CATERPILLAR

Demonstration of a 50% Thermal Efficient Diesel Engine - Including HTCD Program Overview

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Project Officer: Gurpreet Singh Carl Maronde

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2006 DEER conference

Outline

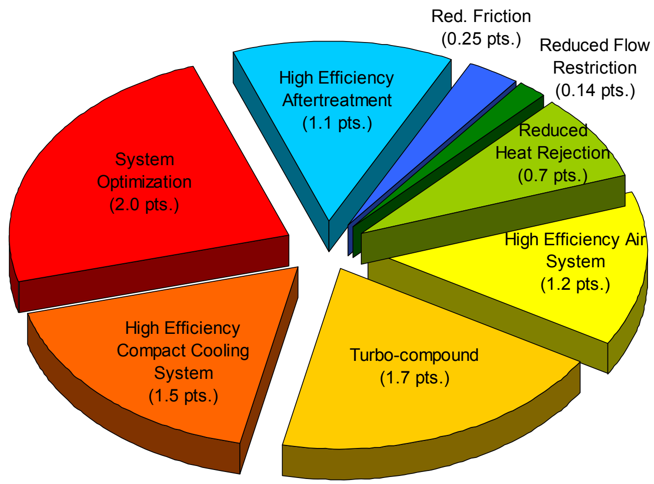
- HTCD Overview
  - Program Objectives & Benefits
- Progress Report on 50% Engine Project
  - Systems Approach
  - Review each of the 8 Building Blocks
    - Concept
    - Status
    - Systems Interactions
    - Challenges
  - Interim System Demonstration
  - Summary and Conclusions

Program Objectives:
Transfer of Technology into Production

HTCD Timeline

2001	2002	2003	2004	2005	2006

From Baseline Efficiency to 50%



DOE HTCD Program Objectives

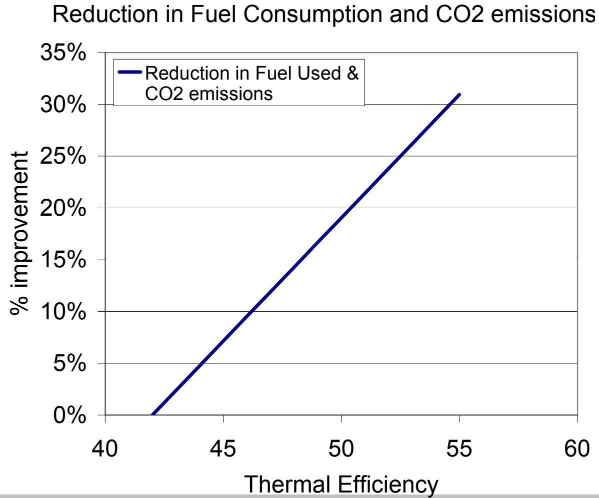
NATIONAL/GLOBAL IMPLICATIONS

- Improved fuel efficiency will:
  - Decrease consumption of non-renewable energy sources
  - Reduce CO_2 emissions output
  - Lower operating costs for end users
  - Decrease dependence on foreign oil supplies

Program Objectives:
Transfer of Technology into Production

DOE/Caterpillar Objectives

- Demonstrate:
  - 2010 On-Highway Engine emissions levels (0.20 g/hp-hr NOx, 0.01 g/hp-hr PM)
  - 50+% thermal efficiency
- System should also:
  - Package within a class VIII on-highway truck
  - Maintain durability and reliability
  - Cost viable

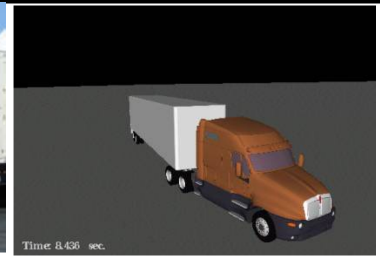


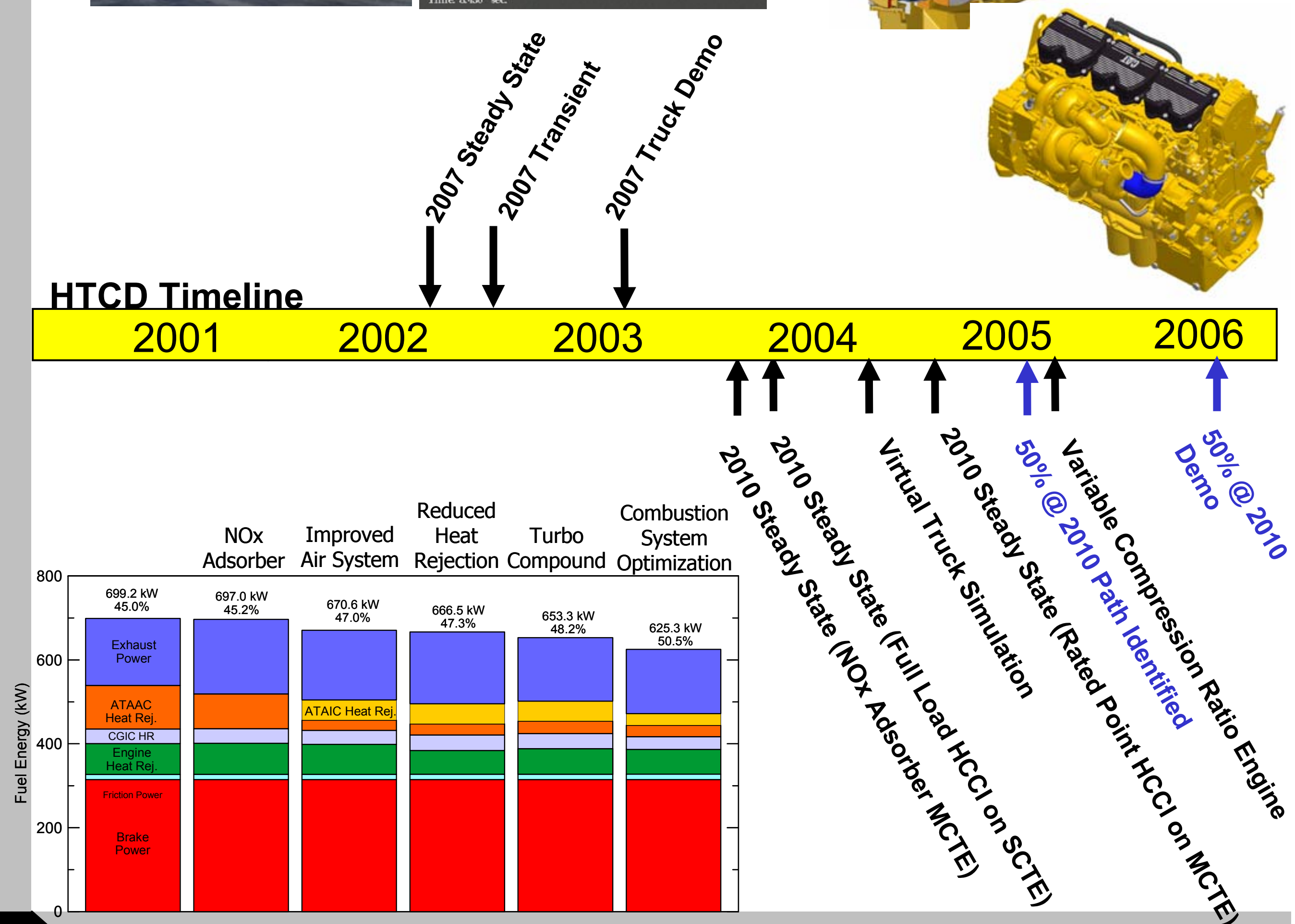
Caterpillar Objectives

- Develop high customer value 2010 On-Highway and 2014 Tier 4 power train systems
  - Evaluate high efficiency building blocks
    - fuel economy benefit
    - durability/reliability
    - cost
    - packaging
    - etc.
  - Integrate building blocks into a 2010 On-Highway and 2014 Tier 4 compliant systems
    - Significant improvement in cycle fuel economy
    - cost effective
    - meets production standards

