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# Super Truck Program: Vehicle Project Review

# Recovery Act –Class 8 Truck Freight Efficiency Improvement Project


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Daimler Truck North America LLC


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Project ID: ARRAVT080

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

## Timeline

- Project start: April 2010
- Project end: March 2015
- Percent complete: 40%

## Budget

- Total project $79,119,736
- Vehicle Budget $47,486,735
  - DOE Share(*) $6,100,000
  - DTNA Share (*) $6,100,000

(*) through Feb, 2012 for vehicle R&D expenses only, engine R&D expenses reported separately

## Barriers

- Resolve thermal & fluid dynamics tradeoffs between Aero & cooling
- Rejecting more heat in a smaller, aerodynamic hood & engine compartment
- Development of safe and efficient High Voltage power distribution, integrating multiple HV energy sources
- Making tradeoffs between efficiency, cost and weight
- Vehicle controls integration (Aux, Hybrid, Powertrain, Waste Heat, Predictive)

## Partners

- Detroit Diesel
- Schneider National, Walmart
- National Renewable Energy Lab
- Oregon State University
- Strick Trailer
- Michelin
- …

# Objectives and Milestone

## Develop and Demonstrate a 50% total increase in vehicle freight efficiency:

- *At least 20% improvement through a heavy-duty diesel engine capable of achieving a 50% brake-thermal efficiency*
- *Identify key pathways towards achieving 55% through modeling and analysis*

| Timeline | Phase Description | Milestones |
|---|---|---|
| 4/10–3/11 | **Analysis:** *(1) Technology Modeling/Analysis and Initial Component Development and Demonstration* | Develop analytical roadmap:<br>• **50% vehicle freight efficiency improvement**<br>• 50% engine brake thermal efficiency |
| 4/11–3/12 | **Specification:** *(2) Experimental Demonstration of Technology Building Blocks for Intermediate Goals* | Experimentally demonstrate technology building blocks:<br>• **25% vehicle freight efficiency improvement** (system level test)<br>• 46% engine brake thermal efficiency |
| 4/12–5/13 | **Design:** *(3) Technology Identifications and Final Component Development and Demonstration* | Identify and initially develop technology building blocks:<br>• 50% vehicle freight efficiency improvement (system level test & analysis)<br>• 50% engine brake thermal efficiency |
| 6/13–6/14 | **Build:** *(4) Experimental Demonstration of Technology Building Blocks for 50% Engine Thermal Efficiency and 50% Vehicle Efficiency* | Experimentally demonstrate technology building blocks:<br>• 50% vehicle freight efficiency improvement (system level test)<br>• 50% engine brake thermal efficiency |
| 7/14–3/15 | **Test:** *(5) Final System Integration and Demonstration* | Experimental demonstration:<br>• 50% vehicle freight efficiency improvement (entire vehicle test)<br>• 50% engine brake thermal efficiency (engine test)<br>• 55% engine brake thermal efficiency (engine analysis) |

# Phase I Milestone Completed ✓

*Analytical Roadmap Development to 50% Vehicle FEI & 50% Engine BTE*

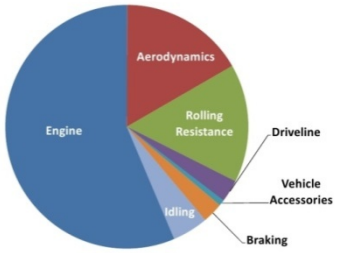
## Baseline Tractor

- 2009 Cascadia 125"BBC, 72"RR
- DD15 Engine 455hp/1550 lb-ft

## Vehicle Test

- Baseline Peformance Measurements
- Highway Cycle (55 &65 mph)
- Idle Cycle (summer, winter)
- City Cycle

