DETROIT DAIMLER

SuperTruck Program: Engine Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

PI: Sandeep Singh (Engine)
Detroit Diesel Corporation
June 20, 2014

Project ID: ACE058

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Timeline

- Project start: April 2010
- Project end: March 2015
- Percent complete: 80%

Budget

- Engine Budget $31,633,001
  - DOE Share* $12,883,779
  - Detroit Share* $12,883,779

* Program spending through March 2014 for engine R&D; vehicle R&D expenses reported separately.

Barriers & Challenges

- WHR performance trade-offs and cooling challenges on-board vehicle.
- Complex controls architecture and integration of powertrain and novel technologies.
- Reliability of prototype systems in development and demonstration phase.
- Low temperature transient emissions controls.
- Realistic 55% engine BTE roadmap.

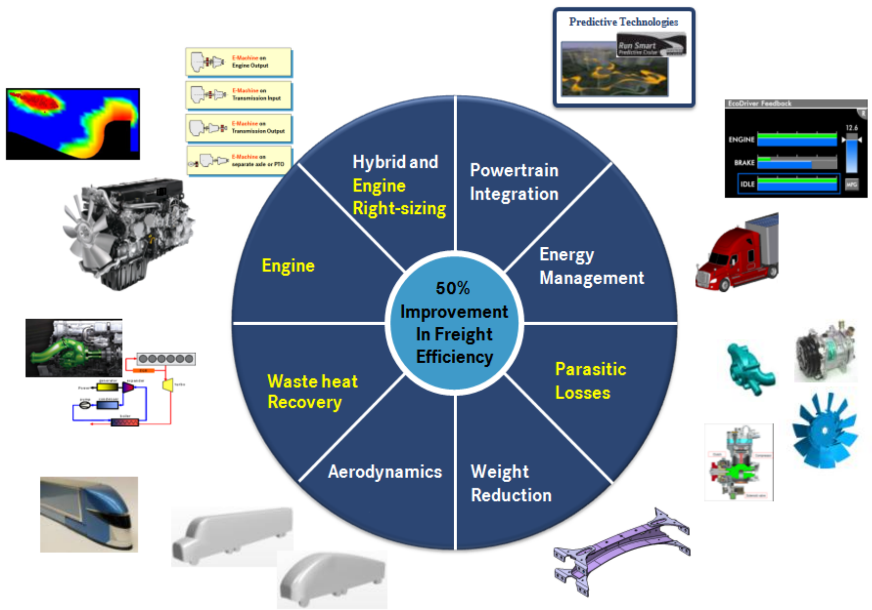
Partners

- Department of Energy
- Oak Ridge National Laboratory
- Massachusetts Institute of Technology
- Atkinson LLC
- Daimler Trucks North America
- Daimler Advanced Engineering

Daimler Truck SuperTruck Program

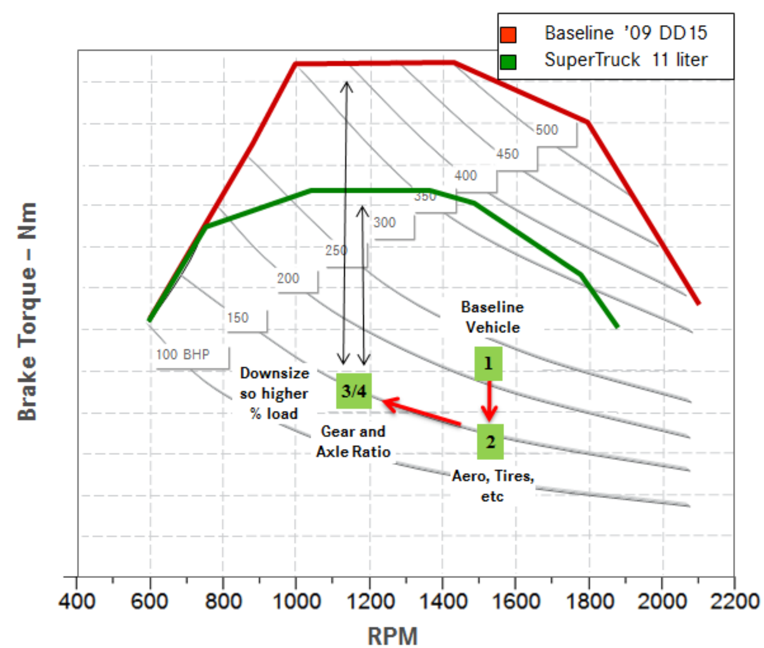
Develop and demonstrate a 50% increase in vehicle freight efficiency:

- 30% increase via vehicle improvements.
- 20% increase via engine improvements; specifically 50% brake thermal efficiency.
  - Identify pathway to 55% brake thermal efficiency via modeling and analysis.