DOE / Caterpillar Engine Programs - Accomplishments & Break-through

- In-Cylinder Components
  - 49% OTE engine demonstrated
- Light Truck (LTCD)
  - HCCI breakthrough
  - Mixed Mode Injection concept
- Electric Turbo Compound (ETC)
  - Integrated system demonstrated on gas stand and engine
- Heavy Truck Clean Diesel (HTCD)
  - Full load HCCI on SCTE, rated on MCTE
  - NOx Adsorber demonstration
  - 2007 emissions capable demonstrator truck in 2003
  - Virtual Truck simulation
  - VCR engine build
  - Advanced Fuel System design
  - Evaluation of 3 paths to meet 2010 emissions
  - 50% overall thermally efficient engine→ Demonstration this year





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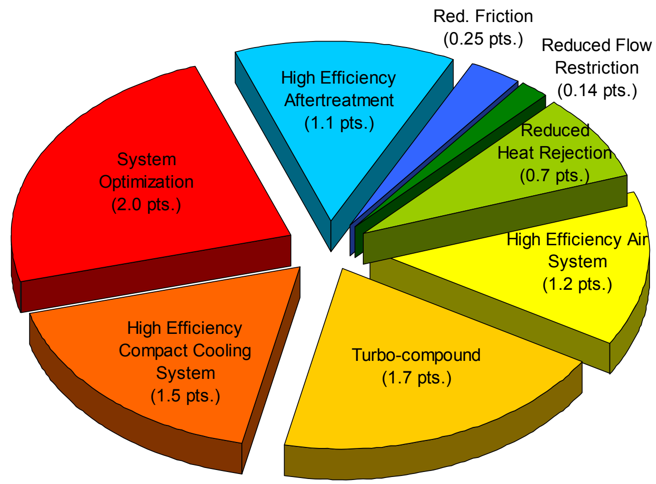
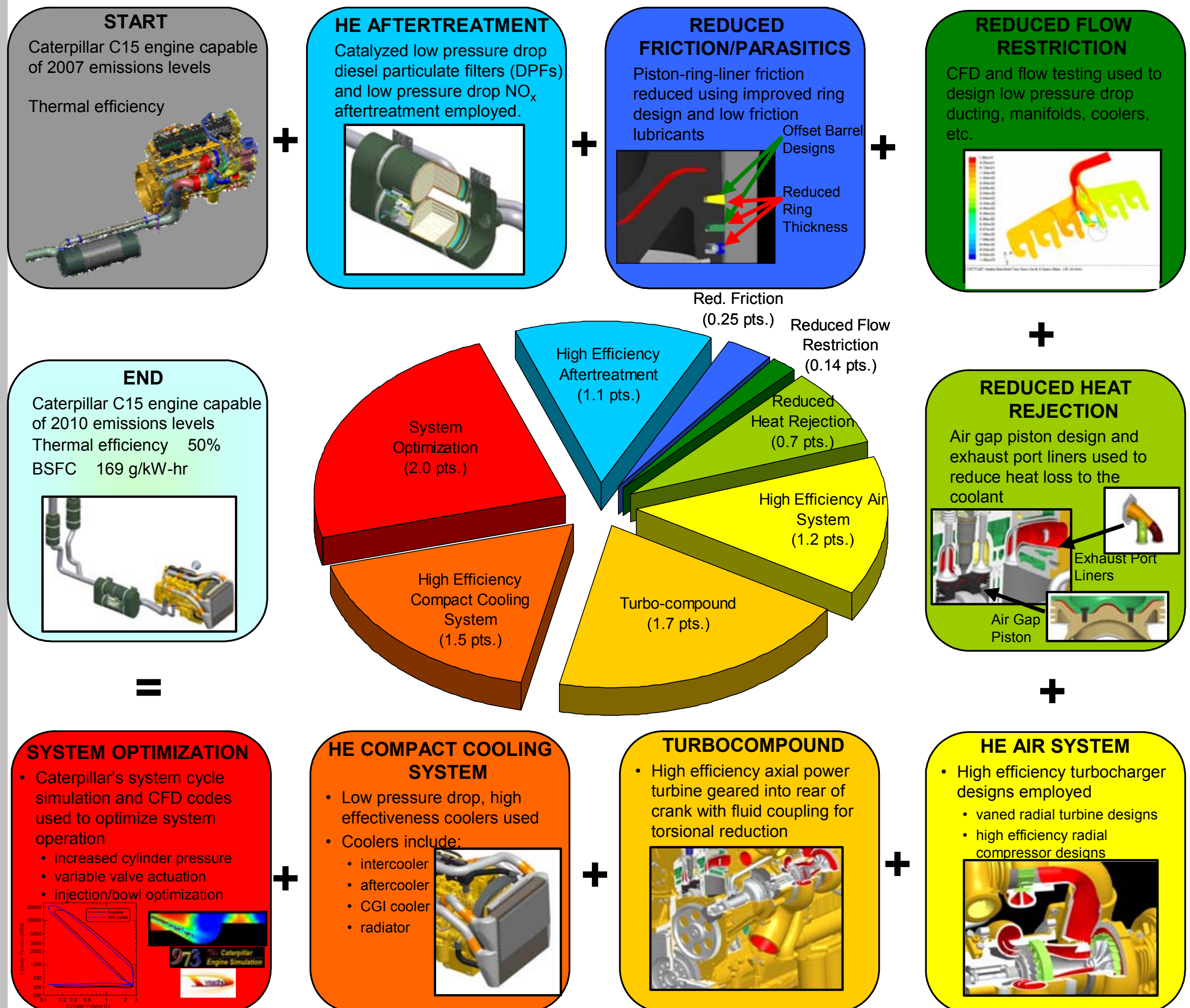


Systems Approach

High Efficiency Demonstrator

- Systems Approach
  - Many building blocks needed
  - Interactions must be carefully considered
  - Integrated package critical
- Demonstration Point
  - 1200 rpm
  - Peak Torque