## Vehicle Energy Balance - Highway

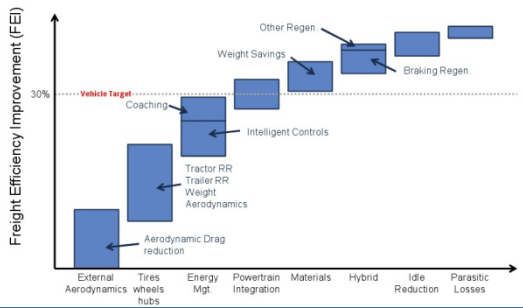



## SuperTruck

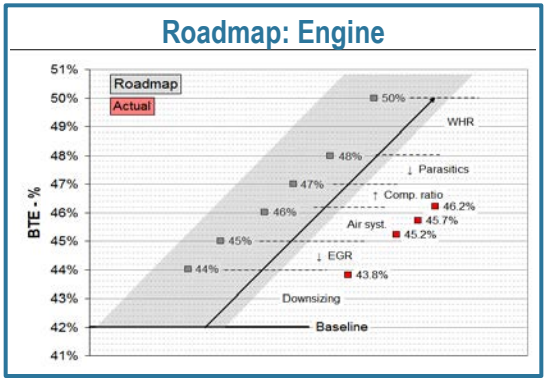
## Modeling & Analysis

- Establish System Level Technical Targets

## Roadmap: Vehicle

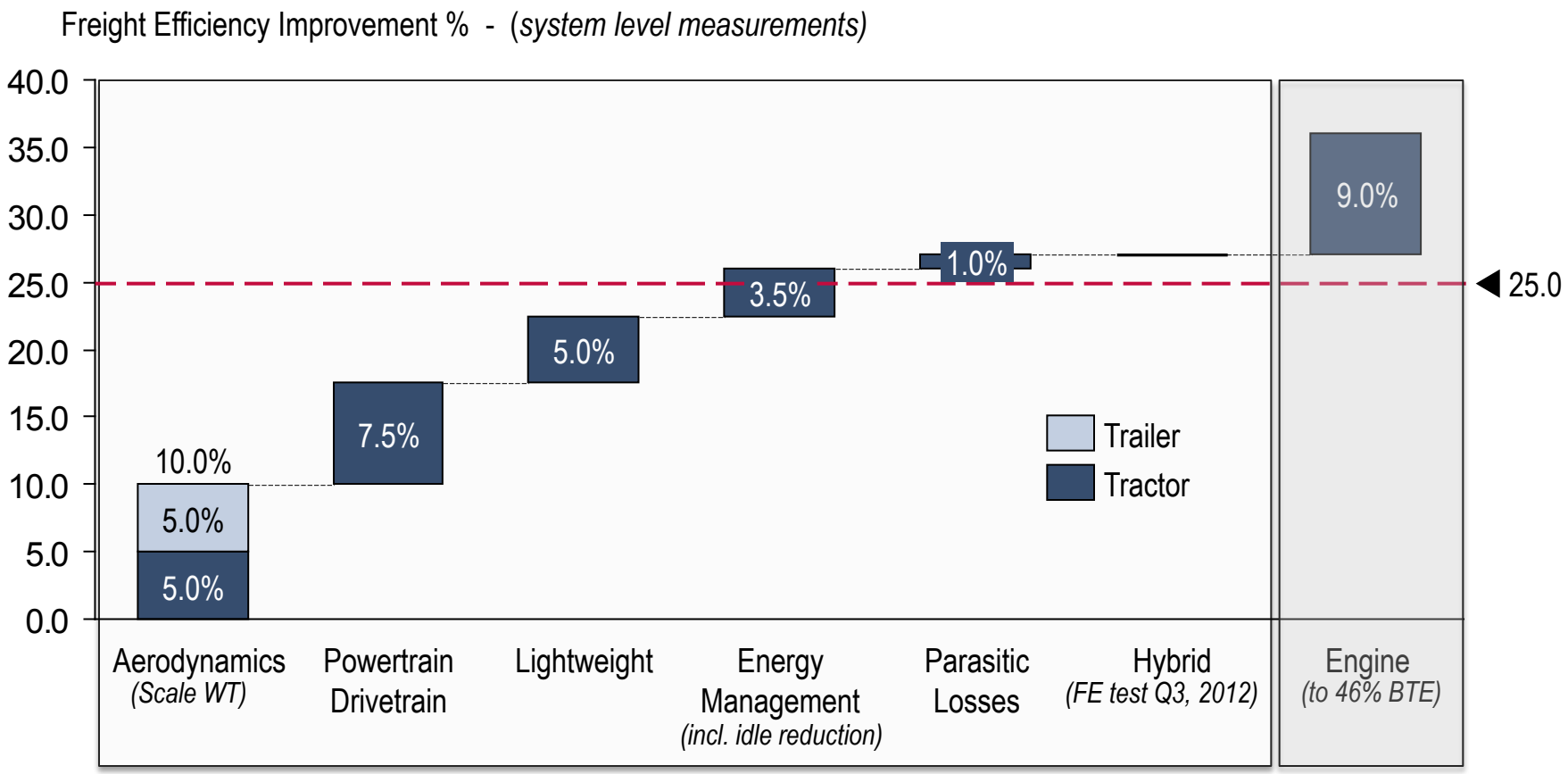



## Roadmap: Engine



# Phase 2 Milestone Status

## *Experimental testing to 25% vehicle freight efficiency*



# Experimental Tests Conducted on 'Tinker' Trucks

Anti-Idle

eHVAC

Cooling Package

HEV / Engine controls Integration

HV Power Distn.