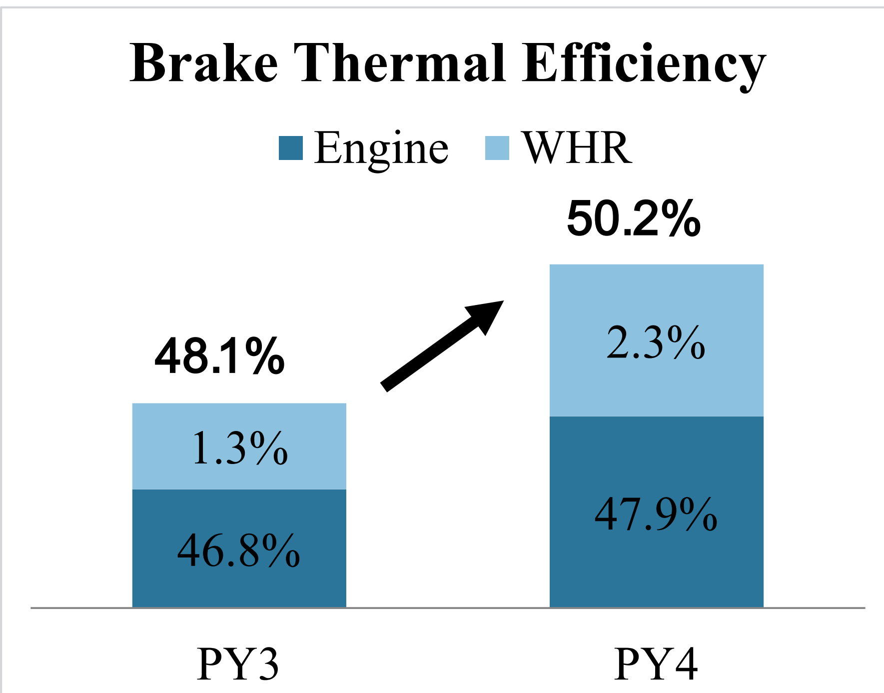
- ARRAVT080 – DTNA SuperTruck vehicle program; PI – Derek Rotz
- ACE058 – Detroit Diesel SuperTruck engine; PI – Sandeep Singh

Engine Downspeed & Downsize



SuperTruck Demonstration Status

- Prototype A-sample SuperTruck vehicle built and being utilized for testing and development.
- Successful integration of complex technologies – EHR, hybrid & HV systems, controllers and network architecture, new cooling layout, new hydraulic systems, powertrain.
- Final demonstration truck builds in progress.



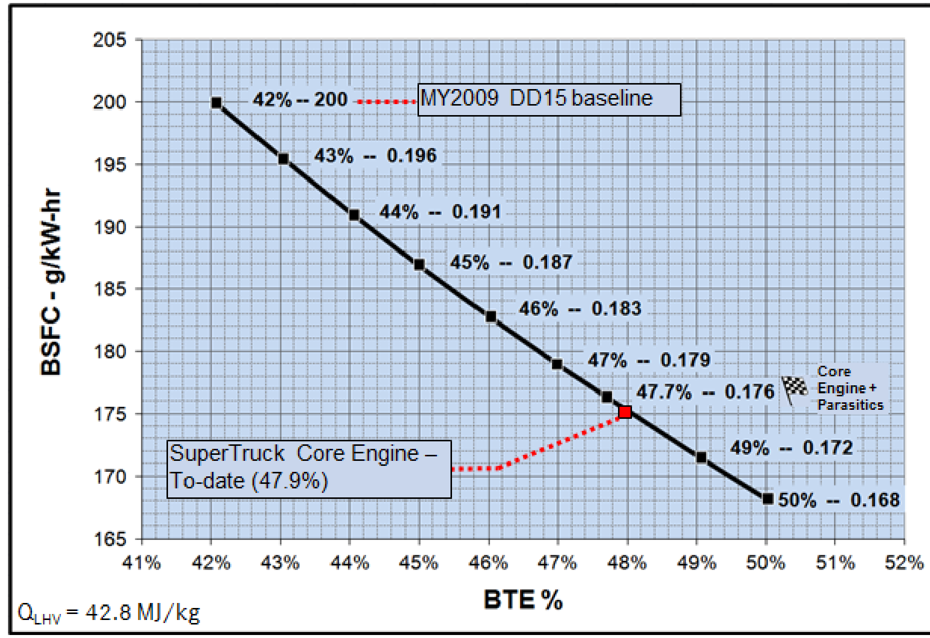
Enablers for Project Year 4 (PY4) BTE Improvement → 2.1%

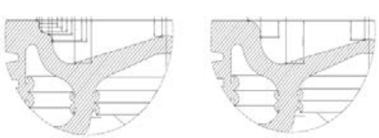
- Further increase in compression ratio (CR), piston bowl and matching injector profile optimization.
- Third iteration of turbo-charger.
- Optimized liner cooling.
- EGR waste heat recovery.
- WHR component and calibration optimization.

