Advanced Technologies

SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer

Engine Systems

DOE Contract: DE-EE0003303

NETL Project Manager: Samuel Taylor

Program Investigator : Dennis W. Jadin, Navistar

DOE MERIT REVIEW

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Department of Energy

Project ID: ACE059

Outline

NAVISTAR Advanced Technologies

- Program Overview
- Barriers and Technology Roadmap
- Approach
- Technical Accomplishments
- Future Work
- Summary

Program Overview

NAVISTAR Advanced Technologies

Goals and Objectives

Demonstrate 50% improvement in overall freight efficiency of a combination Tractor-Trailer:

30/50% improvement achieved through tractor/trailer technologies
20/50% improvement achieved through Engine technologies

Attain 50% BTE Engine

Demonstrate path towards 55% BTE Engine

Barriers

Assemble a cost effective, robust, reduced weight technologies for 50% freight efficiency
Increase BTE while maintaining low engine emissions (simplify NOx aftertreatment)
Non optimum fuel formulation for best efficiency - emission tradeoff

Budget

Total Project Funding:	DOE	$37,328,933
	Prime Contractor	$51,801,146
DOE Funding Received in FY2011:		$ 5,440,636

Navistar and our respective program partnerships thank the DOE Vehicle Technologies Program for their support and funding of this innovative project.

Partners, Collaboration and Coordination with Other Institutions

Navistar	Principal Investigator, Vehicle Systems Integrator Controls Systems, Engine & Vehicle Testing
Behr America	Cooling Systems
Bosch	Diesel Fuel Injection Systems
Federal Mogul	Friction Reduction
Argonne National Lab	Testing of Dual Fuel Engine

Barriers
And Technology Roadmap

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System	Barriers	Technology Roadmap
Engine & Vehicle	Assemble a **cost effective**, **robust**, **reduced** (vehicle) **weight** technologies for 50% BTE.	- Rely on analysis (tradeoff) to select technology - Couple technology to road cycle selection
Engine	Increase BTE while **maintaining low engine emissions** (simplify NOx aftertreatment)	- Improved Technologies (Fuel Injection, Combustion Regimes, WHR, AT, Controls, Lo-Friction, Air Handling, Thermal Management, Advanced Materials)
Engine	Limited experience and understanding of **new high-efficiency combustion regimes** (e.g. PCCI)	- Improve fundamental understanding chemical kinetics - Introduce combustion feedback
Engine	Non optimum **fuel formulation** for best efficiency-emission tradeoff	- Introduce reactivity control (dual fuel)

Approach:
Technology Roadmap - Engine

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Technologies Assembled in 50-55% Demonstrator Engine (highlight 2010-2011 activities)		
Technology Category	**Area of Concentration**	**Status**
Engine	MAXXFORCE 13L	
Advanced Fuel Injection	High Pressure Common Rail increase to 2900 bar	Deployed Oct 2010
New Combustion Regimes	Diesel + PCCI (main path)	Currently used
	Reactivity Control with Dual Fuel (parallel path)	Deploy Sep 2011
Heat Recovery	Electrical Turbocompounding	Deployed April 2010
	Rankine Cycle Applied to EGR flow (optional)	
Aftertreatment	DPF	Deployed April 2010
	Solid Amonia NOx reduction (optional)	Deployed April 2010
Contols	Combustion Feedback	Currently used
	Variable Valve Actuation	
Low Friction Features	Power Transfer	
	Power Cylinder	
	Accessories	
Air Handling	High Efficiency Series Turbocharging (improved by 4%)	Deploy April 2011
	Reduced flow restriction	Deploy April 2011
Thermal Management	Variable Coolant and Fan Clutches	
Advanced Materials	Increased Cylinder Pressure Capability to 220bar	Currently used

Approach:

Technology Roadmap - Technologies

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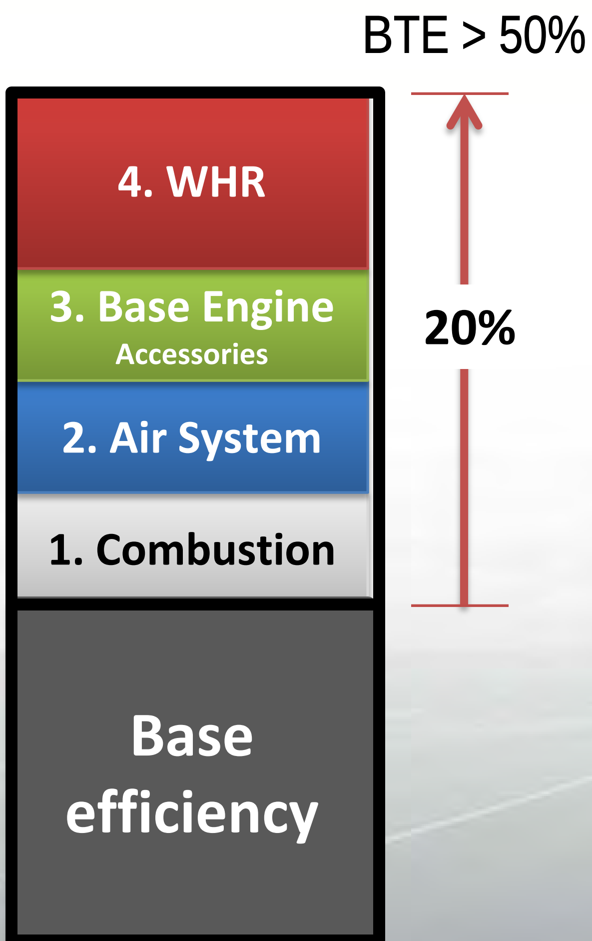

