U.S. DEPARTMENT OF ENERGY
DEER 2011
DETROIT
DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE

Cummins®

Overview of High-Efficiency Engine Technologies

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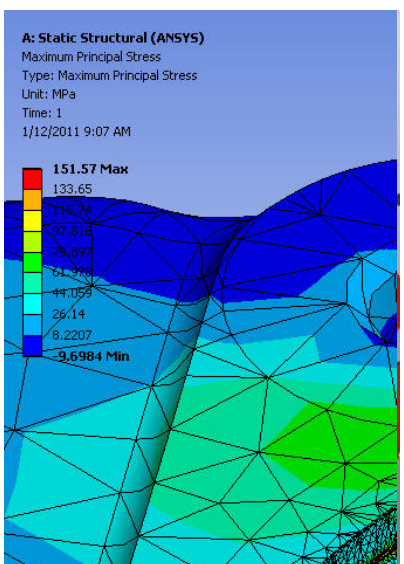
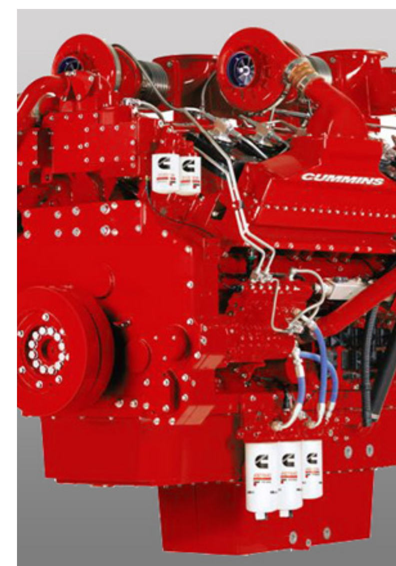
Vice President-Research and Technology
3 October 2011

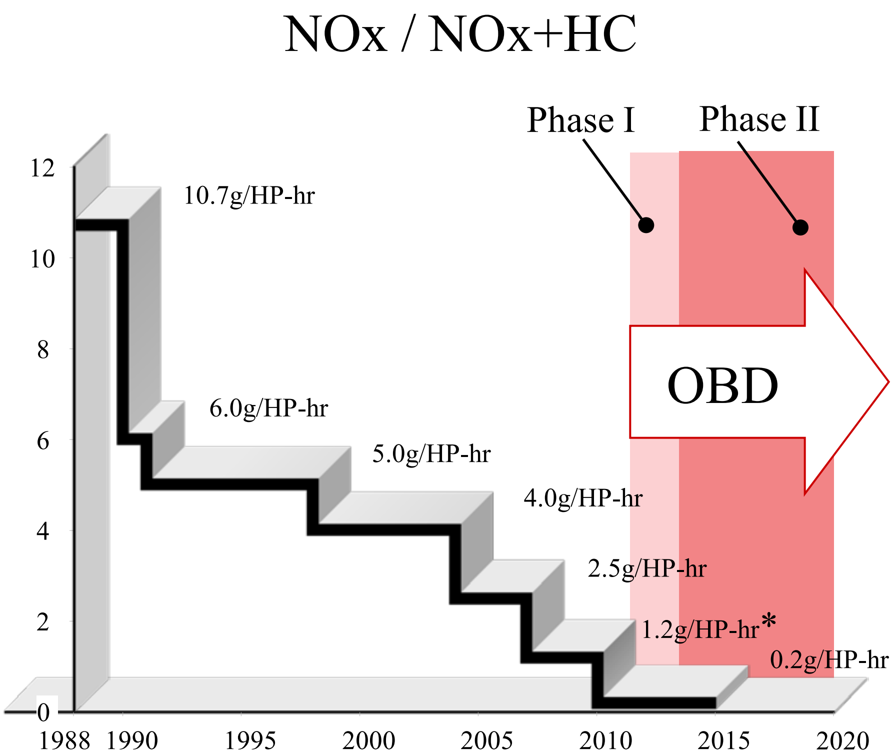


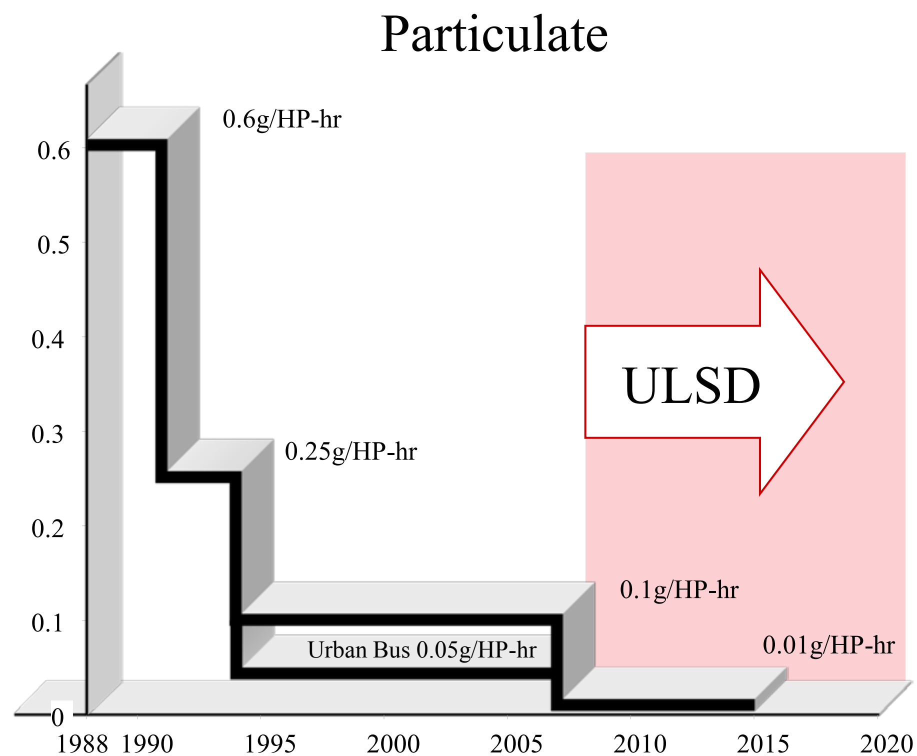



Outline

- History
- Liquid Fuels
  - Diesel Technologies
    - Medium/Heavy Duty
    - Light Duty
  - SI Technologies
- Gaseous Fuels
- Analysis Improvements
- Summary

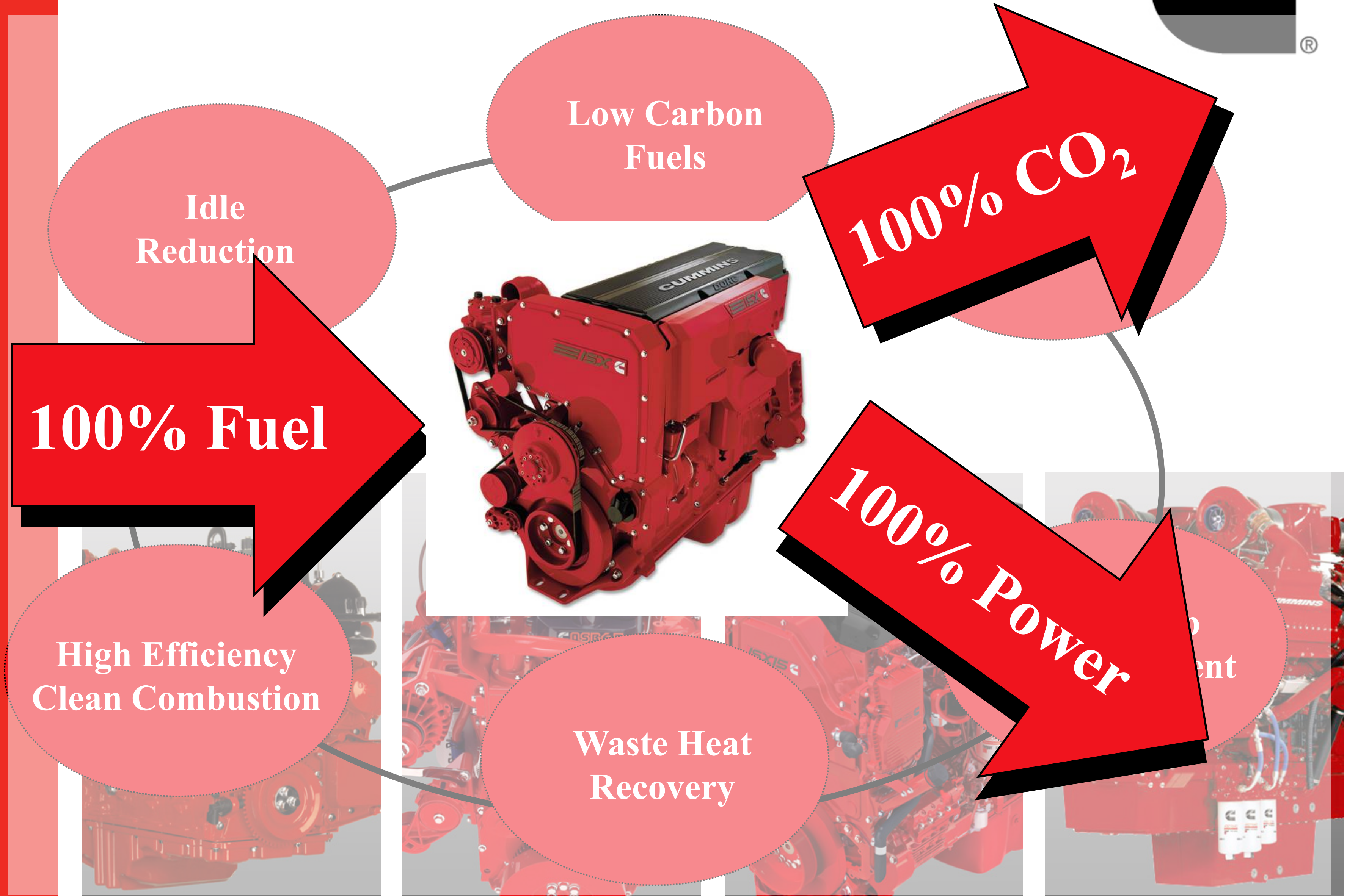
Continued Demands for Emissions Compliance