SuperTruck Core Engine BTE Status

47.9% BTE SuperTruck Core Engine Technology Package

- Downsizing to 10.7L from 14.8L
- Reduced EGR & optimized turbocharger and air system match
- Higher compression ratio, piston bowl optimization, matching injector nozzles
- Variable speed water pump
- Low viscosity oil and higher oil film temperatures
- Piston kit improvements
- High efficiency, lower restriction aftertreatment

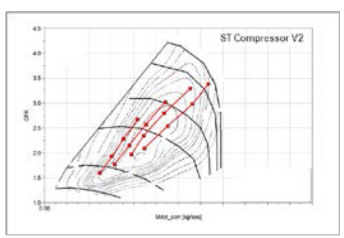




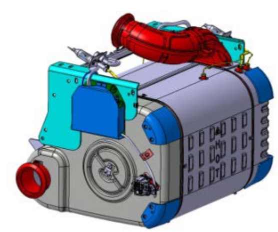
Step Bowl

Omega Bowl

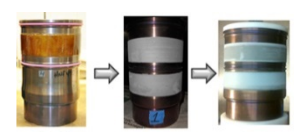
+



+



+

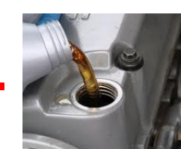


Gen I

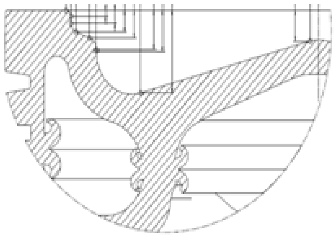
Gen II

Gen III

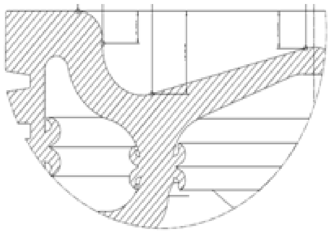
+



Piston and Compression Ratio



Step Bowl

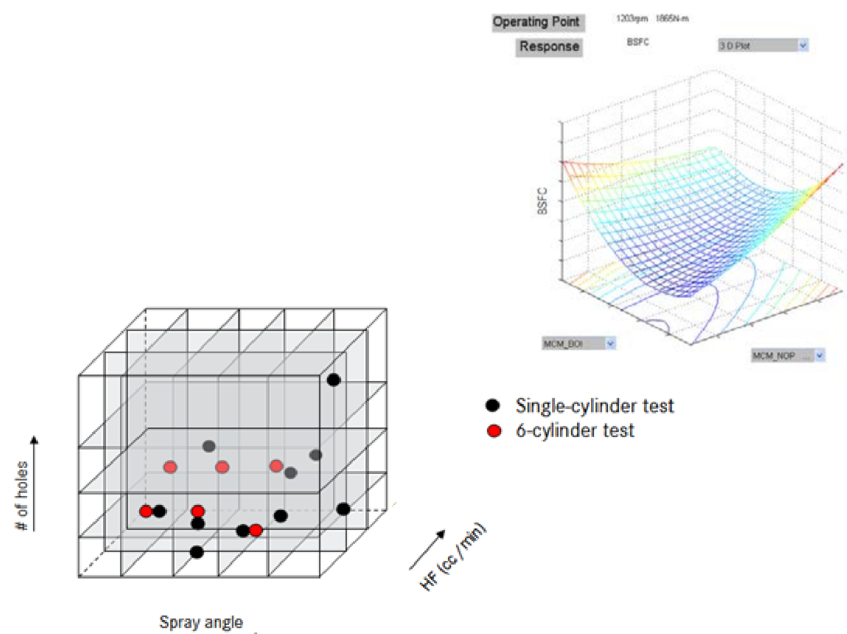


Omega Bowl

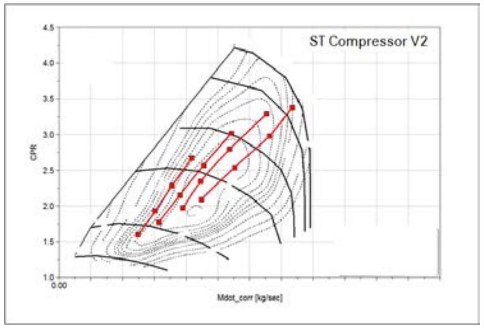
- Optimized combustion package for best fuel economy.
- Peak firing pressure increased by 15%
- Plans to test even higher CR. (55%scoping)
- Efficient part load operation, but challenges with high load durability, head & block design and material, NVH, emissions.

