Development and Demonstration of a Fuel-Efficient HD Engine
(Dept of Energy Supertruck Program)

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Navistar

Technical Session: High-Efficiency Engine Technologies Part 1

DOE DEER CONFERENCE

Monday 3 October 2011
Detroit, Michigan

Acknowledgements: DOE Contract: DE-EE0003303
Industrial Partners: Bosch, ARGONNE, Federal Mogul, WERC

Outline

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Project Goals:
Approach for Fuel Economy

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Baseline
2010 ProStar with MAXXFORCE 13L

Engine — 20%
Combustion-Emissions
Base Engine
Heat recovery

Vehicle — 30%

Hybrid
Dual-Mode Drive
Electrified Accessories

<u>improvement</u> in freight efficiency — <u>50%</u>

Aero
Gap reduction
Aero Drop
Camera Mirrors

Light Weight
SMART tandem axles
Composite cab, trailer
Wide base single tires

Driveline
SMART tandem axles
Composite cab, trailer
Wide base single tires

Supertruck Concept

Engine Baseline and Targets

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MY 2010
MAXXFORCE 13

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

Pushing the technology frontier

2200 bar Common Rail →

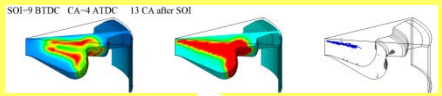
2-Stage turbocharger →

2-stage EGR cooling →

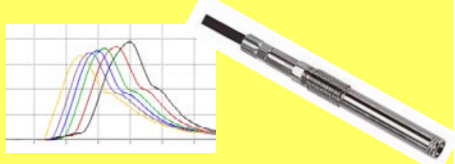
DPF →

Advanced Combustion Concepts

Advanced Simulation

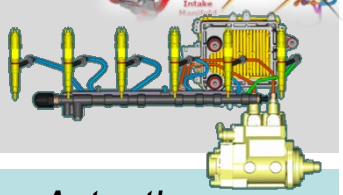


Combustion feedback

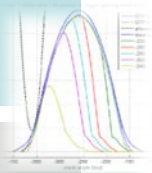


Fuel Reactivity

3000bar capability

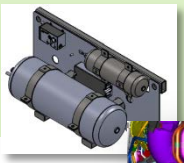


Variable Valve Actuation
High Efficiency Turbochargers

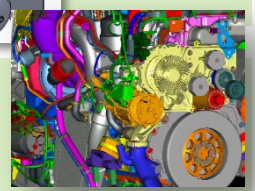


Advanced EGR cooling

Aftertreatment solutions



Base Engine
Friction reduction, PCP
Electrification of accessories



Supertruck Targets

Rated Power	**475hp**
Best BTE	**50%**
Emissions	**HD EPA 2010**

Bottoming Cycles
Electric Turbo-compound
Rankine Cycle, Thermo-electrics

Development Facilities

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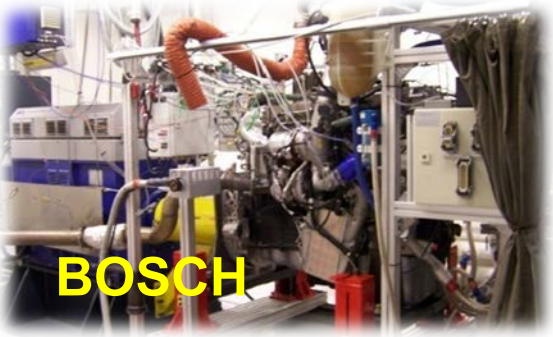
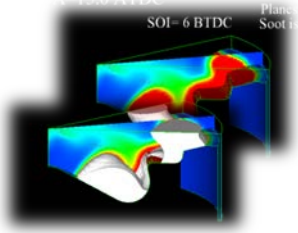
Combustion Development, Emissions Performance Benchmark

