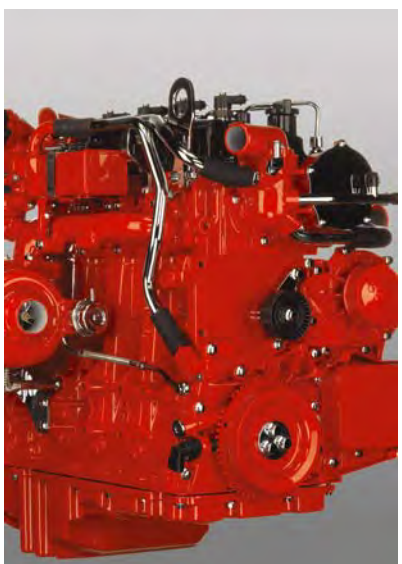
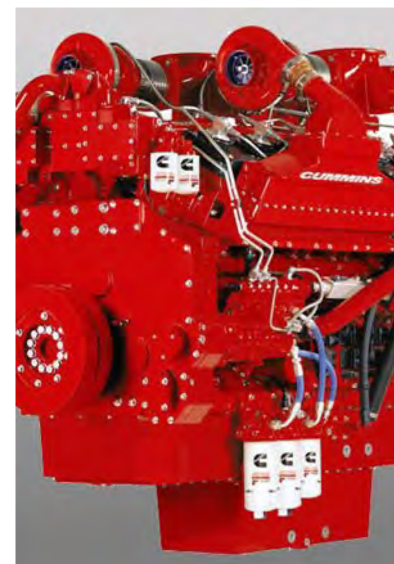
Cummins SuperTruck Program

Technology and System Level Demonstration of Highly Efficient and Clean, Diesel Powered Class 8 Trucks

Donald Stanton - Principal Investigator
Cummins Inc.

May 12, 2011 **Project ID: ACE057**





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Relevance - Program Objectives
(DoE Vehicle Technologies Goals)

All Technologies must meet Current US EPA 2010 Emissions Standards and Transportation/Safety Standards

Objective 1: Engine system demonstration of 50% or greater BTE in a test cell at an operating condition indicative of a vehicle traveling on a level road at 65 mph.

Objective 2

a: Tractor-trailer vehicle demonstration of 50% or greater freight efficiency improvement (freight-ton-miles per gallon) over a defined drive cycle utilizing the engine developed in Objective 1.

b: Tractor-trailer vehicle demonstration of 68% freight efficiency improvement (freight-ton-miles per gallon) over a defined 24 hour duty cycle (above drive cycle + extended idle) representative of real world, line haul applications.

Objective 3: Technology scoping and demonstration of a 55% BTE engine system. Engine tests, component technologies, and model/analysis will be developed to a sufficient level to validate 55% BTE.

Baseline Vehicle and Engine: 2009 Peterbilt 386 Tractor and Cummins 15L ISX Engine

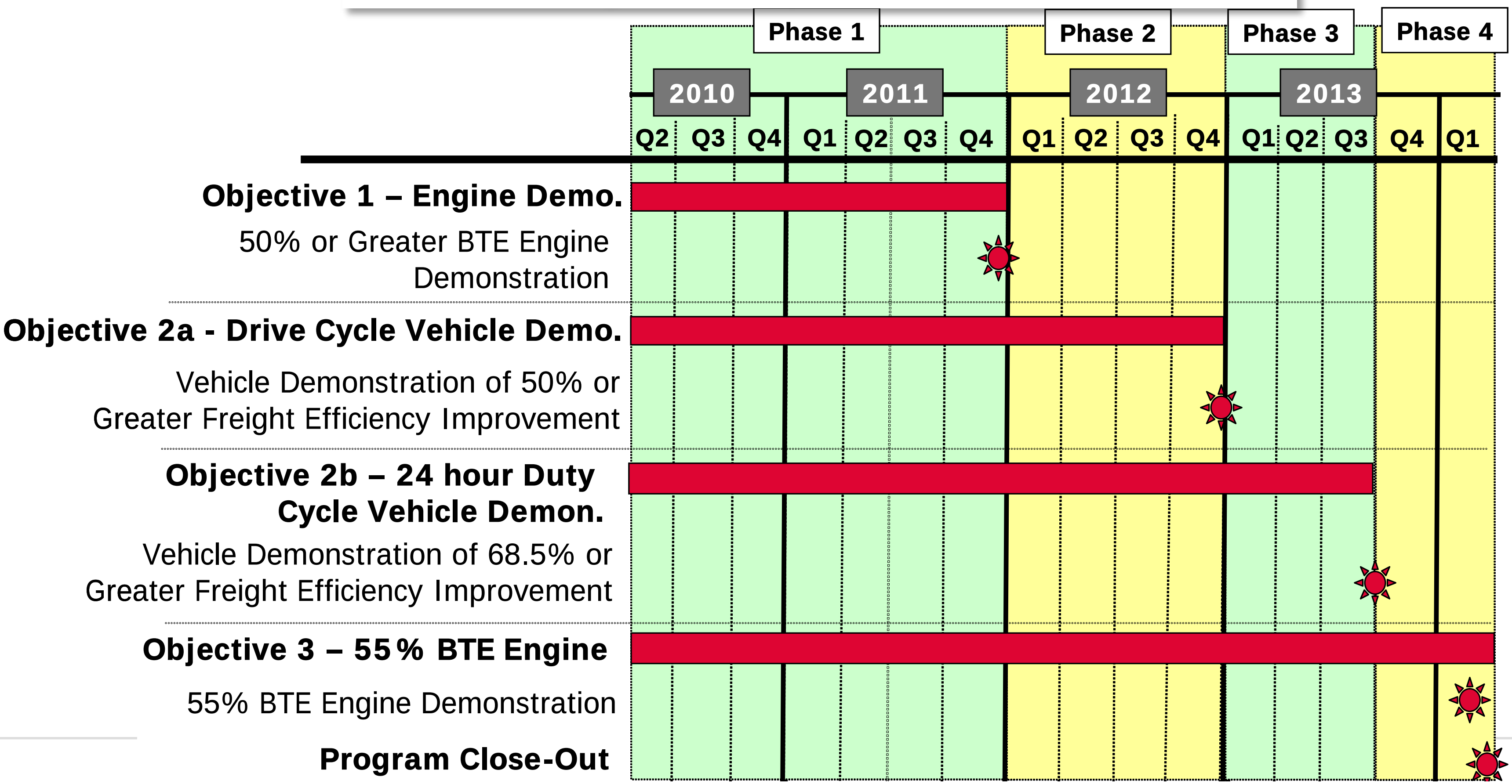
Overview - Program Schedule and Budget

Budget

DoE Share $38.8M (48%)

Contractor Share $42.1M (52%)