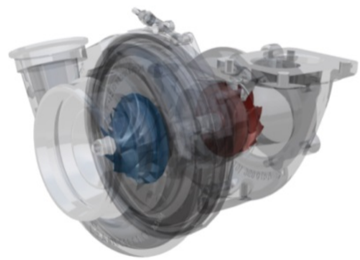
Fuel Injection System

- Best injector and piston combination selected after extensive testing.
- Combination of single cylinder and multicylinder platforms used for this investigation.



Air Handling

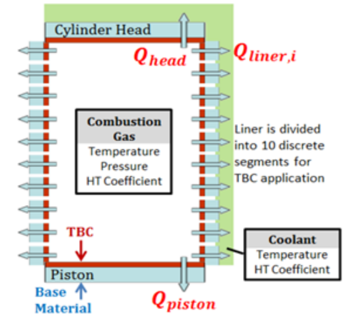


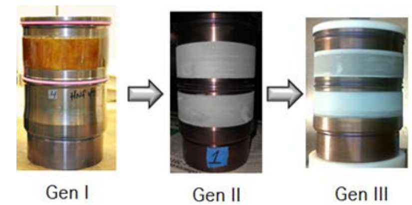


- Turbo sized for reduced EGR and air mass contributing to lower pumping losses.
- Tuned for a downsped engine.
- Engine air system design leverages a lower power rating required for the aerodynamically and parasitically efficient SuperTruck.
- Approach requires a very high efficiency SCR and low backpressure aftertreatment (ATS).

Parasitic Reductions

- Variable speed water pump, lower viscosity oil, bundled cylinder kit improvements.
- Altered cooling to mid-stroke area of the liner (Detroit/MIT).

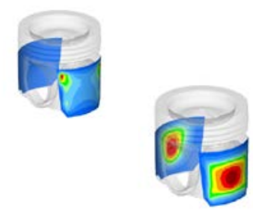


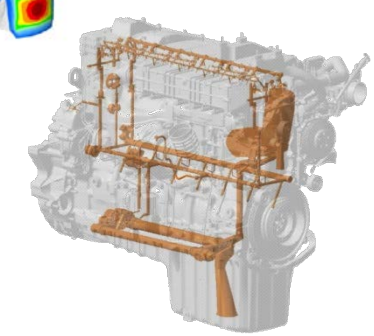


Massachusetts Institute of Technology

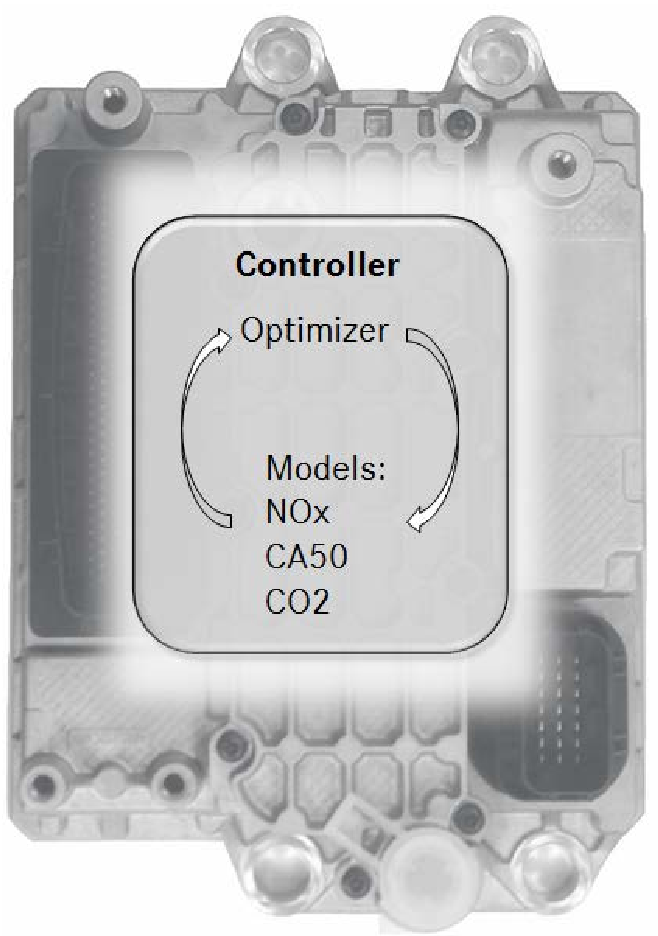
Further Investigations (55% Scoping)…

- Next evolution of liner cooling optimization (Detroit/MIT).
- New lubricant formulation (MIT+oil supplier).
- Oil circuit and pump optimizations (MIT).