- GHG (CO_2) ⟷ Fuel Efficiency
- Currently Unregulated Emissions (NH_3, N_2O, etc.)

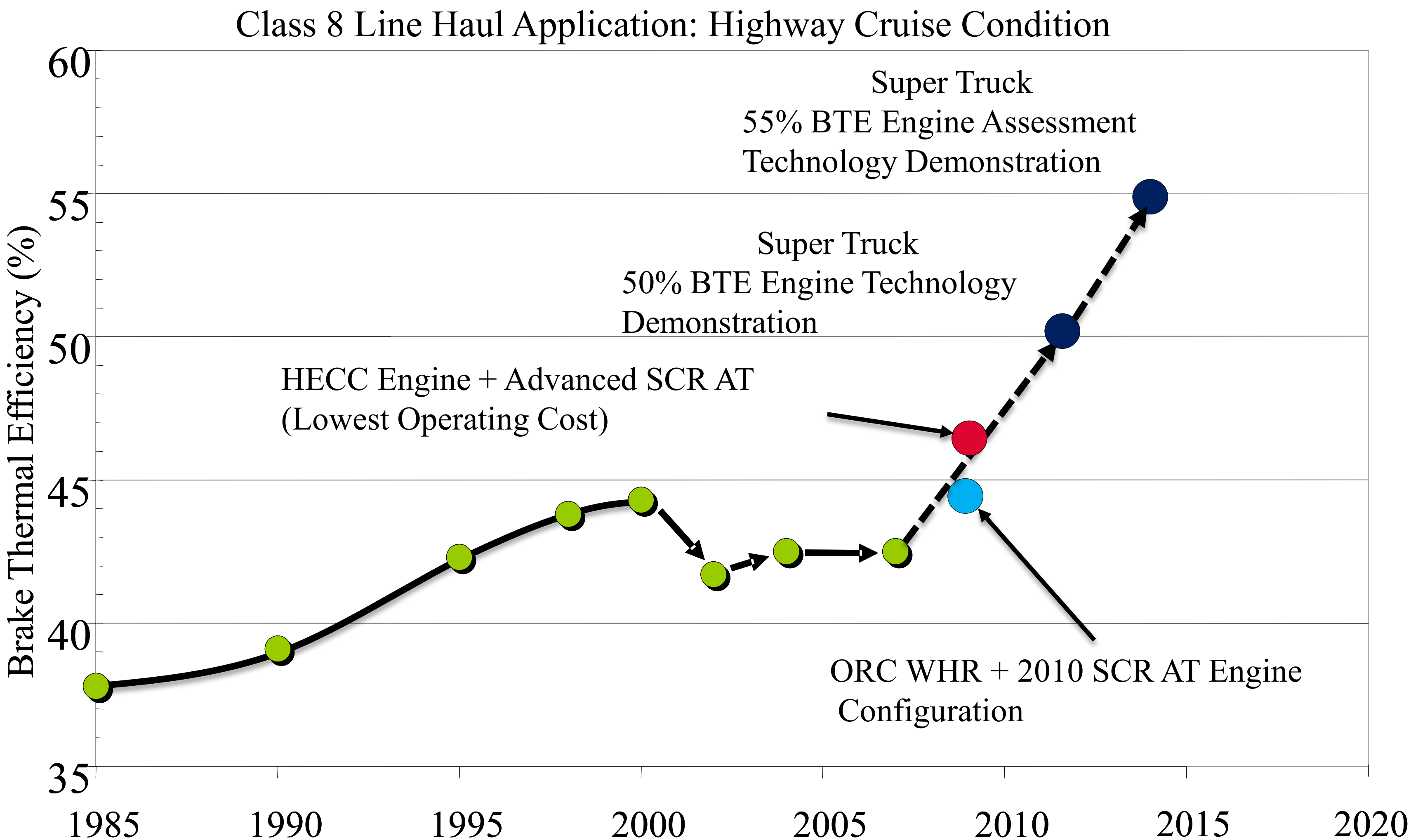
Reducing our CO_2 Footprint



Reducing our CO_2 Footprint

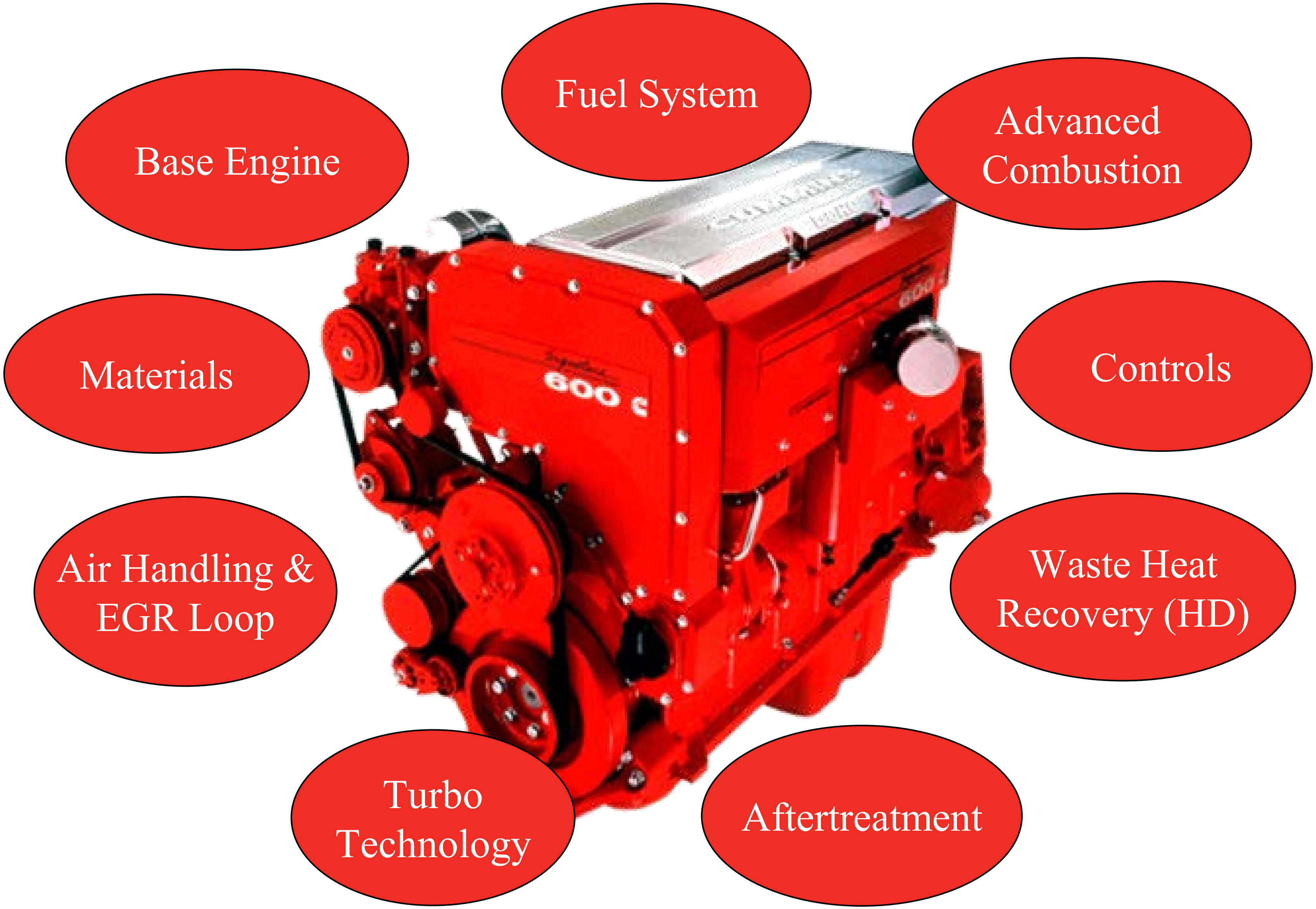
- Low Carbon Fuels
- Hybrids
- Low Temp Aftertreatment
- Waste Heat Recovery
- High Efficiency Clean Combustion
- Idle Reduction

