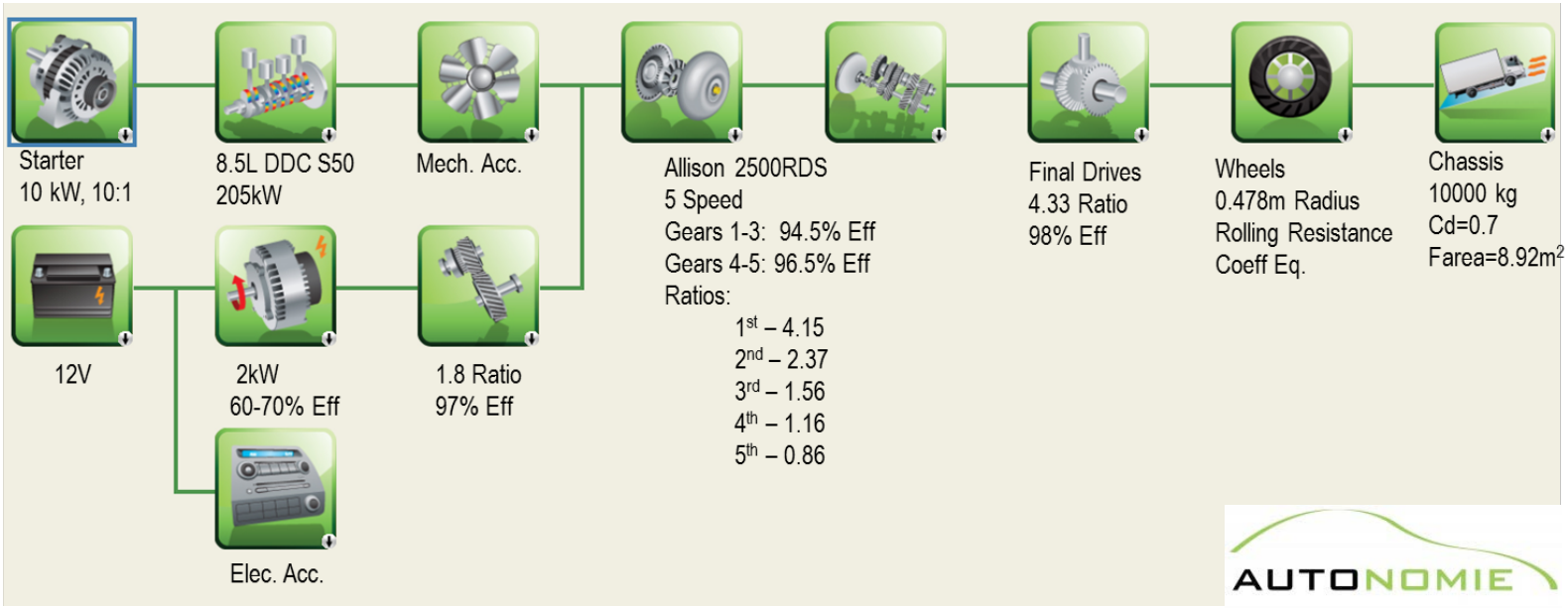
ACCOMPLISHMENT (6): Air Condition System Model

- **Air Conditioning: Medium Fidelity**
  - This model also effects the electrical accessory model as the blower system in most MD and HD applications is between 400-1500W.