4 Year Program: April 2010 to April 2014



Overview - Program Barriers

- Controlling Engine Modes of Combustion
- Engine Downspeed (Reduced Engine Speed)
  - Powertrain components
  - Power Density
- High Conversion Efficiency NOx Aftertreatment
  - Fuel Efficient Thermal Management
- Vehicle and Engine System Weight Reduction
- Underhood Cooling with Waste Heat Recovery
- Powertrain Materials
  - Increased Peak Cylinder Pressure with Cost Effective Materials for Block and Head
  - Thermal Barrier Coatings for Reduced Heat Transfer
- Trailer Aerodynamic Devices that are Functional
- Engine Sensor Technologies

Relevance - American Recovery and Reinvestment Act (ARRA) Goals

- Create and/or Retain Jobs

		Projections	
Year	**2010**	**2011**	**2012**
Full Time Equivalent	75.5	107.5	131.0

States: Indiana, Texas, Michigan, Wisconsin, Tennessee, Illinois, California

- Spur Economic Activity:
  - Greater than $13M Total Spend to Date

- Invest in Long-Term Economic Growth
  - Commercial Viability Assessment
  - Demonstrate Technologies with Acceptable Payback Period
  - Adopt Technologies into Product Plans to Meet GHG and CO_2 Regulations for 2017 and beyond

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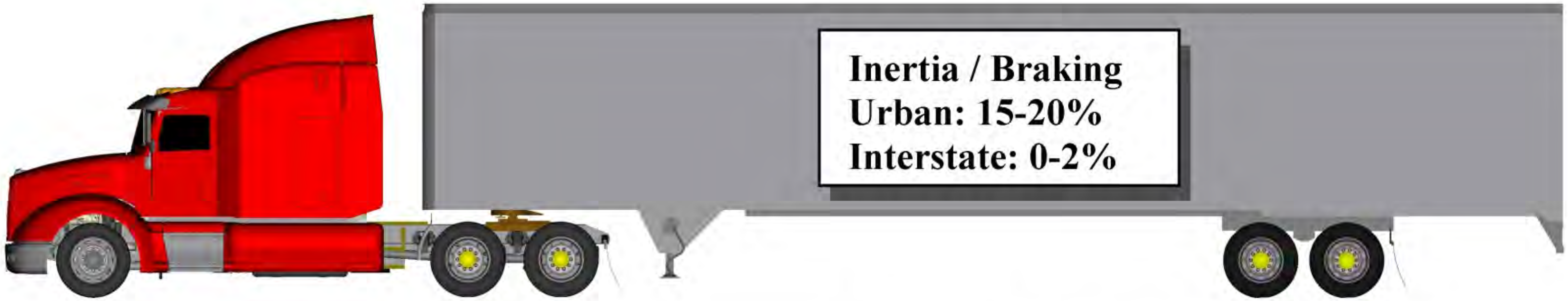
Comprehensive Approach to Fuel Consumption and Freight Efficiency Improvements

Analysis of 27 Drive Cycles for Class 8 Vehicles
with a Variety of Seasons (Summer, Winter, etc.)

Engine Losses
Urban: 58-60%
Interstate: 58-59%

Aerodynamic Losses
Urban: 4-10%
Interstate: 15-22%



Inertia / Braking
Urban: 15-20%
Interstate: 0-2%

Auxiliary Loads
Urban: 7-8%
Interstate: 1-4%

Drivetrain
Urban: 5-6%
Interstate: 2-4%

Rolling Resistance
Urban: 8-12%
Interstate: 13-16%

Weight Reduction

Program Participants - Collaborations

Program Lead

Cummins Inc.
- Cummins Fuel Systems
- Cummins Turbo Technologies
- Cummins Emissions Solutions
- Cummins Electronics
- Cummins Filtration
- Modine
- VanDyne SuperTurbo Inc.
- Oak Ridge National Lab.
- Purdue University

Peterbilt Motors Company
- Eaton
- Delphi
- Modine
- Utility Trailer Manufacturing
- Bridgestone
- U.S. Xpress
- Dana
- Bergstrom

Participants Roles and Responsibilities

Participant	Responsibility
Cummins Inc.	• Prime Contractor • Team Coordination • Engine System • Vehicle Integration
Peterbilt Motors Co.	• Vehicle Build Coordination • Vehicle Integration • Tractor-Trailer Aero
Cummins Turbo Technology	Turbomachinery
Cummins Fuel Systems	Fuel System
Cummins Emissions Solutions	Aftertreatment
Eaton	Transmission
Delphi	Idle Management Technology (Solid Oxide Fuel Cell APU)
Bridgestone	Reduced Rolling Resistance

Participant	Responsibility
Modine	Cooling System Development
U.S. Xpress	• End User Review • Driver Feedback • Commercial Viability
Oak Ridge National Laboratories	Sensor and Diagnostics
Purdue University	VVA and Low Temperature Combustion Controls
VanDyne SuperTurbo	Turbocompounding/Supercharging
Utility Trailer	Lightweight Trailer Technology
Dana	Axle Technology
Bergstrom	HVAC

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Approach – Freight Efficiency Path to Target

	Drive Cycle Vehicle Demonstration	24 Hour Duty Cycle Vehicle Demonstration
Technology	**Freight Efficiency Improvement (%)**	**Freight Efficiency Improvement (%)**
Vehicle Aerodynamics	14%	24%
Engine	25.5%	27%
Transmission/ Axles	3.5%	3.5%
Rolling Resistance	3.5%	3.5%
Route Performance Management	2.5%	2.5%
Idle Management	N/A	10%
Vehicle Weight	3%	3%
Total	**52%**	**73.5%**
Target	**50%**	**68.5%**

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Vehicle Technologies

Technology	Drive Cycle Vehicle Demonstration Freight Efficiency Improvement (%)	24 Hour Duty Cycle Vehicle Demonstration Freight Efficiency Improvement (%)
Vehicle Aerodynamics	Harmonized Tractor-Trailer	Harmonized Tractor-Trailer
Engine	WHR, Low Temperature Combustion, Base Engine, AT, etc..	WHR, Low Temperature Combustion, Base Engine, AT, etc..
Transmission/ Axles	Advanced Transmission, Smart Axle, Shift Optimization Reduced Parasitics	Advanced Transmission, Smart Axle, Shift Optimization Reduced Parasitics
Rolling Resistance	Robustness to wear, low resistance	Robustness to wear, low resistance
Route Performance Management	GPS, Adaptive Cruise, Driver Feedback	GPS, Adaptive Cruise, Driver Feedback
Idle Management	N/A	Solid Oxide Fuel Cell APU
Vehicle Weight	Lightweight tractor and trailer construction, engine weight, etc.	Lightweight tractor and trailer construction, engine weight, etc.
Total	**52%**	**73.5%**
Target	**50%**	**68.5%**