Evolution of Engine System Efficiency

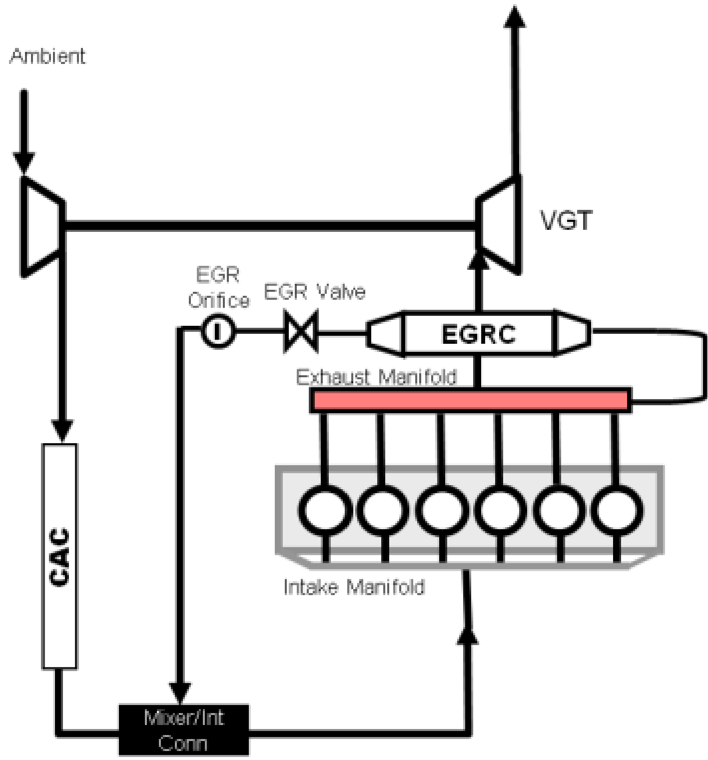


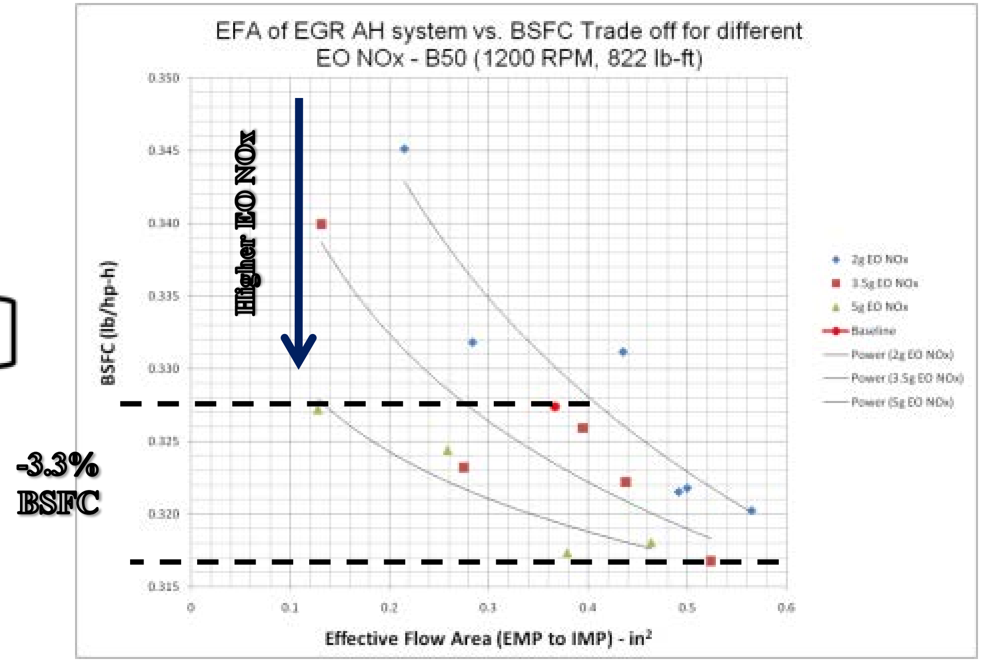
Innovation You Can Depend On

HD & MD Engine Technology Roadmap



Air Handling & EGR Base Architecture





Improved HP Loop EGR System Effective Flow Area

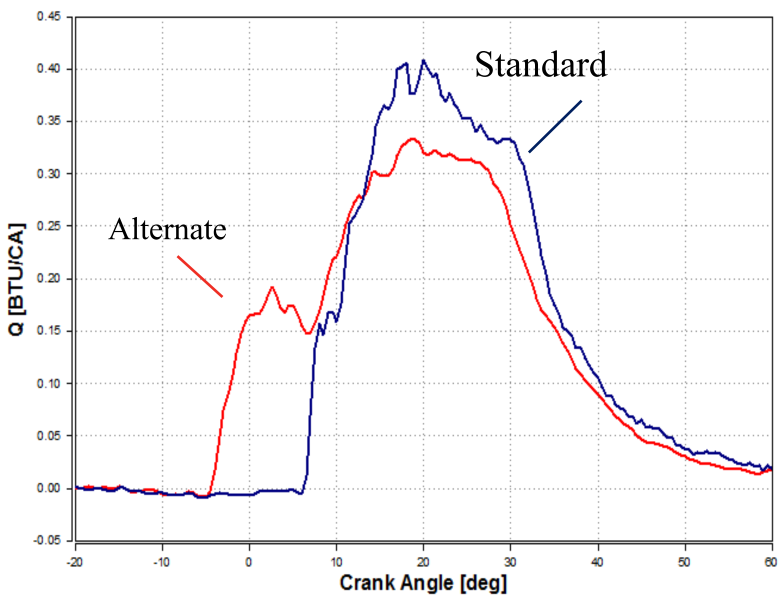
- Potential to improve BSFC by 3% by increasing combined Effective Flow Area
- Current EGR system Effective Flow Area can be increased by 70% with right sized EGR cooler, valve and measurement
- Further improvements to intake and exhaust systems (manifold, ports)

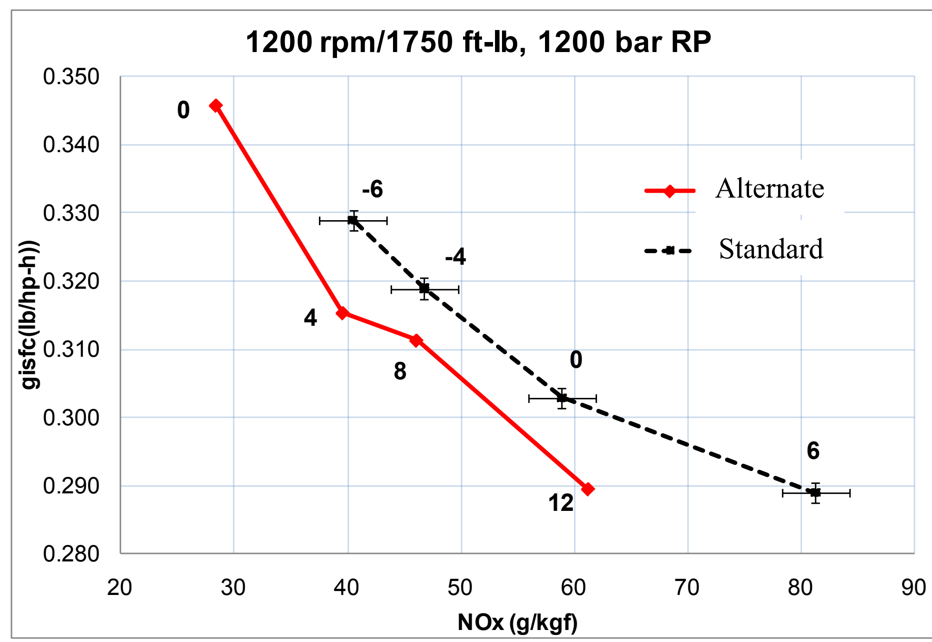
Advanced Combustion Improvements

Manipulation of the in-cylinder combustion event can alter the efficiency and emissions production.