eMotor Starter

**SAE Hybrid Committee**
Standards development for electrification of Powertrain and Accessories

Hybrid 'Tinker' Truck

Rear Axle Config/ Ratio

Direct Drive AMT w/ optimized shifting

Predictive Torque Mgt.

AccuSteer

Clutched Air Comp.

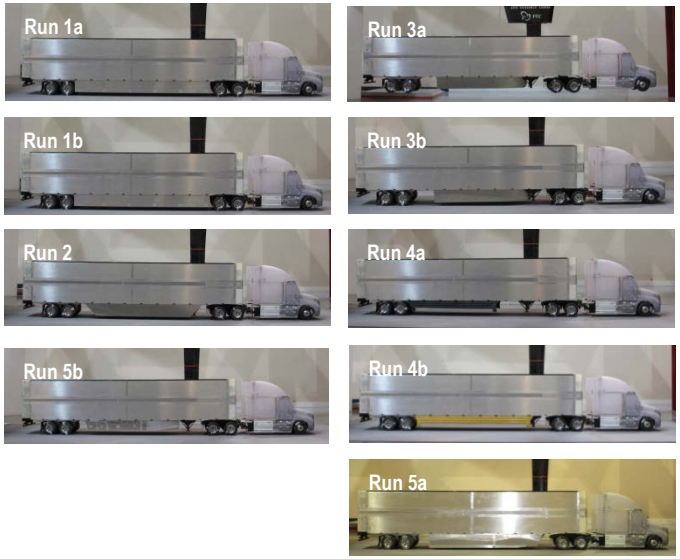
Electronic Air Control

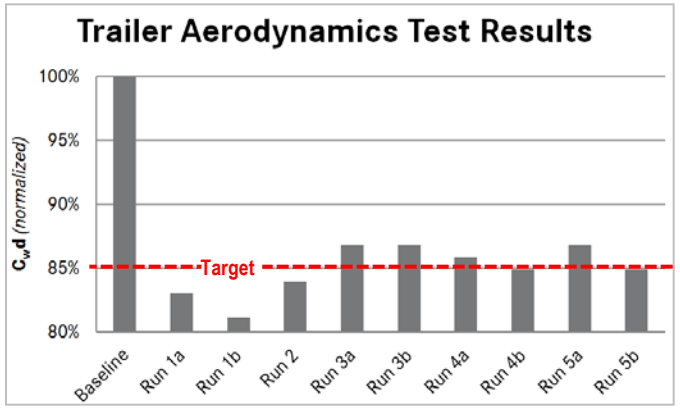
Powertrain & Parasitics 'Tinker' Truck

# External Aerodynamics

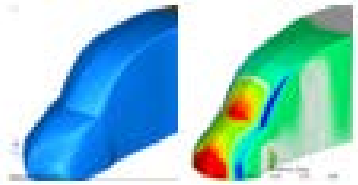
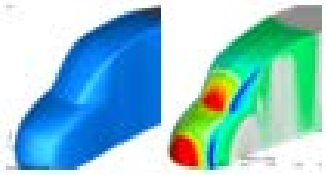
*30% drag reduction target exceeded in CFD and Scale Wind Tunnel Tests*

## Trailer Aerodynamics




## Tractor – Basic Shape Analysis

| | Notional 1 | Notional 3 |
|---|---|---|
| Computational Fluid Dynamics |  |  |
| Scale Wind Tunnel |  |  |
| ΔCd Measured | 15% reduction | 15% reduction |

**CFD and Scale Wind Tunnel Testing**

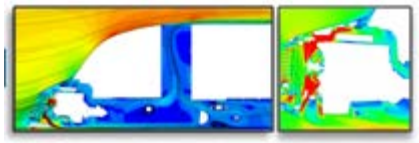
- Conducted steady state, closed grill simulation & testing
- Conducted transient, open grill simulation & testing
- Results correlate