Approach – Engine Technology Roadmap

Base Engine
-PCP
- Friction/Parasitics

Fuel System

Advanced Combustion

Variable Valve Actuation

Controls

EGR Loop

Materials

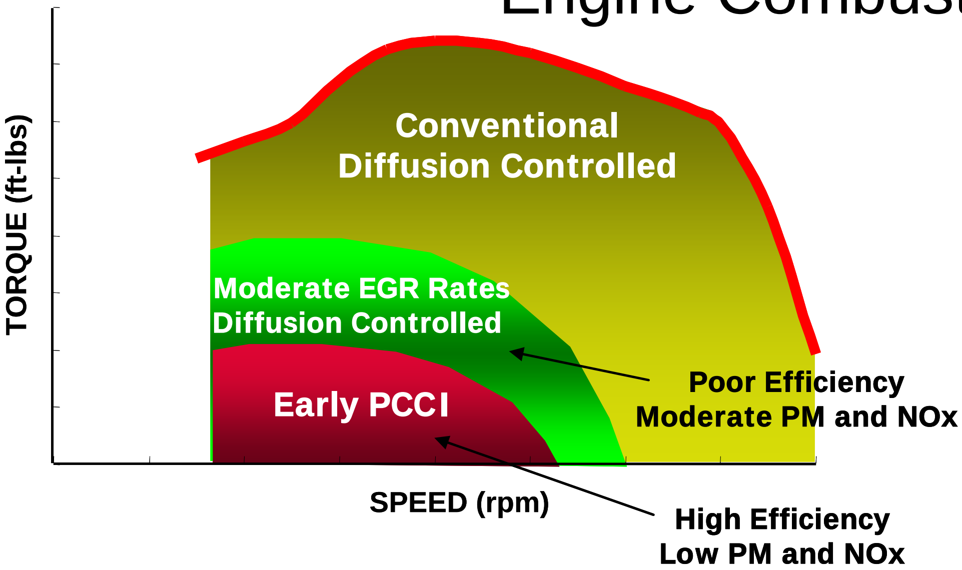
Turbo Technology

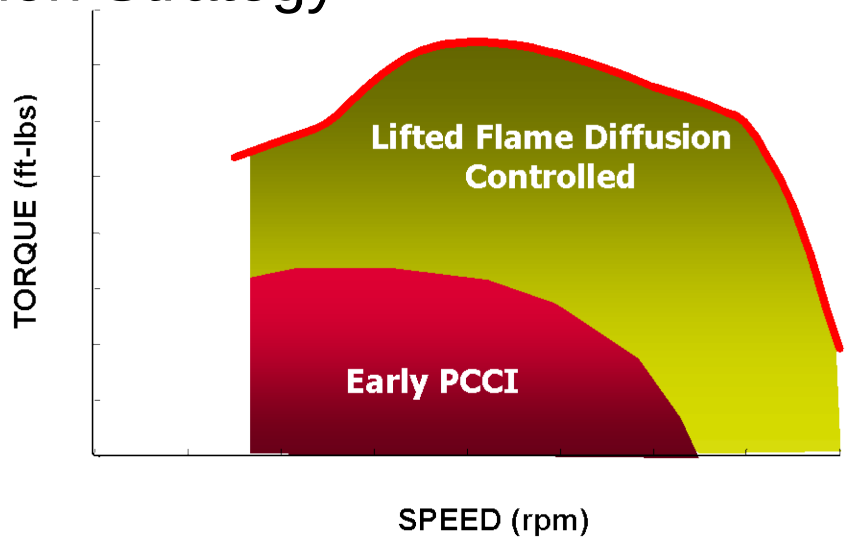
Aftertreatment

Waste Heat Recovery

Approach - Engine System Architecture

Engine Combustion Strategy





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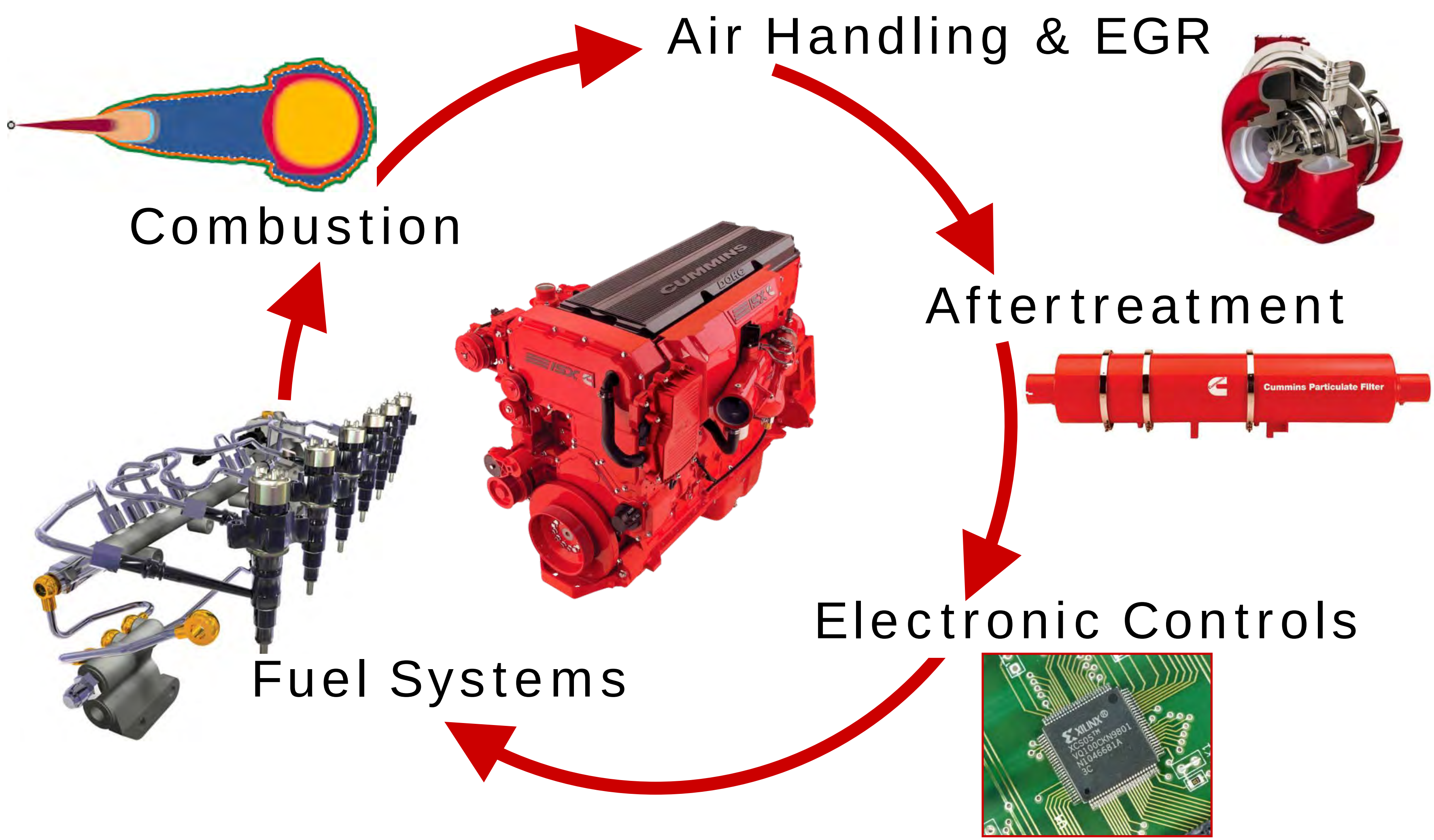