- Fuel injection modulation provides for this effect

Technique enables reduced engine out NOx production and improved fuel consumption





Waste Heat Recovery

Organic Rankine Cycle

Works best for high-EGR flow engine recipes for low-NOx combustion

Converts otherwise wasted thermal energy from the EGR gas stream

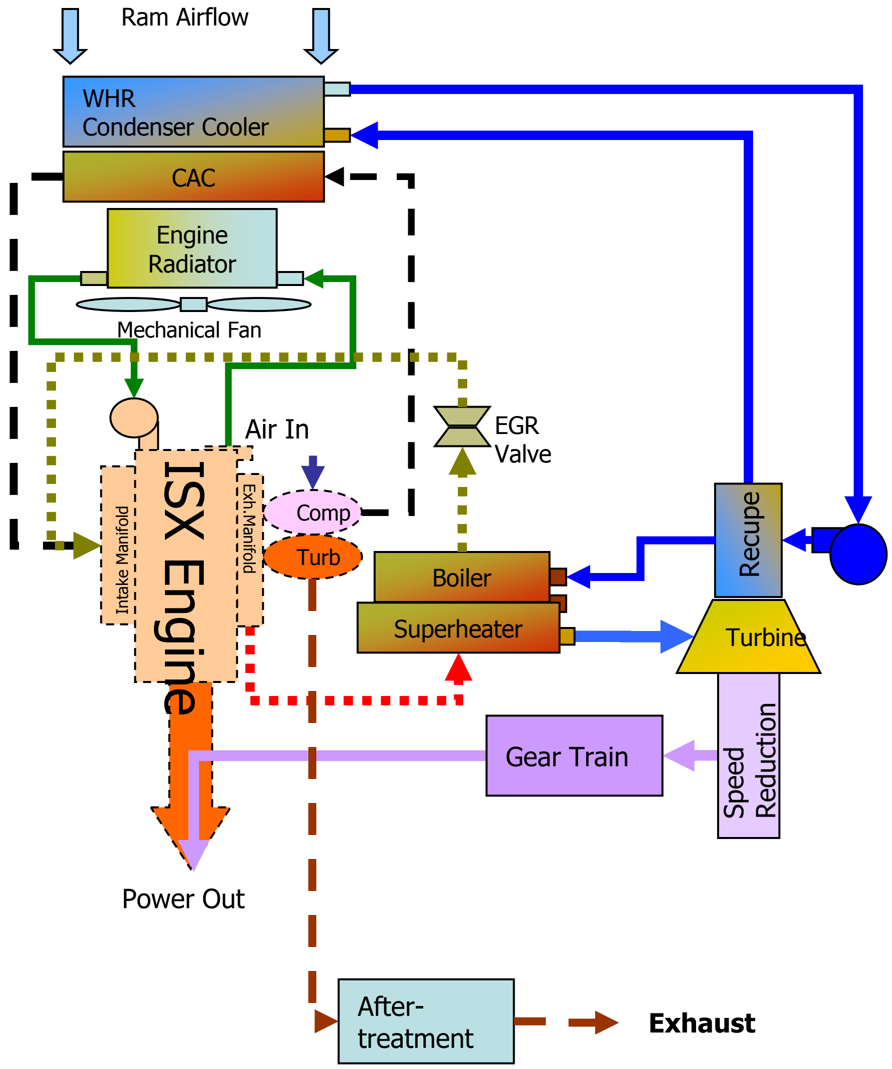
Relieves coolant system of EGR load

Reduces EGR heat rejection load by the energy recovered

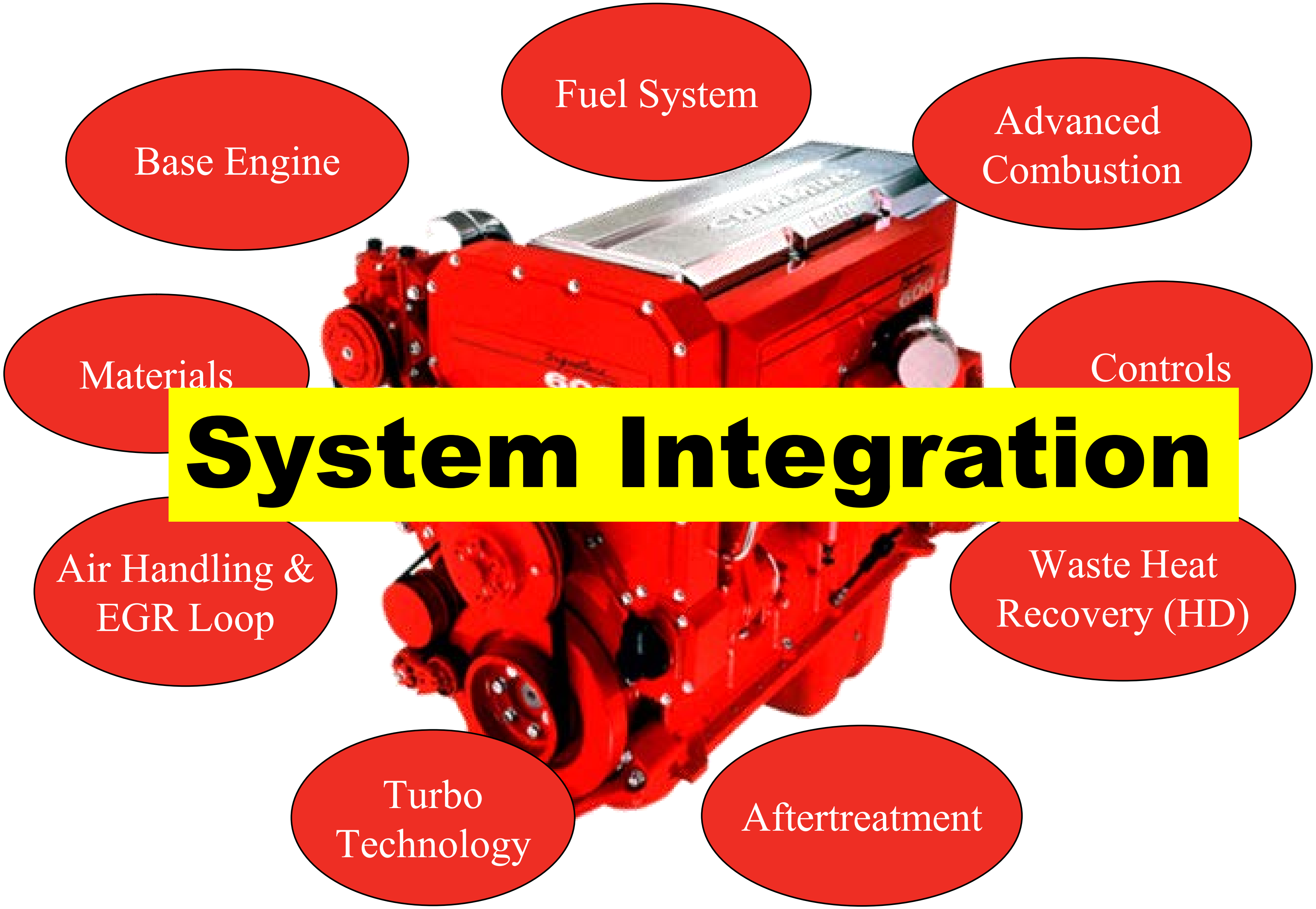
Low GWP fluids now available

~6% Fuel Economy improvement

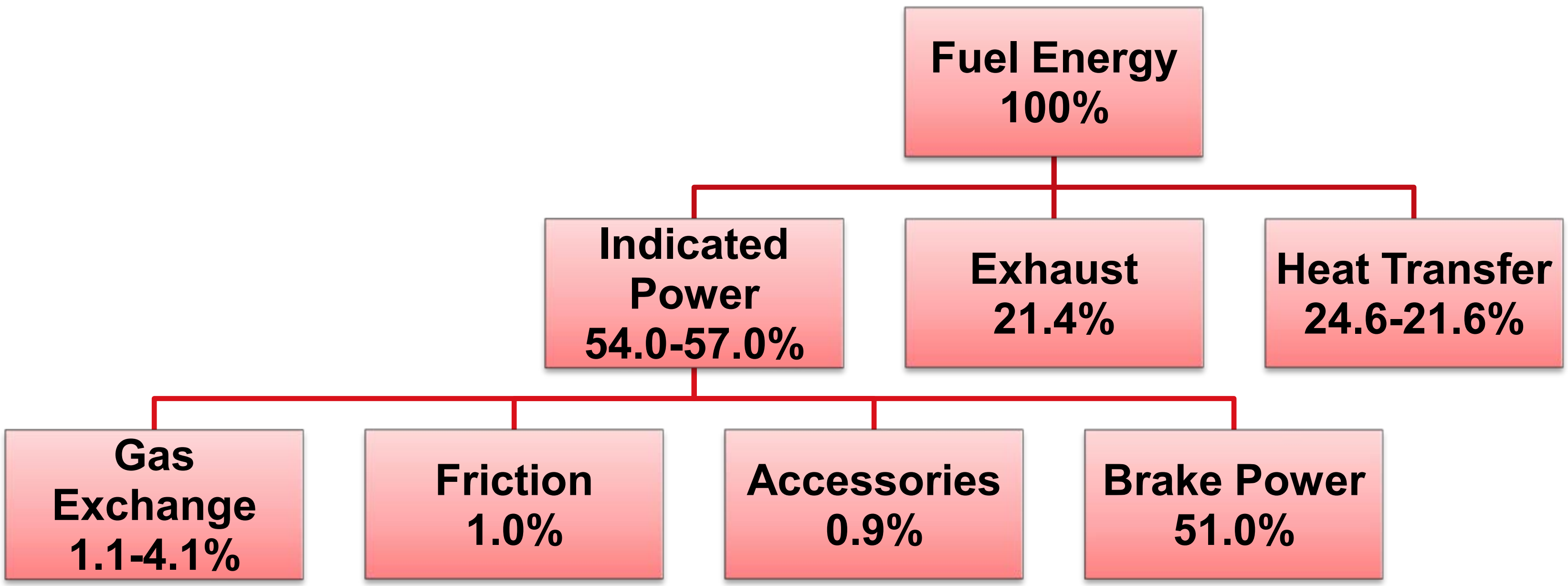
Continue to evaluate alternatives



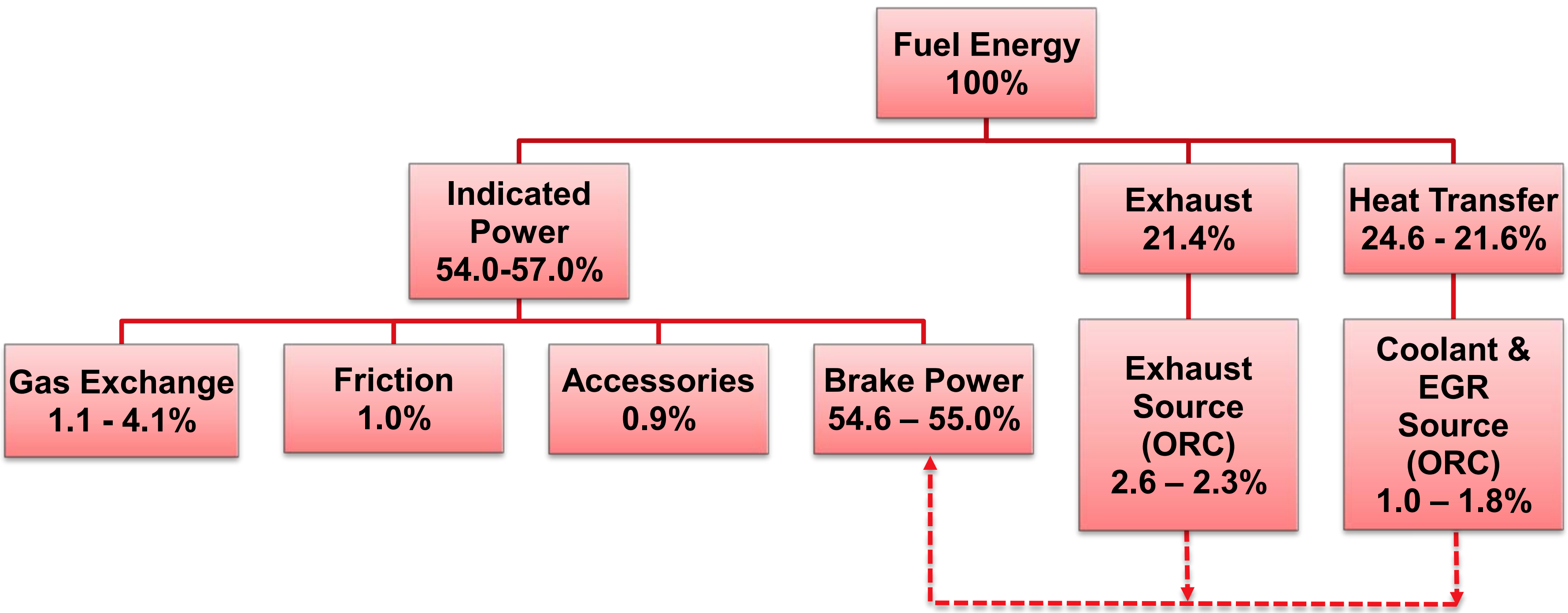