ACCOMPLISHMENT (7): HD Transit Bus and MD P&D Models



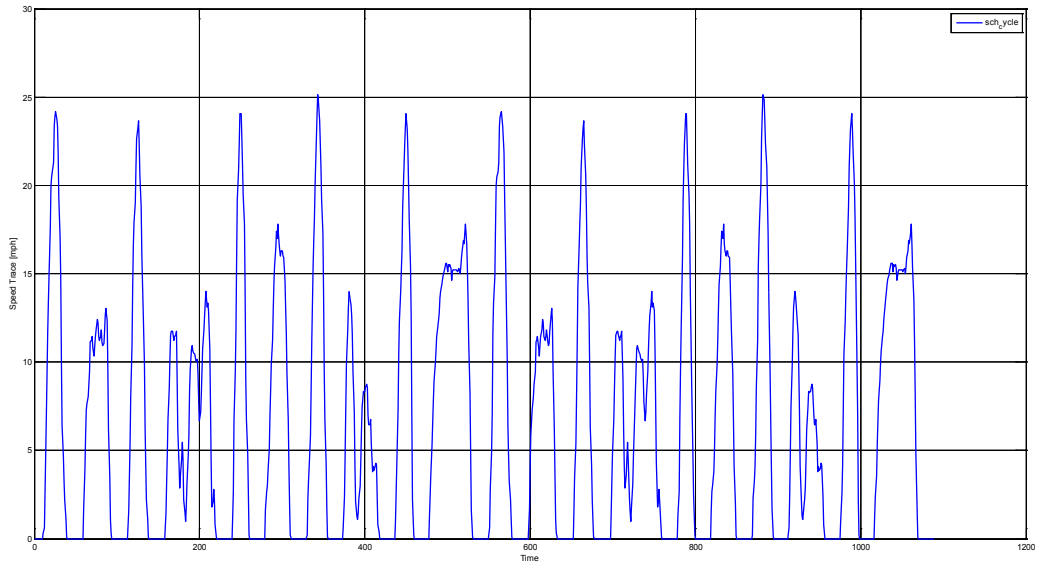


AUTONOMIE

ACCOMPLISHMENT (8): Result of Transit Bus Model

Fuel Economy Results [mpg]					
Data	HHDDT65	Bus RTE Cycle	Arterial Cycle	Manhattan Cycle	Commuter Cycle
All Accessories [mpg]	7.69	2.88	5.38	3.73	7.52
A/C Out [mpg]	7.80	3.08	5.85	3.97	8.00
Cooling Fan Out [mpg]	7.73	2.90	5.41	3.75	7.55
Air Compressor Out [mpg]	7.72	2.92	5.40	3.77	7.55
Power Steering Out [mpg]	7.97	3.24	5.64	4.13	7.82

Manhattan Fuel Consumption Entitlements	
Data	Fuel Consumption % Decrease
A/C Out	6.209
Cooling Fan Out	0.674
Air Comp Out	1.309
Power Steering Out	10.129

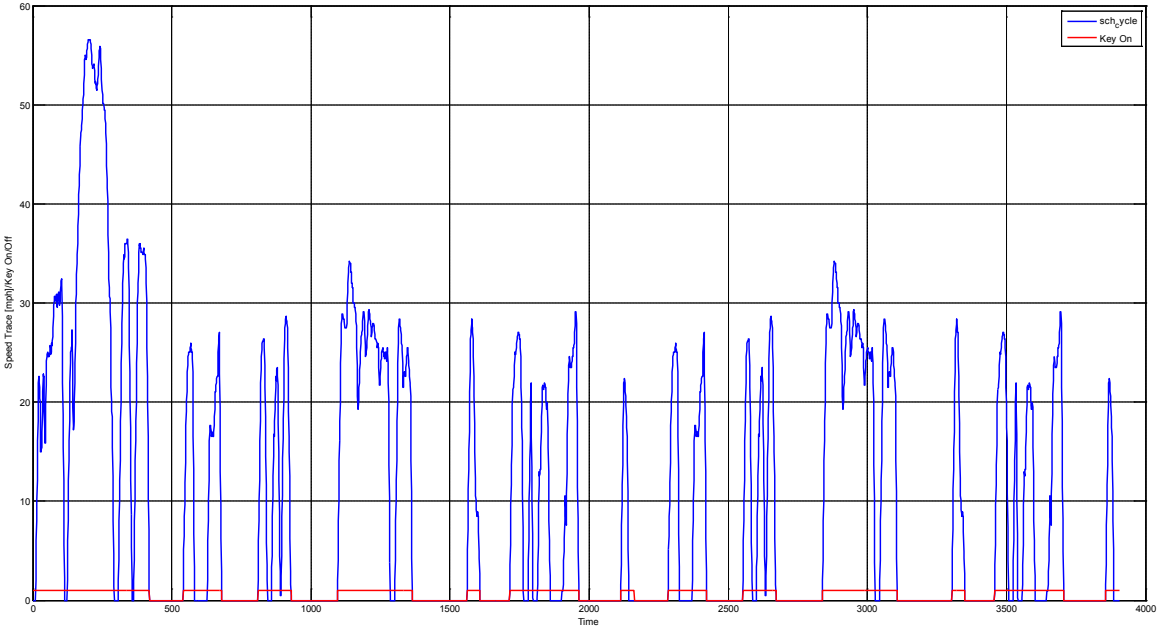


Manhattan Bus Cycle

ACCOMPLISHMENT (9): Result of MD P&D Model

Fuel Economy Results [mpg]				
Data	Utility	HHDDT65	HTUF6 On	HTUF6 On/Off
All Accessories [mpg]	8.97	7.46	7.09	8.09
A/C Out [mpg]	9.04	7.48	7.15	8.32
Cooling Fan Out [mpg]	9.07	7.53	7.15	8.16
Air Compressor Out [mpg]	10.11	7.76	8.03	8.80
Power Steering Out [mpg]	10.20	7.76	8.85	8.11