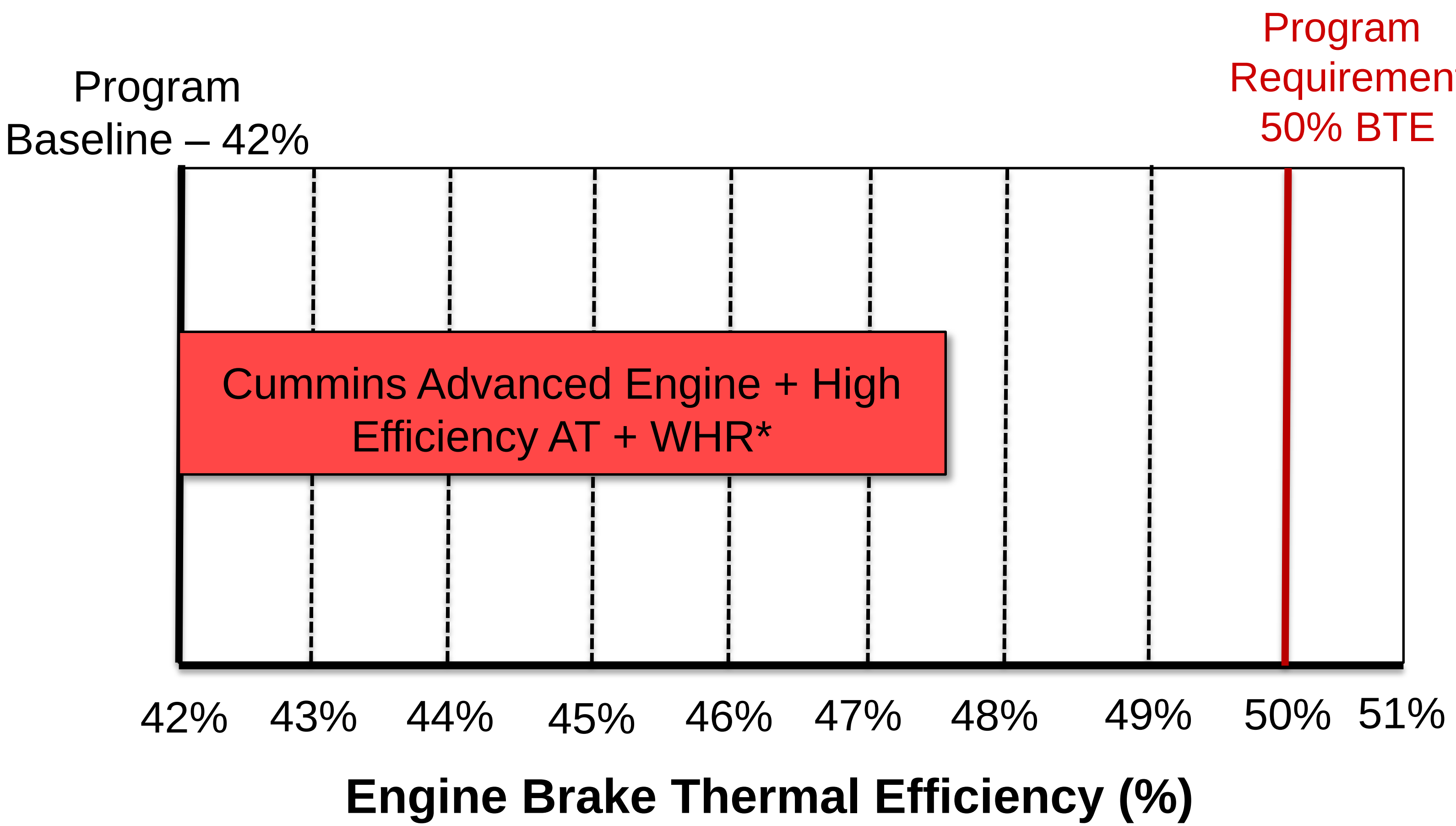
SCR Aftertreatment

Approach - Integration of Cummins Component Technologies



Current Status – Engine System BTE
Engine System **Technical Accomplishment**

Engine System Meets US EPA 2010 Emissions Regulation



*WHR - Cummins Organic Rankine Cycle Waste Heat Recovery

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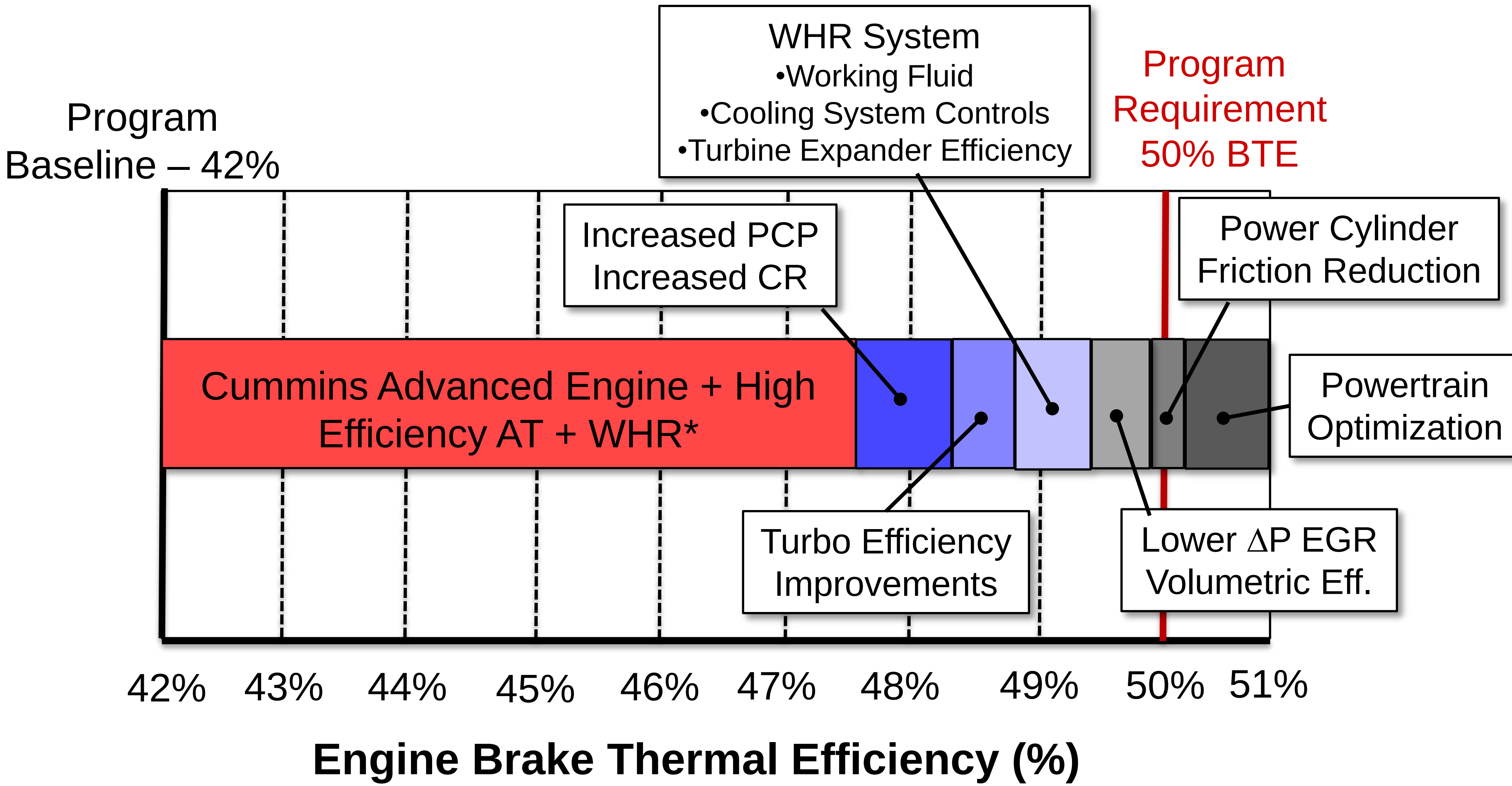
Improvements – Technical Accomplishments

