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The Path to a 50% Thermal Efficient Engine

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DOE Contract DE-FC05-00OR22806
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Prog. Mgr.: Roland Gravel
Tech. Mgr.: Carl Maronde

August 23, 2005
DEER Conference

Outline

- Objectives
- First Law Analysis of Fuel Energy Distribution
- Review of Analysis for 45% Brake Thermal Efficiency at 2007 Emissions Levels
- 50% Brake Thermal Efficiency at 2010 Emissions Levels
- Summary and Conclusions

DOE HTCD Program Objectives

- Diesel fueled engine capable of
  - 2010 emissions levels (0.20 g/hp-hr NOx, 0.01 g/hp-hr PM)
  - 50% thermal efficiency
  - >500,000 miles with only minor maintenance
  - Package must fit within class 8 truck

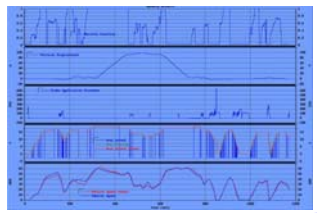
Simulation

Results of Past Research

High Efficiency Building Blocks

Test Hardware

Calibrate Models



System Simulation

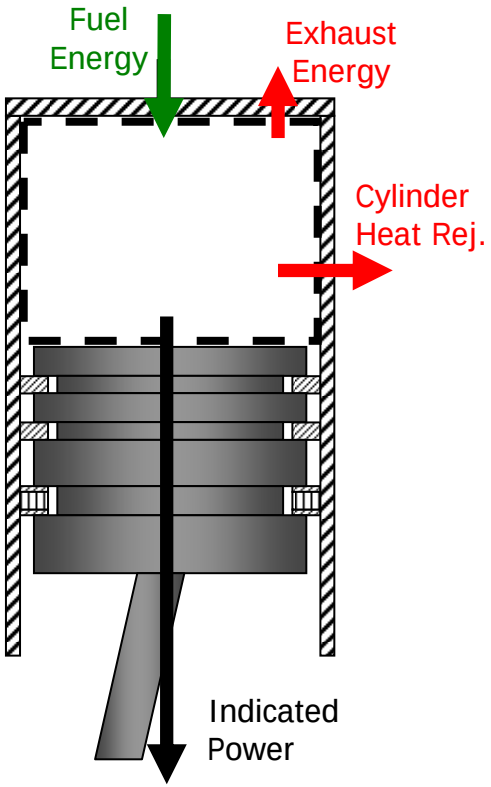
"Real" World Benefit

Does improvement in fuel economy offset the cost and maintain durability?

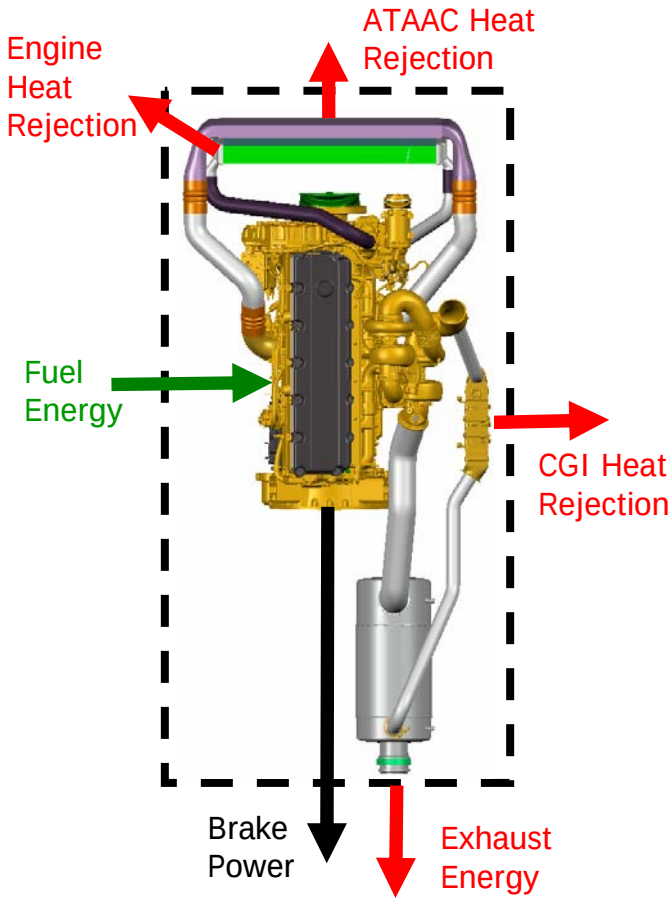
- Program Phasing
  - Phase 1: Analytical validation of 45% thermal efficiency at 2007 OHT emissions levels
  - Phase 2: System simulation of 50% thermal efficiency at 2010 OHT emissions levels with focused component testing

Control Volumes for First Law Analysis

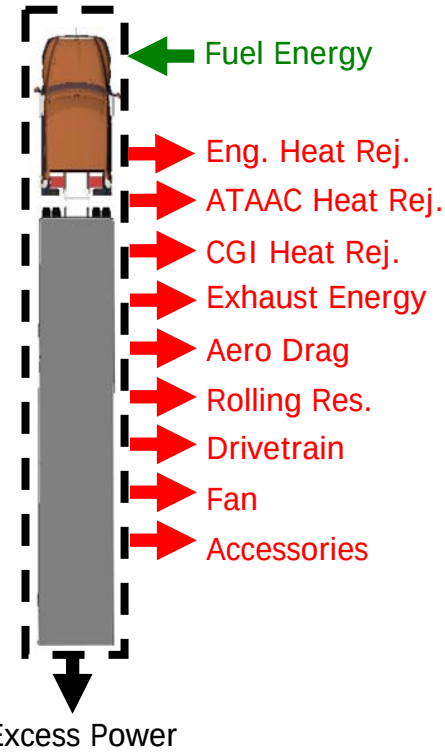
Reciprocator



Engine System

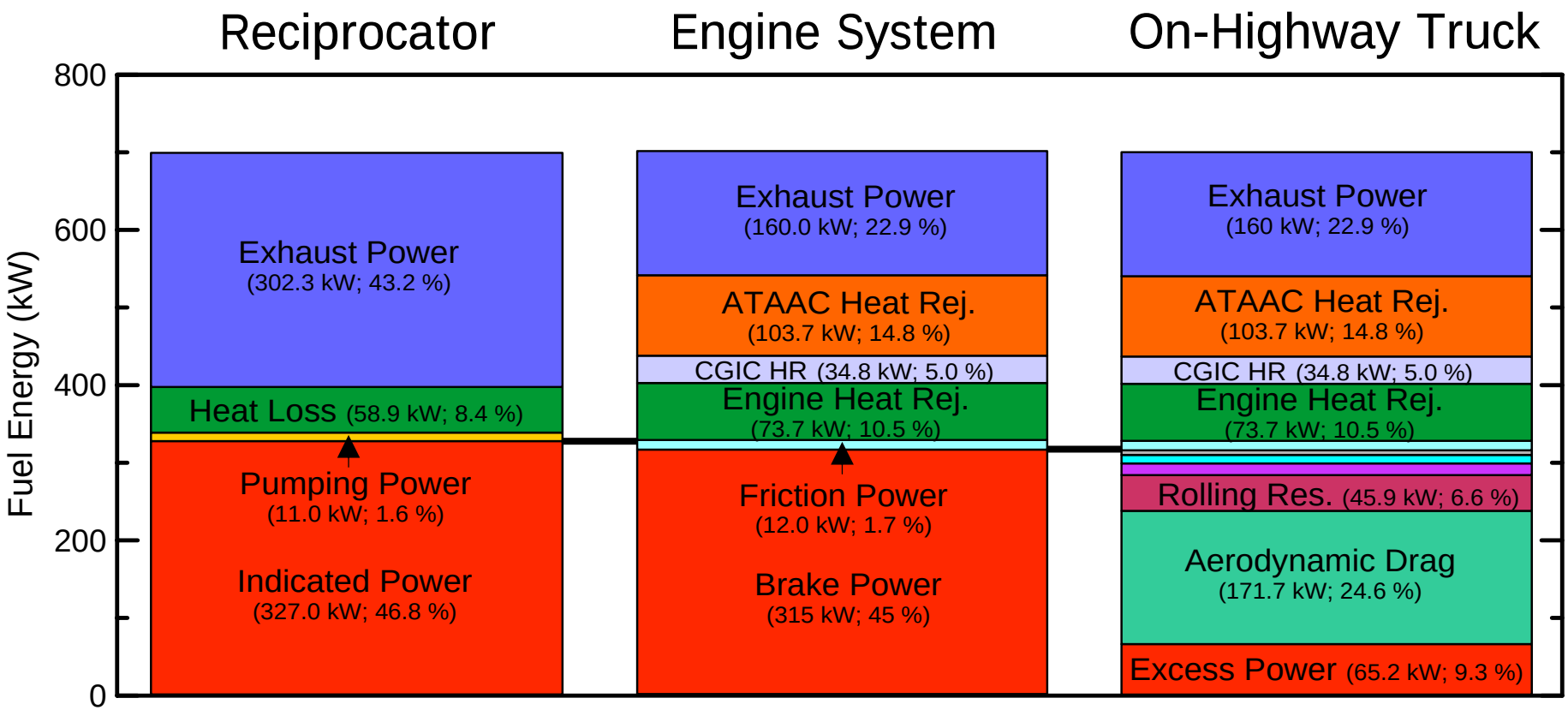


On-Highway Truck



First Law Analysis

- 45% Thermal Efficient Engine (class VIII truck, 1200 RPM, peak torque, fully loaded, 70 MPH)