HD & MD Engine Technology Roadmap



Entitlement: HD Engine Energy Balance



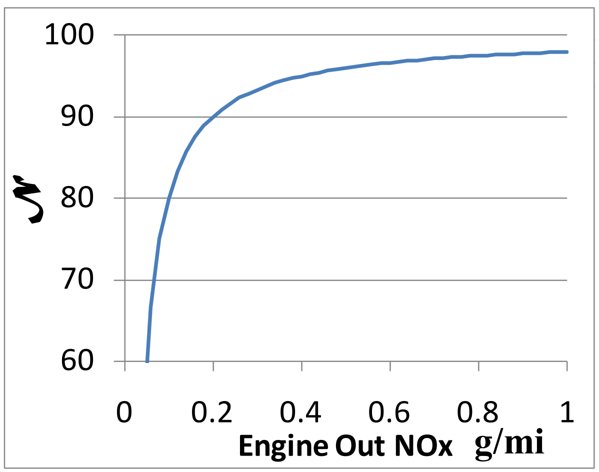
Entitlement: HD Engine Energy Balance (with Waste Heat Recovery)

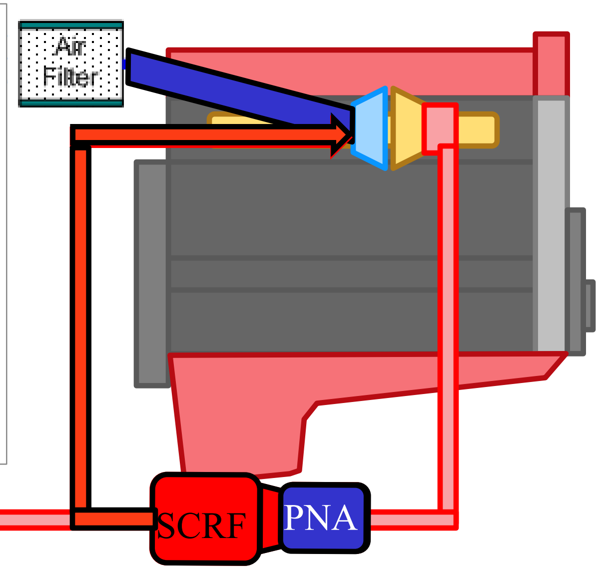


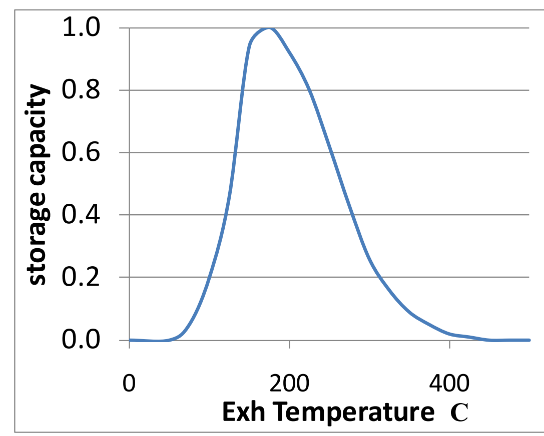
LD-Reduce FE penalty due to Emission Control

Aftertreatment

- Systems must be highly effective just to meet the regulated values – Regardless of engine out levels
- Packaging in order to conserve heat and enable new engine side technologies to be enabled
- Materials improvements to improve warm up times and control emission during the cold start portion of the cycle