# Thermal Management / Cooling

*Cooling concept developed to meet add'l heat rejection while maintaining aero.*

## 3D CFD Thermal Analysis

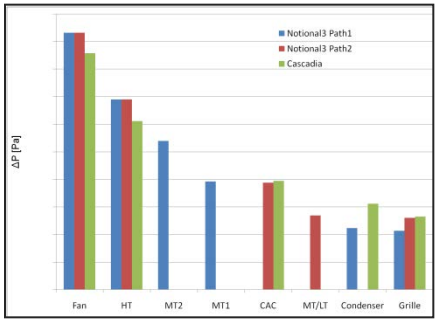
Adequate air mass flow

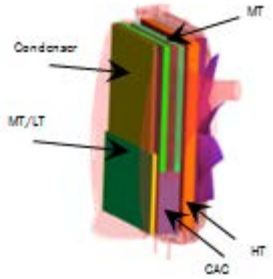


Minimize aero. drag

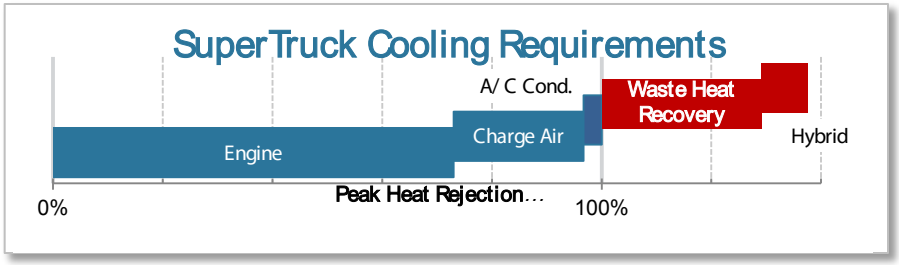
**Analysis Study Complete**
- WHR cooling circuit analysis
- Hybrid cooling circuit analysis
- Alternative layouts and packaging
- Cooling Performance analysis

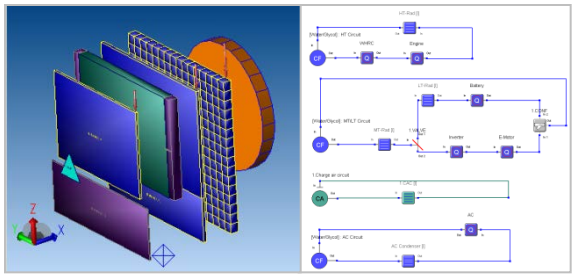
### Pressure Drop Analysis




## 1D Thermal Analysis

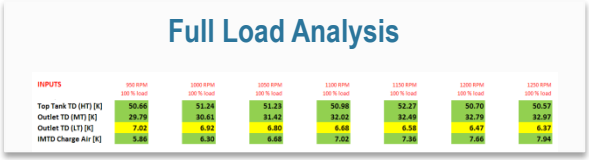


### Load Sweep Analysis

| INPUTS | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1200 RPM 55 % load | 1200 RPM 60 % load | 1200 RPM 65 % load | 1200 RPM 70 % load | 1200 RPM 75 % load | 1200 RPM 80 % load | 1200 RPM 85 % load |
| RESULTS | | | | | | | |
| Top Tank TD (HT) [K] | 58.37 | 62.86 | 67.43 | 69.98 | 69.97 | 69.79 | 69.77 |
| Outlet TD (MT) [K] | 37.86 | 41.32 | 44.89 | 44.92 | 40.47 | 35.86 | 31.84 |
| Outlet TD (LT) [K] | 9.65 | 9.68 | 9.70 | 9.72 | 9.73 | 9.75 | 9.76 |
| IMTD Charge Air [K] | 8.13 | 8.93 | 9.94 | 11.16 | 12.46 | 13.75 | 14.98 |

### Full Load Analysis



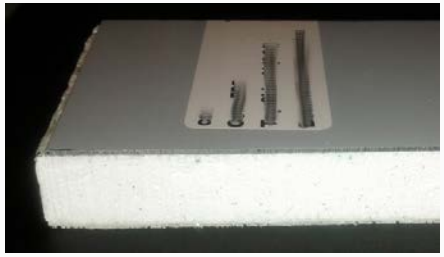
| INPUTS | 950 RPM 100 % load | 1000 RPM 100 % load | 1050 RPM 100 % load | 1100 RPM 100 % load | 1150 RPM 100 % load | 1200 RPM 100 % load | 1250 RPM 100 % load |
|---|---|---|---|---|---|---|---|
| Top Tank TD (HT) [K] | 50.66 | 51.24 | 51.23 | 50.98 | 52.27 | 50.70 | 50.57 |
| Outlet TD (MT) [K] | 29.79 | 30.61 | 31.42 | 32.02 | 32.49 | 32.79 | 32.97 |
| Outlet TD (LT) [K] | 7.02 | 6.92 | 6.80 | 6.68 | 6.58 | 6.47 | 6.37 |
| IMTD Charge Air [K] | 5.86 | 6.30 | 6.68 | 7.02 | 7.36 | 7.66 | 7.94 |