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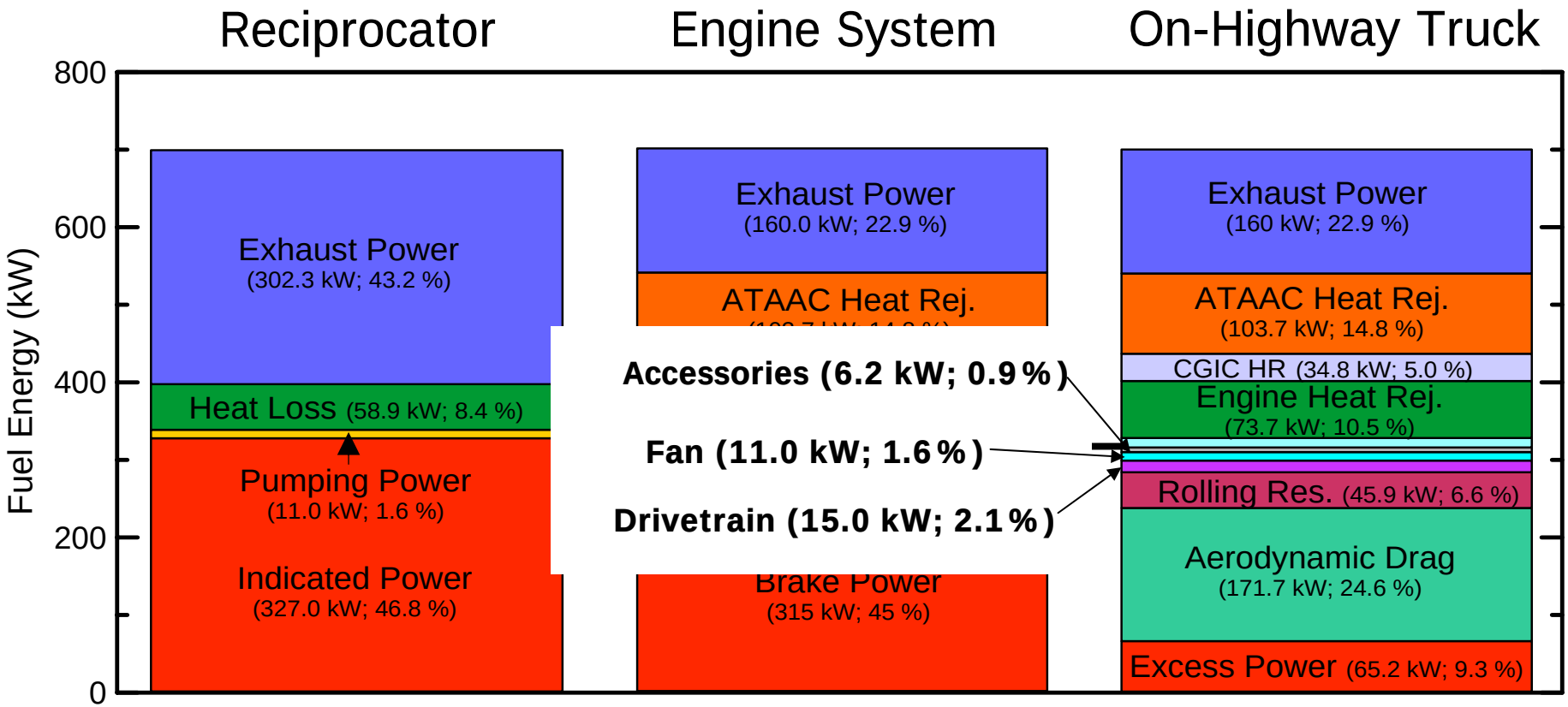
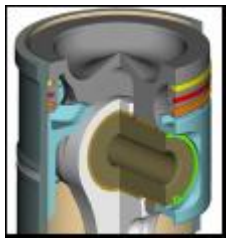
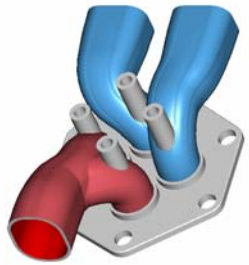


Phase 1: 2007 45% Thermal Efficiency

Reduced PRL Friction

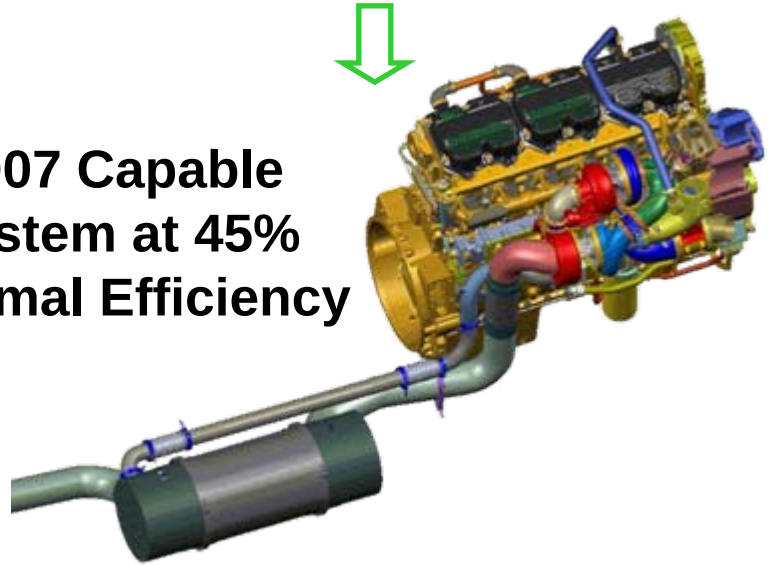


High Efficiency Air System

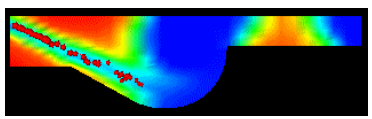


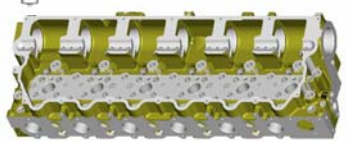
Improved Port Design

2007 Capable System at 45% Thermal Efficiency

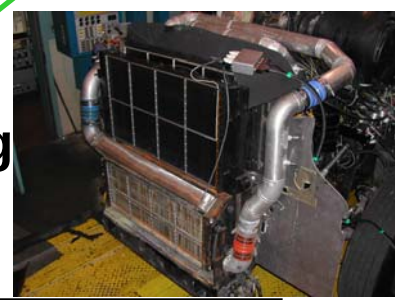


Combustion System Optimization





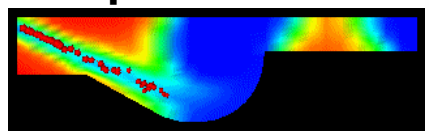
High Efficiency Compact Cooling System



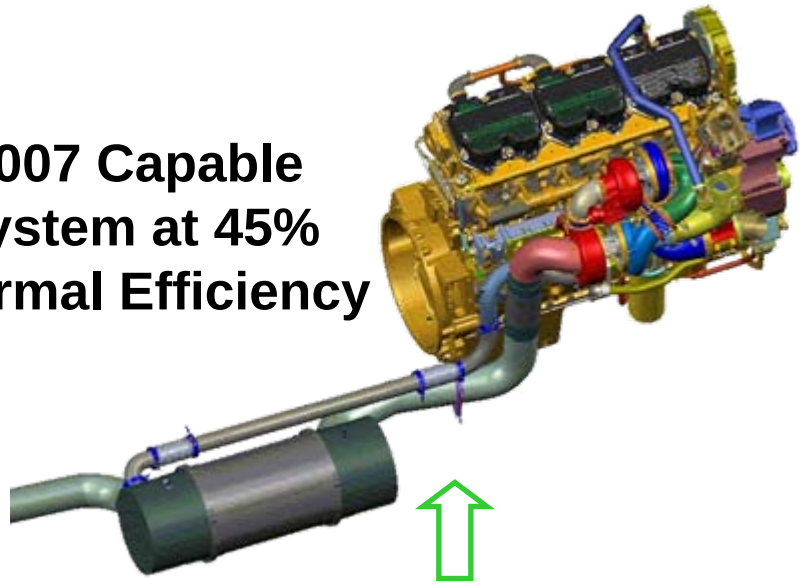
Phase 2: 2010 50% Thermal Efficiency

NO_x Reduction

Combustion System Optimization



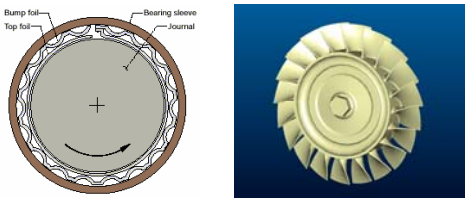
2007 Capable System at 45% Thermal Efficiency



Turbo-Compound

Reduced Heat Rejection

Improved Air System



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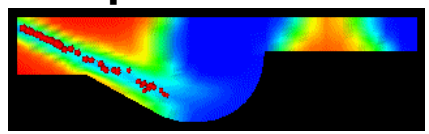
Phase 2: 2010 50% Thermal Efficiency

NO_x Reduction

Combustion System Optimization



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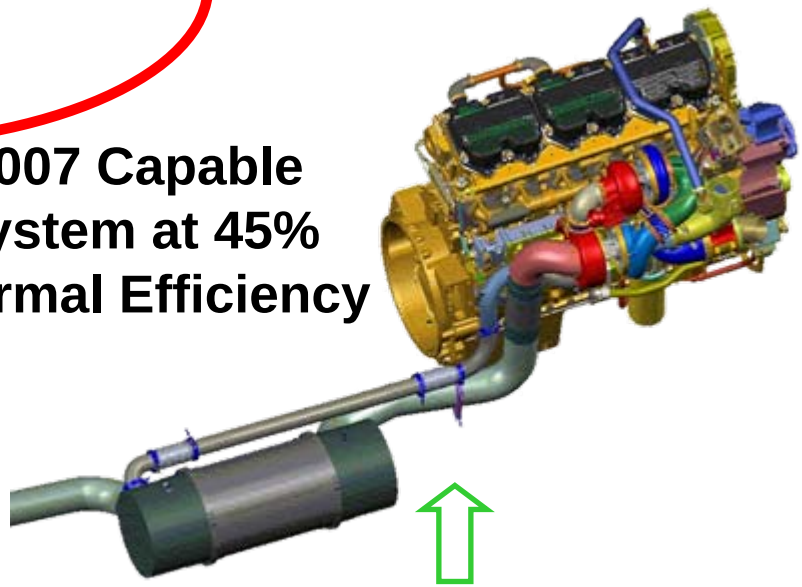