SuperTruck Engine Control Approach

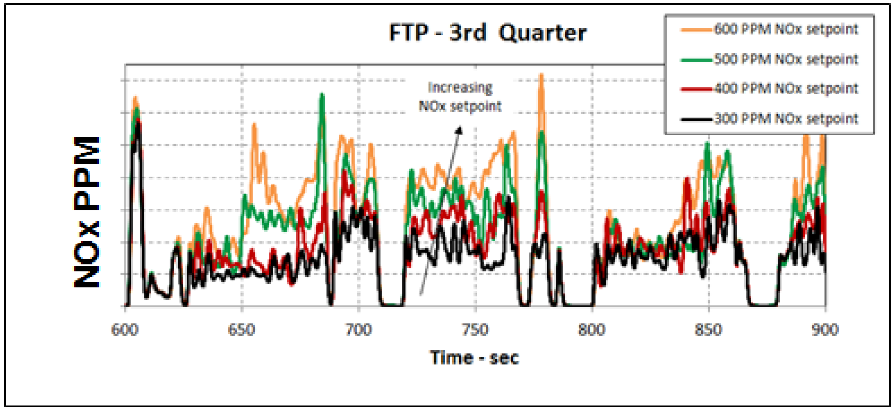


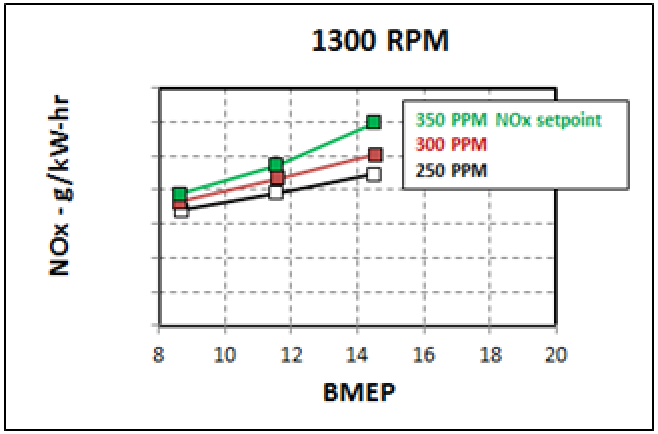
- Model based controls (MBC) optimize fuel economy and constraint emissions in real time.
- Extensive transient & steady state mapping used to calibrate engine models.
- Both offline & real time optimization of engine set-points for improved transient performance & fuel economy.

Engine Controller Accomplishments

- Controller implemented on a micro-autobox on-board vehicle.
- Standardized and reduced calibration process for each hardware iteration.
- Real time optimization on dynamometer successfully drives the engine to a broad range of emissions/fuel economy trade-offs.
- Preparation for demonstration vehicle testing is currently underway, to quantify transient fuel economy impact on the vehicle.

- Future development of MBC includes
  - Predictive route adaptation
  - Environmental and aging adaptation
  - Virtual sensing for diagnostics