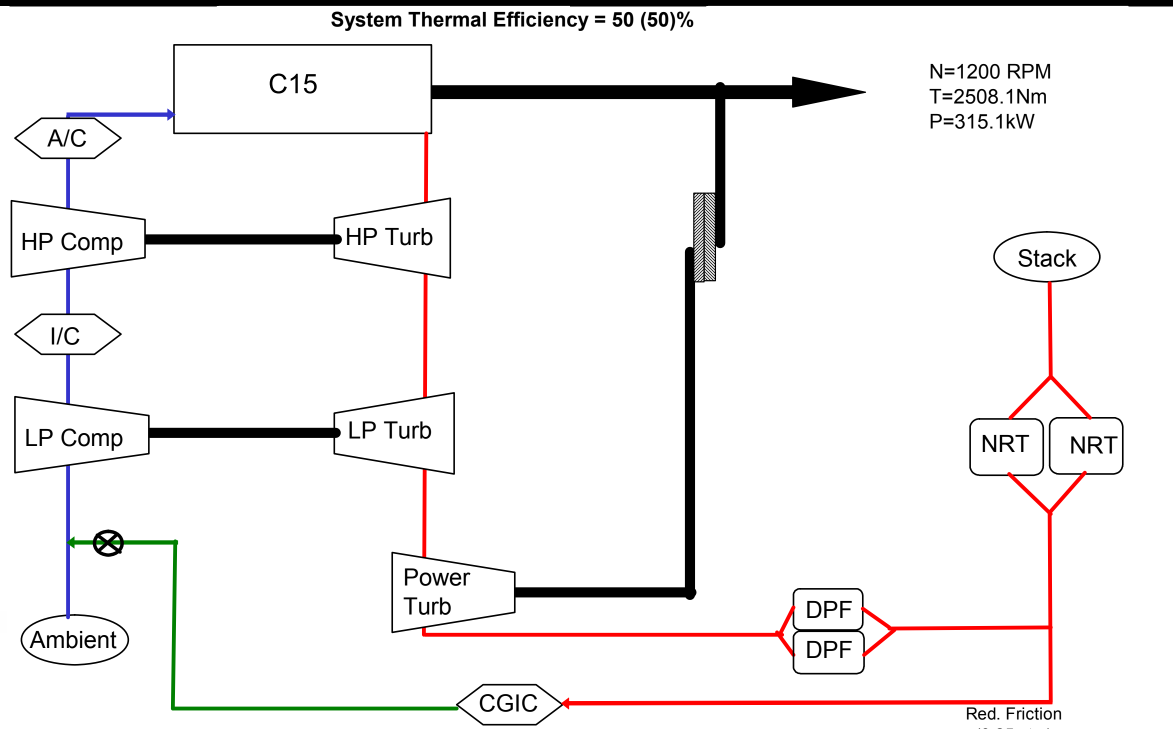
The Path to 50% Thermal Efficiency

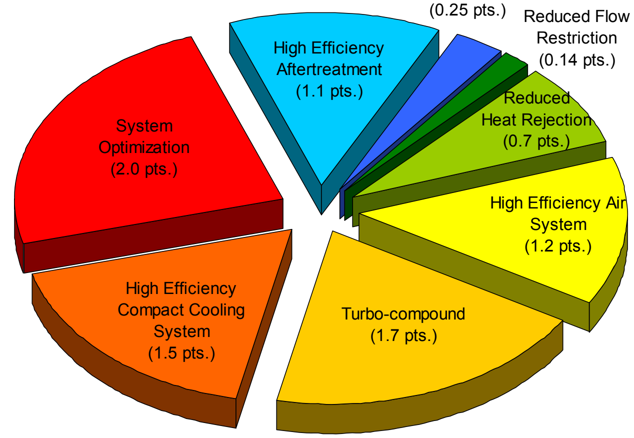


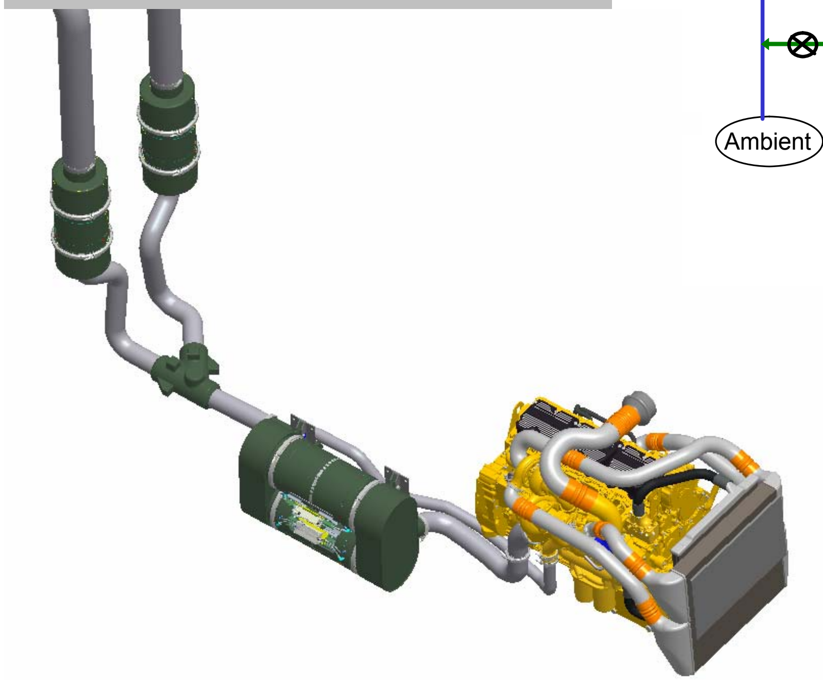
System Schematic

High Efficiency Demonstrator

- Systems Approach



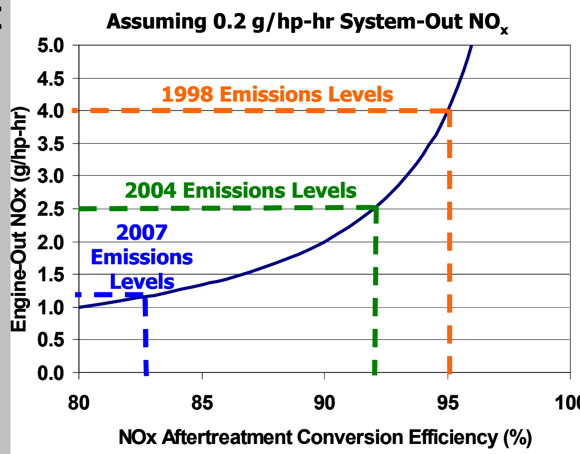


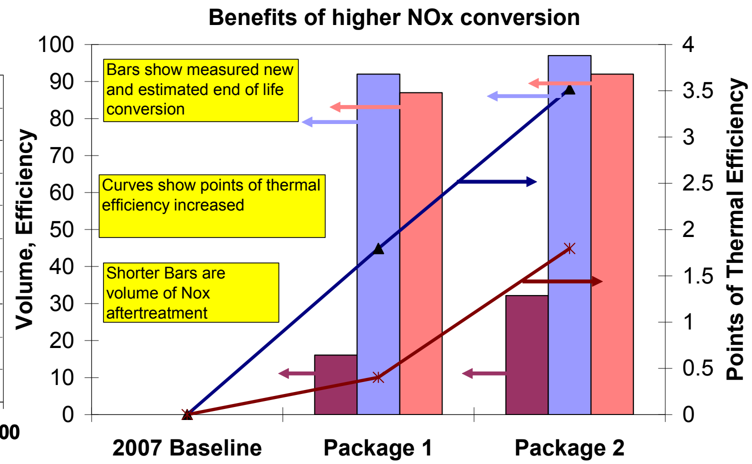


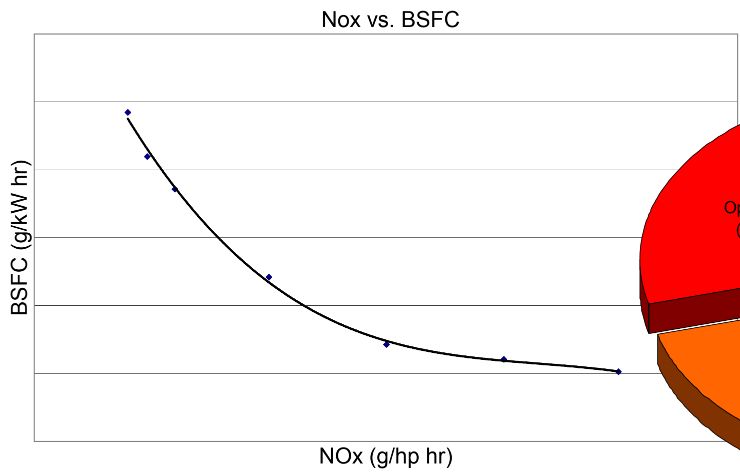
Building Block 1 – High Efficiency Aftertreatment