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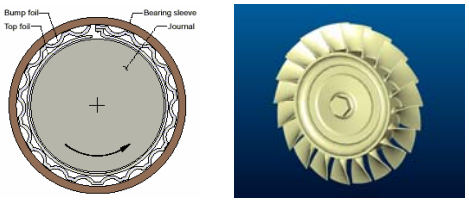

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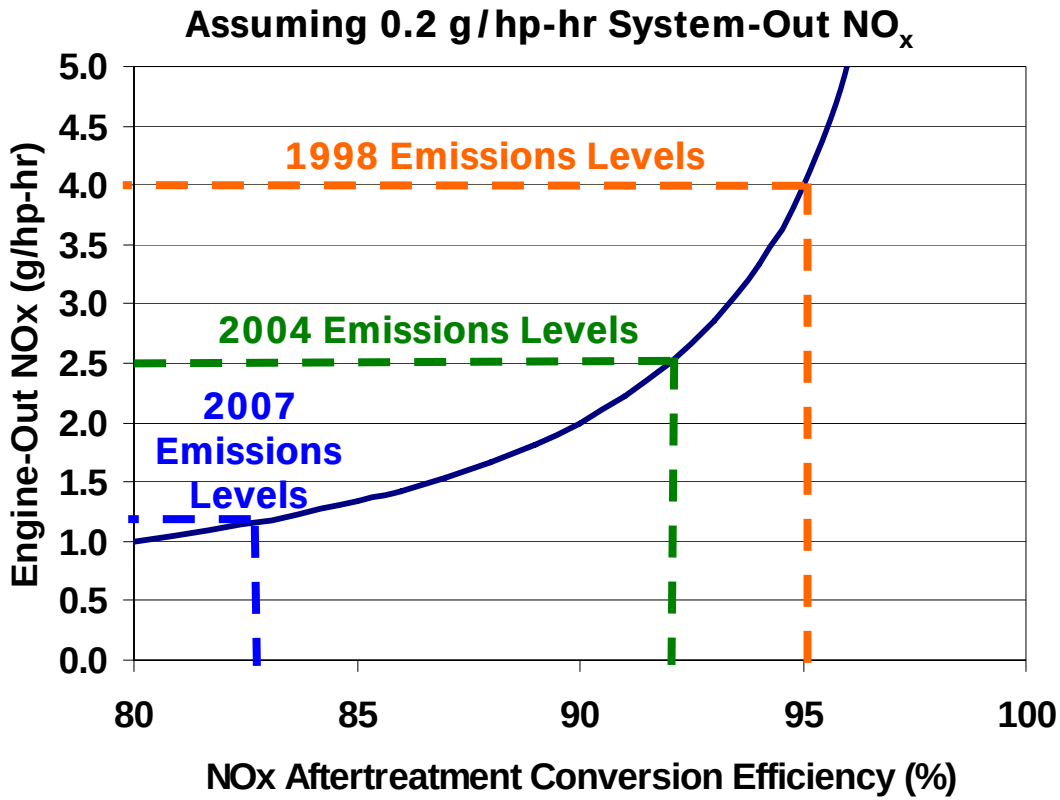
NO_x Reduction

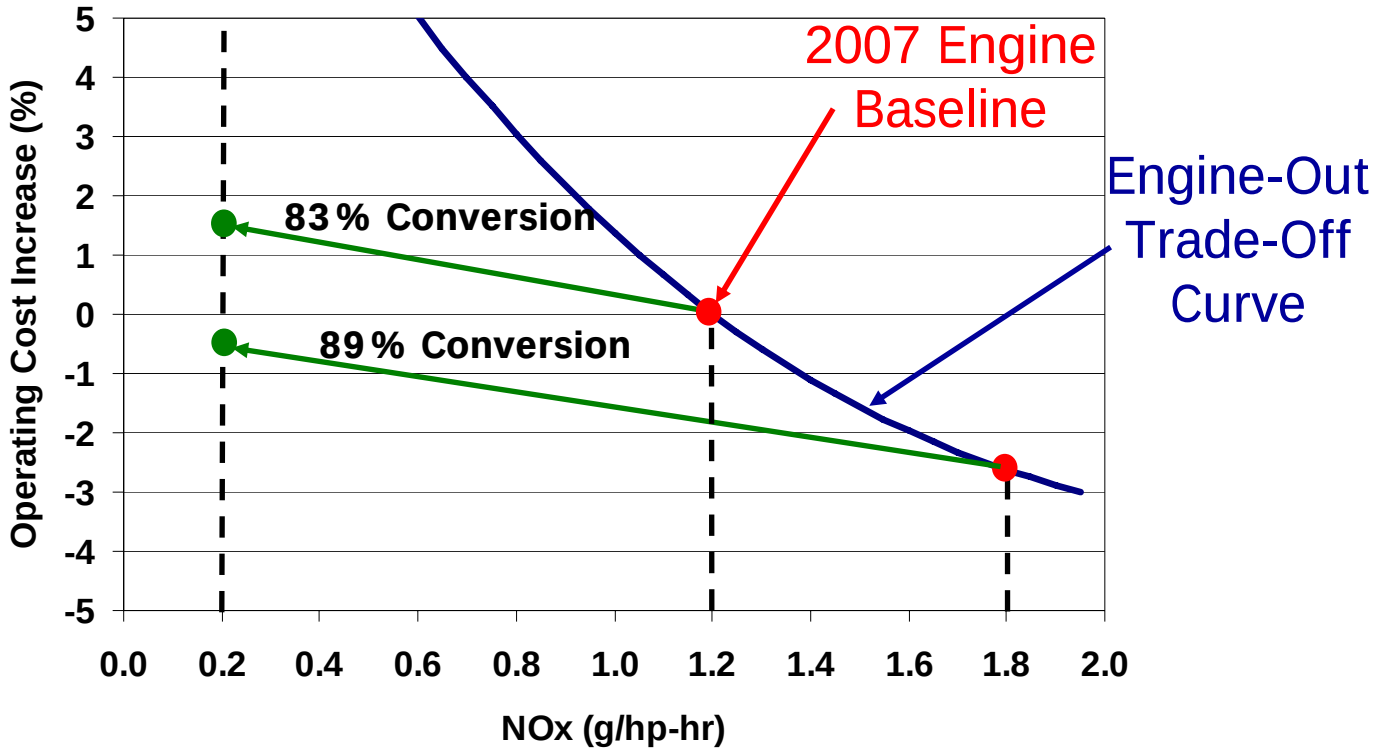
- Industry is investigating several technologies for achieving 2010 system-out NO_x levels
  - HCCI
  - High diluent concentration
  - Urea SCR
  - NO_x Adsorber
- For engine systems employing aftertreatment, engine-out emissions level is determined by conversion efficiency



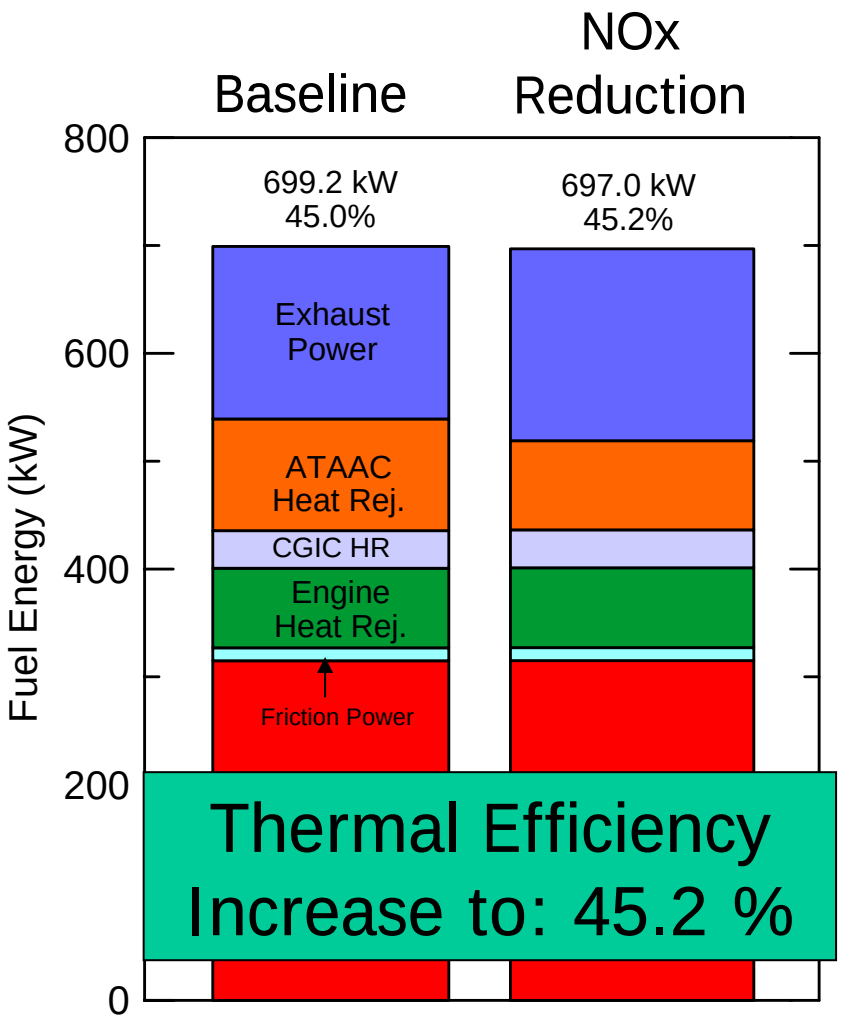
- Conversion efficiencies above 90% possible

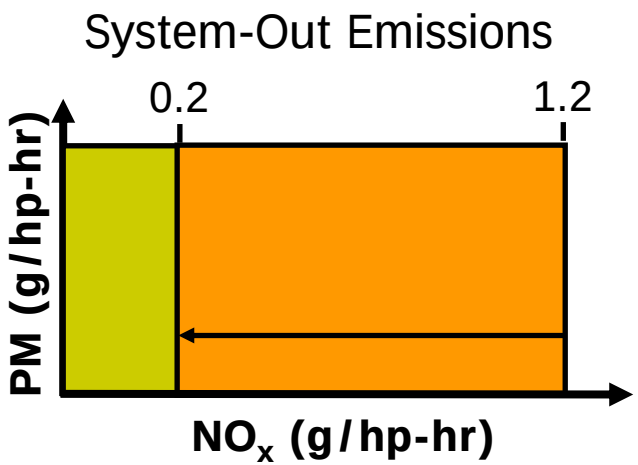
NO_x Reduction

- Conversion of NO_x requires additional operating cost in the form of urea, fuel for richening the exhaust stream, etc.
- At high conversion efficiencies system optimization more than compensates for operating cost penalty