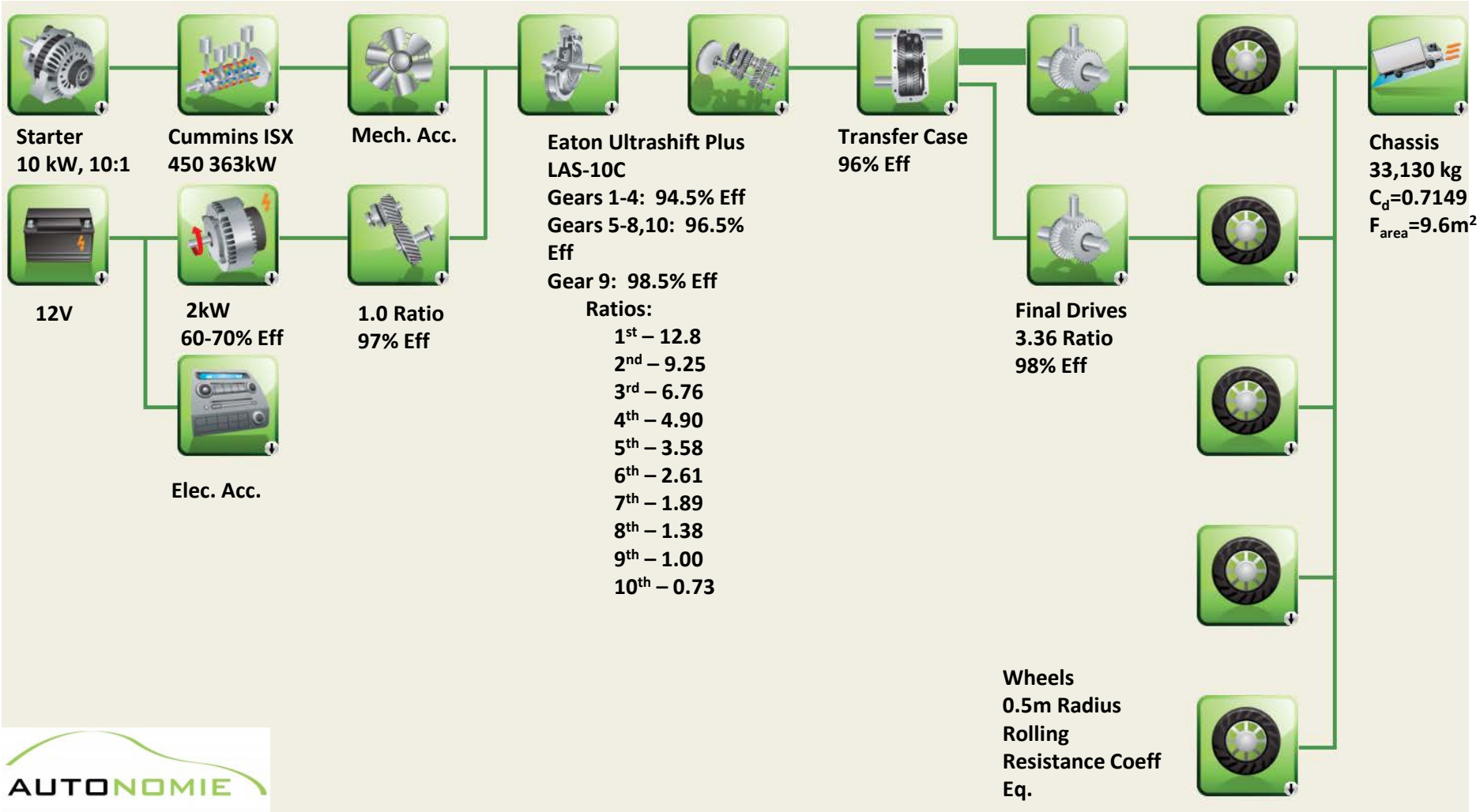
HTUF6 On/Off Fuel Consuption Entitlements	
Data	Fuel Consumption % Decrease
A/C Out	2.756
Cooling Fan Out	0.848
Air Comp Out	8.104
Power Steering Out	8.528