Heat Recovery Technology

BOSCH

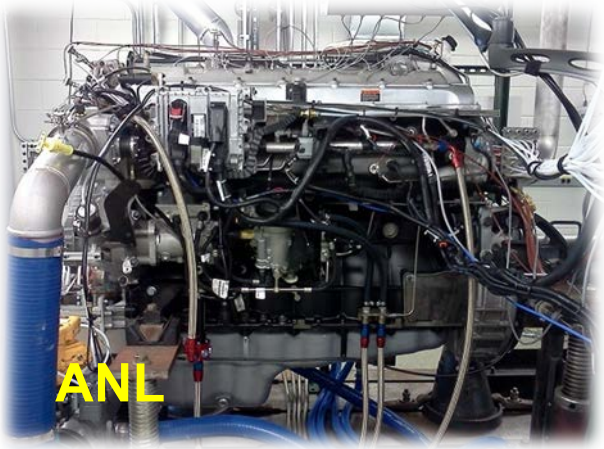


High-injection pressure capability

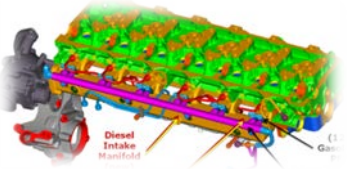


CFD-Engine correlations

Argonne National Labs



Fuel Reactivity



Cylinder head redesign with PFI system installation

Federal Mogul

Friction Benchmark

Supertruck Development Plan

Technology Introduction

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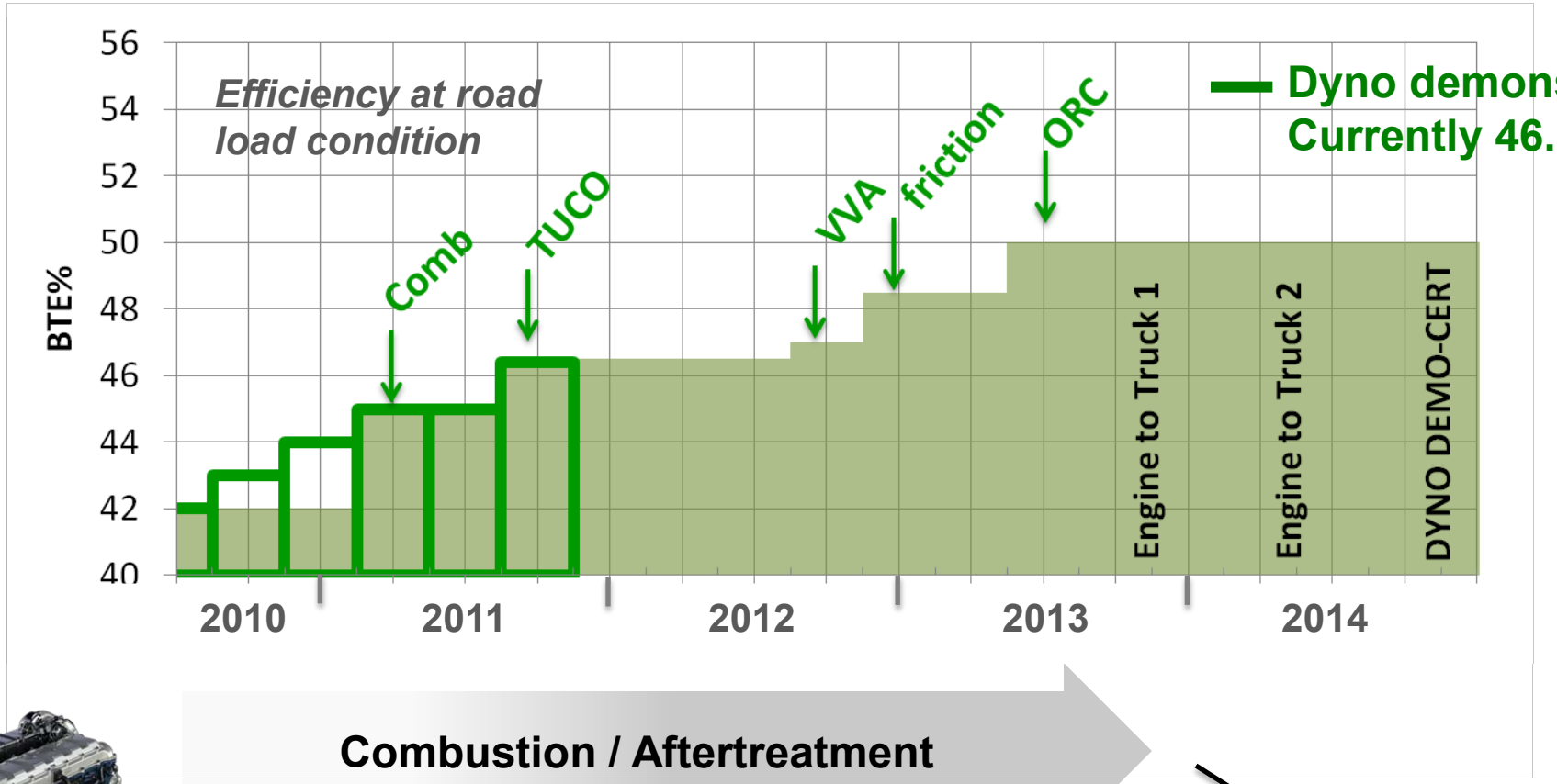