Fuel Energy Distribution



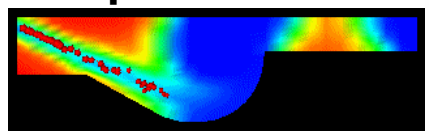


- Production Challenges
  - long term degradation
  - replenishment of reductant
  - low temperature operation
  - packaging
  - cost

Phase 2: 2010 50% Thermal Efficiency

NO_x Reduction

Combustion System Optimization



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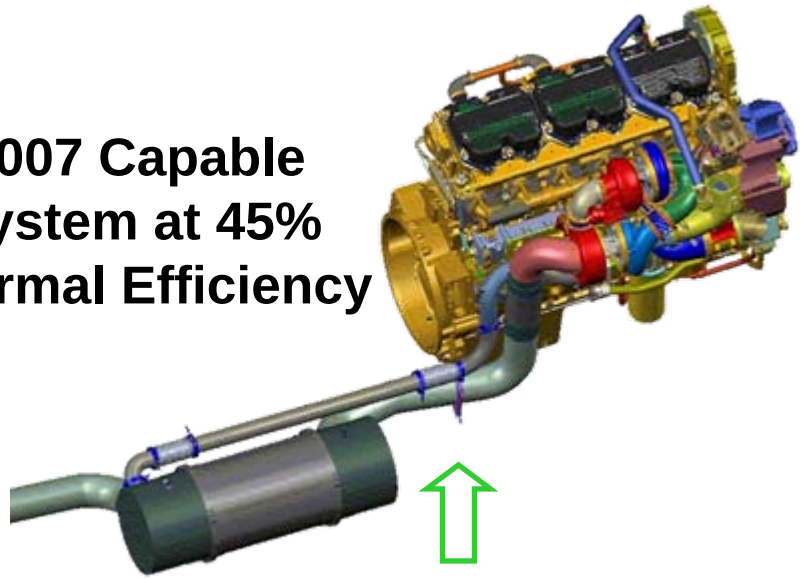

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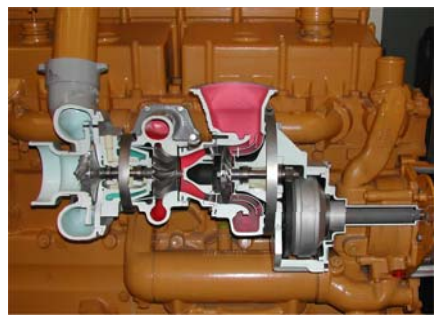
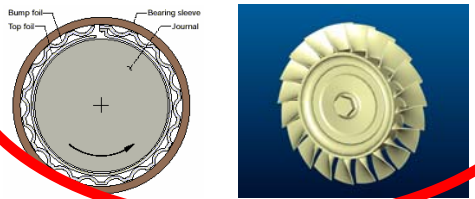


Reduced Heat Rejection

Improved Air System



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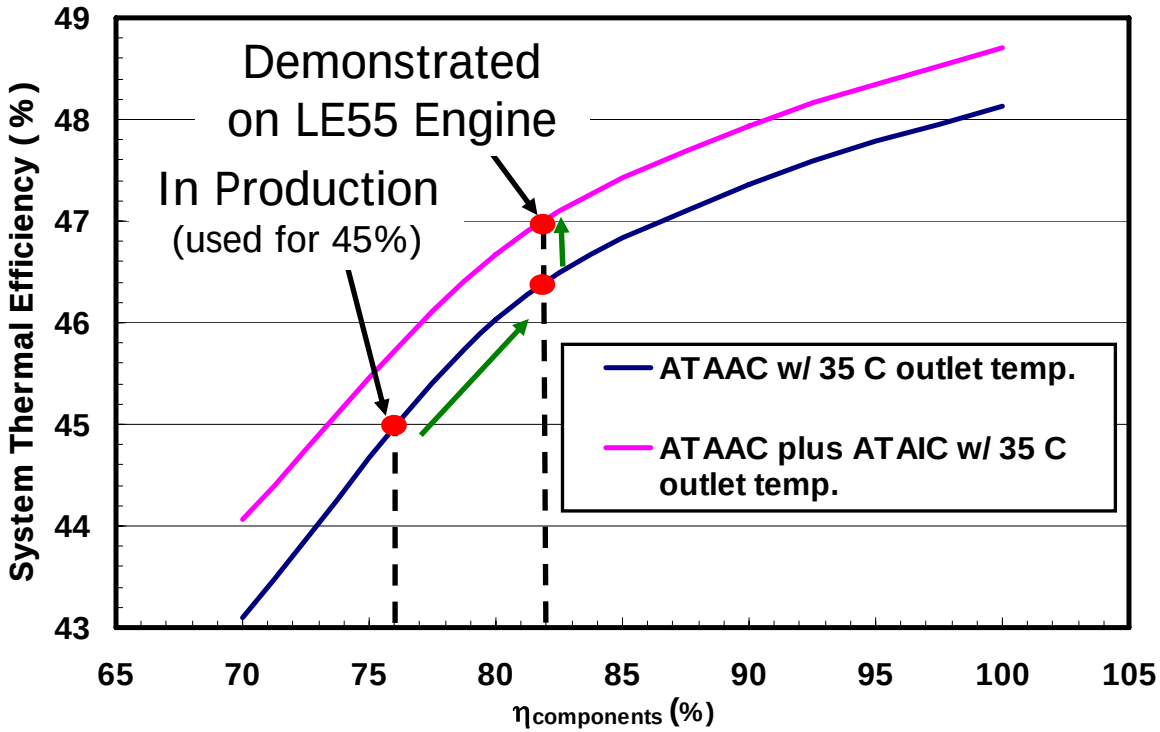
Improved Air System

- Series turbochargers must be used in order to provide the optimum boost levels
- High efficiency compressor, turbine, and bearing designs continue to improve air system component efficiencies
- Intercooling can further improve the efficiency of the system



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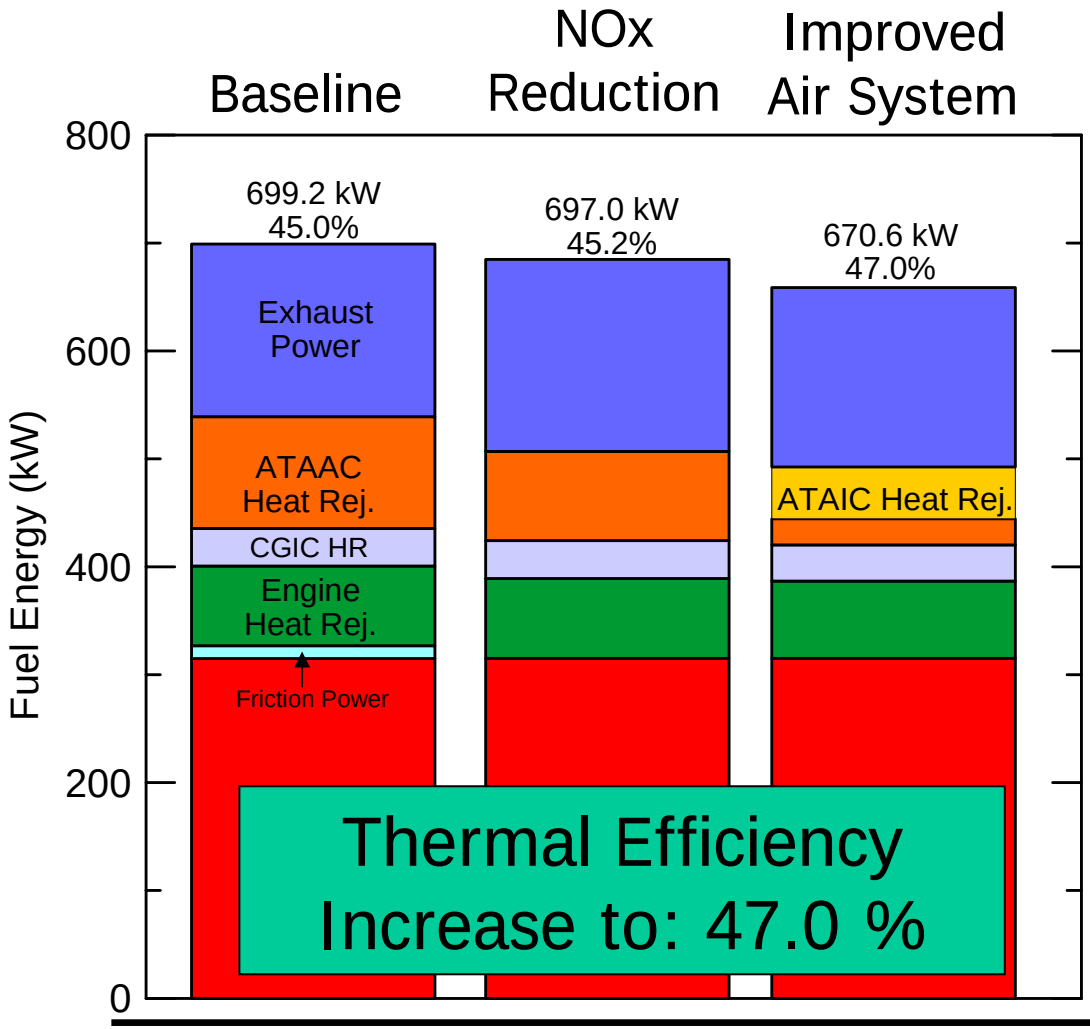