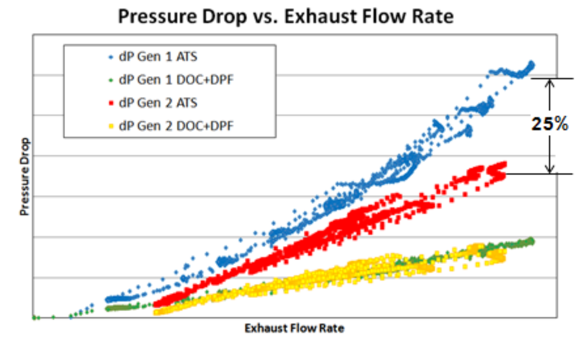


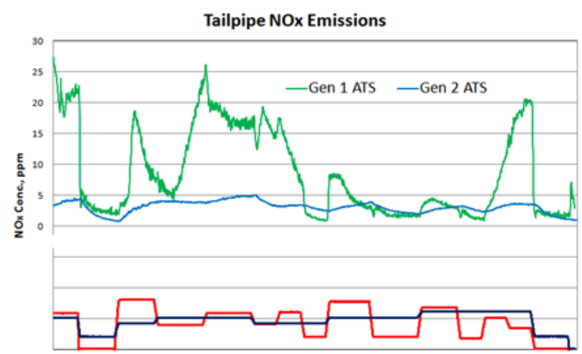


Aftertreatment System

ATS

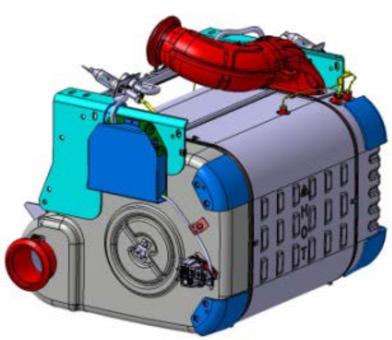
- Lower backpressure device
- High performance SCR catalyst, thin-wall DPF, high flow DEF doser
- Insulated exhaust and ATS on the vehicle
- Very high NOx conversion over the road to maintain emissions compliance with high engine out NOx (steady state)





Engine

- Low EGR reduces pumping losses.
- Lower backpressure further reduces pumping losses.
- Higher engine out NOx:PM ratio lends to an over the road passive regeneration tendency.
- Savings in over the road active regeneration fuel.

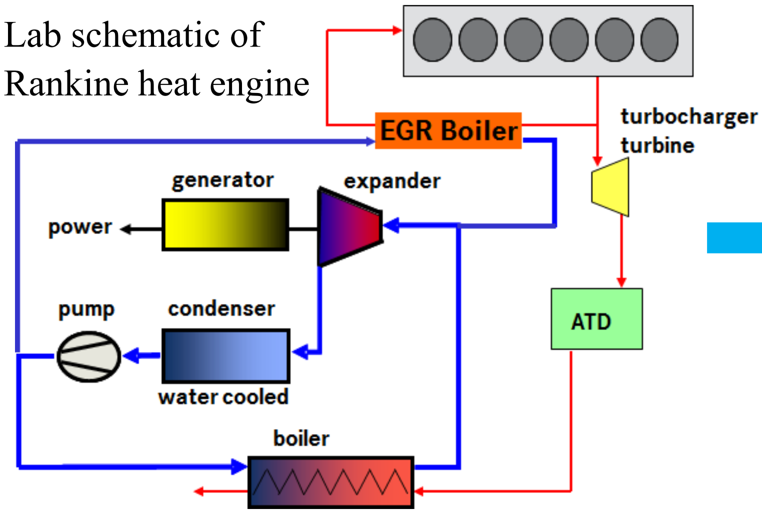


Emissions Compliance

- EPA10 RMC and road load compliance demonstrated.
- Low temperature transient challenges being addressed by engine+ATS systems approach
- Real world degradation/ aging of a system required to consistently perform at high efficiency is a challenge

Waste Heat Recovery (WHR)

Lab schematic of Rankine heat engine

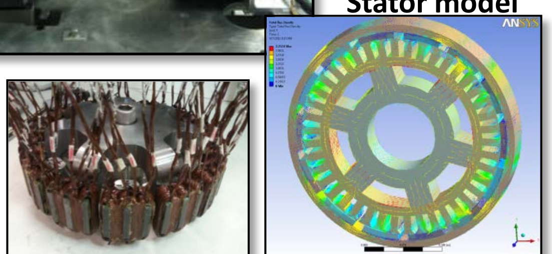


- System functional on A-sample SuperTruck prototype.
- Successful integration with the HV hybrid system and a modified cooling package.