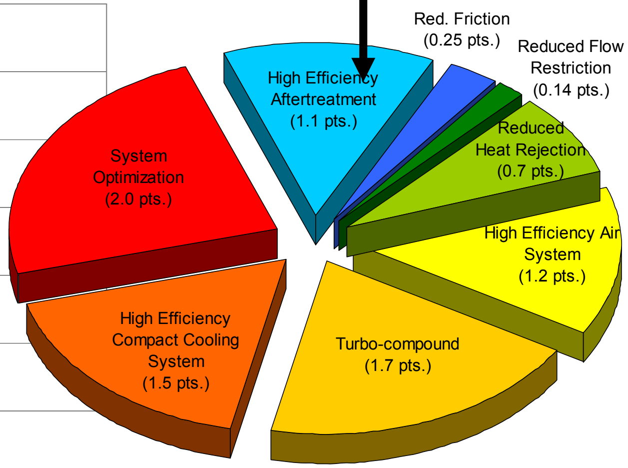
Building Block 1 – High Efficiency Aftertreatment

- Concept
  - Low back pressure design
  - High conversion efficiency aftertreatment
- Status
  - Engine demonstrated
- System Interactions
  - Package size vs. conversion efficiency (Engine out NOx /PM)
  - Package size vs. back pressure (expansion ratio across turbo machinery)
- Challenges
  - Long term degradation
  - Low temperature operation
  - Reductant
  - Regeneration /Transient dosing (conversion efficiency)
  - Packaging
  - Cost









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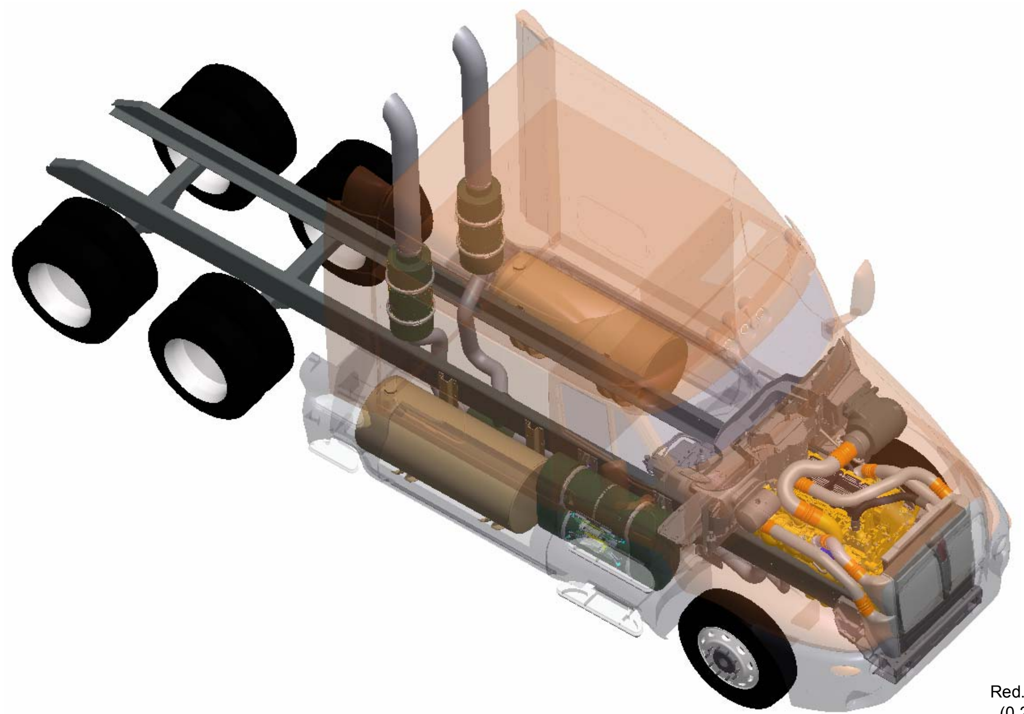
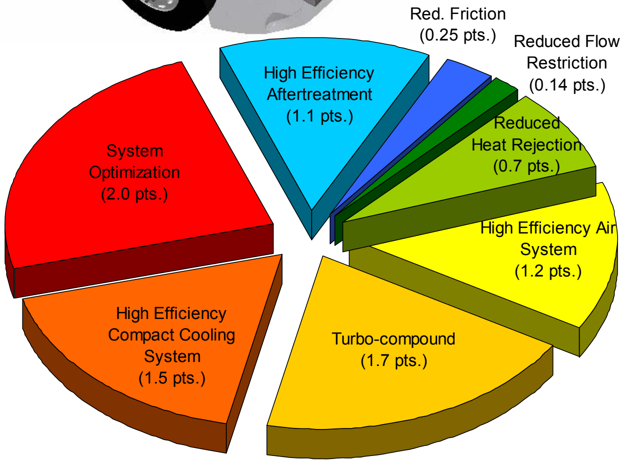
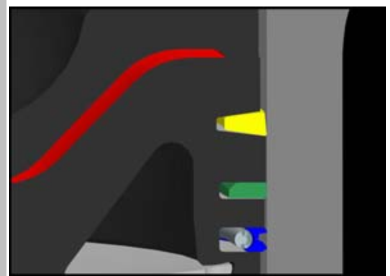




Building Block 2 – Reduced Friction/Parasitic

Building Block 2 – Reduced Friction/Parasitic

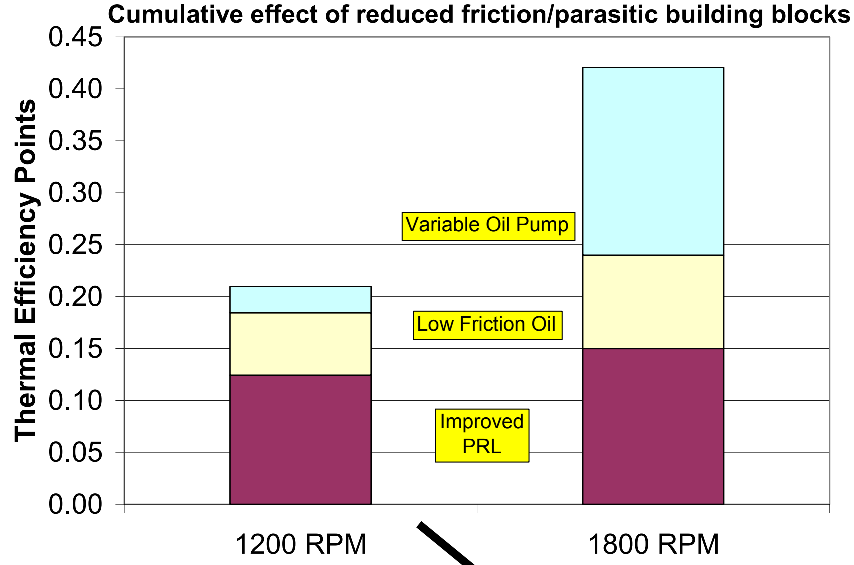
- Concept
  - Reduced PRL friction through improved ring design
  - Lower friction oil
  - Reduced parasitic load through variable flow oil pump
- Status
  - Engine demonstrated
- System Interactions
  - Oil consumption (effect on DPF size for ash intervals)
  - Any blow-by effect on system efficiency
- Challenges
  - Oil control
  - Benefit / Cost for variable flow devices