Goal: Leverage Technologies and Optimum Integration to attain:

- ✓ 50% max BTE
- ✓ 20% improvement over the engine map

Evaluation at Highway Road-Load Conditions (65mph and 65,000lb vehicle weight)

Approach:
Technology Roadmap - Timeline

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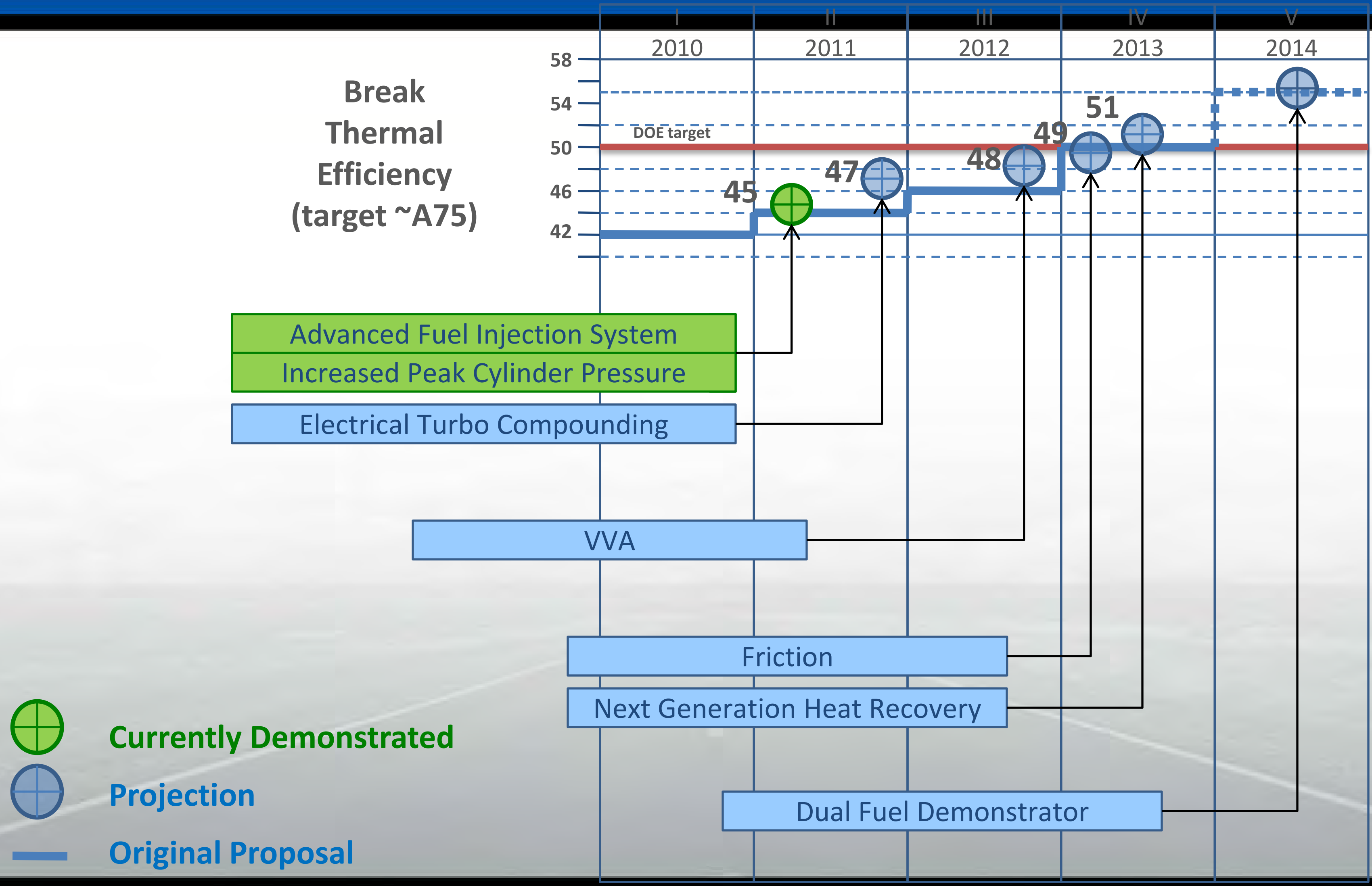

Approach:
Engine Baseline

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Base Engine

MY 2010 MAXXFORCE 13

Rated Power	475hp
Best BTE	42%
Engine out NOx	0.35g/bhp-hr

Technical highlights:

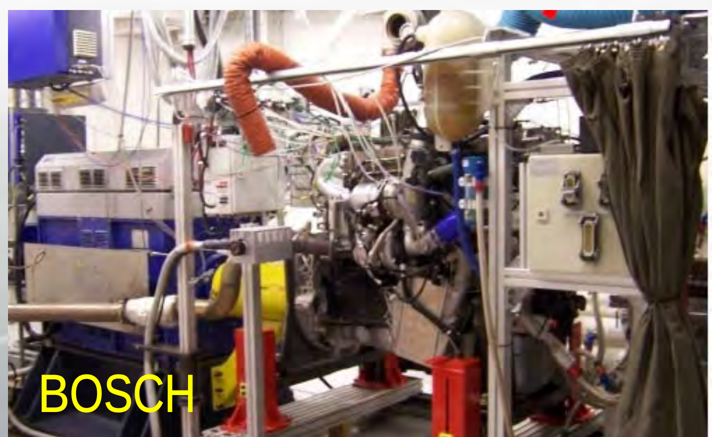
- ✓ 2200 bar Common Rail
- ✓ 2-Stage turbocharger with intercooler
- ✓ 2-stage HP loop EGR cooling

Program leverages skilful teams and modern testing facilities

Navistar – MLP : Combustion Development
Heat Recovery Technology
Emissions
Performance Benchmark

BOSCH – FH: Fuel Injection System Strategy

ANL: Fuel Reactivity



Accomplishments:
1. Combustion Efficiency

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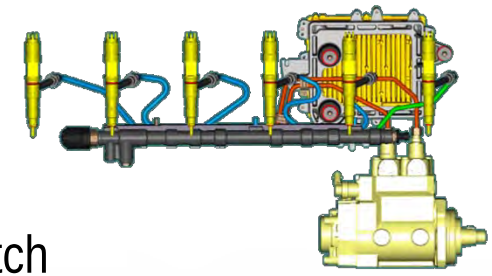
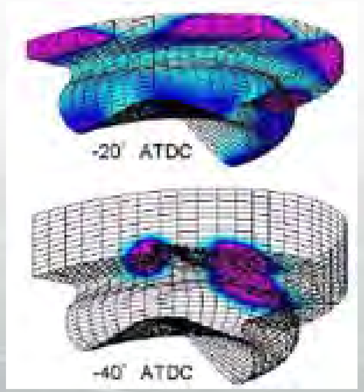
Comprehensive CFD and DOE techniques

- ✓ Coupled simulation and experimental work
- ✓ Enhanced CFD code
- ✓ Detailed Fuel Injection System Mapping (2200 to 2900bar)
- ✓ **Guide hardware selection** for improved injector – bowl match
- ✓ **Guide multiple Injection** strategy



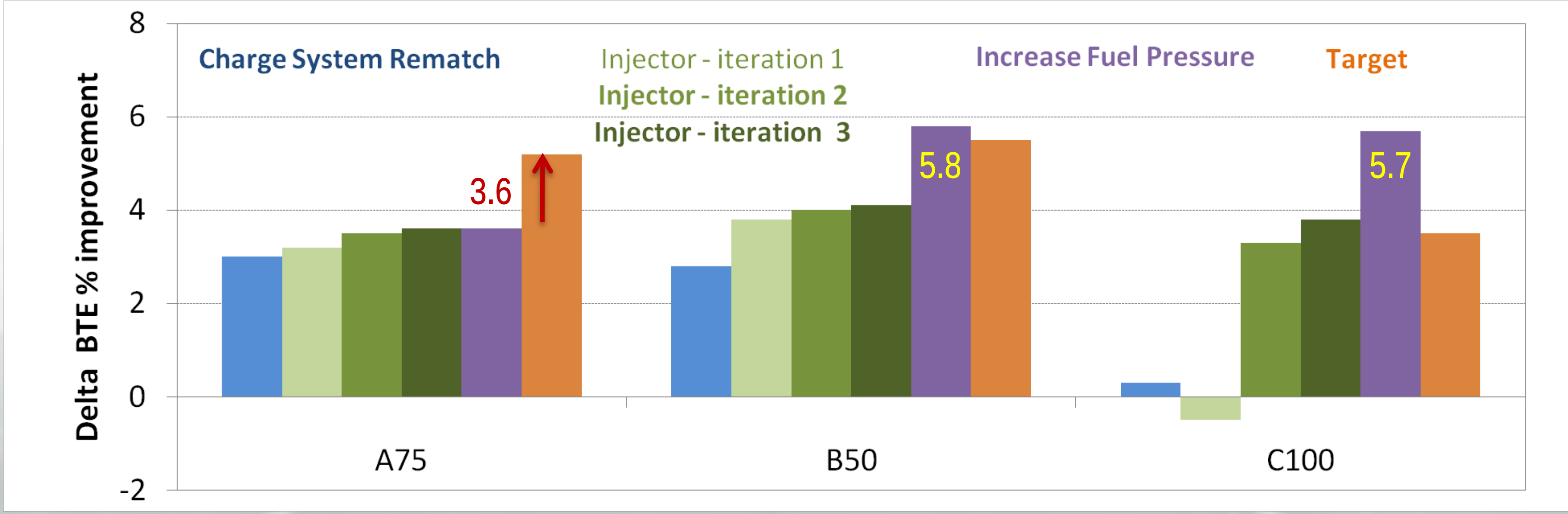
Optimum NOx-PM-BTE

- ✓ Leverage Navistar EGNR technology
  - Minimum NOx for 'breakpoint' with engine technology package
- ✓ Target DPF regeneration fueling 0-1%