(Based on Analysis and Engine Component Testing)

Engine System Meets US EPA 2010 Emissions Regulation



*WHR - Cummins Organic Rankine Cycle Waste Heat Recovery

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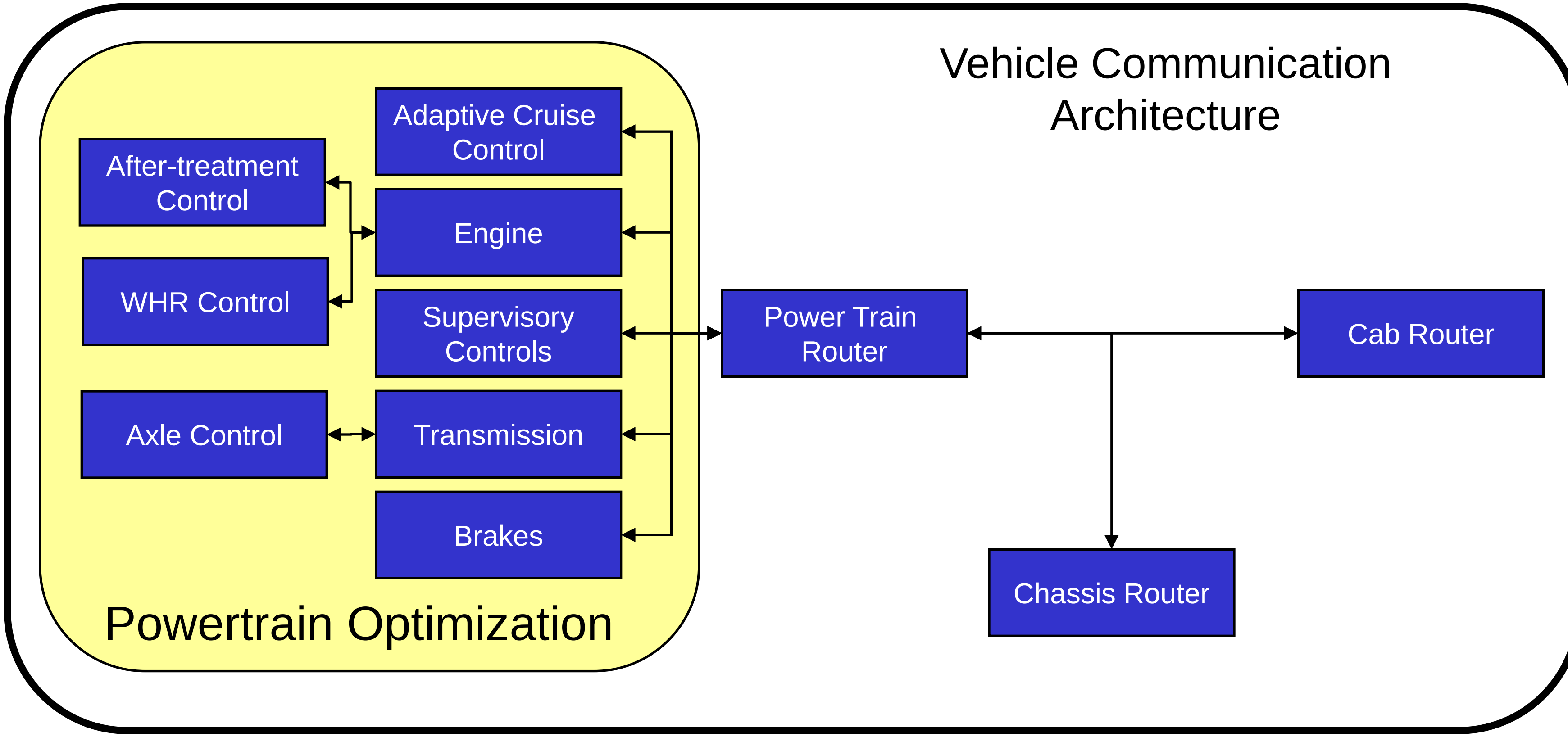
Vehicle and Powertrain Communication Architecture – Technical Accomplishments



- Establish requirements for future vehicle communication architecture
- New level of vehicle and powertrain optimization for fuel efficiency (Algorithms completed and Simulation Completed: Hardware-in-the-loop testing on-going)

Milestones and Technical Accomplishments

- March 2010 to March 2011 – **Technical Accomplishments**
  - Analysis of Path to Target for Engine and Vehicle Efficiencies
  - Baseline Vehicle Testing
  - Engine Demonstration of 47% BTE & US EPA Emissions
  - CFD Analysis of Vehicle Demo. #1 Aero
  - Integration of Cummins Waste Heat Recovery System
  - Design of Advanced Transmission
  - Performance Assessment of SOFC APU
- March 2011 to March 2012 – **Future Work**
  - Engine Demonstration of 50% BTE (Objective 1)
  - Vehicle Testing of Advanced Transmission
  - Testing of Tractor – Trailer Aerodynamics Solution
  - Design Freeze for Vehicle Demonstration #1 (Objective 2a)
  - Design Complete of Second Generation of SOFC APU