MAXXFORCE 13

Combustion / Aftertreatment

Heat Recovery

Base engine improvements

50% BTE and Vehicle Demonstration

Advanced Concepts *Fuel Reactivity*

55% BTE dyno demonstration

Efficiency Roadmap

Target a combined 50%

At road load condition

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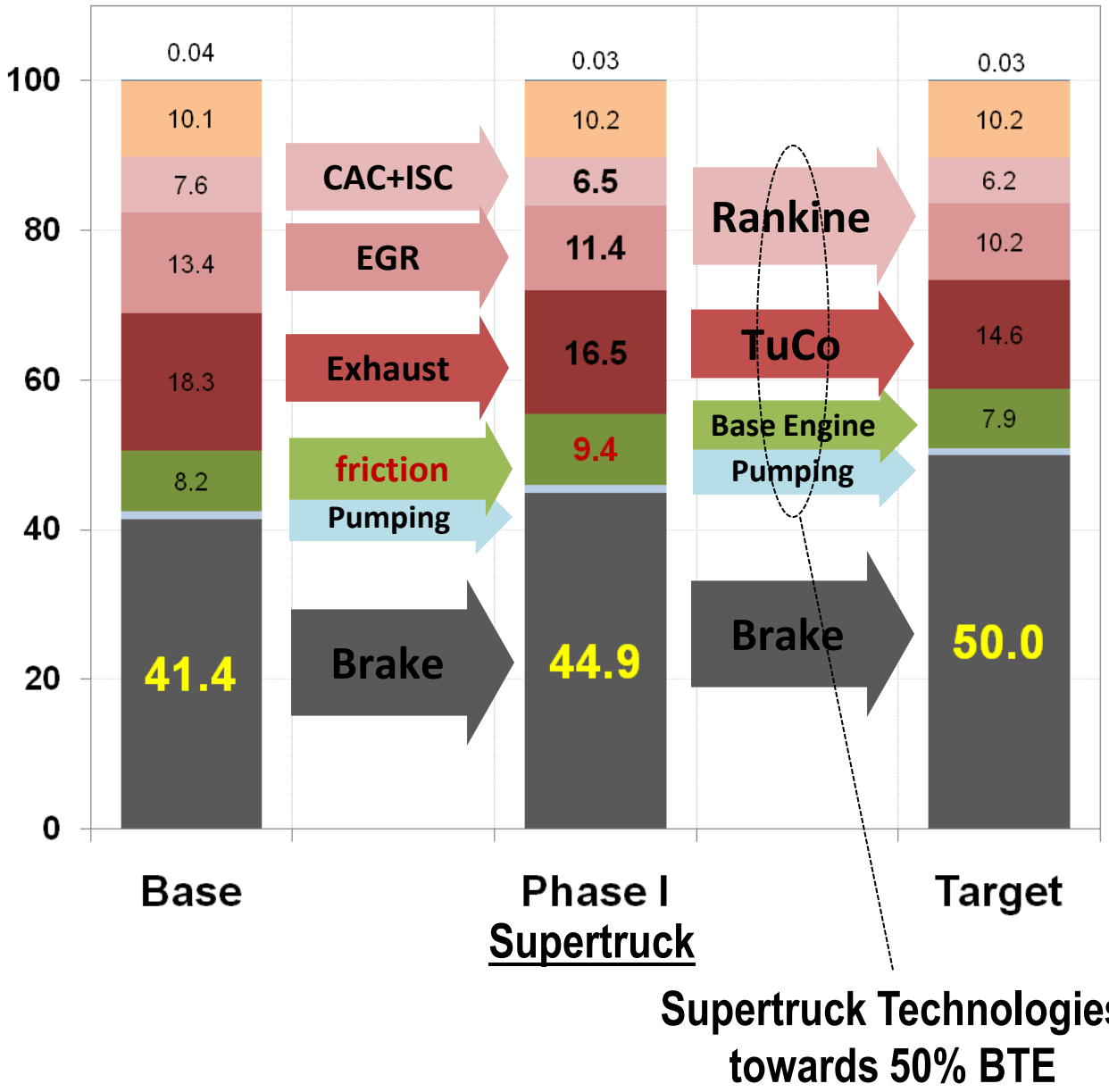