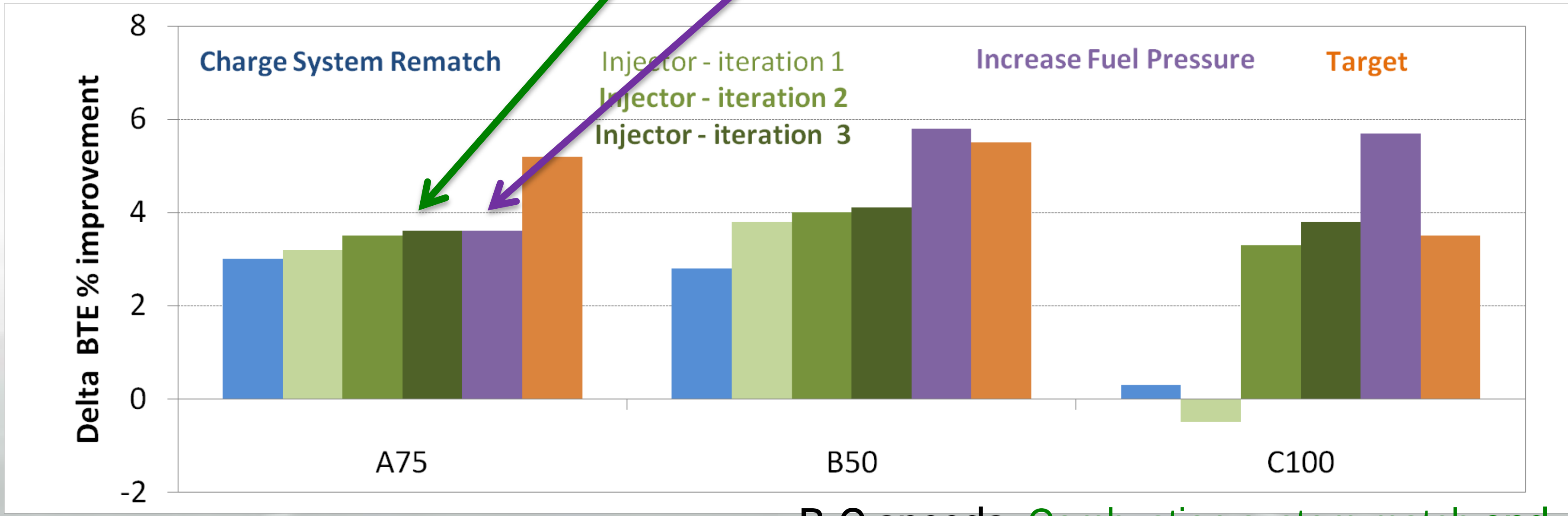
Accomplishments:
1. Combustion Efficiency (cont.)

- ✓ Phase I tests yielded 3 - 6% BTE improvements across engine map
- ✓ Targets were met in B-C speeds
- ✓ Further work necessary at the A speed



Phase I test data

<u>A speed</u>: Combustion system match optimization was limited
Fuel Injection system played a minor role

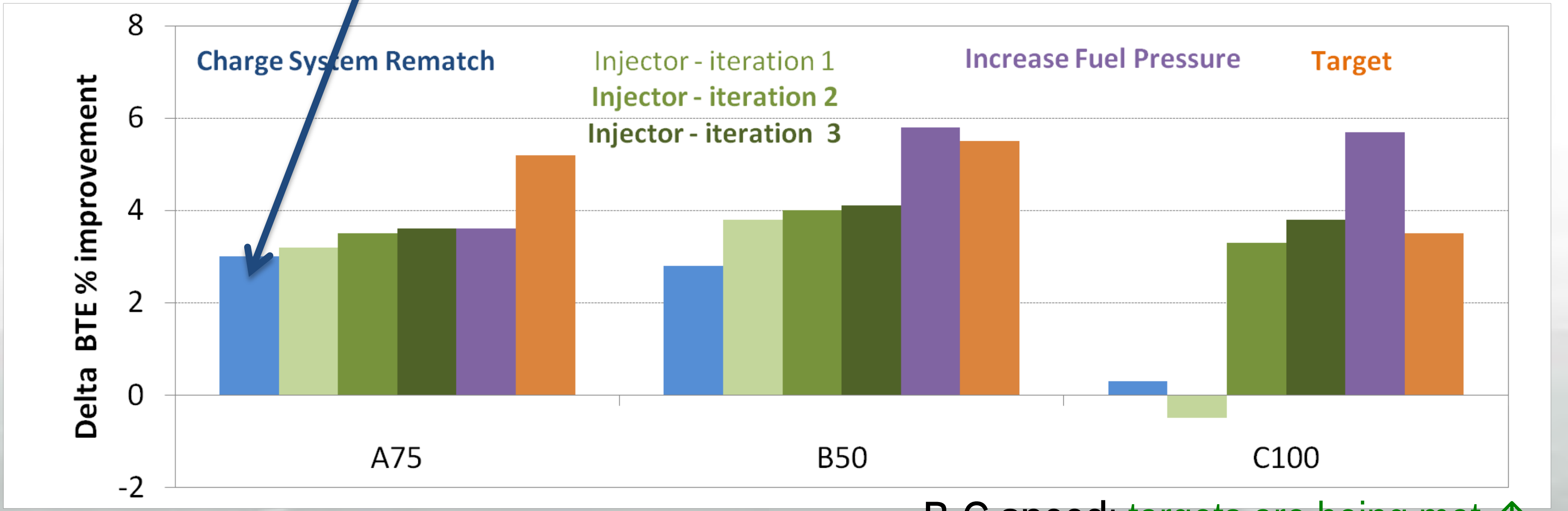


<u>B-C speeds</u>: Combustion system match and FUP played major roles

Phase I test data

2. Air System

A speed: Charge air improvement was significant but more is needed
→ Next Gen turbocharger hardware target 4% turbomachinery eff increase
→ May have to relax current engine-out NOx target benchmark