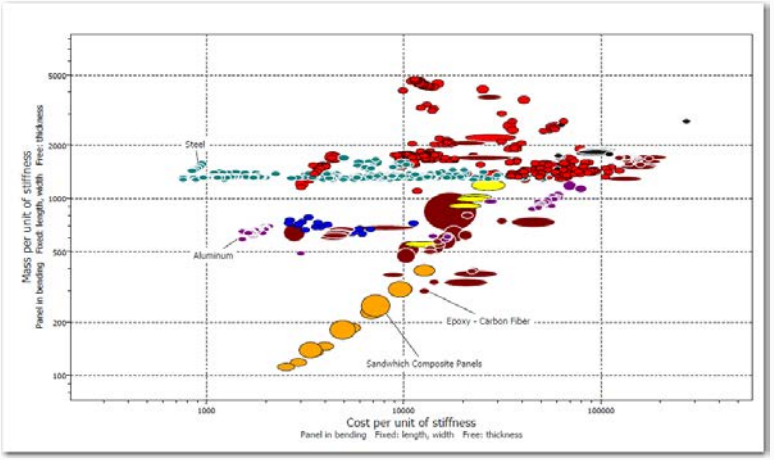
# Lightweighting

*Chassis analysis and tests to 4.5 – 5.8% FEI reduction, Cab analysis on-going*

## Cab Exterior

- Target floor, side/backwall, roof, hood systems
- Evaluate & test lightweight, low cost sandwich structures
  - Cores - foams, honeycomb
  - Faces – Al, FRP






## Frame Rails

- Composite designed, installed & tested
- Low Cost Aluminum designed & installed

## Next Steps

- Cross member development
- Complete Load-Optimized frame design in conjunction with lightweight suspension

**Physical Test of Composite Rail – 1st Revision**

| Mechanical Property | Symbol | Day Cab Reqs. | Sleeper Cab Reqs. |
|---|---|---|---|
| ➔ Vertical Bending Stiffness | $(EI_Y)$ | Exceeds | Meets |
| Lateral Bending Stiffness | $(EI_Z)$ | Falls Between | Falls Between |
| Torsional Stiffness | $(GJ_R)$ | Exceeds | Meets |

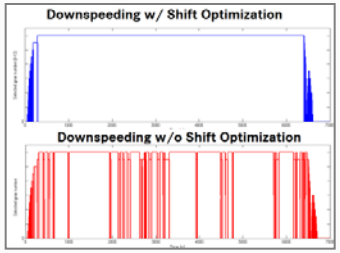
# Powertrain Drivetrain Integration

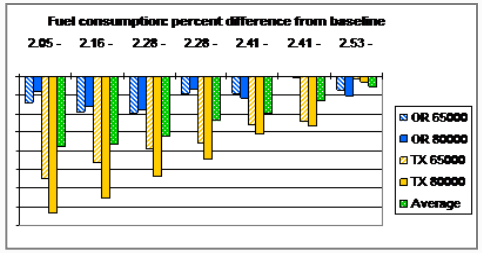
*7.5% FEI measured with further tests scheduled*

## Engine Downspeeding

### Modeling & Analysis

- Gear ratio Optimization on Transmission/Axle
- Shift strategy Optimization
- Gradeability / Startability




### Testing

- Transmission/Axle Ratio Performance Q2, 2012

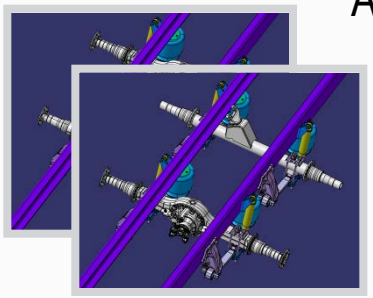
## Tires/Wheels/Hubs

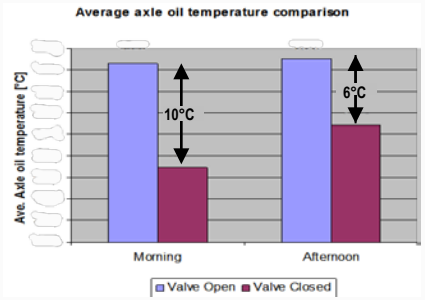
- Reduced Rolling Resistance
- Lightweight Wheels/Hubs
- Aero. Enhancements