Milestone 1: Engine Thermal Efficiency

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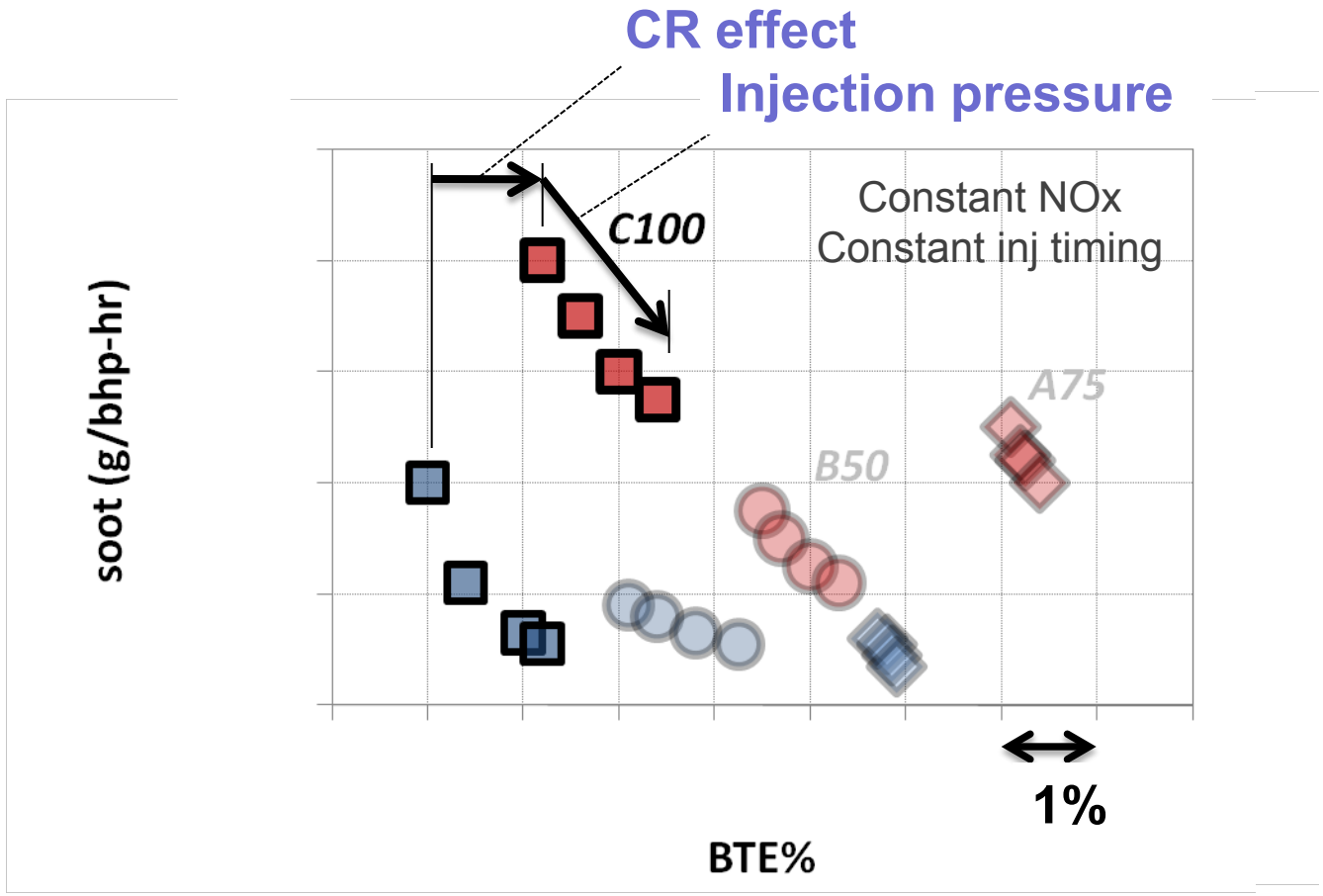
Road Map

Currently demonstrated
+3% BTE gain (to 45%)

- ✓ *Minimize engine out NOx – Soot*
- ✓ ***Maximize BTE***
- ✓ *Optimize :*
  Injection timing
  Fuel pressure
  Injection events
- ✓ *Optimize Hardware:*
  Compression ratio
  Cooling system



	BTE (CR)	BTE (Inj Press)
A75	+1.3%	+0.5%
B50	+1.3%	+1.0%
C100	+1.2%	+1.2%

Milestone 2: Turbocompounding

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Recover exhaust energy

Demonstrated at road load condition:

+1.4% BTE gain

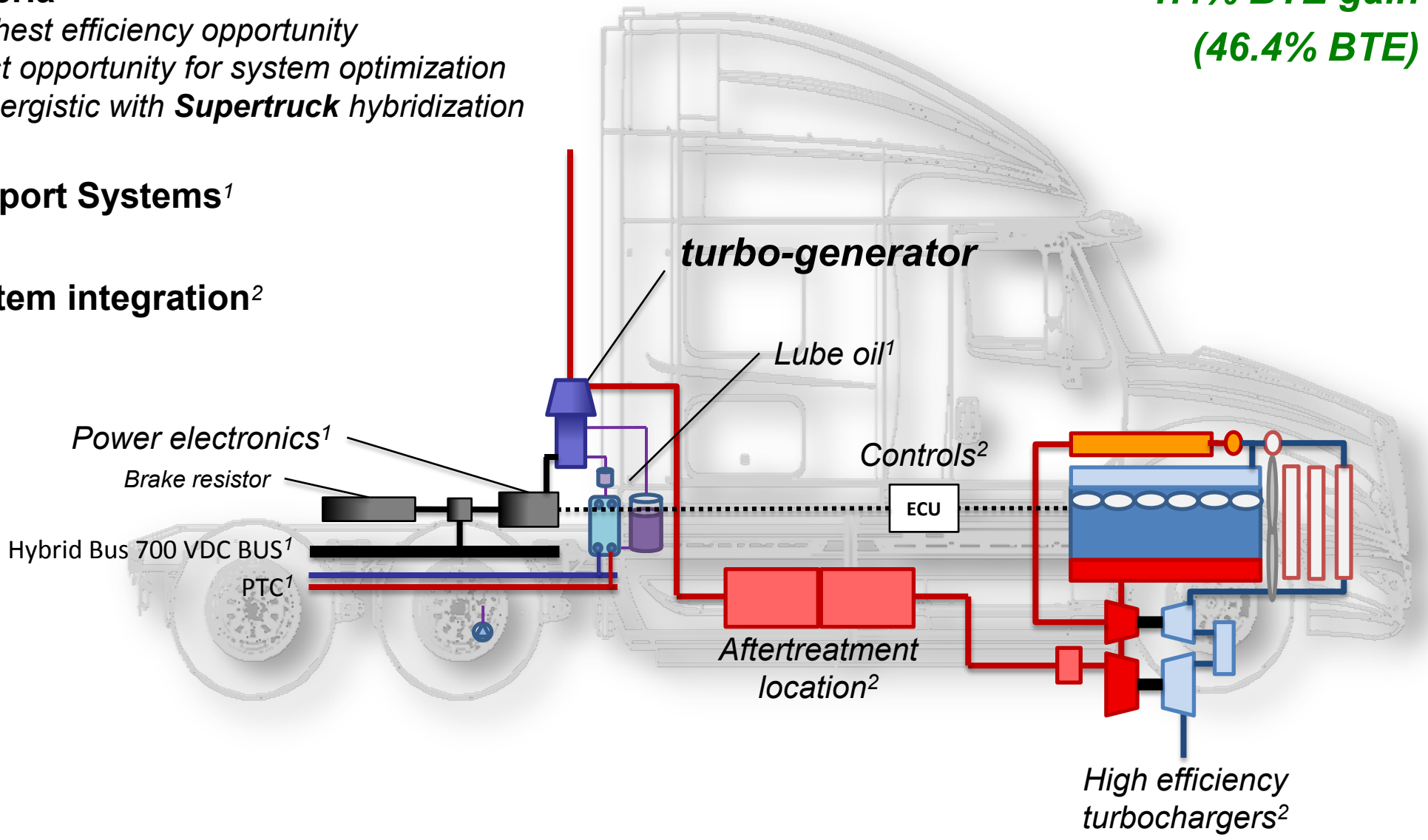
(46.4% BTE)