Coupled Expander Generator

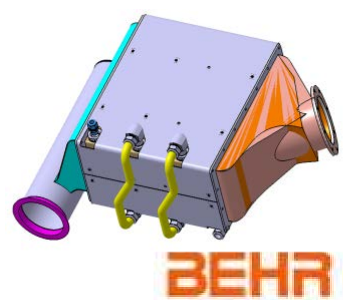
Wound field, no-rare earth e-machine

Stator model



Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

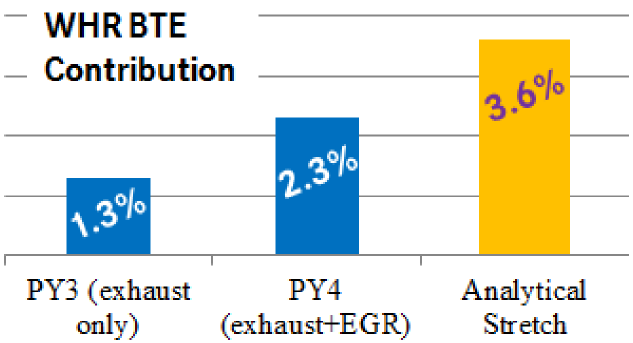
Boiler



Scroll Expander

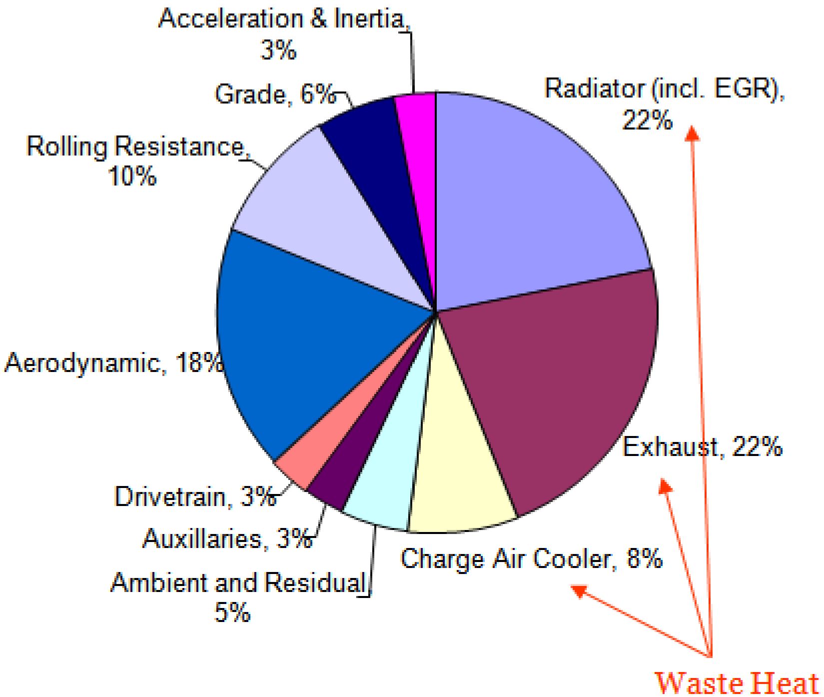
Prototype Components

WHR Progress & Accomplishments



Waste Heat Sources	Temperature Potential	Quantity
Exhaust	High	High
EGR	High	Low
CAC	Low	Low
Coolant	Low	High

- Primary contributor to PY4 efficiency improvement is EGR heat recovery and component optimizations.
- Current approach has numerous vehicle integration challenges.
- Analytical stretch projections assume improved component efficiencies, CAC heat recovery, and a low temperature condenser approach.
- Analytical stretch may prove to be impractical with state of the art vehicle technology.

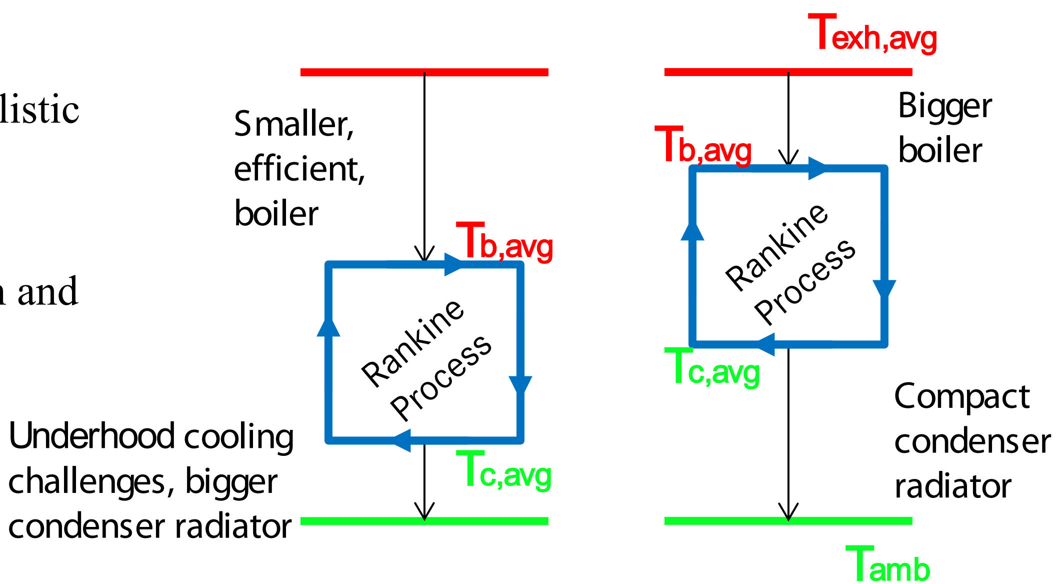


WHR Vehicle Integration

	Electrical Vs. Mechanical Feedback	
	Electrical	Mechanical
Pros	Better energy management	Higher efficiency
Cons	Hybrid dependent	System sealing challenges w/ shaft seals, mag coupling etc.