MD HTUF6 Cycle

ACCOMPLISHMENT (10): Baseline Vehicle Model for Line Haul

- **Based upon Kenworth T700**



ACCOMPLISHMENT (11): Overnight Idle Mitigation Better Application than Hybrid System for the Day's Cargo Haul

- **Based on our simulation results, HD Line Haul is not a good full hybridized accessory candidate 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 in their optimum condition at these speeds.
  - Accessories at engine cruising speeds are less than 1.5% of the typical LH engine power.
- **Idling (especially overnight) is a significant concern when considering reducing fuel consumption and emissions from Line Haul Sleeper Trucks, but is often necessary for the driver during the over night hotel.**
  - A truck burns **4-7 gallons of diesel** when idling for 8 hours.
  - Trucks are also often forced to wait for long periods during trailer loading and unloading; this is another example of excessive idling. Trucks are required to be standing by in order to move when needed.

Chassis Vehicle vs. Simulation Fuel Economy

Data	WHVC	Utility	CARB Transient	55mph Cruise	65mph Cruise	HHDDT65	Cummins Proprietary Cycle
Chassis Summery [mpg]	5.40	4.78	3.90	8.17	6.54	N/A	N/A
Model [mpg]	5.41	5.08	4.26	7.77	6.67	6.31	6.04
Percent Error	0.19	6.28	9.23	4.90	1.99	N/A	N/A
Percent Error Average	4.52						

Fuel Consumption Entitlements

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

ACCOMPLISHMENT (12): 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 engine integrated system which will allow elimination of overnight idling, connectivity with shore power, engine start/stop capability, optimized cooling capacity via electric fans, regenerative braking, and traction assists to the engine.**

COLLABORATION AND COORDINATION

- **Cummins, Inc.**
  - Data from Instrumented Fleet Test Vehicles
  - Supporting Tasks for Model Development and Validation
  - Cummins Proprietary Drive Cycles
- **Meritor CRADA (VSS072 – FY2013)**
  - HD engine and powertrain dynamometer measurements in ORNL's Vehicle Systems Integration Powertrain Test Cell. (torque, fuel rate, emissions, etc.)
- **Related ORNL Activities**
  - ORNL Heavy and Medium Truck Duty Cycle "real world" database.
  - Advanced Heavy-Duty Engine Systems and Emissions Control Modeling and Analysis (VSS048)

PROPOSED FUTURE WORK

- **FY2014**
  - **Create testing platform for accessories in the VSI Component Test Cell or on the Cummins Fleet Test Vehicle to validate accessory models.**
  - **Develop models for hybrid accessories.**
  - **Build APU and eAPU model and collect eAPU data.**
  - **Start development of hybrid prototypes and controls.**
  - **Design proposed integrated eAPU system**
- **FY2015**
  - **Test hybrid prototypes and refine controls in the VSI Component Test Cell.**
  - **Outfit powertrain with the finished hybrid eAPU system allowing to:**
    - **Integrate the system as a whole on the powertrain**
    - **Test and refine vehicle system controls**
    - **Exercise new prototype system in real world drive cycles using powertrain-in-the-loop testing to validate the system and collect experimental results.**

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 system that is developed based on the modeling and simulation work.
- **Technical accomplishments and progress**
  - **Completed** first round of foundational physics based accessory models.
  - **Exercised** different MD and HD vehicle models to determine which system application and architecture best benefits the project.
- **Collaborations:**
  - **Industry**: Cummins, Meritor
  - **Government**: DOE Advanced Combustion and Engines, ORNL's Fuels, Engines, and Emissions Research Center, and ORNL's Center for Transportation Analysis
- **Proposed Future Work**
  - **Develop** new vehicle and system model of the ORNL and Cummins' proposed engine integrated eAPU design.
  - Complete **testing** of both the conventional accessories and the new prototype systems to **validate the newly developed accessory models.**
  - Perform **component testing** to finalize **controls development** and then integrate the new system into a powertrain for **system validation.**