Criteria

- highest efficiency opportunity
- best opportunity for system optimization
*- synergistic with **Supertruck** hybridization*

Support Systems[1]

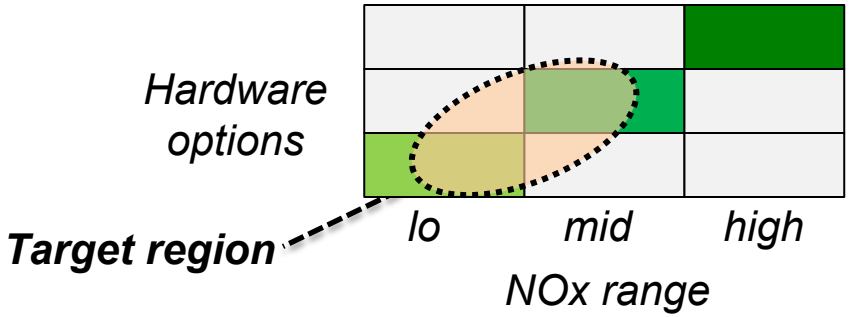
System integration[2]



Milestone 2: Turbocompounding (TuCo)

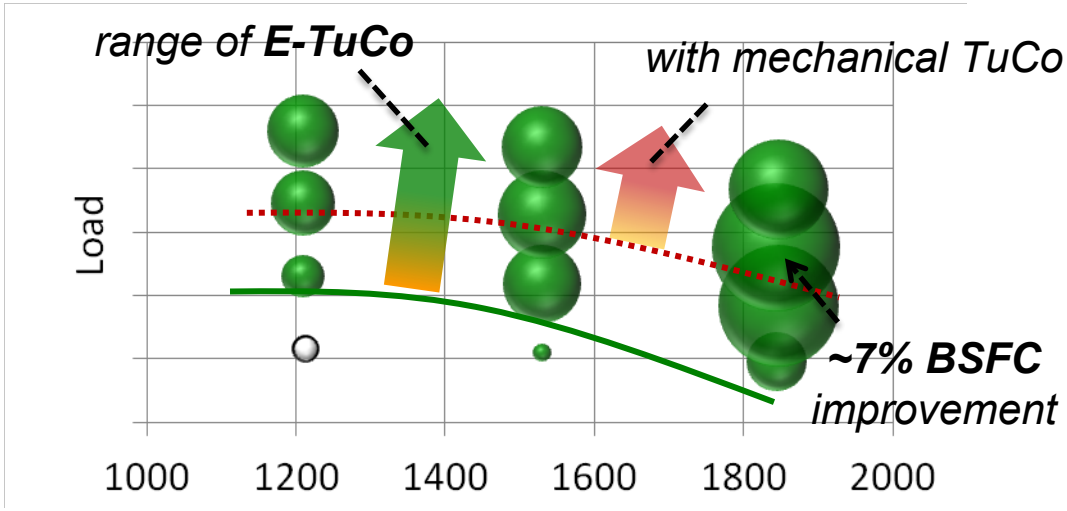
Optimizing work

- *Load distribution across turbine wheels*
- *Couple hardware with flow targets (emissions)*
- *Leverage simulation tools*