B-C speed: targets are being met ↑

Phase I test data

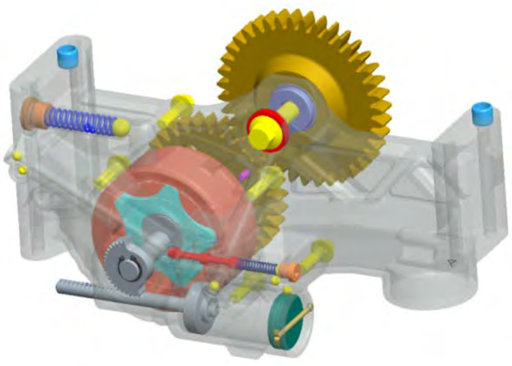
- ✓ Three major engine categories are being considered (13 subsystems)
- ✓ Three performance categories are addressed
- ✓ Target BTE improvement of 1 or more percent

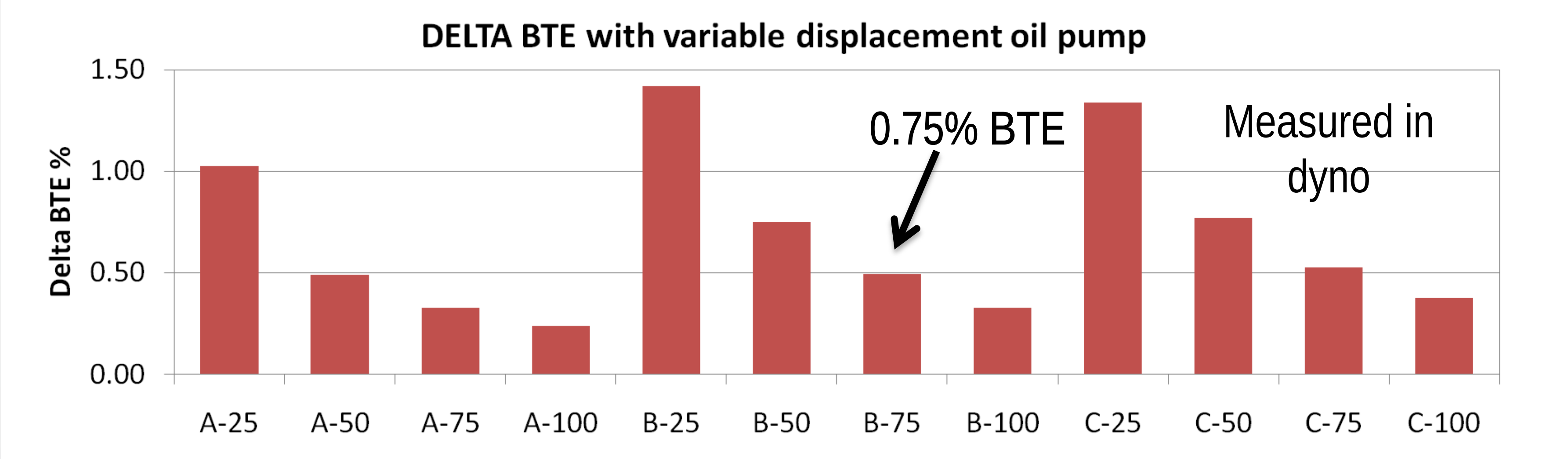
	# of sub systems	Categories: Friction	Categories: Increased Cylinder Pressure	Categories: Thermal Management	Procurement Benchmarks	**Comprehensive Friction Test** at Federal Mogul Target Start November 7 2011
Power Cylinder	5				on target	
Power Transfer	5				on target	
Crankcase	3				on target	
		Projected 1% BTE	Projected 220 bar High target 240 bar	Projected 0.5% BTE (vehicle)		

3. Base Engine (VOP)

Several Base Engine components are ahead of schedule, including the advanced Variable Oil Pump

- ✓ The VOP is effective in the drive cycle
- ✓ Provides 0.75% BTE improvement at B50 (lab tests)