### Testing

- 1st Round of Testing Complete
- 2nd Round of Testing Q4, 2012

## Axles





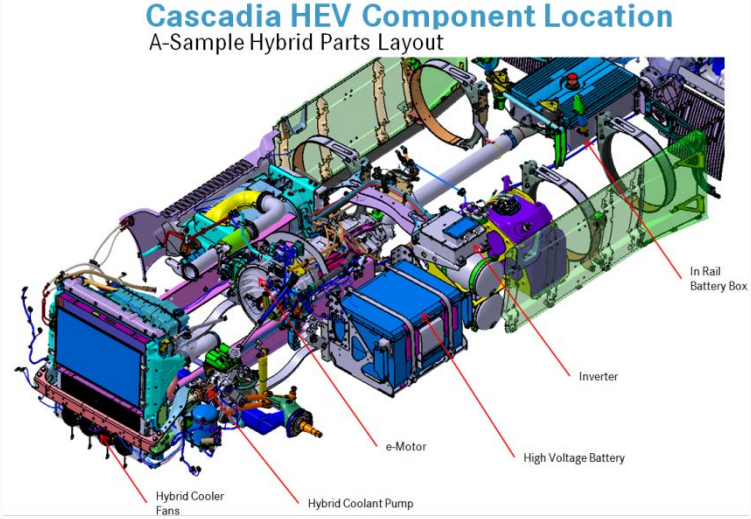

### Axle Testing

- Gear Oil Temperature Management
- Gear Oil Formulations
- Axle Configurations (traction enhanced 6x2)

# Hybrid A-Sample

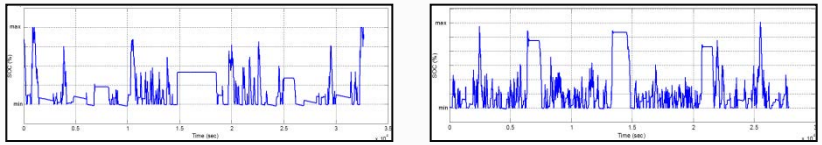
*Analysis complete for sizing & performance, tests scheduled in Q3 2012*

## Digital Mockup




## Modeling & Analysis

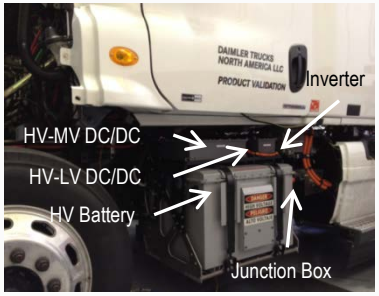
- Fuel Economy Estimation
- Component Sizing

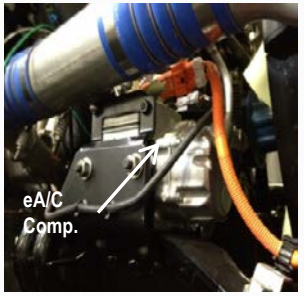


*(e.g. Battery SoC Analysis)*

## Hardware & Testing

- A-sample hardware installed
- Controls logic & EE integration (Hybrid + eHVAC)
- Functional testing on-going




## Vehicle Testing

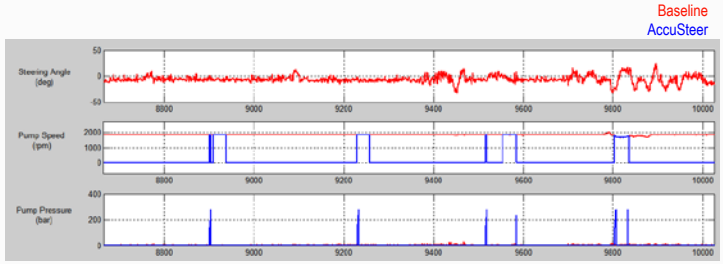
- eHVAC Q1, 2012
- Highway /City FE test scheduled Q3, 2012