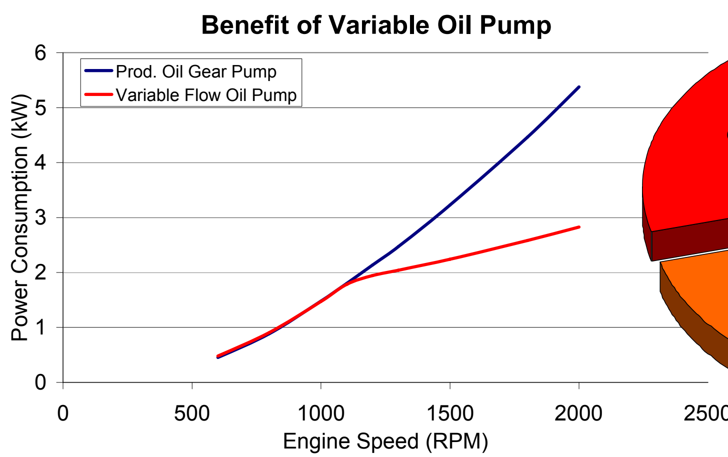


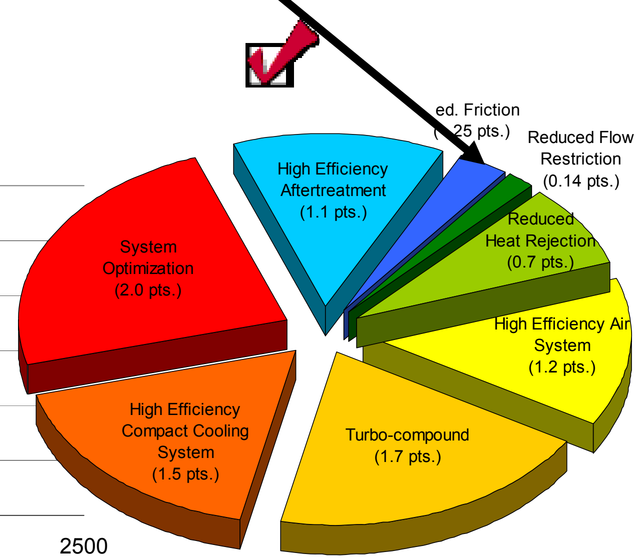
Improved PRL

•Reduced Ring Thickness

•Offset Barrel Designs



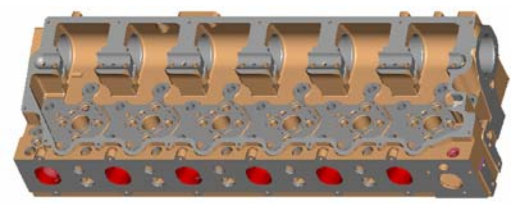


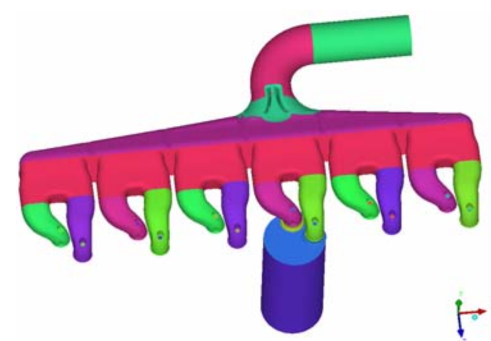


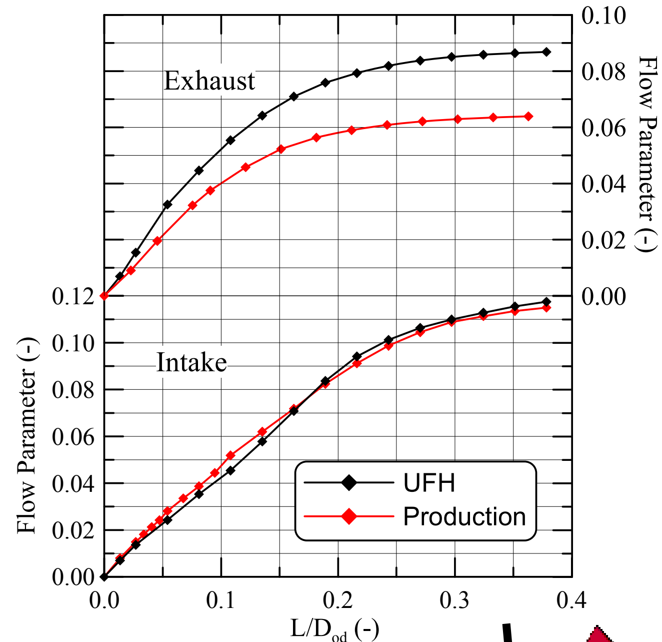
Building Block 3 – Reduced Flow Restriction

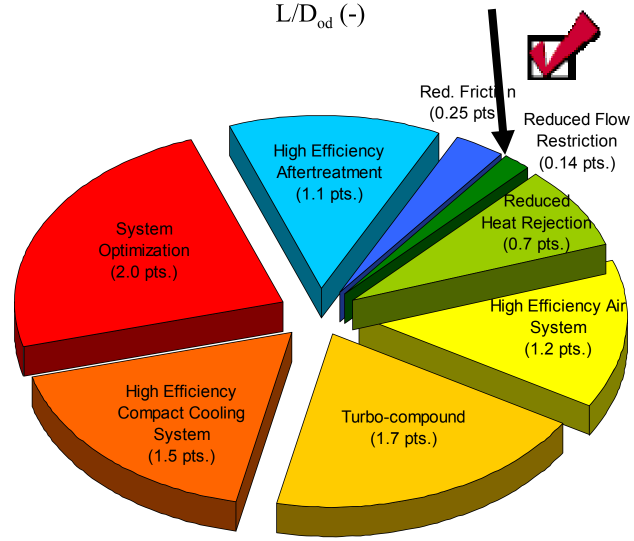
Building Block 3 – Reduced Flow Restriction

- Concept
  - Improved manifolds and port design
- Status
  - Simulated engine benefit
  - Parts Procured
  - Flow Bench Demonstrated
- System Interactions
  - Flow passages versus Strength Capability
- Challenges
  - Benefit / Cost
    - Capital





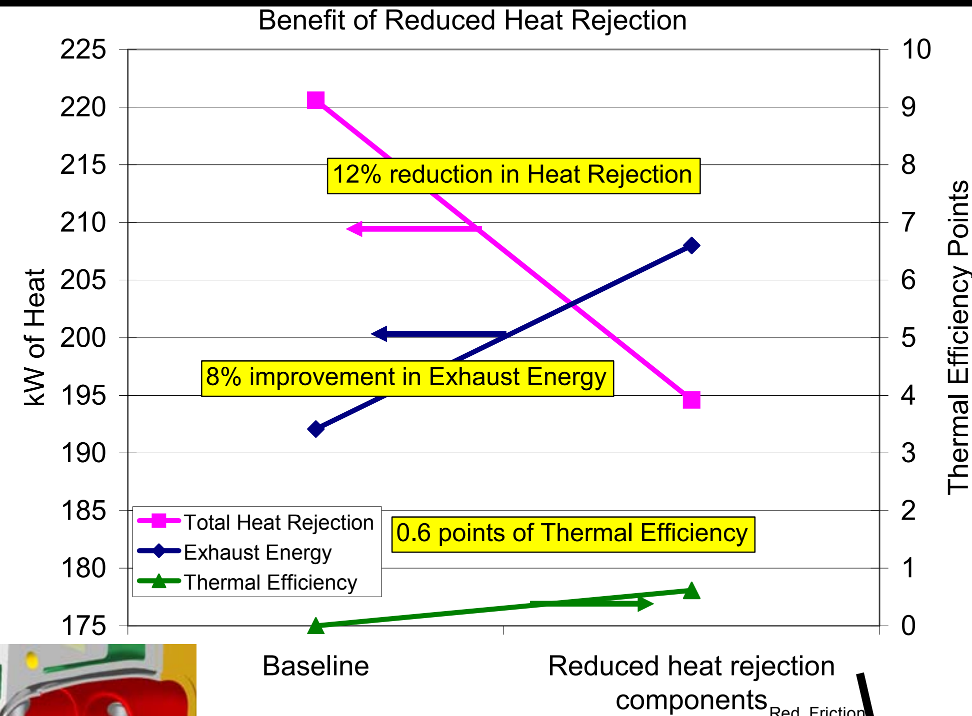


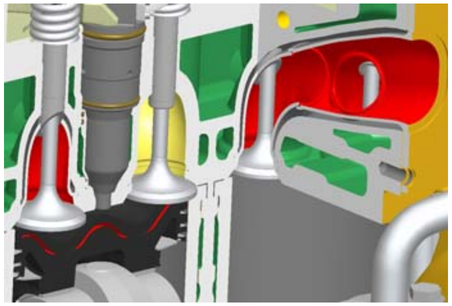


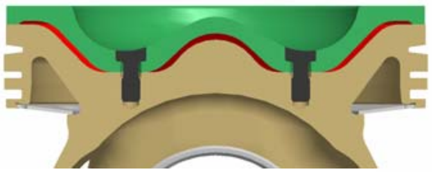
Building Block 4 – Reduced Heat Rejection