ACKOWLEDGEMENTS

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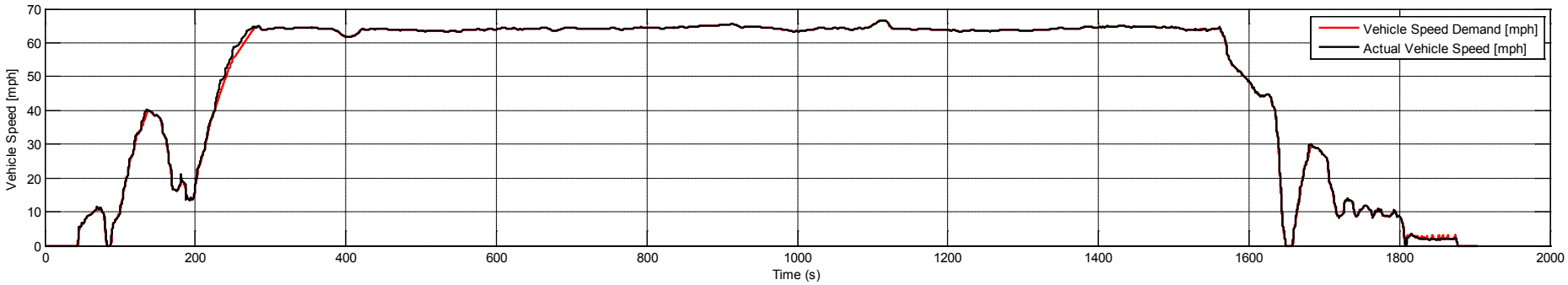
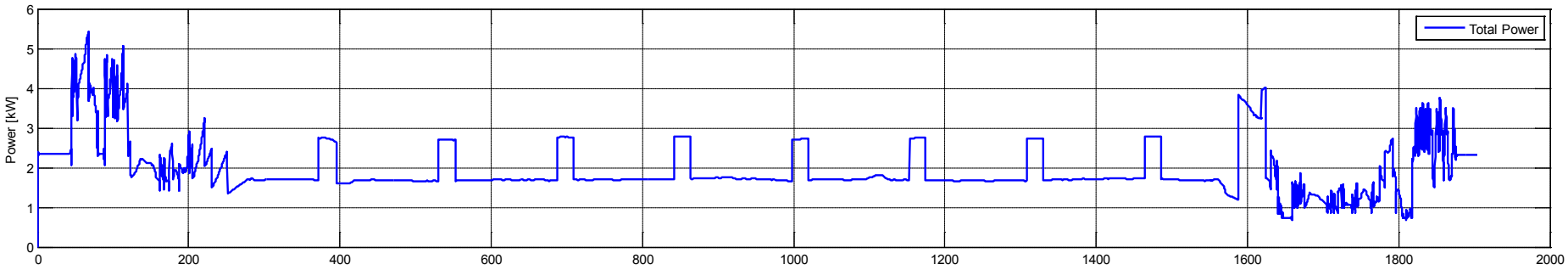
Technical Backup Slides

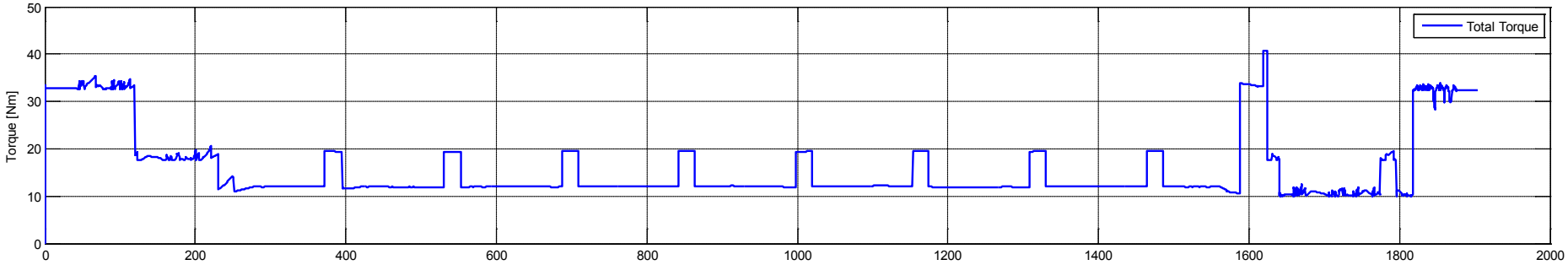
Acronym Definitions

- MD- Medium Duty
- HD- Heavy Duty
- P&D – Parcel and Delivery
- 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
- HTUF6 - Hybrid Truck Users Forum Class 6
- OEM- Original Equipment Manufacturer
- ORNL- Oak Ridge National Laboratory