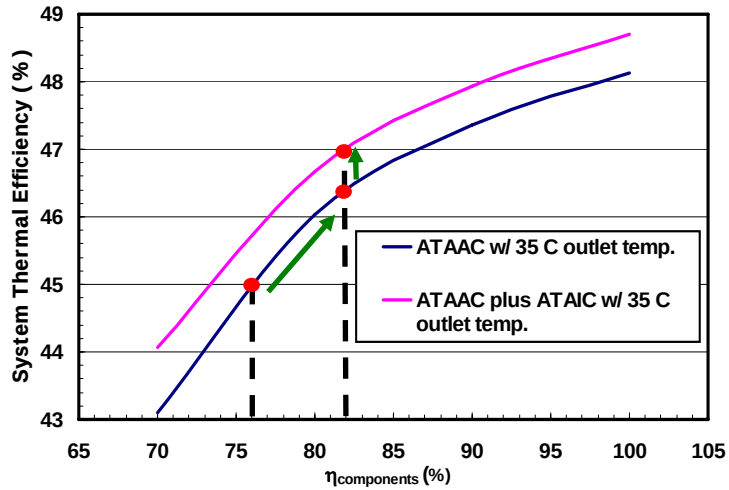

- Production Challenges:
  - packaging
  - cost
  - map width

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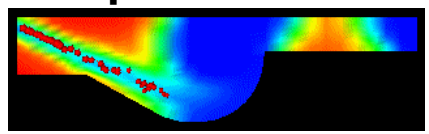
Phase 2: 2010 50% Thermal Efficiency

NO_x Reduction

Combustion System Optimization



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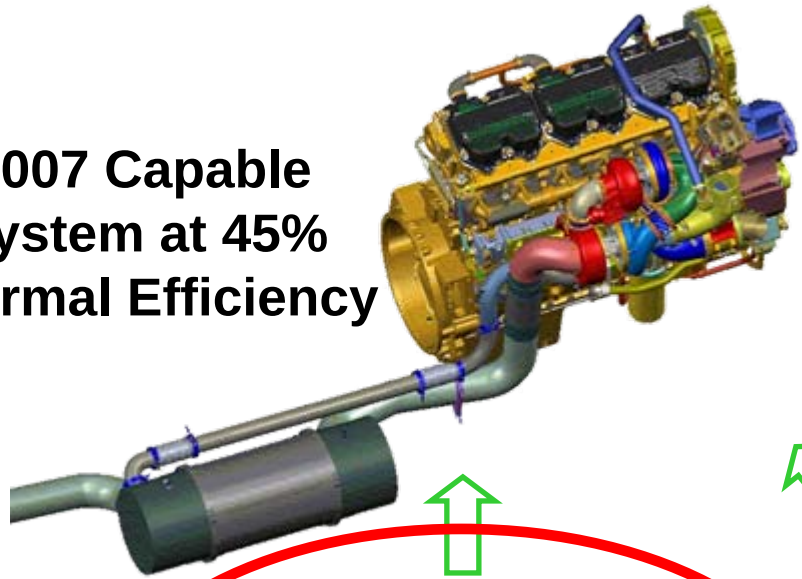
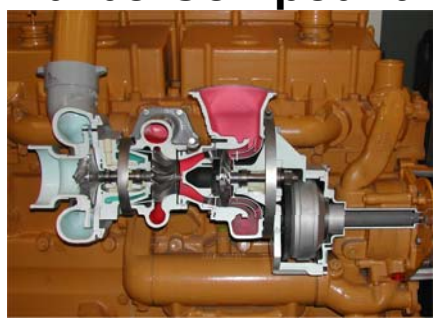
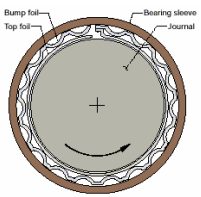


Turbo-Compound



Reduced Heat Rejection

Improved Air System



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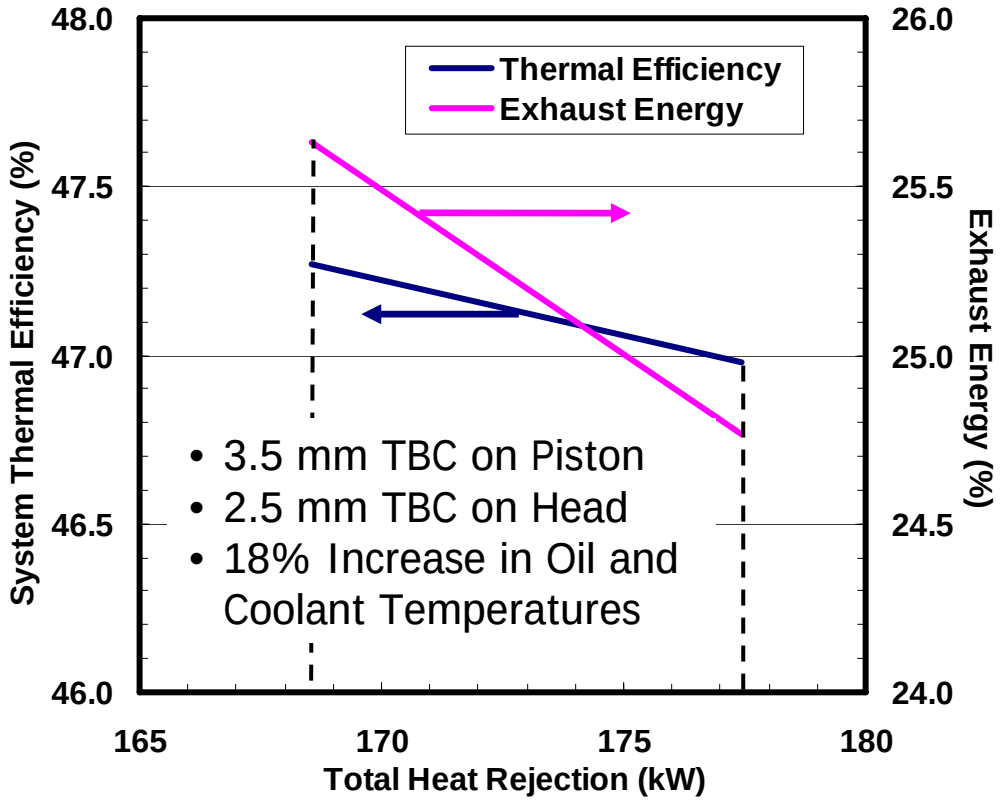
Reduced Heat Rejection

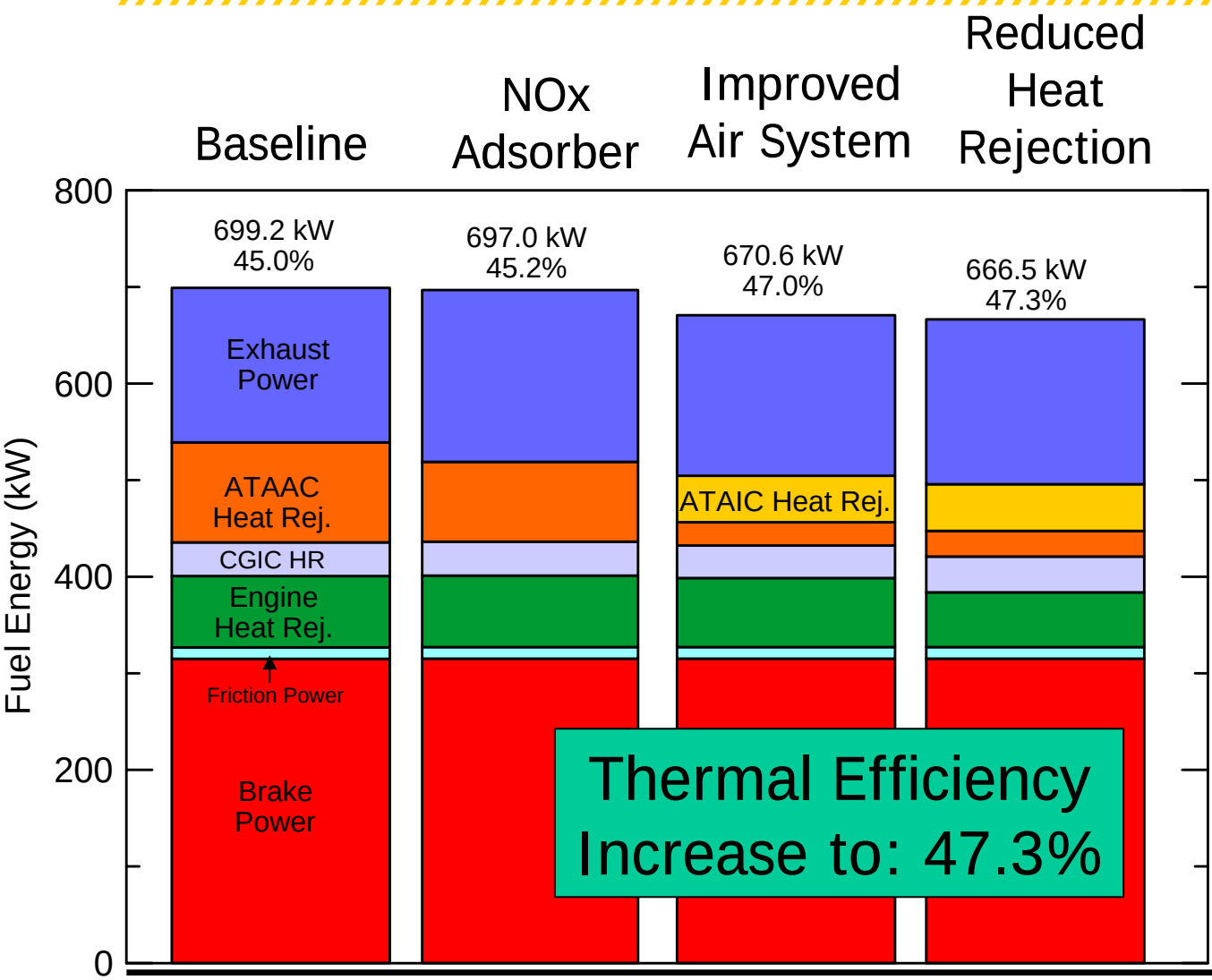
- Reducing heat rejection:
  - low thermal conductivity components, coatings, or designs
  - selective cooling
  - higher coolant temperatures