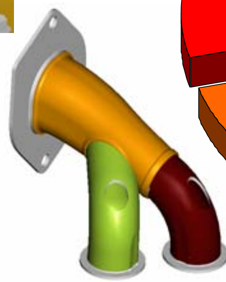
Building Block 4 – Reduced Heat Rejection

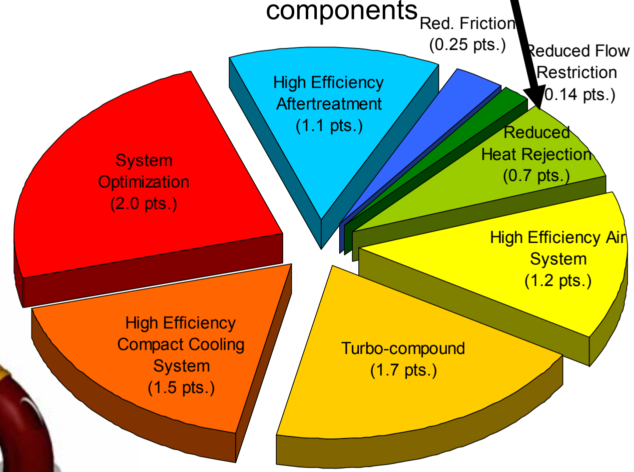
- Concept
  - Air Gap Piston
  - Exhaust Port Liner
- Status
  - Simulated engine benefit
  - Procurement in process
- System Interactions
  - Increased in-cylinder temps vs. emissions
  - Top ring area temps vs. piston deposits\
  - Increased exhaust energy for high efficiency air system and Turbo compound
- Challenges
  - Benefit / Cost
  - Durability







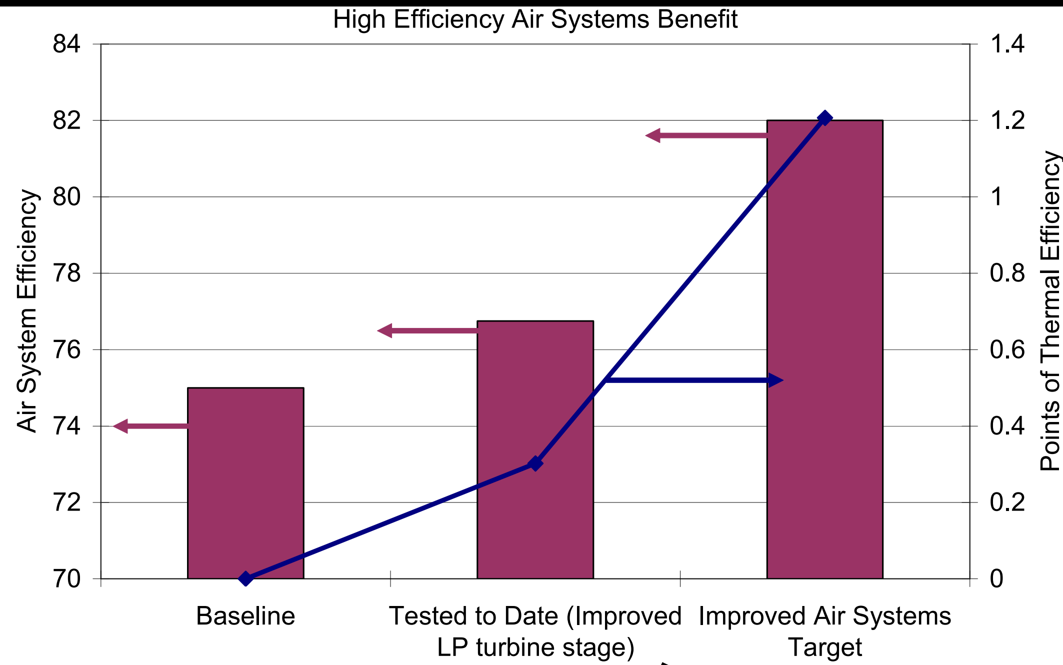


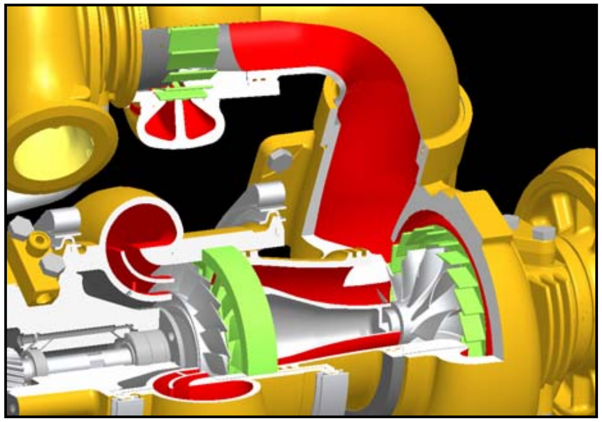


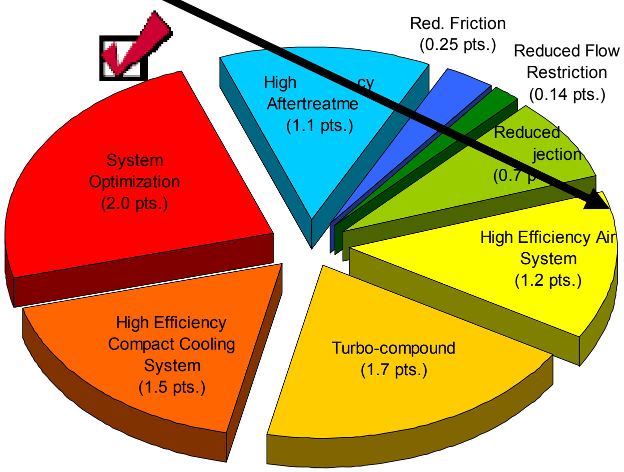
Building Block 5 – High Efficiency Air System

Building Block 5 – High Efficiency Air System

- Concept
  - Improved Aerodynamic design of turbine & compressor wheels
  - Vaned design for housing
- Status
  - Simulated engine benefit
  - Procurement in process
  - Gas Stand Demonstrated
- System Interactions
  - Sized for use with turbo-compound system & IVA
- Challenges
  - Benefit / Cost
  - Map width