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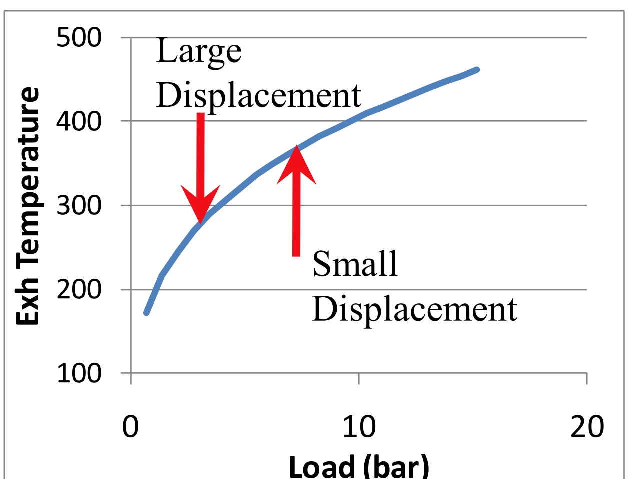
LD-Reduce FE Penalty due to Emission Control

Base Engine

- Operate the engine at higher loads in order to make heat for the aftertreatment.
- Design with thermal conservation features to enable aftertreatment to operate at optimum levels.
- Materials developments to support the above;
  - High power density – bearings, power cylinder, etc.
  - Thermal barrier, low conductivity, and insulating materials



$$Q = K^{*}A^{*}dT$$

Material	K (W/m*K)
Cast Iron	43-55
Stainless Steel	12-18

Photo courtesy Federal Mogul – IROX bearings

Liquid SI Technology Trends

Fuels

- Expanding fuel options (gasoline, alcohols, CNG, LPG)

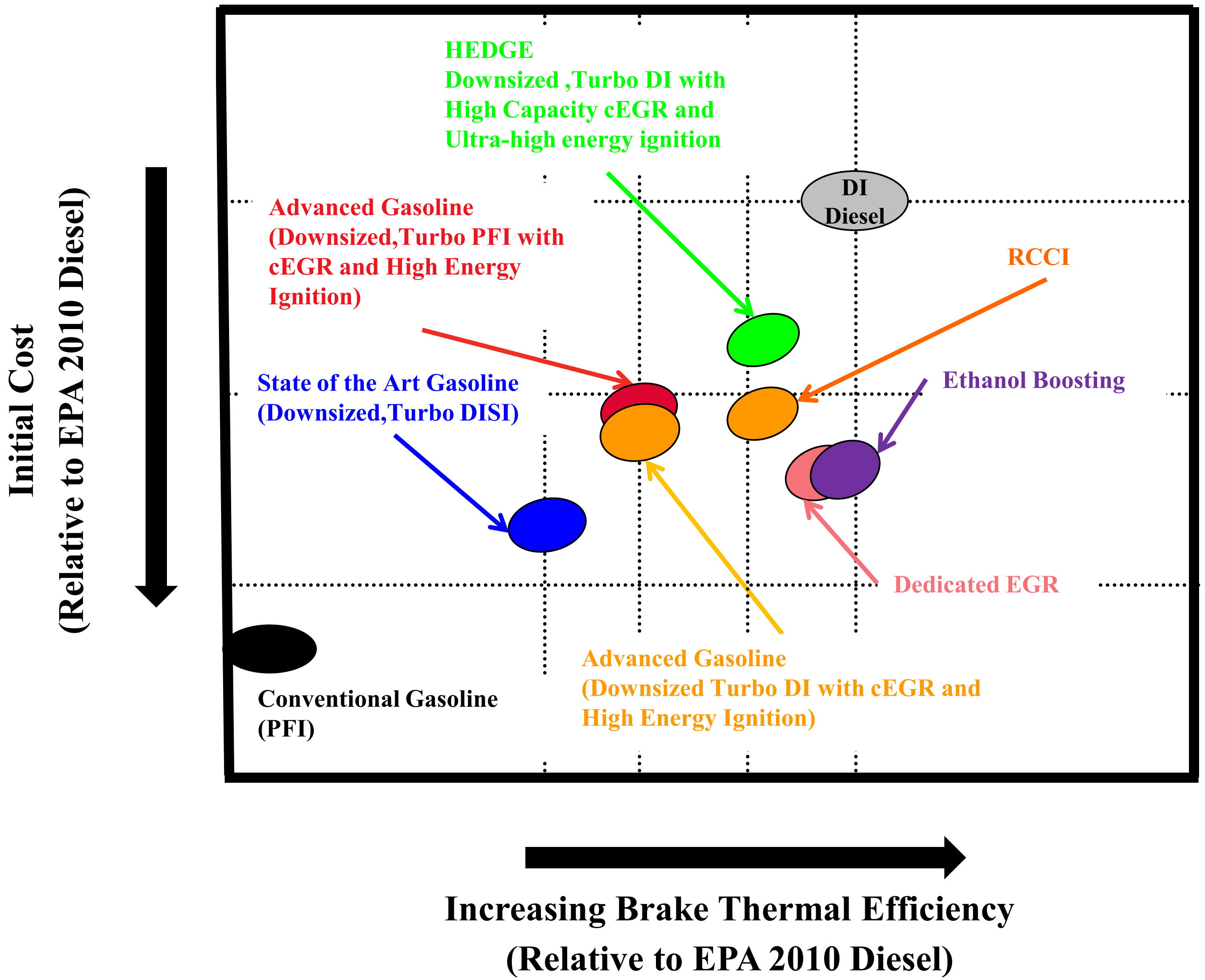
New Combustion System Enablers

- Flexible Valve Timing
- High Tumble Systems
- High/Ultra High Energy Ignition

Combustion Concepts

- Mixed mode combustion (lean and stoichiometric)
- Dilute Combustion
  - Lean Burn
  - Cooled EGR
- Chemical Modulation
  - RCCI (Single or Dual Fuel)
  - Ethanol Boosting (Dual Fuel)
  - Dedicated EGR