Low Heat Rejection Components from ICC Program

- Reduced heat rejection increases exhaust energy more than thermal efficiency



Fuel Energy Distribution



- Production Challenges:
  - durability
  - cost

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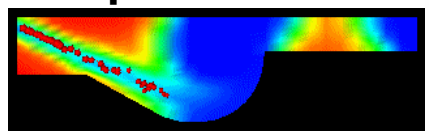
Phase 2: 2010 50% Thermal Efficiency

NO_x Reduction

Combustion System Optimization



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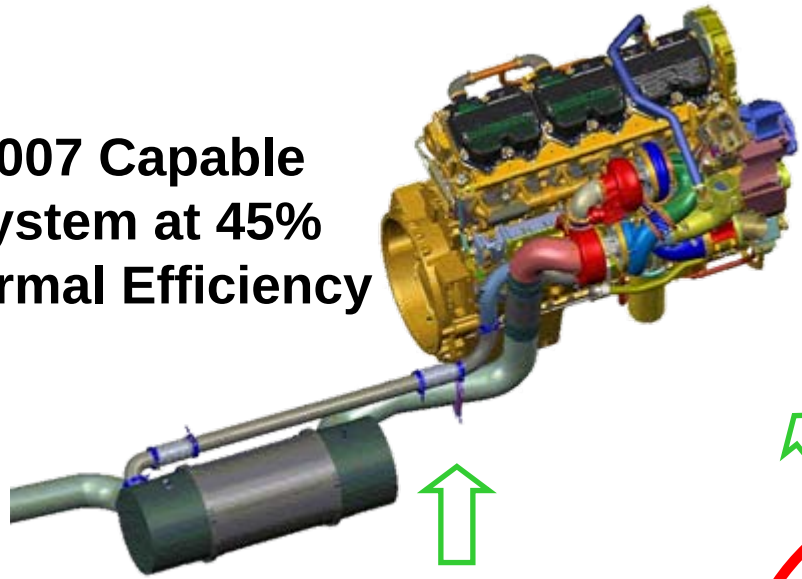
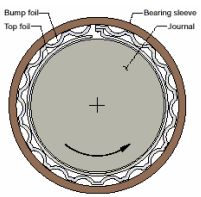


Turbo-Compound

Reduced Heat Rejection

Improved Air System



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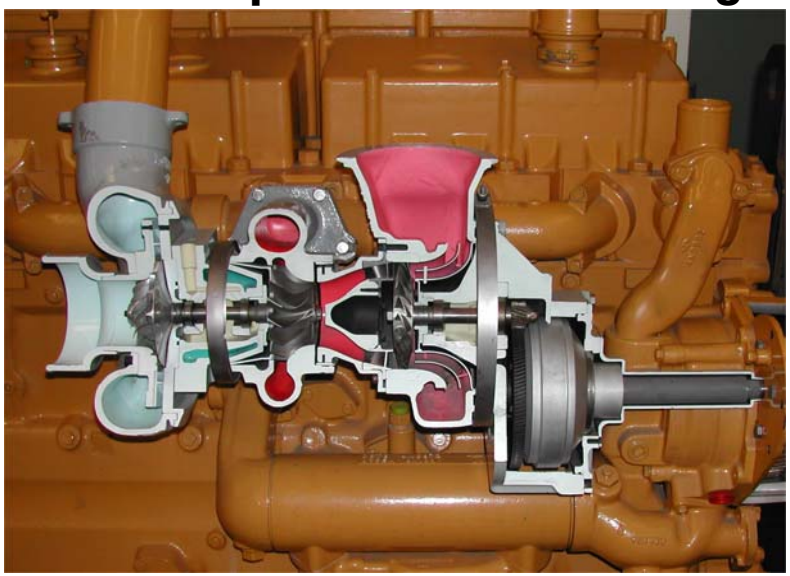
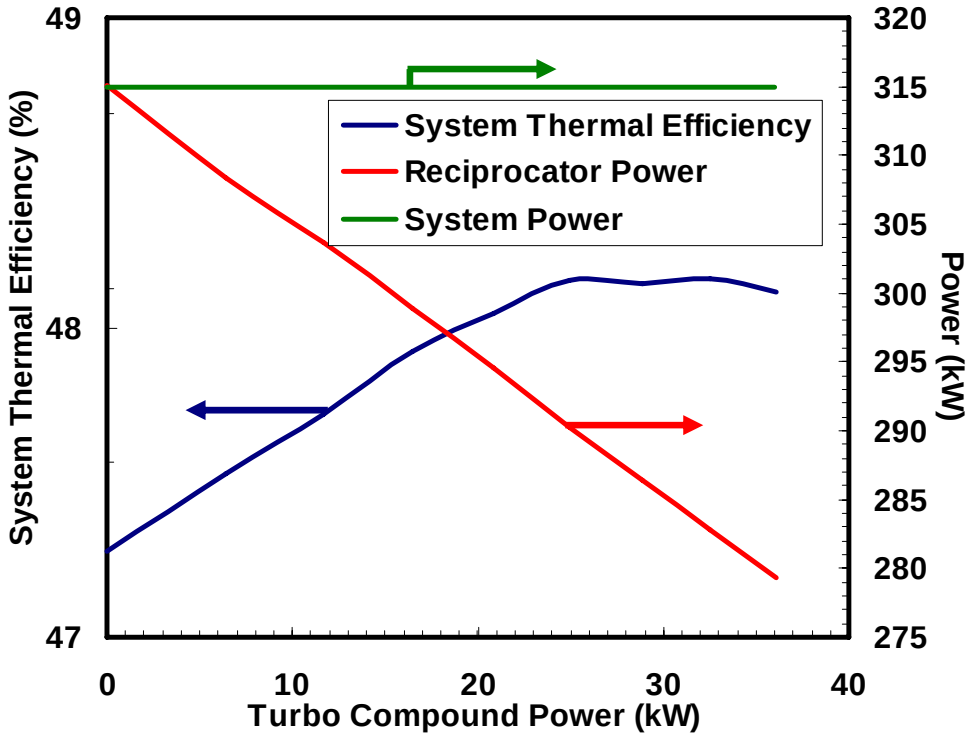
Turbo-Compound

- Turbo-compound consists of:
  - power turbine
  - power transfer to drive train
  - spring or fluid coupling

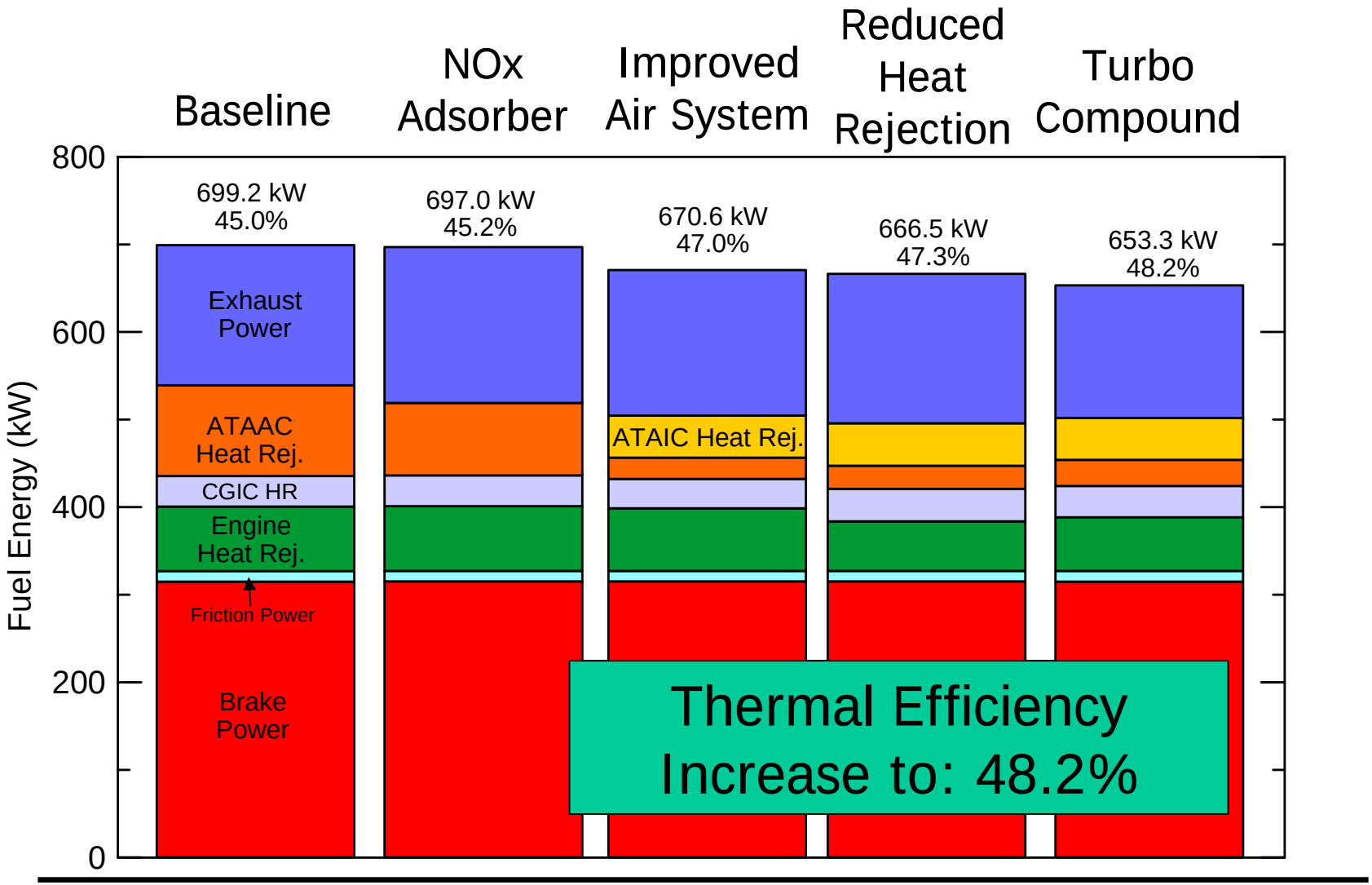
Turbo-Compound on LBSFC Engine





- Production Challenges:
  - packaging
  - cost
  - operating range

Fuel Energy Distribution



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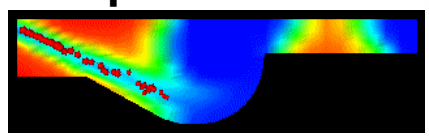
Phase 2: 2010 50% Thermal Efficiency