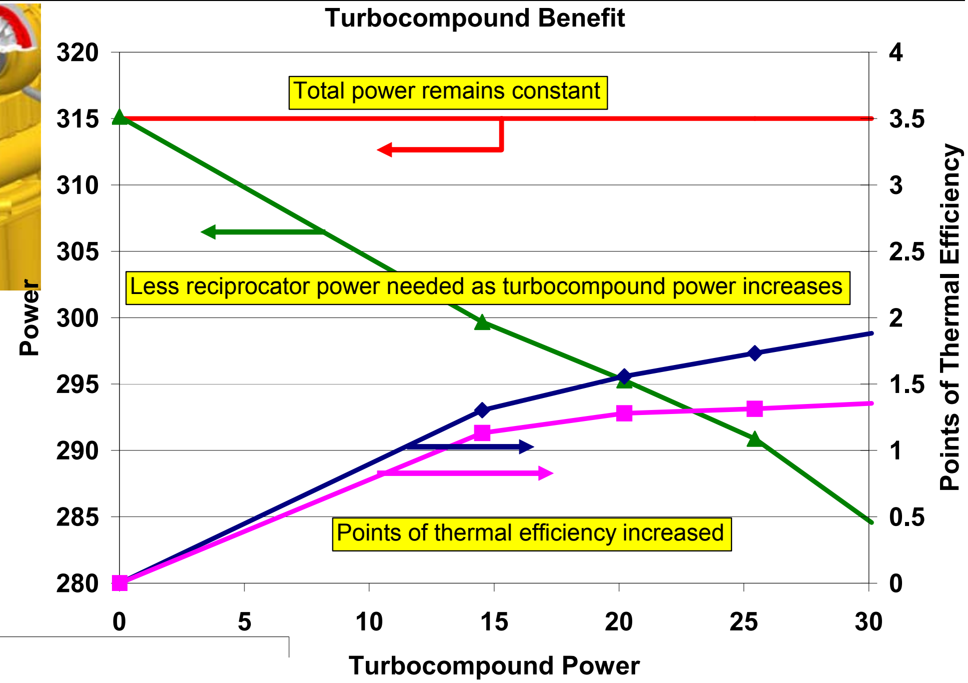


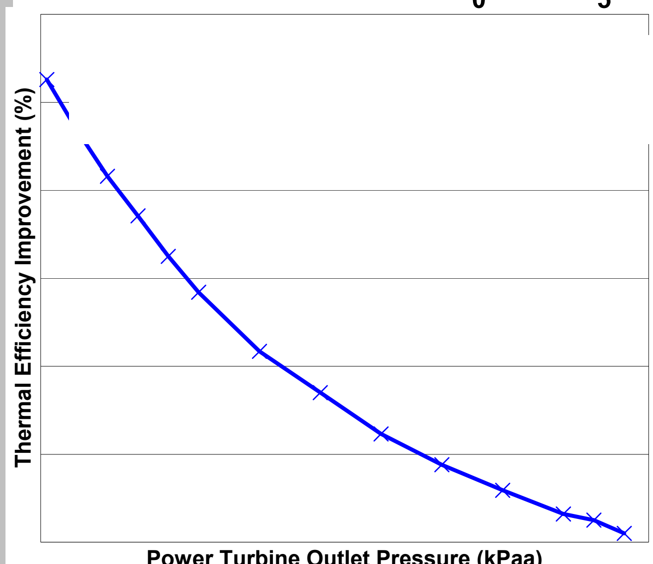


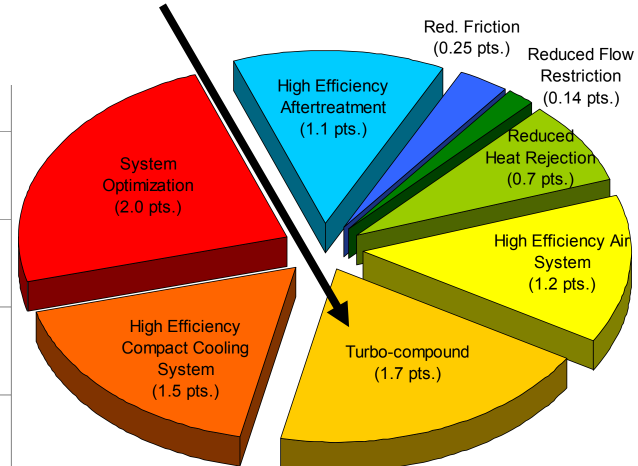
Building Block 6 – Turbo Compound

Building Block 6 – Turbo Compound

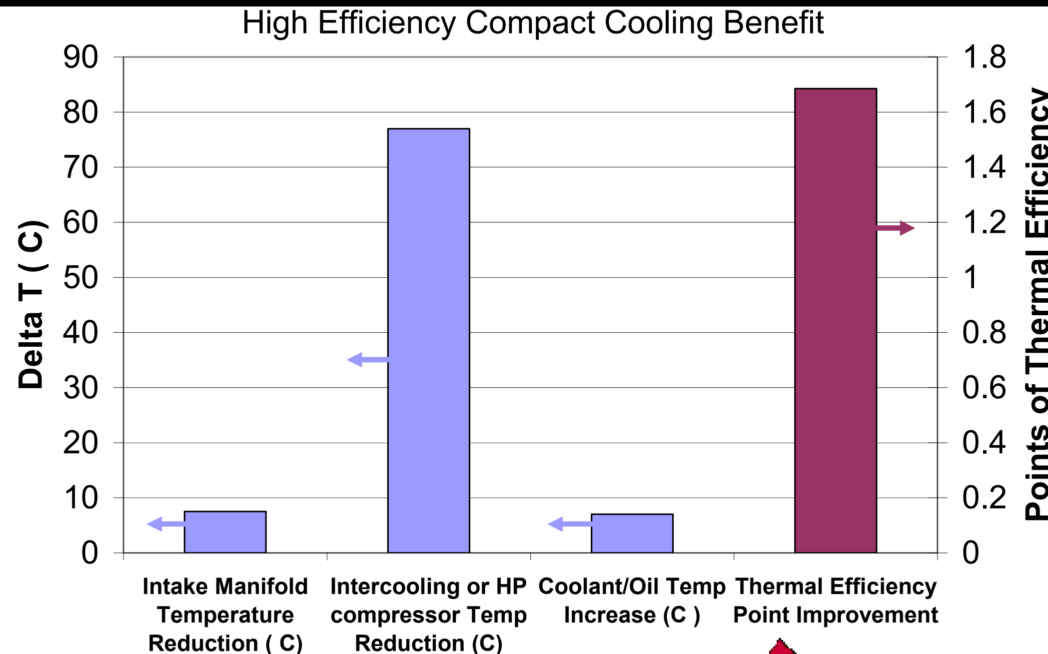
- Concept
  - High Efficiency Axial Turbine geared to rear gear train
- Status
  - Simulated engine benefit
  - Procurement in process
- System Interactions
  - Optimized power vs. A/T Package size (back pressure)
  - Optimized reciprocator power vs. turbo compound power
- Challenges
  - Benefit / Cost
  - Packaging





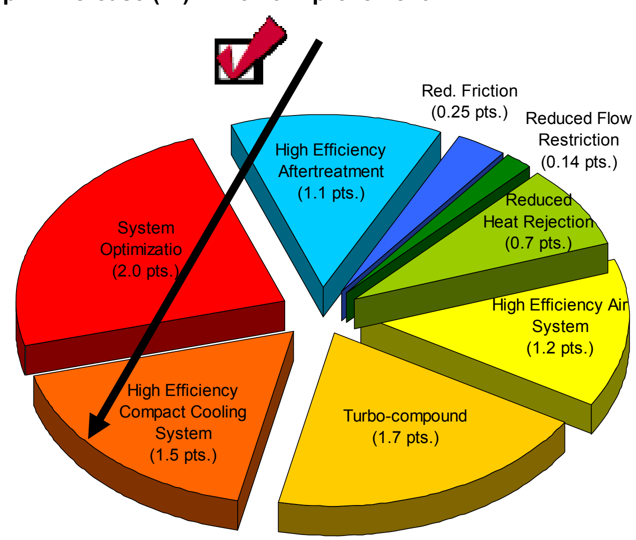


Building Block 7 – High Efficiency Compact Cooling System



Building Block 7 – High Efficiency Compact Cooling System

- Concept
  - Intercooling
  - Lower Intake Manifold Temps
  - Higher oil and coolant temps
  - Lower pressure drop
- Status
  - Engine Demonstrated
- System Interactions
  - Package size vs. fan flow pressure drop across core
  - Oil and coolant temps vs. air side pressure drop
- Challenges
  - Benefit / Cost
  - Packaging