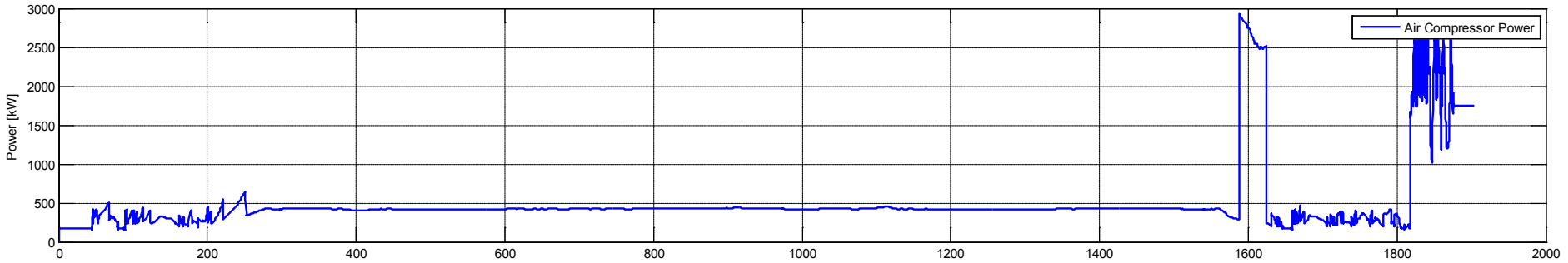
HHDDT65: Accessory Examples, Totals

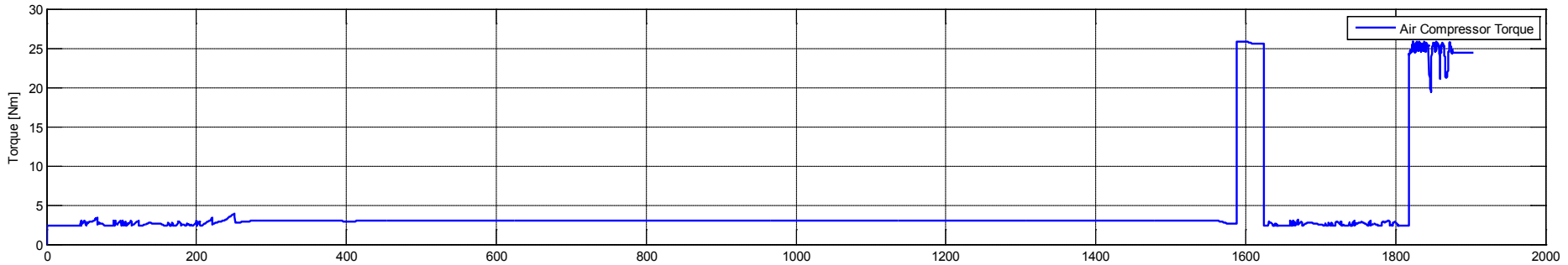


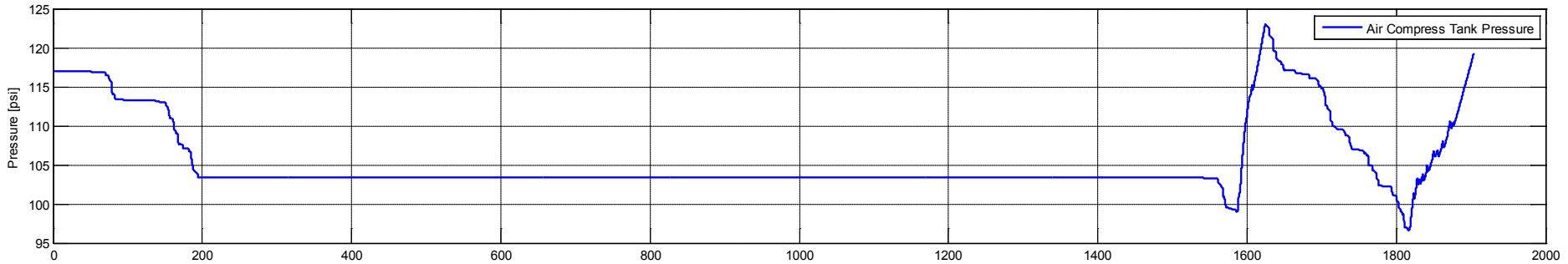




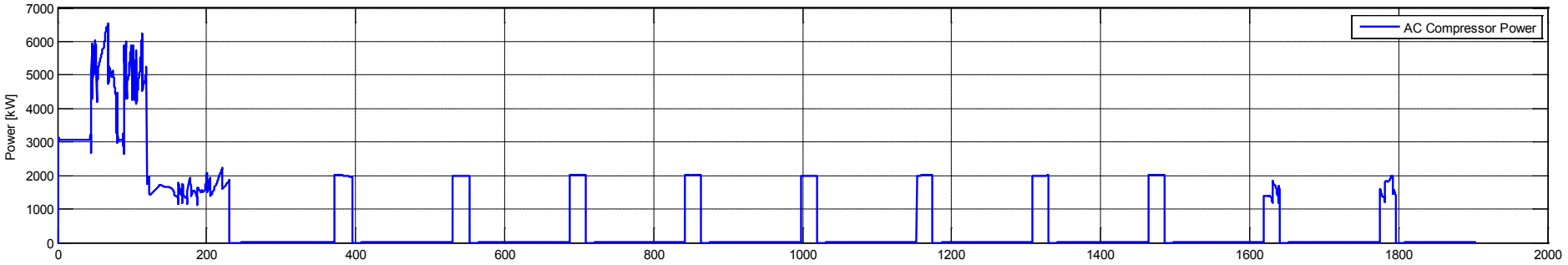
HHDDT65: Accessory Examples, Air Compressor