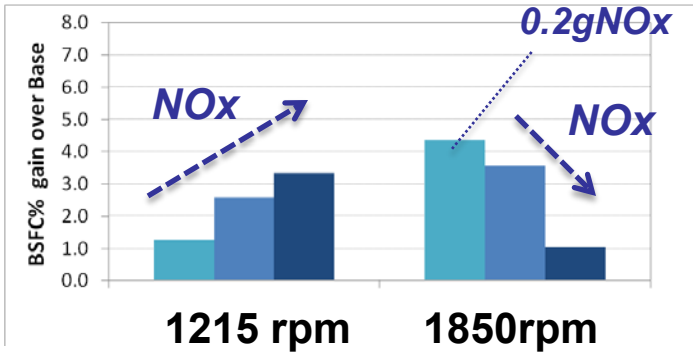
Current test results

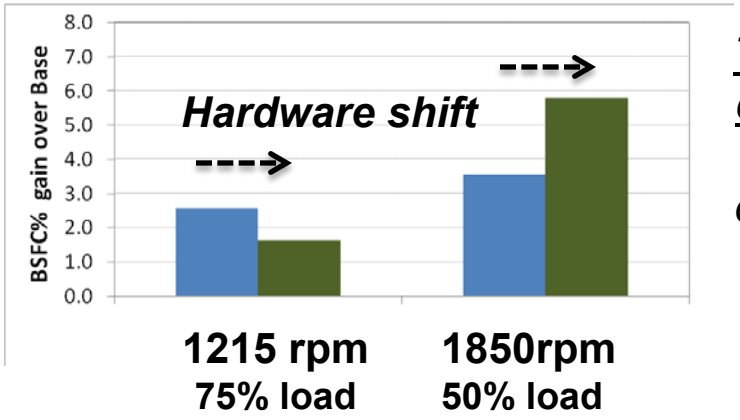
✓ *Broader range of improvement from mechanical turbocompounding*



Challenges of optimization

Varying emissions at fixed hardware configuration





Two hardware configurations at same emission level

Milestone 3: Base Engine

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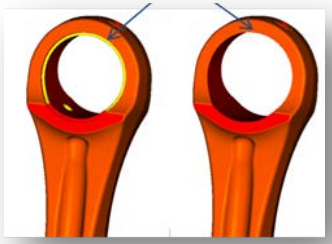
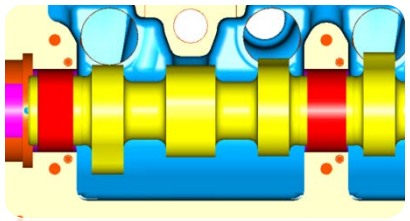
- ✓ **Up to 2% BTE gain possible across base engine improvements**
- ✓ **Target is 1.5% BTE gain.**

Piston and liners

Bushings

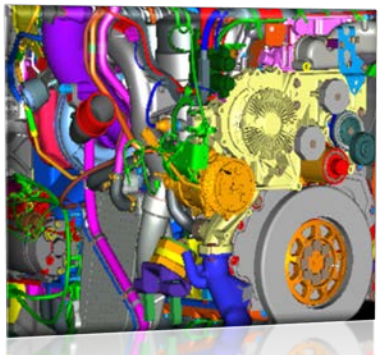


Low friction camshaft



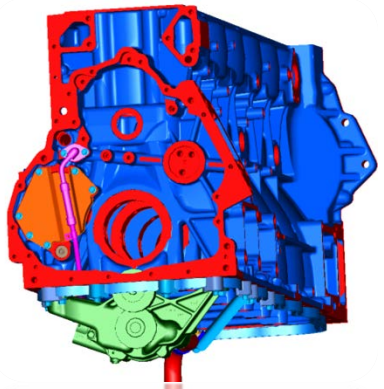
	Categories		
	Friction	Increased Cylinder Pressure	Thermal Management
Power Cylinder	+	+	
Power Transfer	++	+	
Crankcase	+++		++

Light weight crank



Cooling system

Lube oil system



Milestone 4: Rankine Cycle

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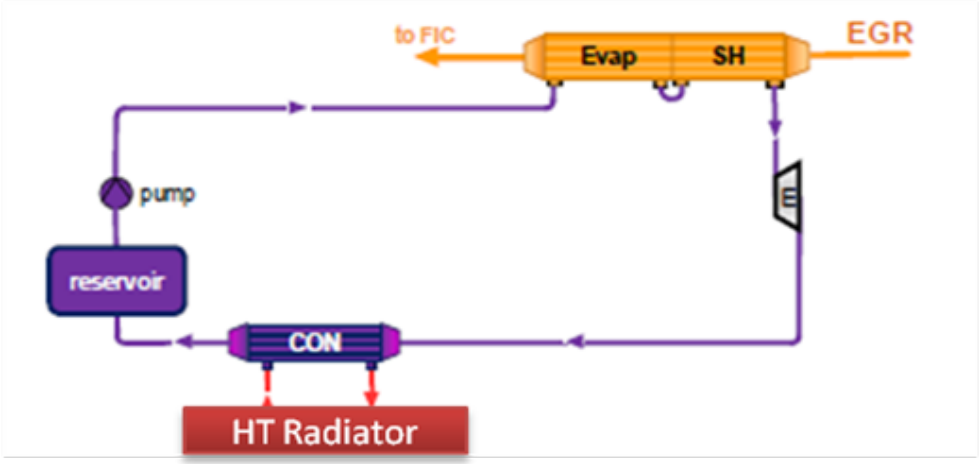
Cycle Criteria:

*Achieve **target intake manifold temperature**;*
***Package** in the vehicle;*
*Produce **fuel economy** benefit;*
***Safety** and crashworthiness;*
Cost and cost/performance ratio;
Reliability, durability, and product life;
Serviceability and service intervals;
Minimal weight increase.