Process Temperature Impact on Design

- WHR vehicle cooling requires a holistic approach.
- Integrated vehicle, engine & WHR system models leveraged for design and layout.



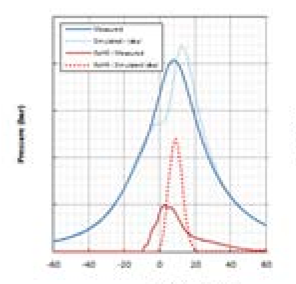
ORNL Collaboration on Dual Fuel

Detroit engine at ORNL

- Explore dual-fuel operation within the constraints of a stock engine
  - Potential petroleum displacement in conventional modes
  - Potential η% and emissions impact in low temperature combustion (LTC) modes (55% BTE scoping)
- Evaluate LTC and limitations on a multi-cylinder engine
  - Combustion stability & phasing
  - High PMAX, dP/dt & EGR
- Detroit engine modified for PFI natural gas, DI diesel
  - Fyda Energy Solutions providing Sequential PFI hardware
- Engine installation and system integration underway, dual-fuel experiments scheduled for Summer 2014

Promotional photos from Fyda Energy Solutions

- Fundamentally targeting a more optimum ROHR at part load, within the mechanical constraints of the engine



55% BTE Scoping Activities in 2014

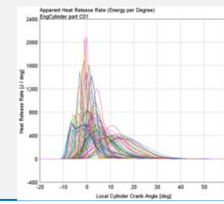
Sub-System Testing

Analytical

Combustion

Even Higher CR
LTC & Dual fuel

Ideal HRR scoping
In-cylinder insulation



WHR

Mechanical
Feedback

Component optimization,
Beyond exhaust recovery,
Low temperature condensation

E-TC

Air System

Further EGR
reduction

High efficiency turbo,
Low restrictions

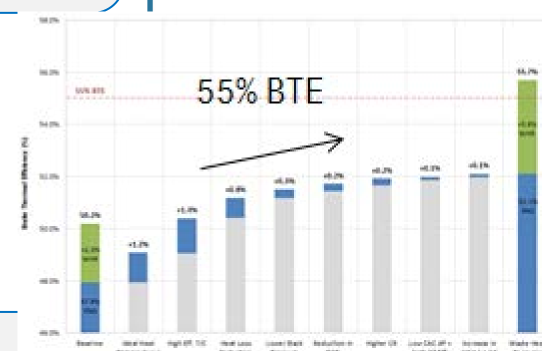
Friction Reduction

Liner insulation iterations,
New oils

Oil circuit
modifications

Engine Simulations

Parameterized models for engine design & configuration impact on part load efficiency



Preliminary analytical estimates for 55% BTE roadmap

SuperTruck Partnerships and Collaborations

Department of Energy: → Roland Gravel → Gurpreet Singh
→ Ken Howden → Carl Maronde

Engine

Massachusetts Institute of Technology
Atkinson LLC
BOWMAN Energy Recovery Systems
Air Squared 40 Years of Scroll Technology
DAIMLER
Oak Ridge National Laboratory
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Aftertreatment

CORNING
JM Johnson Matthey
Eberspächer

Hybrid

FUSO
MBtech Mercedes-Benz technology
Mercedes-Benz
itk ENGINEERING

Aero/Cooling

CD-adapco
BEHR
MODINE

Powertrain/Parasitics

DETROIT Transmission
DAIMLER Daimler Trucks North America
Bendix

Fleet

SCHNEIDER NATIONAL
Walmart Save money. Live better.

SuperTruck Program Summary

- 50.2% engine BTE demonstrated including WHR.
- Weight neutral engine target; downsized engine with WHR.
- WHR functional on prototype A-sample SuperTruck.
- Remaining 1 year of SuperTruck.
  - Demonstrate efficacy and FE advantage of model based real time engine controls on-board the demonstrator SuperTruck vehicle.
  - Performance and controls tuning for engine & WHR ongoing for demonstrator chassis.
  - Demonstrator chassis and truck build ongoing; FE and performance demonstration to start September.
  - Sub-system level testing and analysis for 55% BTE building blocks initiated.
  - Final reporting.