Gasoline Technology Pathways to Efficiency



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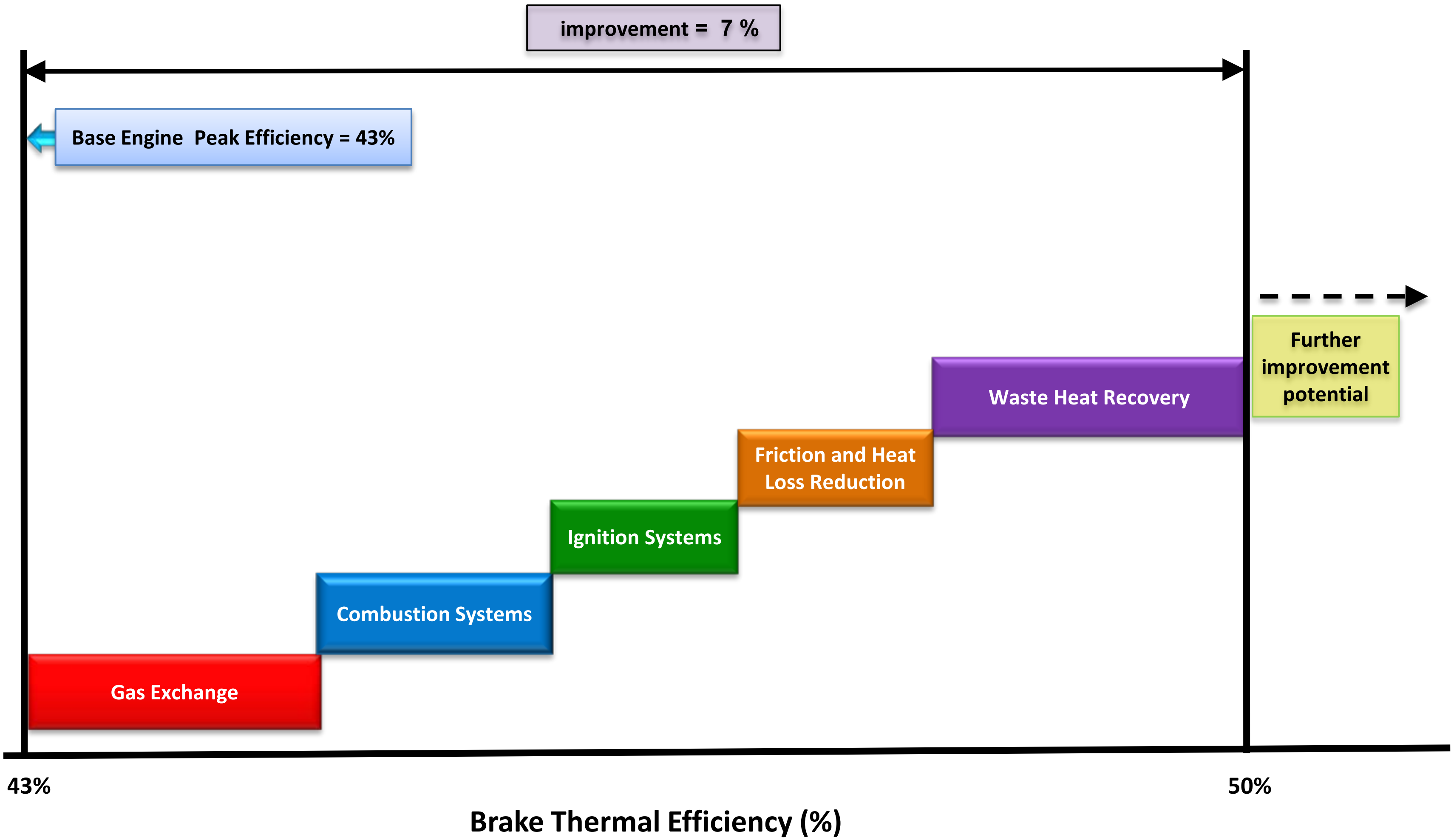
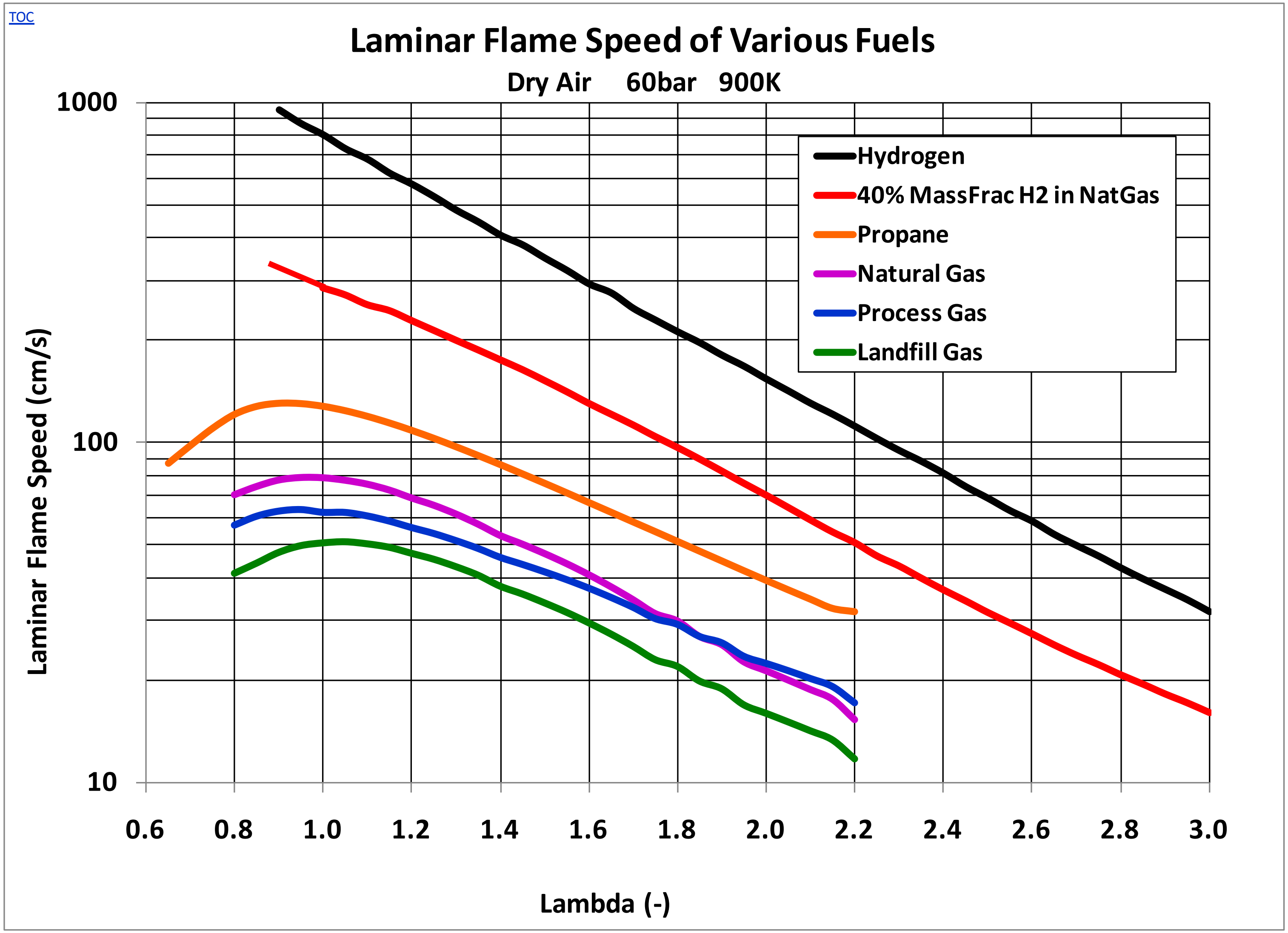
Path to SI Gas High Brake Thermal Efficiency (BTE)

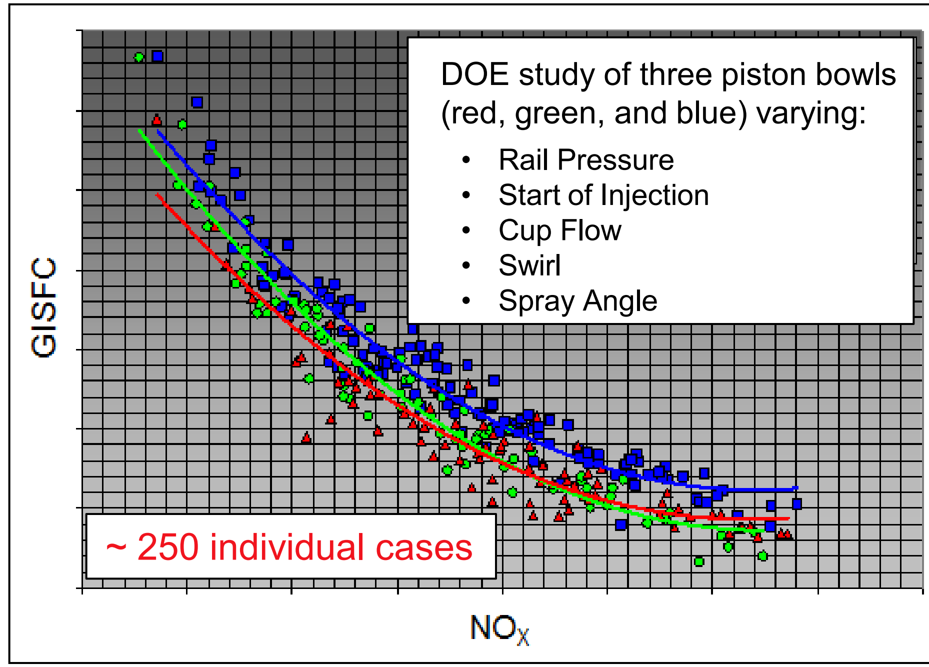


Non-Standard Gases: Successful utilization requires an understanding of the laminar flame speed for correct engine tuning

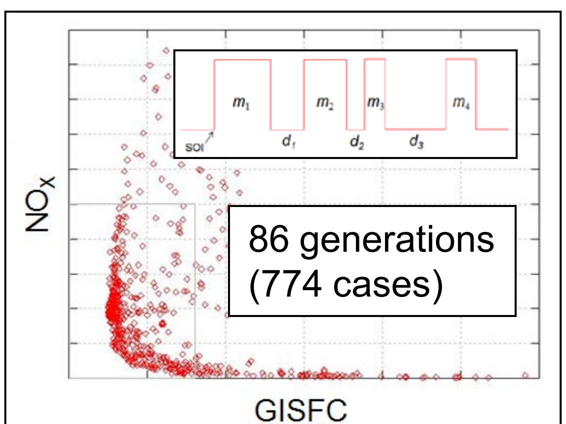


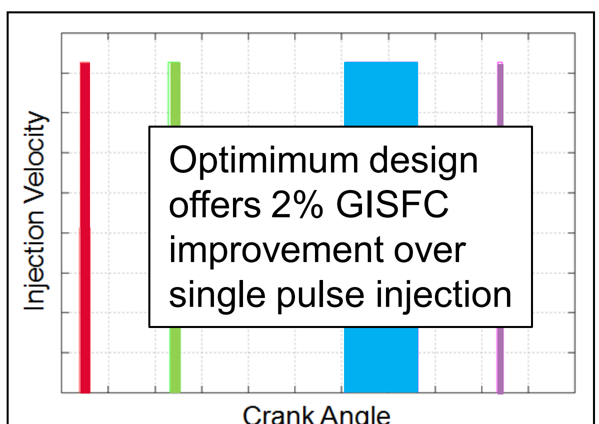
Diesel Combustion Analysis Led Design (ALD)