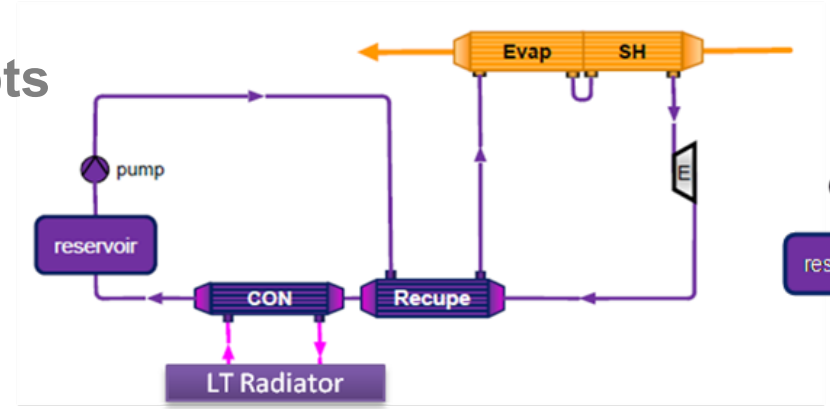
Evaluation of Fluids

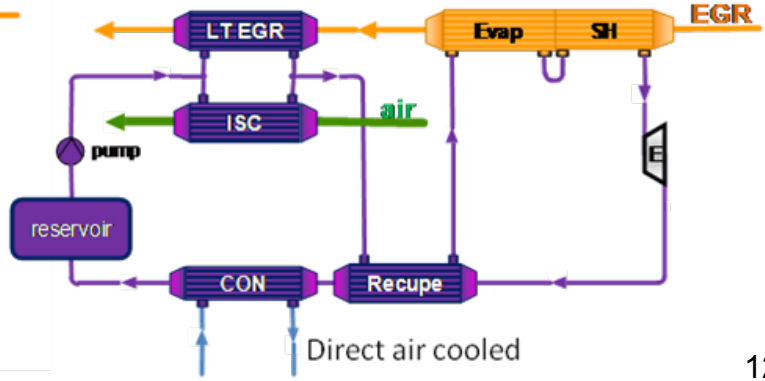
Critical temperature, pressure
Triple point temp, Psat at -40˚C, 25˚C
Flammability (in air)
Decomposition temp (˚C), products
GWP, ODP
Cost/L (Approx)
Specific gravity at 25˚C

BSFC Improvement*	HTR Cooled Condenser
Road Cycle [1]	3.1%
Road Cycle [2]	3.9%
USSET	4.9%

*Estimates

Alternative Concepts





Advanced BTE Concept
Impact of Fuel Reactivity

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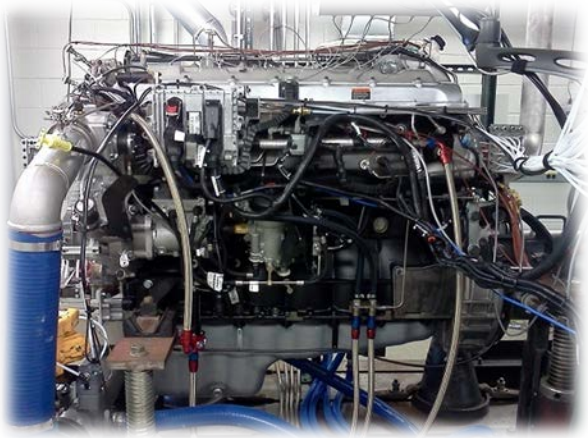
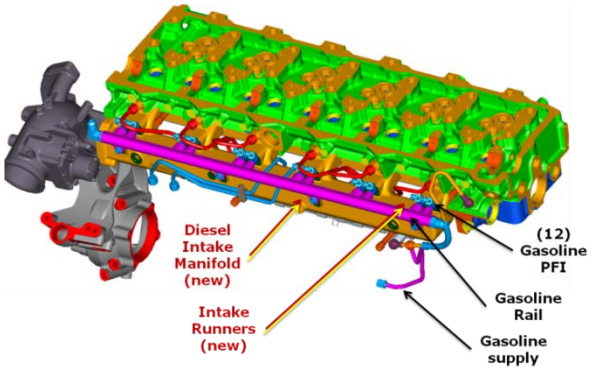
The High Efficiency Diesel MAXXFORCE13:
- ✓ *Engine operates at gross thermal efficiencies of **51-55%***

Single Cylinder Research engines with advanced or two fuels:
- ✓ *Engines have shown similar efficiencies (e.g. PPC [1], RCCI [2])*
- ✓ *Fuel reactivity shows significantly improved engine out emissions*
- ✓ *Challenges exist to make this "feasible"*