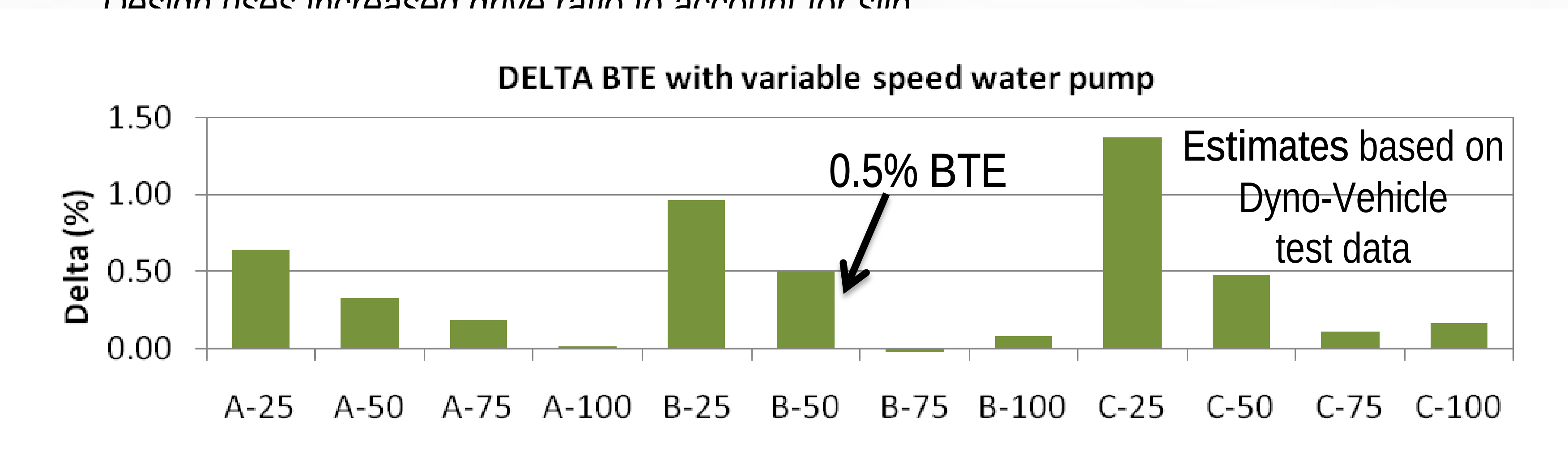




Accomplishments:
3. Base Engine (VWP)

Engine and Vehicle teams are collaborating in the implementation of an advanced <u>Variable Speed Water Pump</u>

- ✓ Pump works in conjunction with vehicle variable speed fan
- ✓ Effective in the drive cycle (0.5% BTE improvement at B50)
- ✓ Savings based on simulation using engine and vehicle data.
    - *Assumes fan speed adjustment to keep same coolant temperature*
    - *Estimates retain boiling criteria*
    - *Design uses increased drive ratio to account for slip*



Accomplishments:
4 . Heat Recovery

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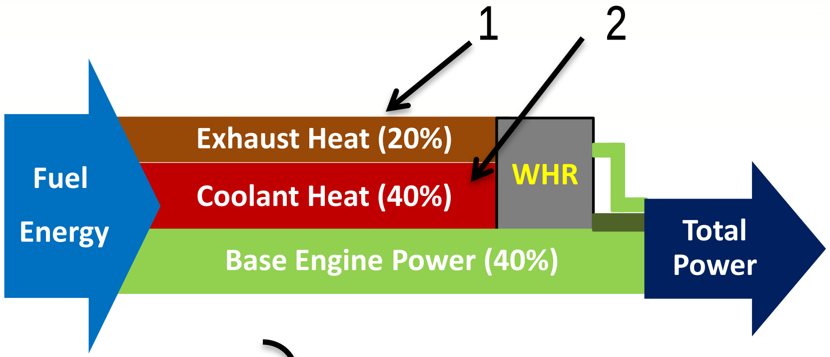

Sources of Waste Heat Recovery considered:

a) Turbo-compounding
   a) Recovers energy from the exhaust
   b) Adds a turbine wheel *placed behind aftertreatment*
   c) Requires redesign of turbo system *(high efficiency units to counteract increased backpressure)*

Installed in Test Cell April-2011

Deploy on Truck Sep-2011

b) Rankine Cycle
   - ✓ Recovers energy from EGR circuit and coolant
   - ✓ Builds upon Navistar GEN 1 hardware
   - ✓ Synergistic with high EGR

Feasibility (cost effective) study in place

4a. Heat Recovery (Turbo-compound)

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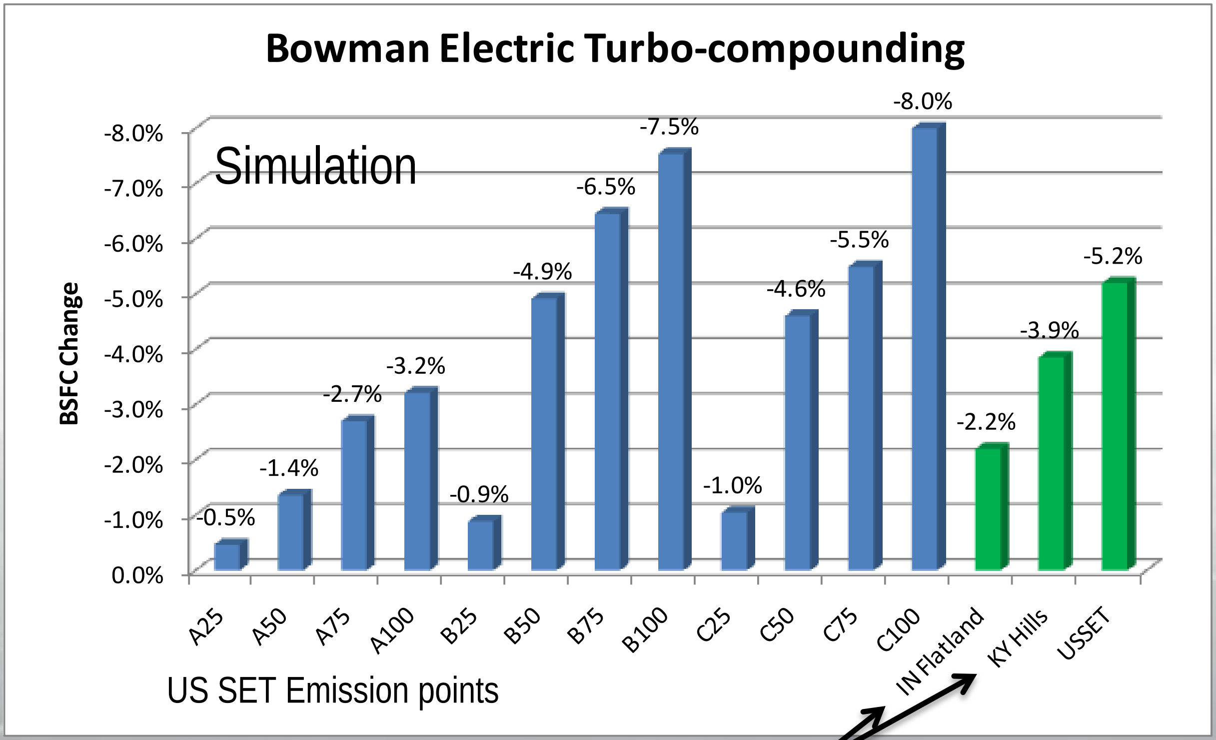
- ✓ Electric turbocompounding (ETC) design complete and installed in test cell
- ✓ Hardware tests begin April 2011
- ✓ Estimations completed (5% BSFC improvement at B50)