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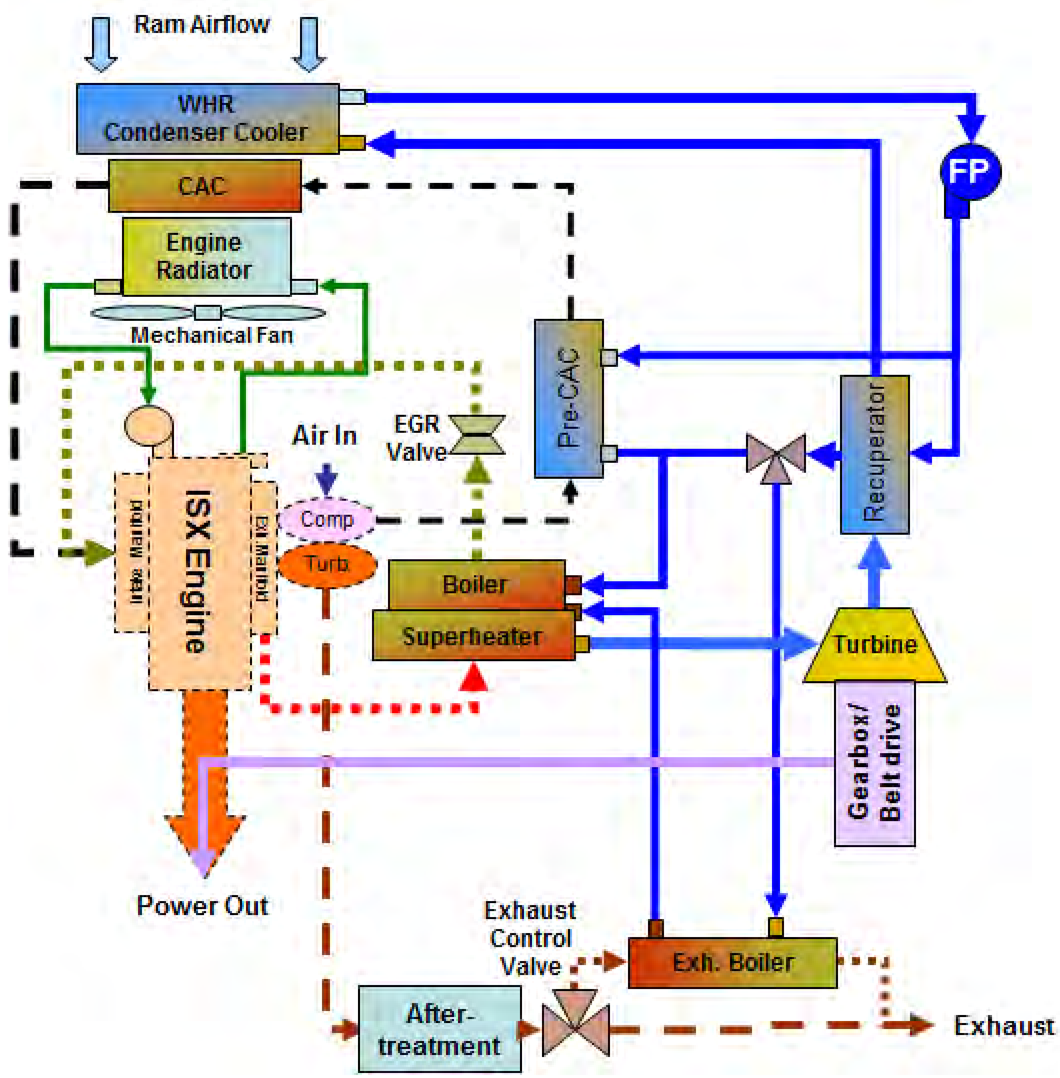
Summary

- Program remains on schedule with 100% milestone completion
- Meeting the goals for American Recovery and Reinvestment Act (ARRA)
- Completed baseline vehicle testing
- Engine efficiency and vehicle freight efficiency roadmaps updated with evidence to meet or exceed targets
- Current engine BTE is 47.5%. Identified and implementing technology to exceed 50% BTE target (Objective 1)
- Significant progress on the Cummins Waste Heat Recovery system
- Cummins Component Business technology development on schedule
- Completed design of advanced transmission – part procurement on-going
- Vehicle packaging and integration proceeding without any major issues
- Completed CFD analysis of tractor-trailer aerodynamic design for vehicle #1 (Objective 2a)