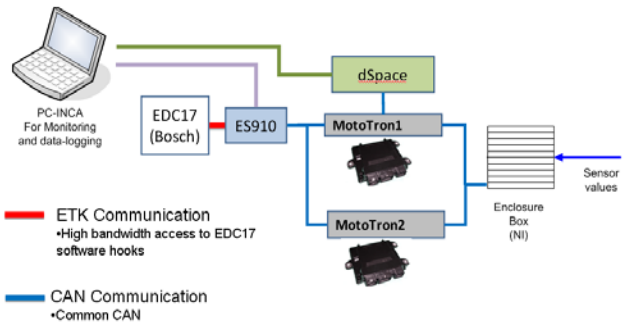
MAXXFORCE13 has been reworked to operated in Dual Fuel mode



MAXXFORCE13 Dual Fuel at ARGONNE



Dual Fuel Cylinder Head



Dual Fuel Controller and strategy

[1] Path to High Efficiency Gasoline Engines, Bengt Johansson, DEER 2010
[2] High Efficiency Fuel Reactivity Controlled Compression Ignition (RCCI) Combustion, Rolf D. Reitz, DEER 2010

Fuel Reactivity
Challenges and Opportunities

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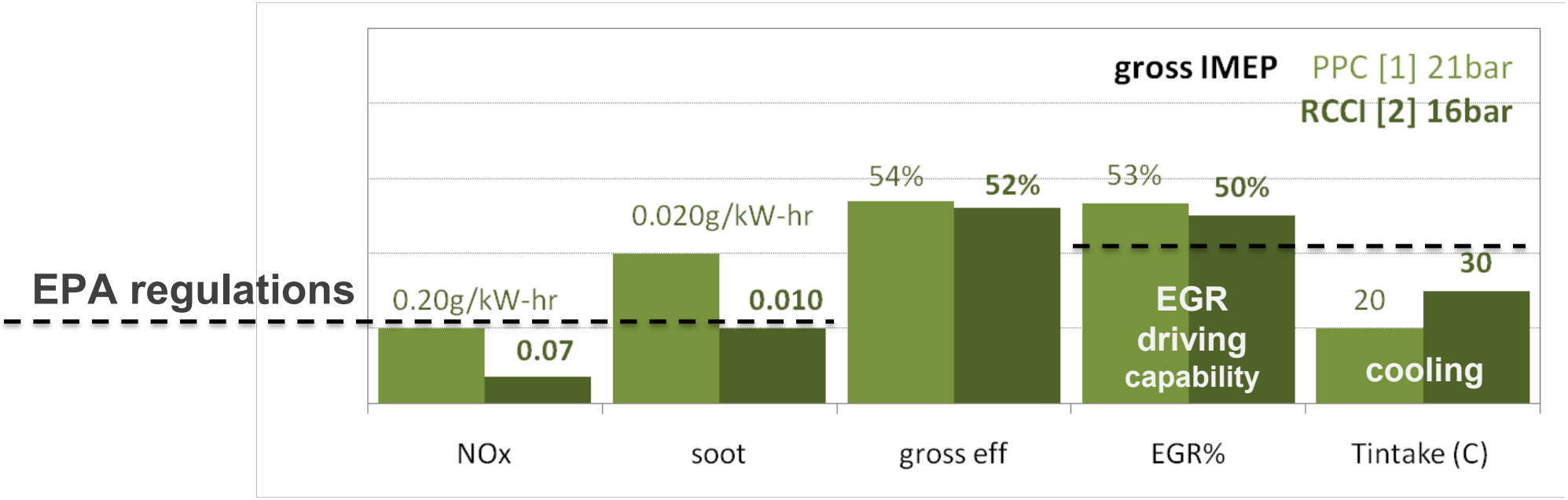

	Emissions	Efficiency	Engine Technologies
Diesel Fuel	Challenging in-cylinder Costly aftertreatment	Retains high efficiency	In production
Fuel Reactivity	Reduce engine out emissions to 2010 levels	High Efficiency	Challenging conditions to attain in production

Enablers with the MAXXFORCE13 Dual Fuel and Advanced EGR

- **VVA**
- **Combustion Feedback**
- **Variable Geometry Turbos**

Summary

NAVISTAR ENGINE GROUP

Project is focused on assessing and developing engine and vehicle technologies to **improve freight efficiency** for class 8 truck and trailer.

The MAXXFORCE 13L engine is **well posed to deliver 50% BTE**

The work to date includes:

- ✓ Milestone 1: Combustion optimization demonstrated efficiency improvement of 3% BTE
- ✓ Milestone 2: Demonstrated turbocompounding improvement of 1.4% BTE
- ✓ Milestone 3: Base Engine Technologies selection targeting 1.5% BTE gain
- ✓ Milestone 4: Rankine Cycle Selection (including hardware, refrigerant) targeting 1.5% BTE gain

In addition:

- ✓ Engine has been prepared to examine the impact of Fuel Reactivity

Acknowledgements

Engine Project Partners

CFD
- WERC

Fuels
- ARGONNE NATIONAL LABS

Enabling Technologies
- BOSCH
- FEDERAL MOGUL

Thank You

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