Navistar vehicle road cycle benchmarks

ETC Hardware, coolant and power electronics cart

Accomplishments:
4b. Heat Recovery (ORC)

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✓Organic Rankine Cycles have been evaluated:
- ORC extract heat from the EGR stream and can tap into other heat sources
- Evaluating most effective condenser cooling (high and low temperature coolant circuit loops, air-cooled)
- Evaluating working fluid
- Evaluating recuperator circuit

✓ Challenges of ORC:
- System complexity, weight and size
- Achieve emissions (must maintain EGR and intake manifold temperatures)
- Operate under transient conditions
- System cost

✓ Target Decision Point will be in May 2011
- Summarize efficiency gains, controls, costs
- Outline next steps

Accomplishments
Technology Integration

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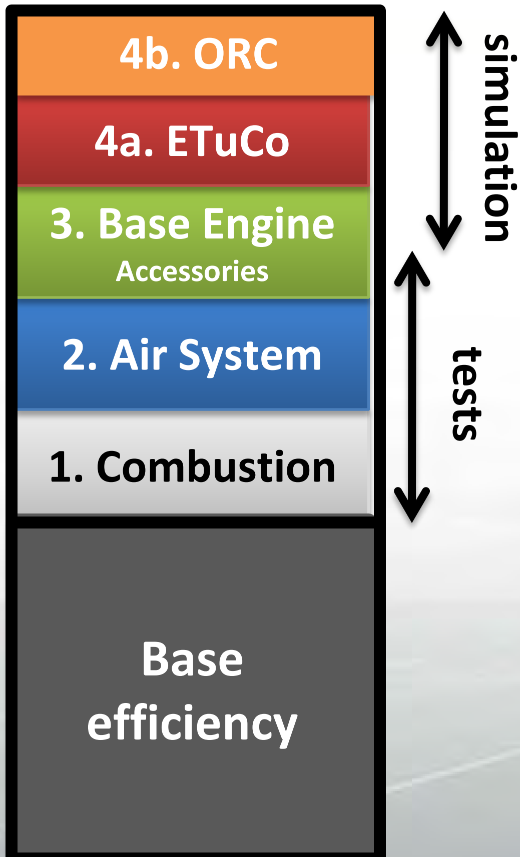
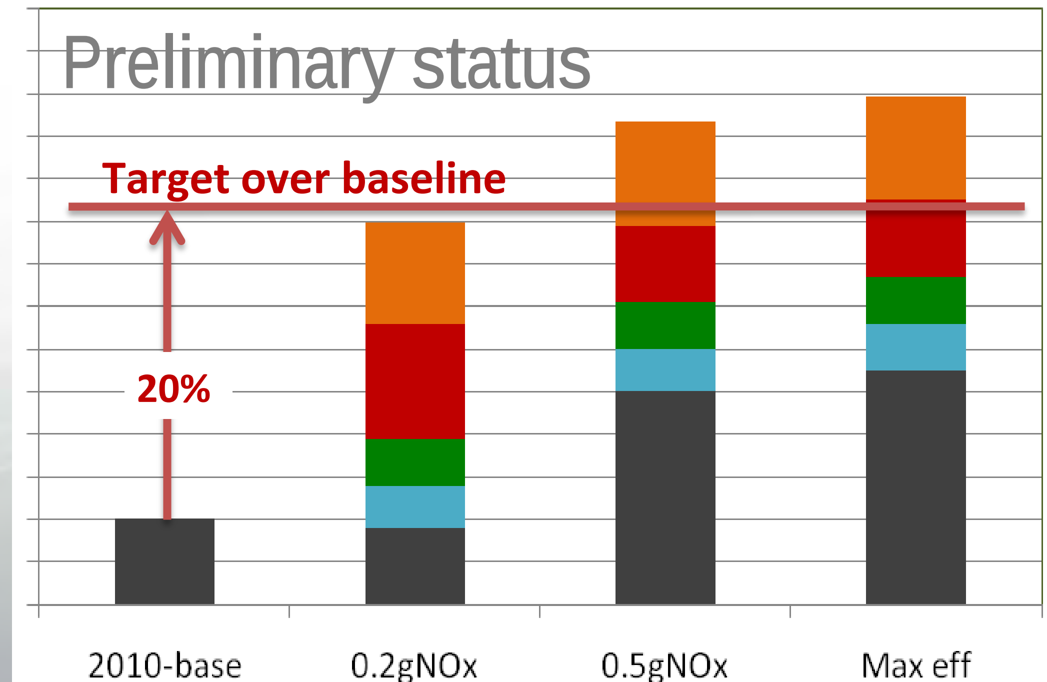