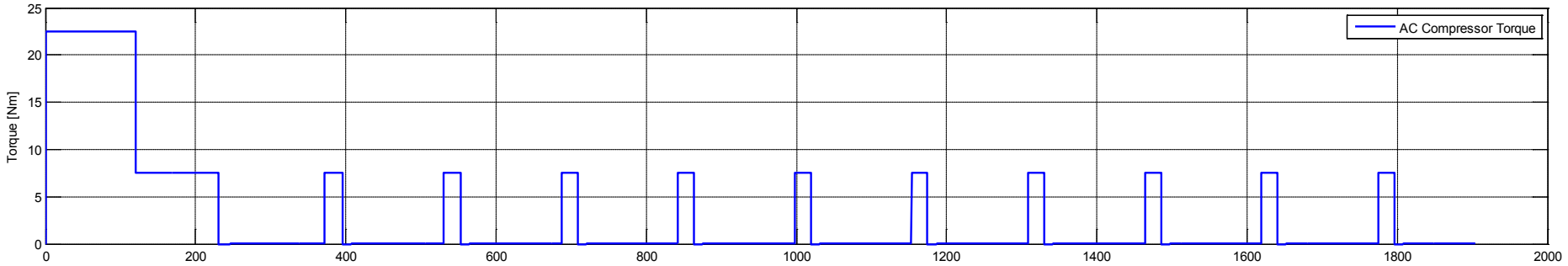


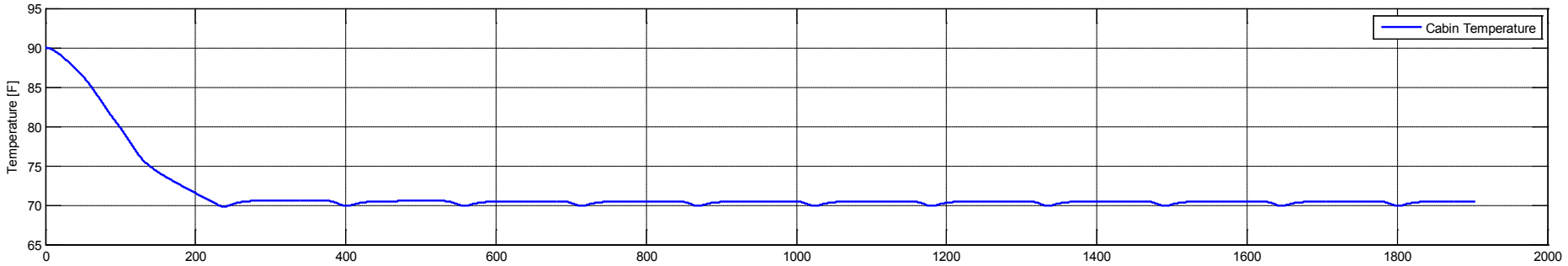




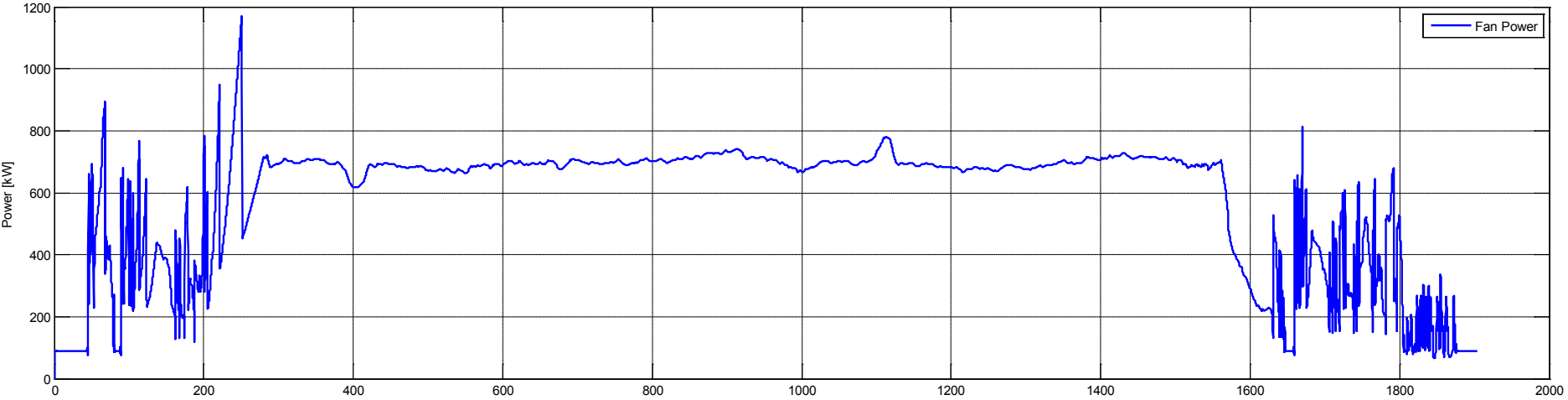
HHDDT65: Accessory Examples, Air Conditioning