NO_x Reduction

Combustion System Optimization



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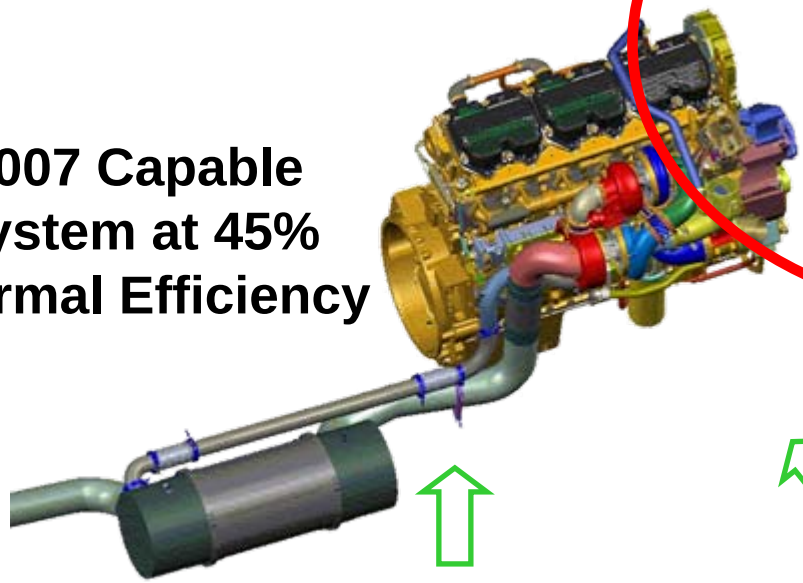
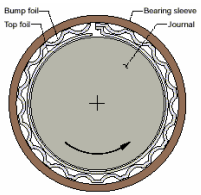


Improved Air System



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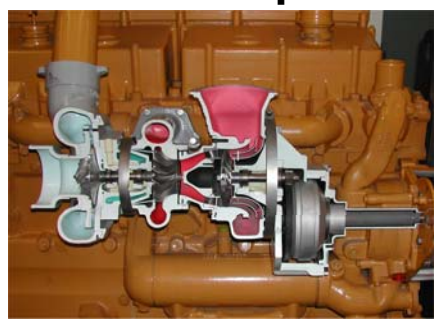
Turbo-Compound



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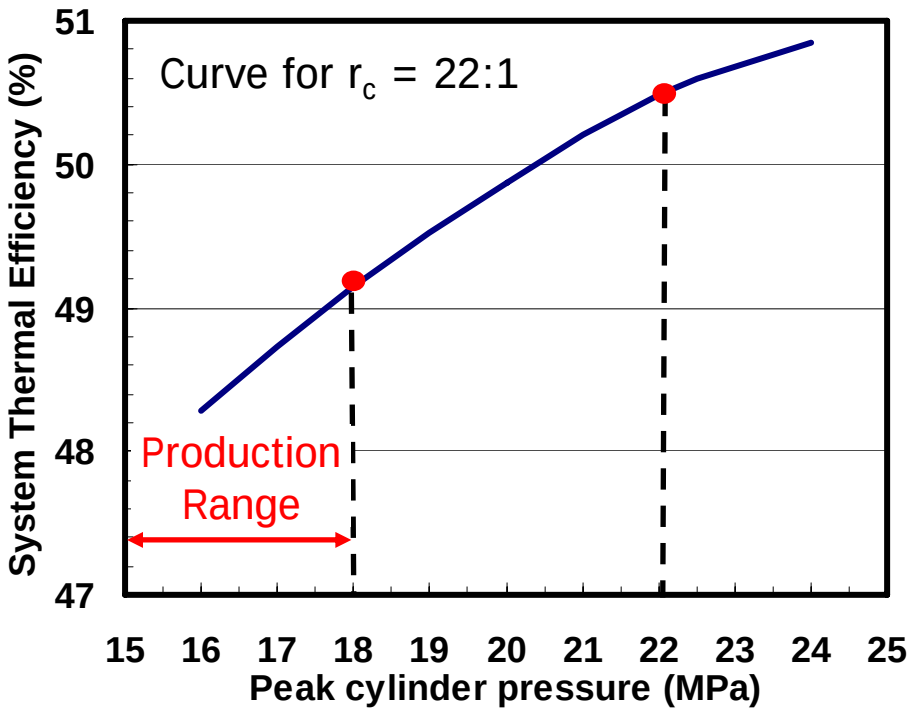
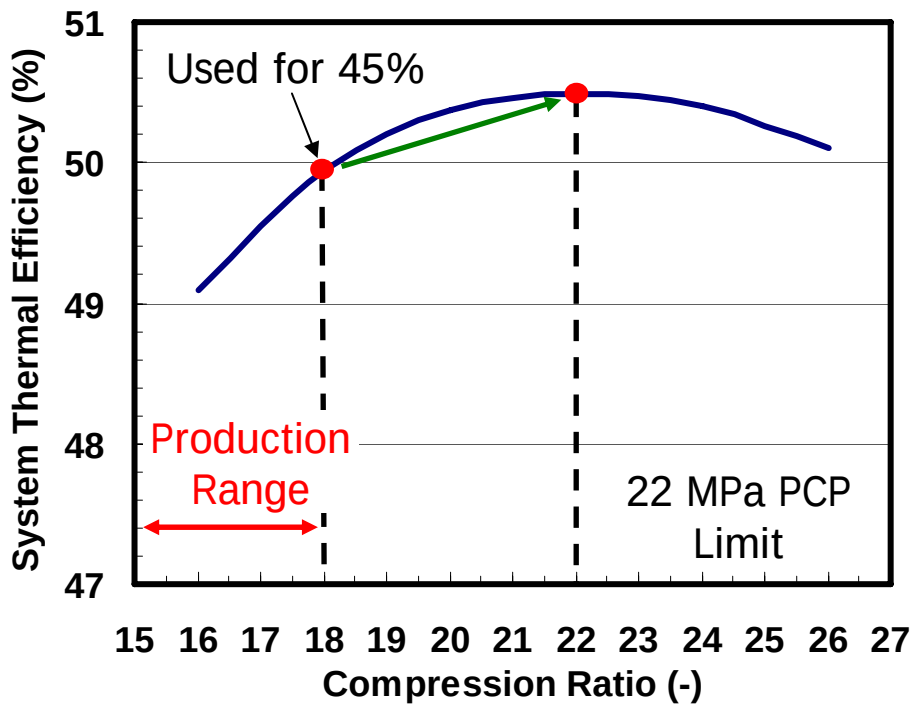
System Optimization

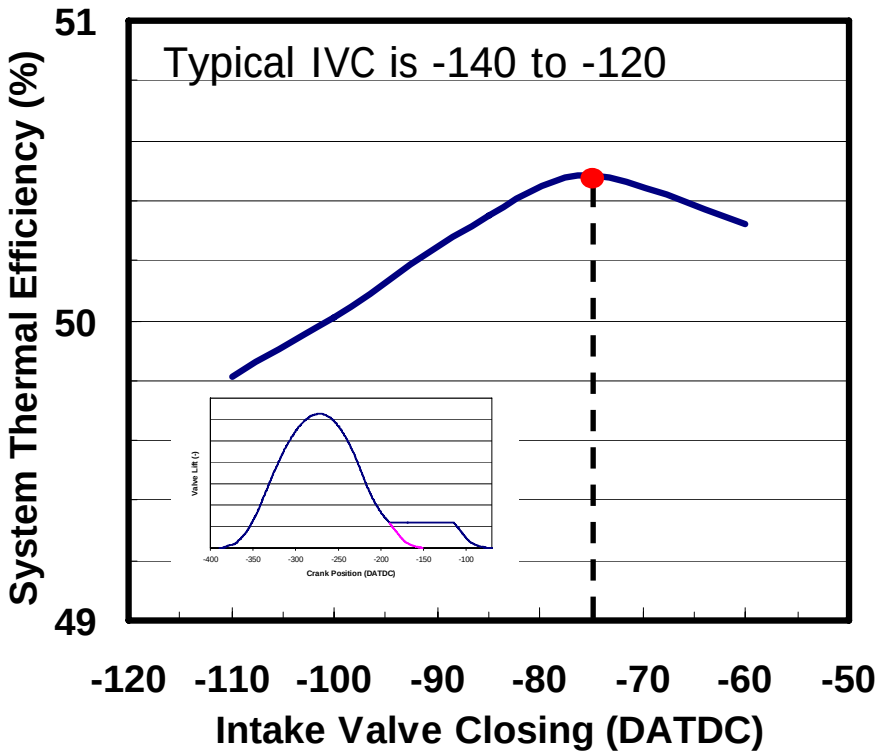
- Optimize system operation for peak efficiency
  - peak cylinder pressure
  - compression ratio