- ✓ Technology selection stacks up differently with capability to manage engine emissions
- ✓ ETC with improved combustion and base engine improvements are close to the proposed targets.



55% BTE target with Dual Fuel Engine

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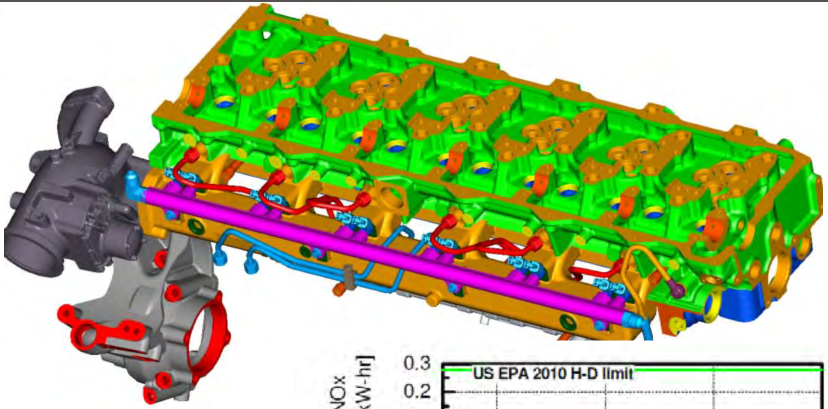
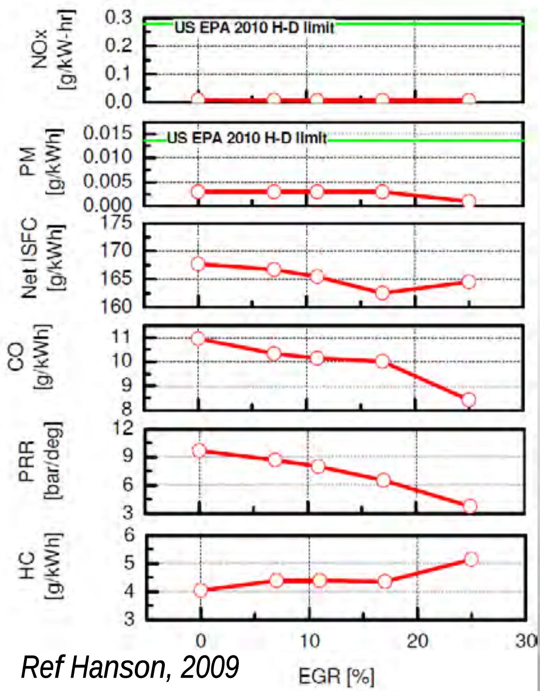
Engine Modifications (completed April 2011)
- ✓ New intake plenum with PFI installation
- ✓ Modified head with improved flow

Close collaboration with WERC:
- ✓ Extensive CFD simulation
- ✓ Support engine design hardware selection
- ✓ Establish operating boundary conditions

Benefits:
- ✓ High efficiencies
- ✓ Clean combustion (e.g. de-content NOx aftertreatment)

Enablers:
- ✓ Hi-EGR capable engine
- ✓ Hi-efficiency charge air system, previously developed combustion feedback technology (DE-FC26-05NT42413)





Ref Hanson, 2009

Remaining Activities for 2011

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Electrical Turbo-compounding (ETC) Engine:

- Complete dyno demonstration of ETC hardware by July 2011.
- Deploy ETC unit on hybrid vehicle with controls and power electronics, and demonstrate functionality by Sept 2011.

Efficiency and Emissions Demo Engine:

- Integrate second ETC hardware onto hi-efficiency development engine.
- Demonstrate interim Break Thermal Efficiency target of 3%-5% BTE gain.

Other Activities:

- Deploy Dual-Fuel engine to Argonne as facility becomes available (approx. July 2011)
- Complete Organic Rankine Cycle feasibility study – if results are positive deliver design architecture and project plan for Phase II.

Project Summary

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Approach: Project is focused on assessing and developing engine and vehicle technologies to improve freight efficiency while providing a cost effective, robust and reduced weight combination class 8 truck and trailer integrated design.

Technical Accomplishments: The MAXXFORCE 13L engine is well posed to:

- Deliver 20% BTE gain across the engine map and the 50% MAX BTE target as seen from present tests and projections from heat recovery.
- To date the following technologies have been incorporated:
  - Extended peak cylinder pressure capability (190→220 bar)
  - Higher injection pressure (2200→2900 bar)
  - Electrical turbo-compounding with advance air system (results due July 2011)
- The following systems will be procured and put on test stand in 2011:
  - Dual Fuel Engine (May)
  - Friction reduction Package (Sept)