# Parasitic Losses

*Testing & Analysis show up to combined 1.5% FEI potential*

## Power Steering

Closed Center Steering Gear
*(constant pressure, variable flow)*




### Modeling & Analysis Complete

- Performance Estimate
- Component sizing, controls developed
- Hardware procured
- Installation and Test scheduled for Q2, 2012

## Air System

Clutched Air Compressor + Electronic Air Dryer

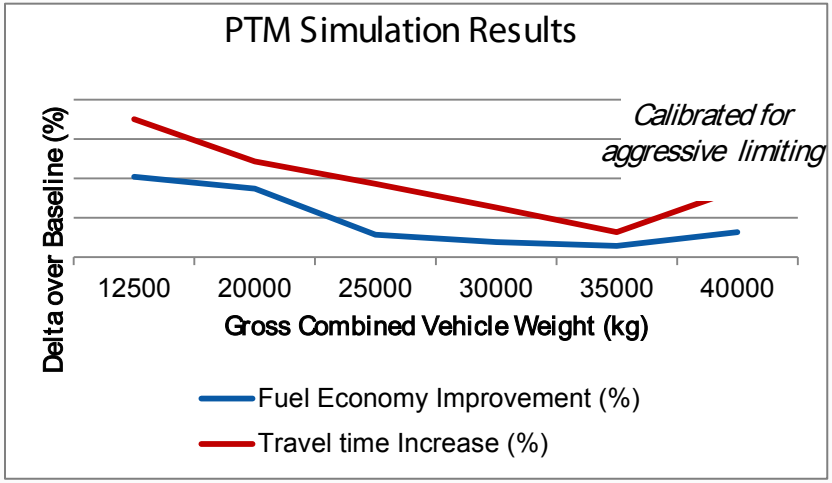
### Air System Testing Complete ✓

- Significant reduction in purge cycles
- Lower average compressor power

# Energy Management

## Predictive Torque Management

Limits torque based on vehicle mass and road grade to limit excessive accelerations, via J1939 TSC1




## Vehicle Testing Complete ✓

- City Cycle route – up to 2.4% savings measured
- Customer Field Test: 5 tractors, 3 mo, >100,000 miles
- Driver Survey

## Eco-Driver Feedback

### Development Status

- A-Sample application complete, based on 4 criteria
- Fuel & Fleet Test Scheduled
- Customer field Test

## Predictive Auxiliary Load Mgt.

Intelligently controls thermostatic valve, coolant pump & fan based on predictive engine load, and 3D Digital Maps.

Heated Thermostat

Variable Speed Pump

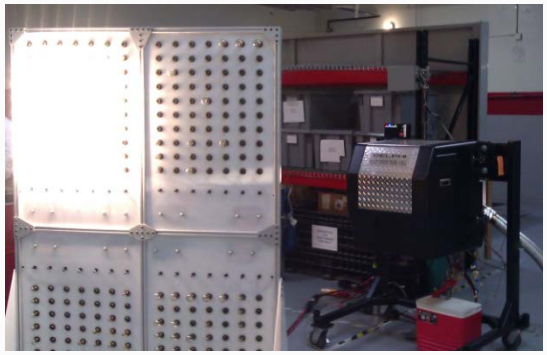
### Development Status

- 2 state coolant Pump successfully tested
- Controls developed, hardware installed & functionally tested
- Fuel Economy Test for thermostat & full variable pump scheduled for Q2, 2012

# Energy Management Anti-Idling

*Completed testing indicates program on track to meet 4% FEI targets*

DELPHI



## Solid Oxide Fuel Cell Testing ✓

- SOFC idle fuel consumption during overnight periods
- Power output sweep
- SOFC max power output for prolonged time periods
- Startup and shutdown measurements.

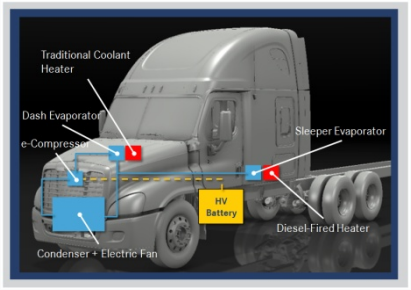
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

## Cab Thermal Testing ✓

- Thermal Soak
- Heat Transfer
- Thermal Imaging
- Air Exchange
- Insulation /Radiant Barrier

## Hybrid & Parked eHVAC

- Controls development complete
  - e-fan
  - e-compressor
  - engine start/stop
- eHVAC Test scheduled end Q1, 2012