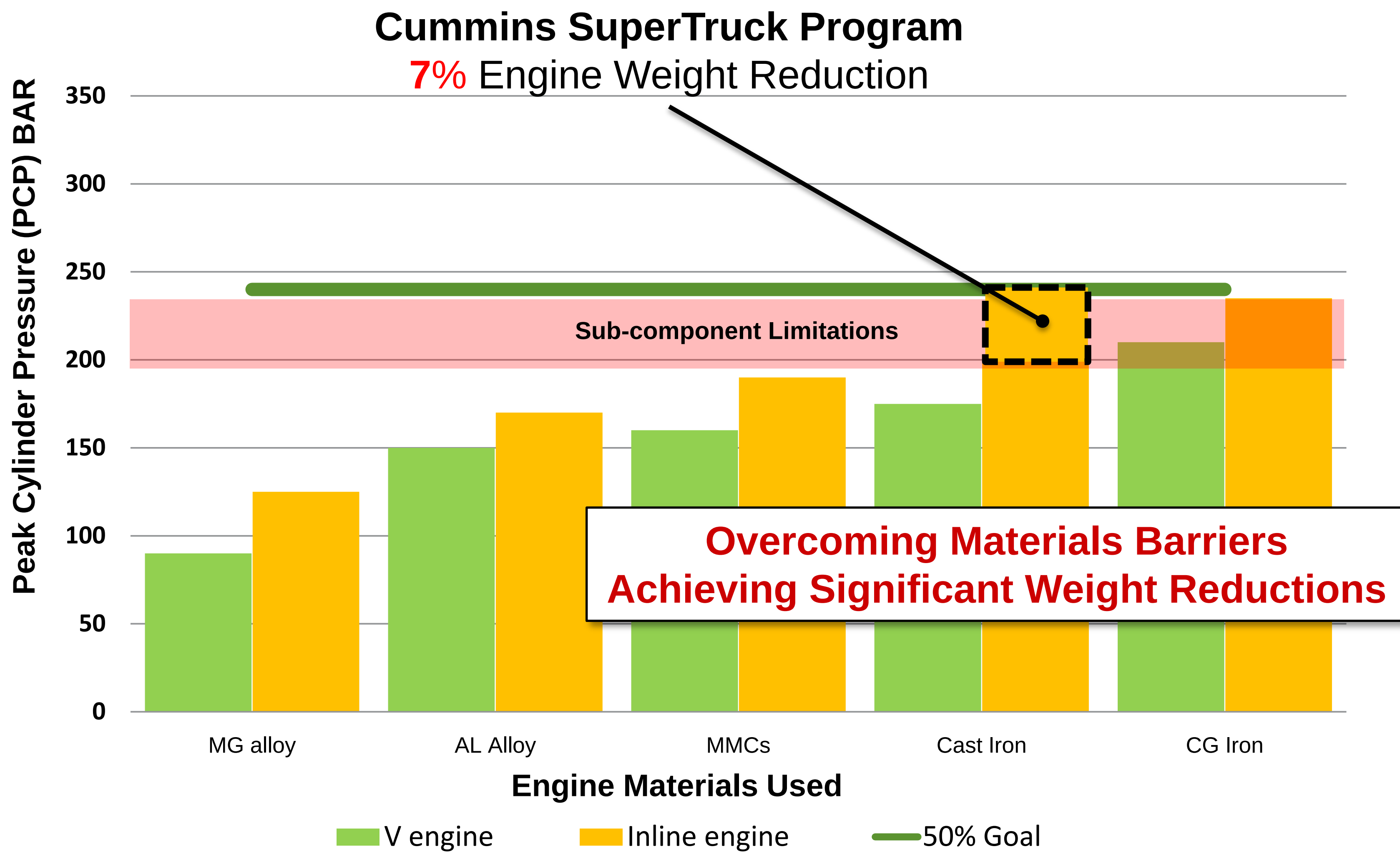
Technical Back-Up Slides

Cummins Waste Heat Recovery

- Organic Rankine Cycle
- Recovery of:
  - EGR
  - Charge Air
  - Exhaust heat
- Mechanical coupling of WHR power to engine
- Fuel Economy improvement of ~6%
- Reduced system size for vehicle packaging



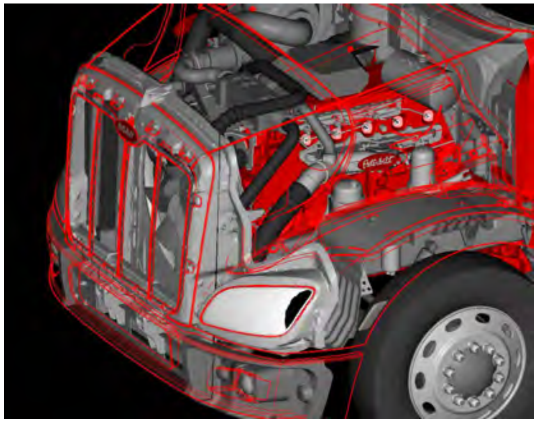
Progress Beyond Current Material and Engine Design Limits – Cylinder Pressure

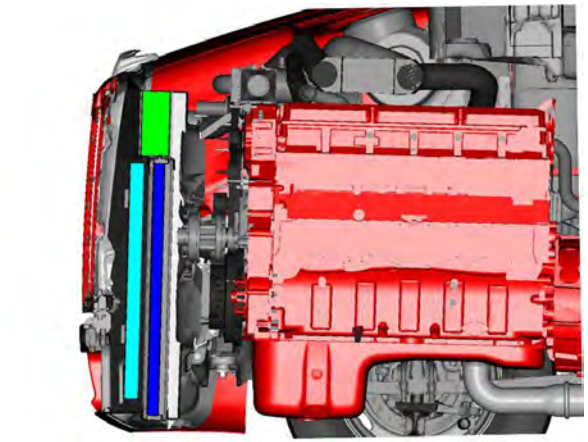


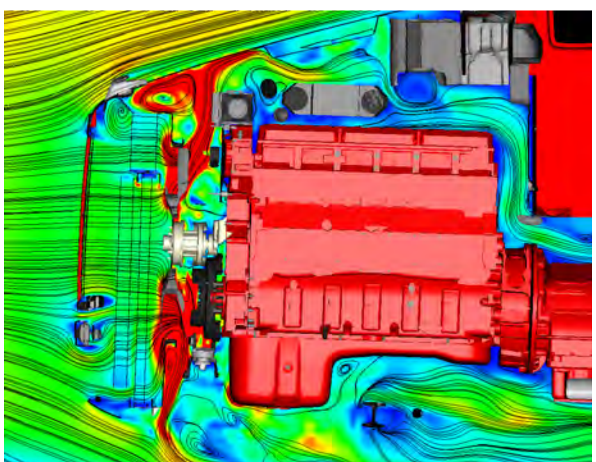
Source: Gibbs, J. et al., "Materials Support for 21st Century Truck: Lightweighting and Propulsion Material," National Academy of Sciences Review of the 21st Century Truck Partnership – Phase 2, November 15, 2010.

Vehicle and Engine Cooling System Design Underhood Air Flow and Temperature Analysis

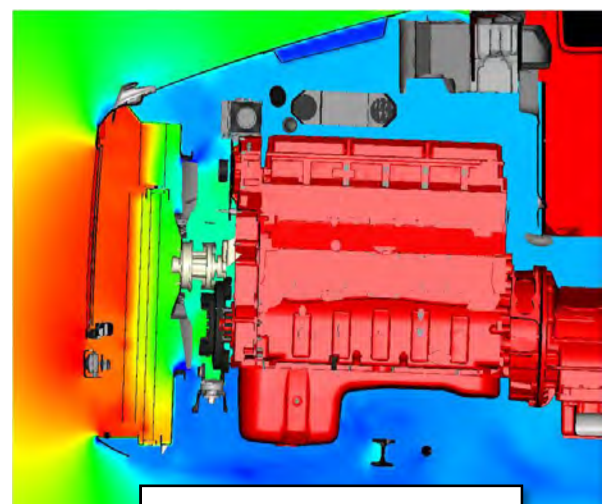
Successful Packaging of the Engine + Waste Heat Recovery In the Aerodynamic Vehicle Design