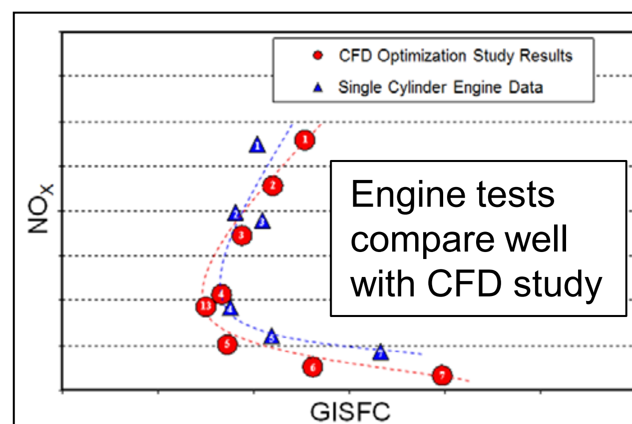
- Model Improvements
- 10x cycle time reduction
- Process automation
- Bio-derived diesel kinetics



Four Pulse Multiple Injection Automated Optimization Study







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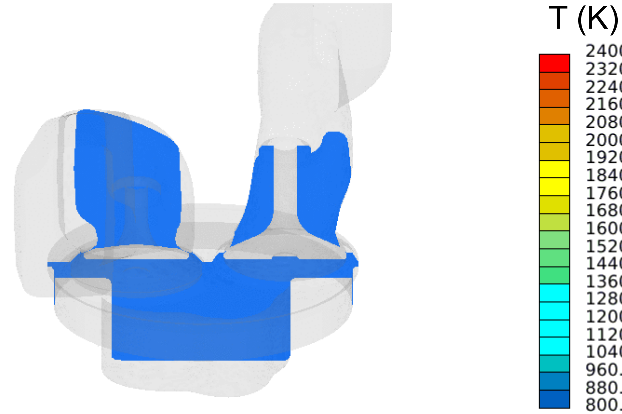
Analysis Led Design (ALD)-Knock Prediction

Knock Modeling

- 2000 step tabulated chemistry

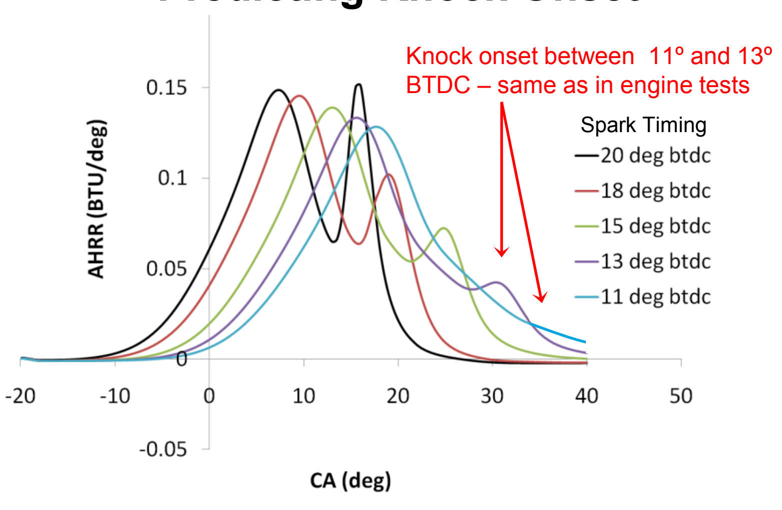
- PDF-based combustion-turbulence interaction.

Knock Simulation with a Dual Spark

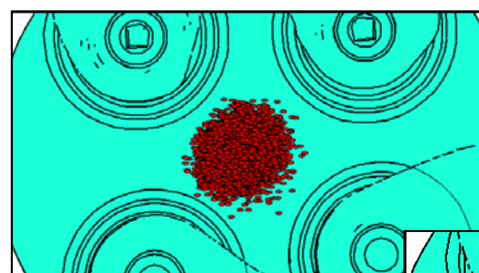


Knock onset occurs in bottom of piston bowl

Predicting Knock Onset

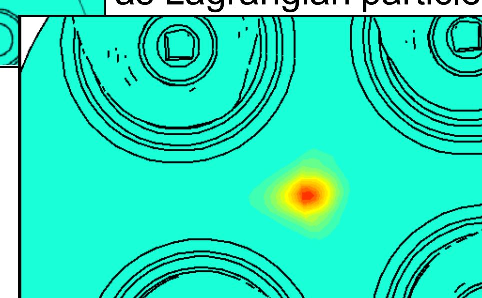


Predicting Spark Ignition



Spark energy from plug is transferred to incylinder charge via flamelet kernels modeled as Lagrangian particles.

Flamelet kernals then generate the macroscopic flame kernel that initializes the combustion model



PreSICE Workshop Report

Executive Summary (1 page)

Introduction (3 pages)

Research and Development Foci:

Sprays

- Research needs (4 pages)
- Expected software tools (1 page)
- Impact on future vehicles (1 page)

Stochastic In-cylinder Processes

- Research needs (4 pages)
- Expected software tools (1 page)
- Impact on future vehicles (1 page)

Conclusion (1 page)

Report complete by March 31

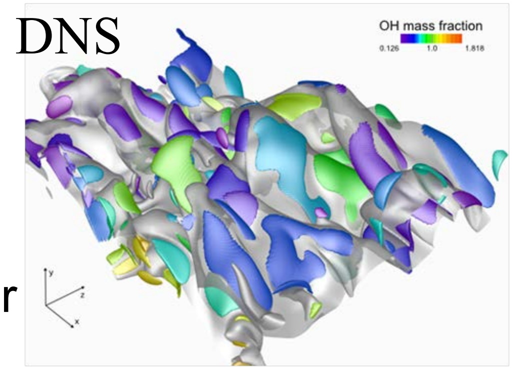
Hierarchy of software tools is needed

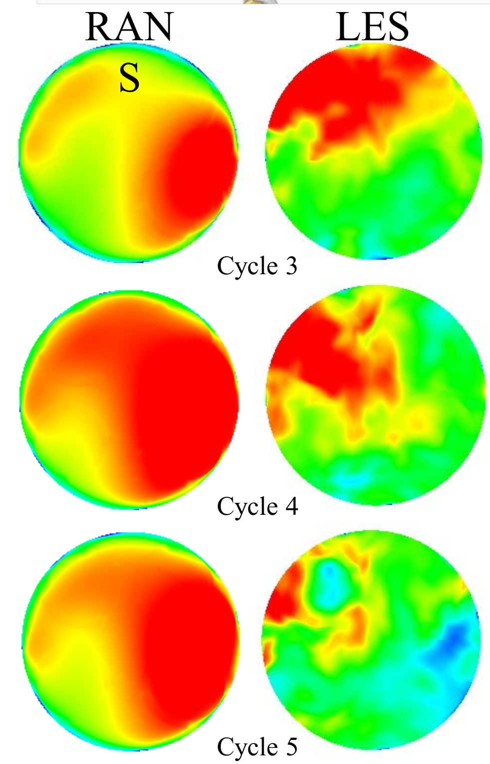
Direct Numerical Simulation (DNS) – Extremely high fidelity simulation tools that enable scientific discovery

High-Fidelity Large Eddy Simulation (LES) – Fine resolution and stringent error control will provide insight for modeling and the bench-mark for computations encompassing the full complexity of stochastic engine flows and sprays

Engineering LES – The design tool for minimizing cyclic variability. Less demanding computationally to allow simulations of many cycles or design optimization, but modeling of small scale processes needs refinement

Reynolds-Averaged Navier Stokes (RANS) approaches – The current workhorse of industry will continue to play a dominant role in multi-parameter optimization. Improved sub-model accuracy will lead to more optimum designs





Temperature at Start of Injection

Summary

Significant efficiency improvements already in or headed to production

More opportunities still available to improve IC engine efficiency-introduction will be driven by cost

Improvements in simulation capability will continue to be an important enabler

Significant opportunity to reduce petroleum consumption

Design for low CO2 manufacturing

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