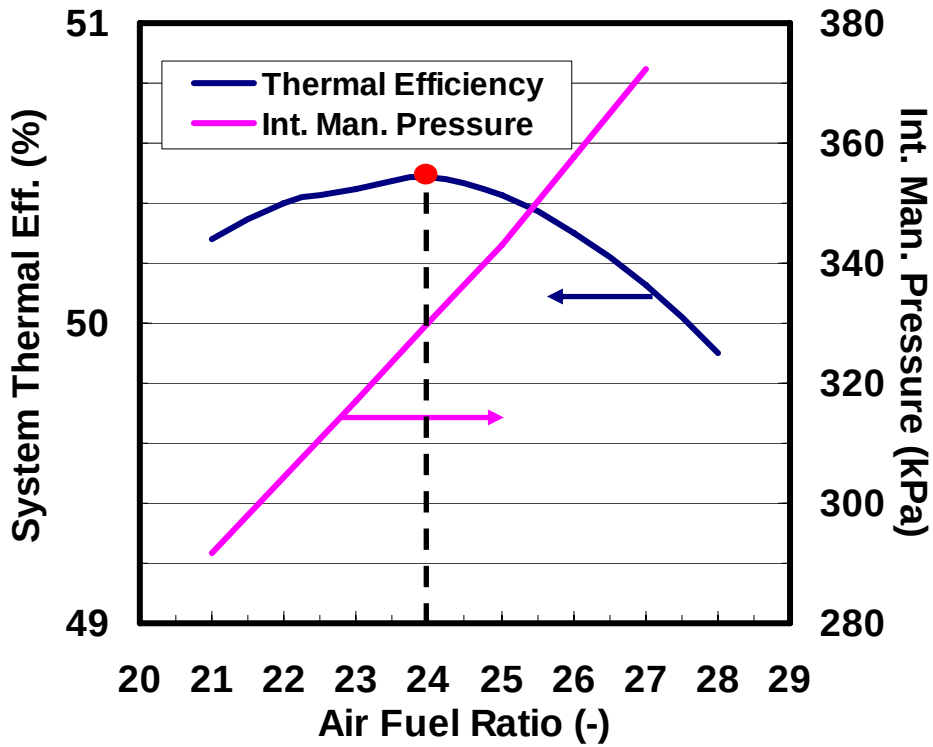




System Optimization

- Optimize system operation for peak efficiency
  - intake valve actuation
  - air system sizing for proper boost level





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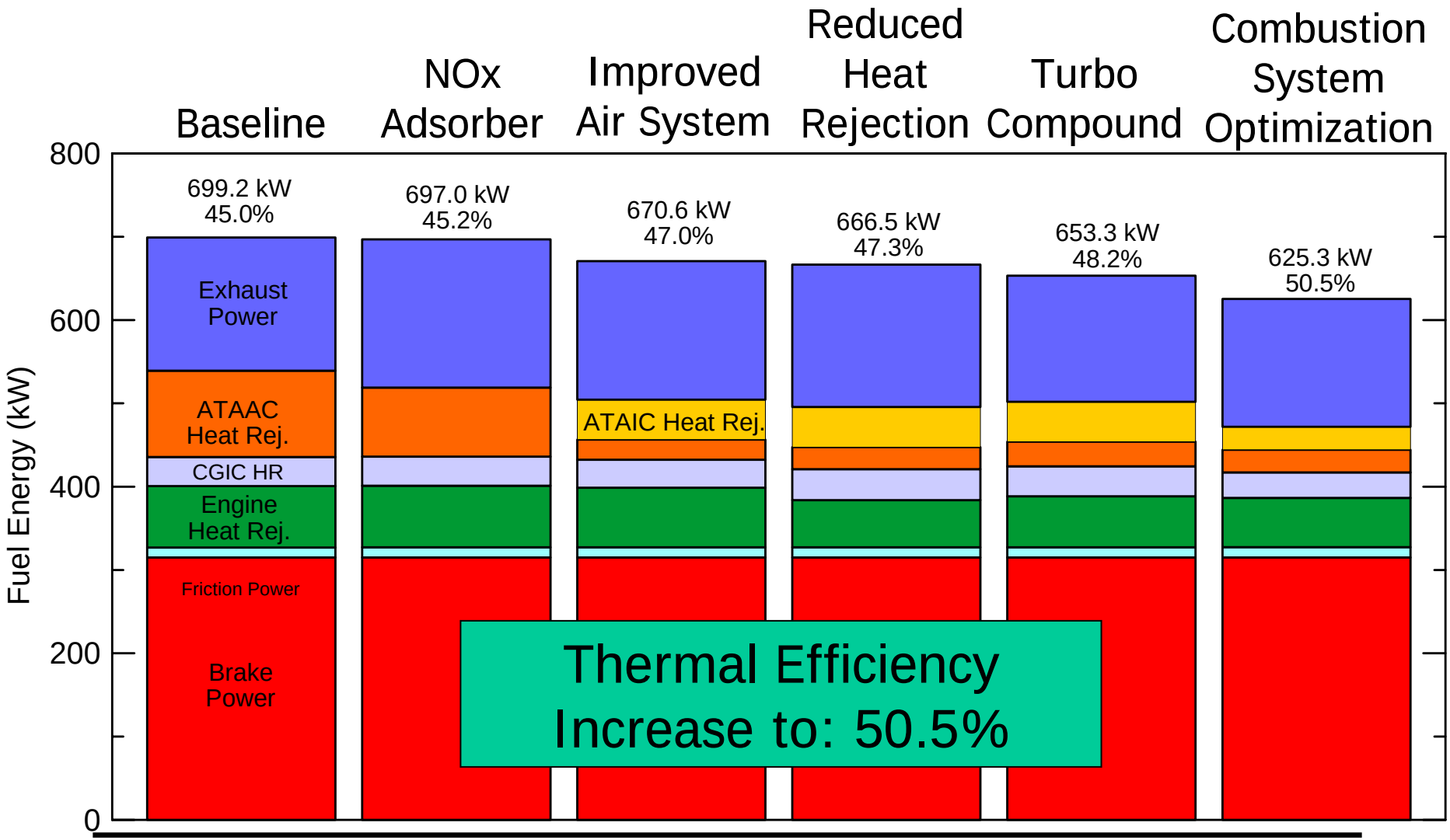
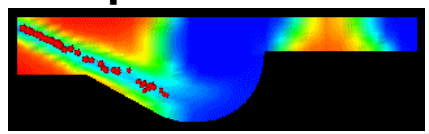


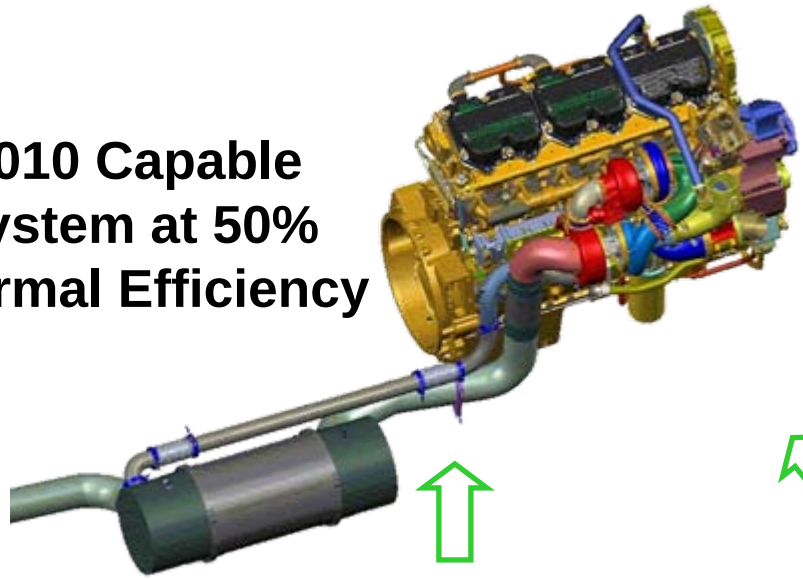
Phase 2: 2010 50% Thermal Efficiency

NO_x Reduction

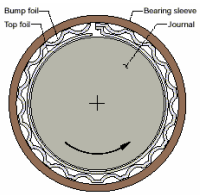
Combustion System Optimization



2010 Capable System at 50% Thermal Efficiency

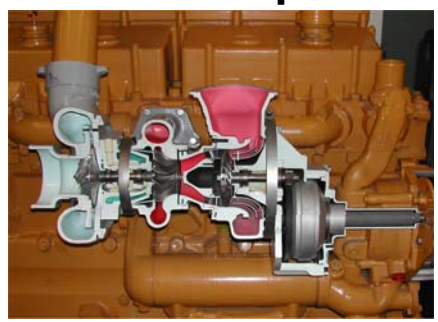


Improved Air System



Reduced Heat Rejection

Turbo-Compound



CATERPILLAR

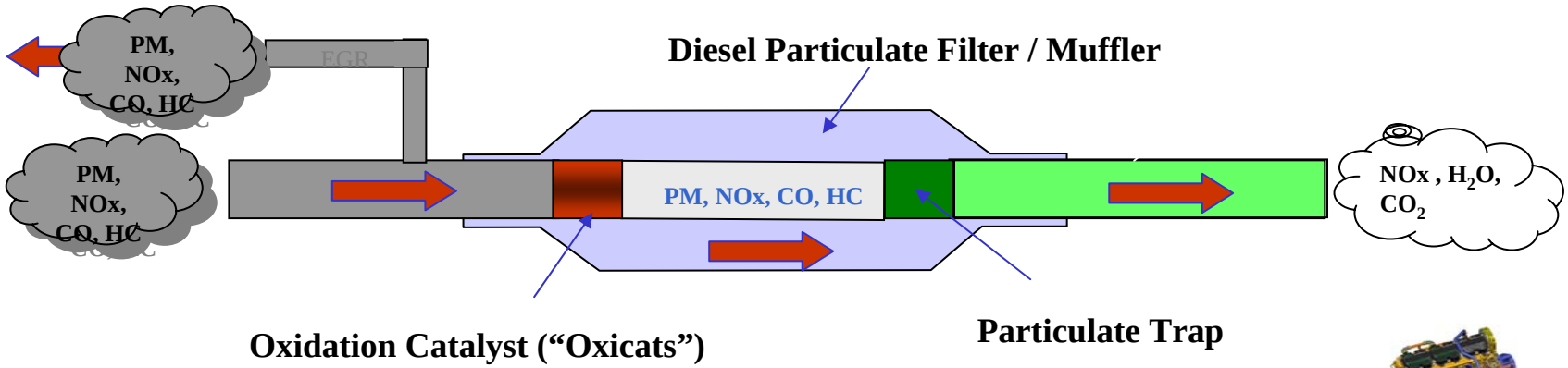
U.S. DOE

Summary and Conclusions

- Conducted first law analysis of fuel energy distribution
- Reviewed path to a 45% thermal efficient engine that meets 2007 emissions levels
- Identified path to 50% thermal efficiency while meeting 2010 emissions levels
- Discussed challenges to high efficiency components going into production
- Focused testing of high efficiency components continues through this final phase of our cooperative research program

EGR vs. CGI

EGR NOx Solution



Clean Gas Induction