# SuperTruck Partnerships and Collaborations

Department of Energy:

- ➔ Roland Gravel
- ➔ Gurpreet Singh
- ➔ Carl Maronde

## Energy Management

NREL

DELPHI

OSU Oregon State University

Telogis

## Hybrid

FUSO

MBtech Mercedes-Benz technology

Mercedes-Benz

itk ENGINEERING

## Aero/Cooling

ARC Auto Research Center

CD-adapco

SILVER EAGLE

MODINE

## Lightweighting

OSU Oregon State University

'TORAY'

STRICK Trailer

INMAGUSA

## Powertrain/Parasitics

DETROIT Engine Transmission

CONMET Pointing the Way

MICHELIN

ACCURIDE

Bendix

ASHLAND

## Fleet

SCHNEIDER NATIONAL

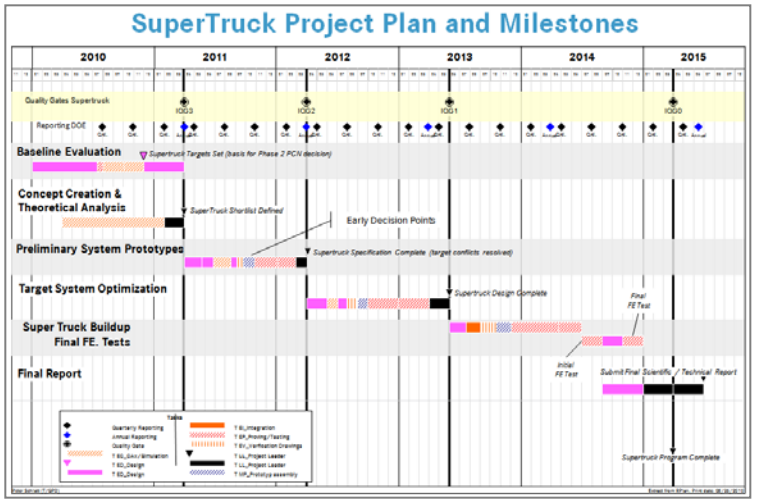
Walmart Save money. Live better.

# Vehicle Summary and Future Work

Successful completion of phase 1 & phase 2 targets on schedule

Technology Building blocks to 25% FEI measured

- Aerodynamics / Cooling
- Powertrain / Parasitics
- Anti-idling
- Lightweighting
- …




Next Steps

- Continued System Level Testing
- Complete Full-Scale Cab Exterior Model for Aero
- Buildup of preliminary ST Chassis for System Integration
- Complete Integrated Tractor/Trailer Development for Lightweighting & Aero

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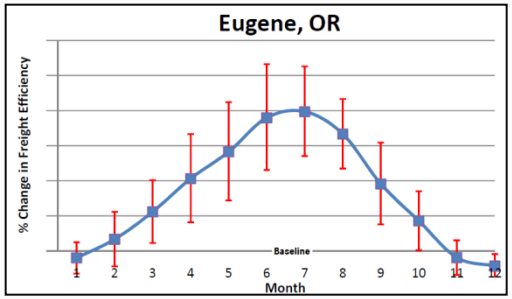
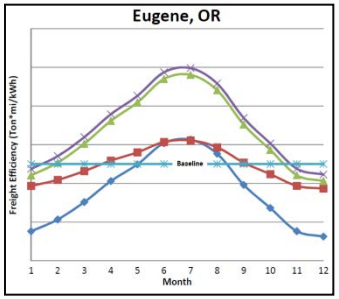
# Technical Backup Slides

# Energy Management

## Solar




**Irradescence & Temp Analysis**




**Solar Cell Comparison**

### Modeling & Analysis

- Freight Efficiency potential identified
- high-variability in performance

### Vehicle Testing

- Scheduled Q2, 2012

## Efficient Operations

### Algorithm Developent Complete

- Routing based on fuel consumption

### Verification/Validation & Tests

- Simulation-Routing Verification work on-going
- Fleet Analysis, Q2 2012

# Engine Summary and Future Work

- Engine has demonstrated 46.2% brake thermal efficiency
- Plans firmly in place for next level of performance improvement:
  - Higher compression ratio including new piston bowl and injector tip
  - Iterate SCR design for lower pressure drop
  - Reduced engine parasitics
  - Continue controls development and refinement
  - Waste heat regeneration development
    - Expander and generator
    - Add EGR waste heat recovery
    - Integrate onto vehicle