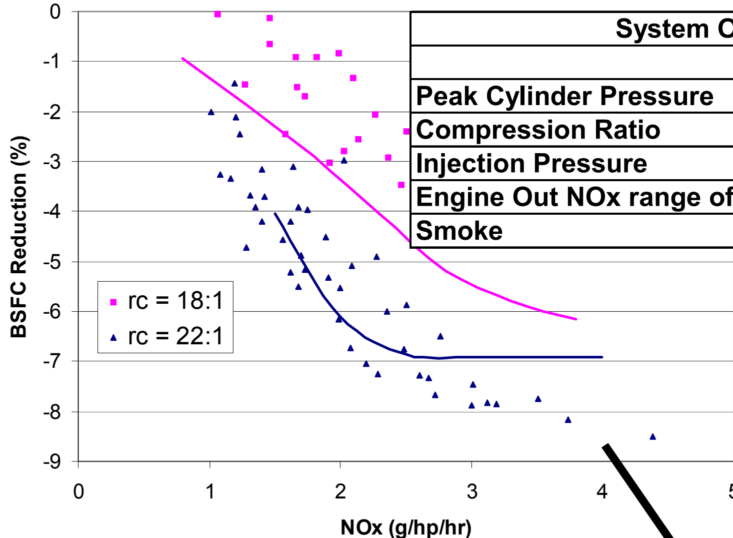


Building Block 8 – System Optimization

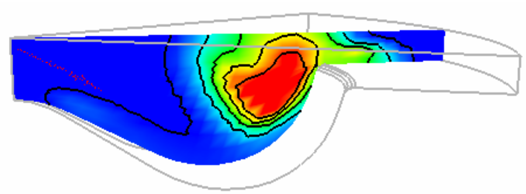
Building Block 8 – System Optimization

- Concept
  - Higher Peak Cylinder Pressure
  - Higher Compression Ratio
  - Higher injection pressure
  - Optimized CGI settings
  - Optimized IVA settings
  - Optimized nozzle and bowl
- Status
  - Engine Demonstrated
- System Interactions
  - PCP needed for Compression ratio increase
  - Piston Bowl for higher compression ratio vs. smoke
  - Parasitic vs. Burn Rate vs. Smoke
  - IVA vs. CGI vs. Smoke vs. Heat Rejection
- Challenges
  - Durability
  - Benefit / Cost

Engine demonstrated benefit of increasing compression ratio

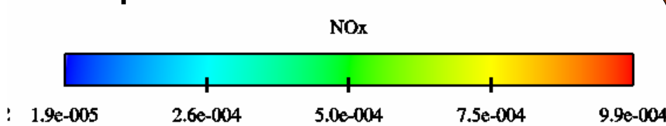


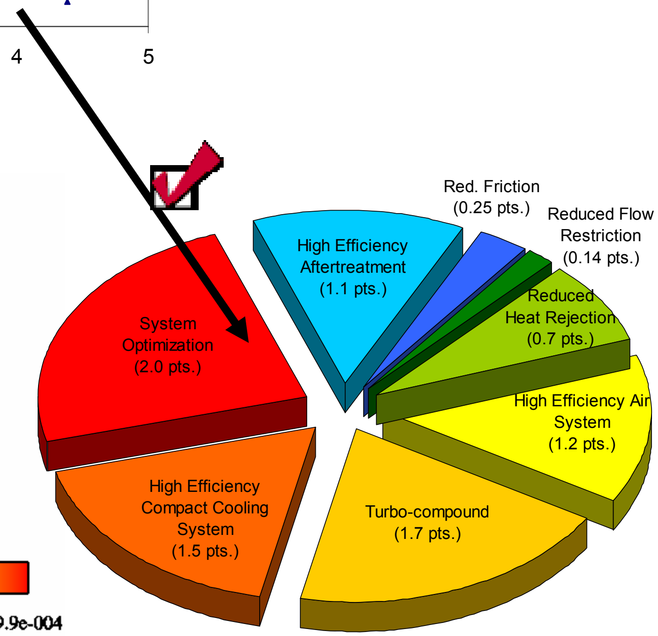
System Optimization Parameter table			
	Range		Units
Peak Cylinder Pressure	Base	22	Mpa
Compression Ratio	18	22	
Injection Pressure	Base	25% increase	
Engine Out NOx range of interest	2	3	g/hp hr
Smoke		<1.5	AVL



3D Combustion Analysis

Optimization Process





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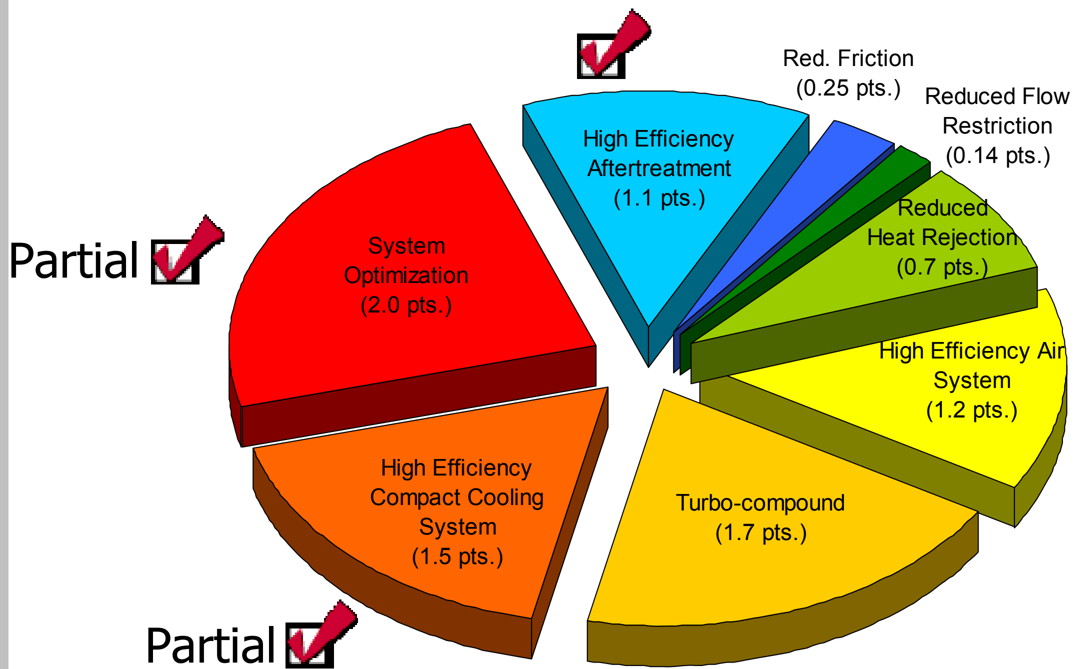

Table of Key Data		
Thermal Efficiency	45.5	%
BSFC	186	g/kw hr
Speed	1200	rpm
Load (peak torque)	2508	Nm
Engine out NOx	2.5	g/hp hr
Engine out Smoke	<1.5	AVL
System out NOx	2010 compliant	
System out PM	2010 compliant	

Summary and Conclusions

HTCD program an excellent example of government industry cooperative research

- Key accomplishments reviewed

Integrated system approach to achieve 50% overall thermal efficiency (~17% improvement) identified

- Concepts explained
- Status presented
- Key system interactions addressed
- Challenges being addressed

Integrated design completed for Class 8 truck

Interim system demonstration

- ~ 46% overall thermal (~7% improvement)

Final demonstration scheduled to be completed by Sept 30th, 2006.

Future DOE programs to deliver 55% overall thermal efficiency (HECC) and fuel economy improvement through exhaust waste heat recovery (EWHR)

- Still 22% of the heat leaves the stack with current demonstration

Thanks to the DOE for their assistance in achieving significant results