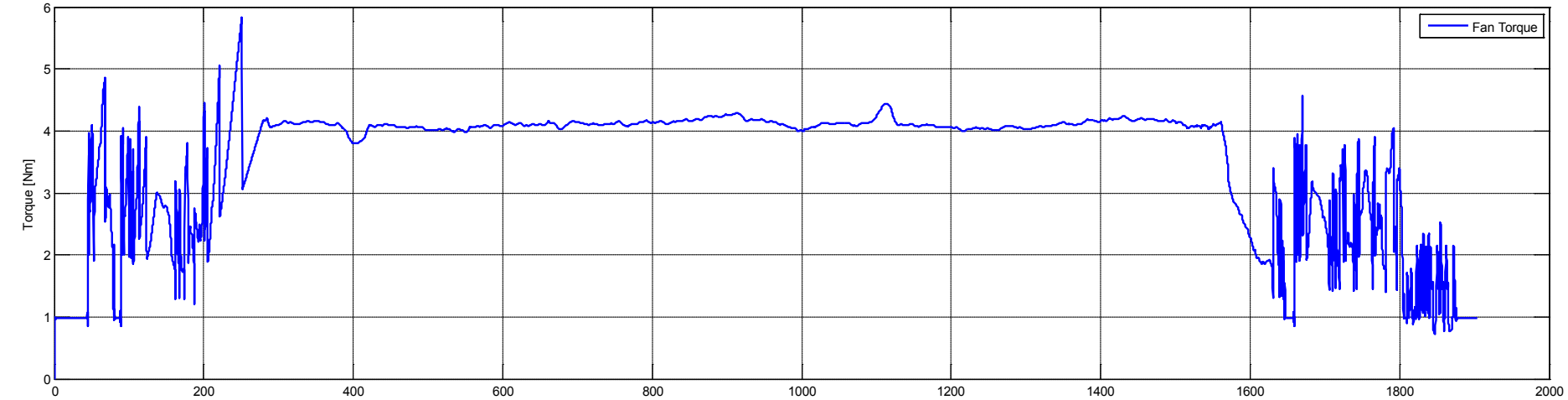






HHDDT65: Accessory Examples, Cooling Fan





HHDDT65: Accessory Examples, Power Steering