Velocity Profile



Pressure Differential

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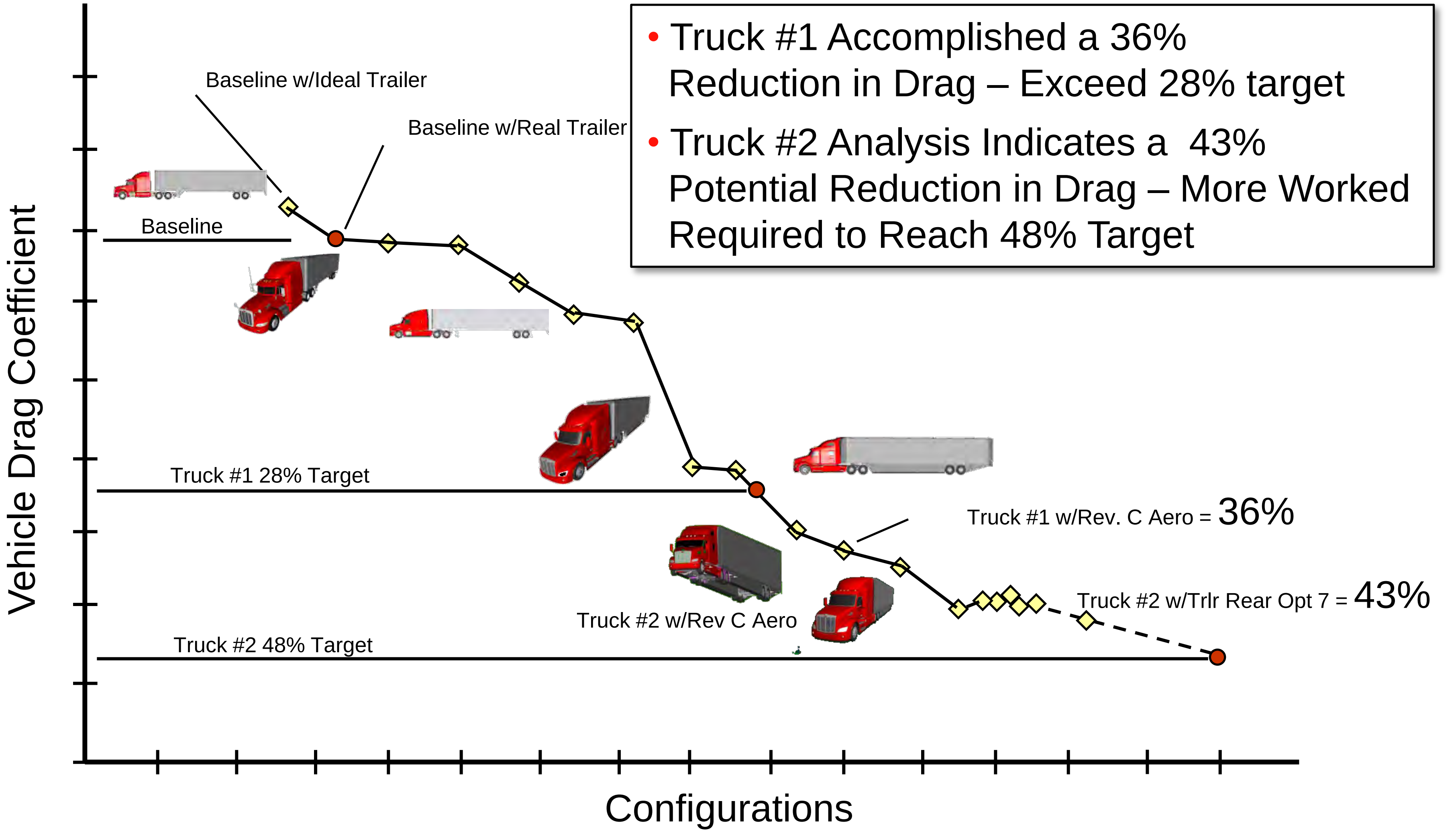
Vehicle Aerodynamics **Technical Accomplishments**



- Truck #1 Accomplished a 36% Reduction in Drag – Exceed 28% target
- Truck #2 Analysis Indicates a 43% Potential Reduction in Drag – More Worked Required to Reach 48% Target

* Cd's Shown Are Adjusted to SAE J1252 Baseline Using % Average Deltas From 0 and 6 Degree CFD Runs

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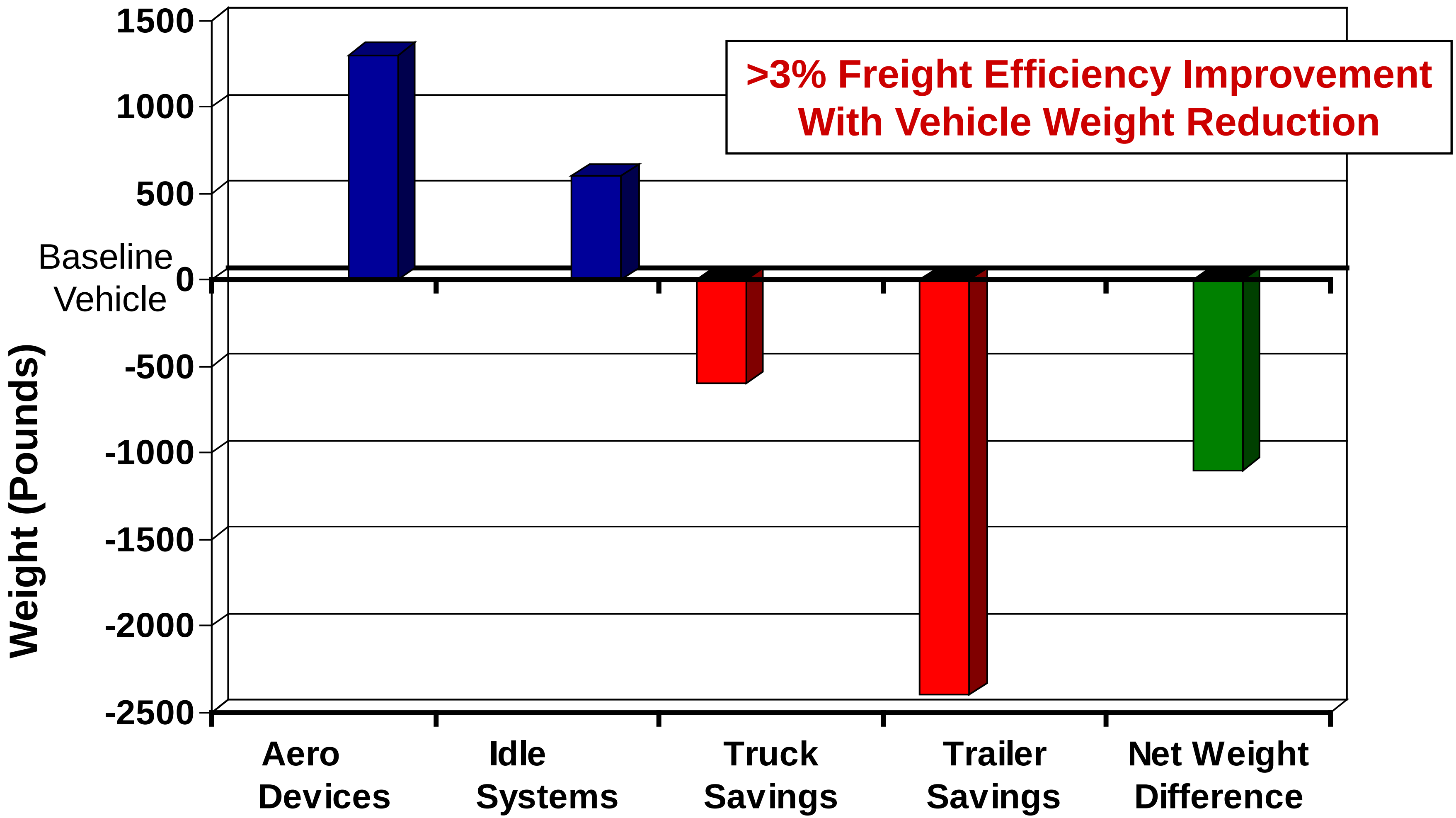
Vehicle Weight Reduction – Freight Efficiency Improvement (Technical Accomplishment)



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