SuperTruck Program: Engine Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

PI: Kevin Sisken (Engine)
Detroit Diesel Corporation
May 16, 2013

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: 60%

Budget

- Engine Budget $31,633,001
  - DOE Share* $8,802,373
  - Detroit Share* $8,802,373

* Program spending through February 2013 for engine R&D; vehicle R&D expenses reported separately.

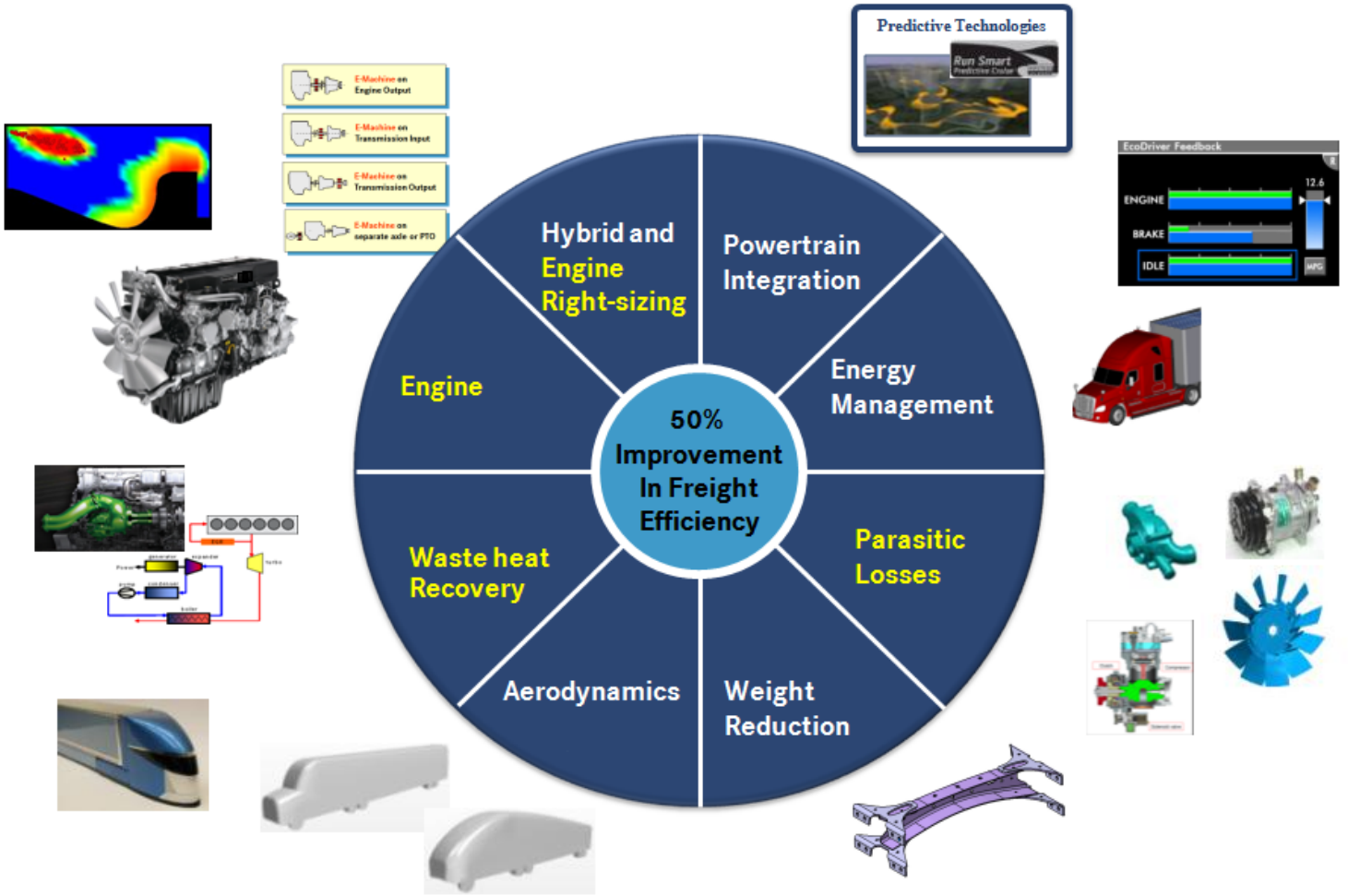
Challenges

- Getting systems to work together in vehicle; new vehicle, new cooling system, hybrid, new controllers for engine and vehicle, downsized engine, new combustion system , new turbocharger, high efficiency aftertreatment, waste heat recovery, etc.

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



- ARRAVT080 – DTNA SuperTruck vehicle program; PI – Derek Rotz, reported @ Crystal Gateway
- ACE058 – Detroit Diesel SuperTruck engine; PI – Kevin Sisken, reported @ Crystal City

SuperTruck Objective

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.

Status

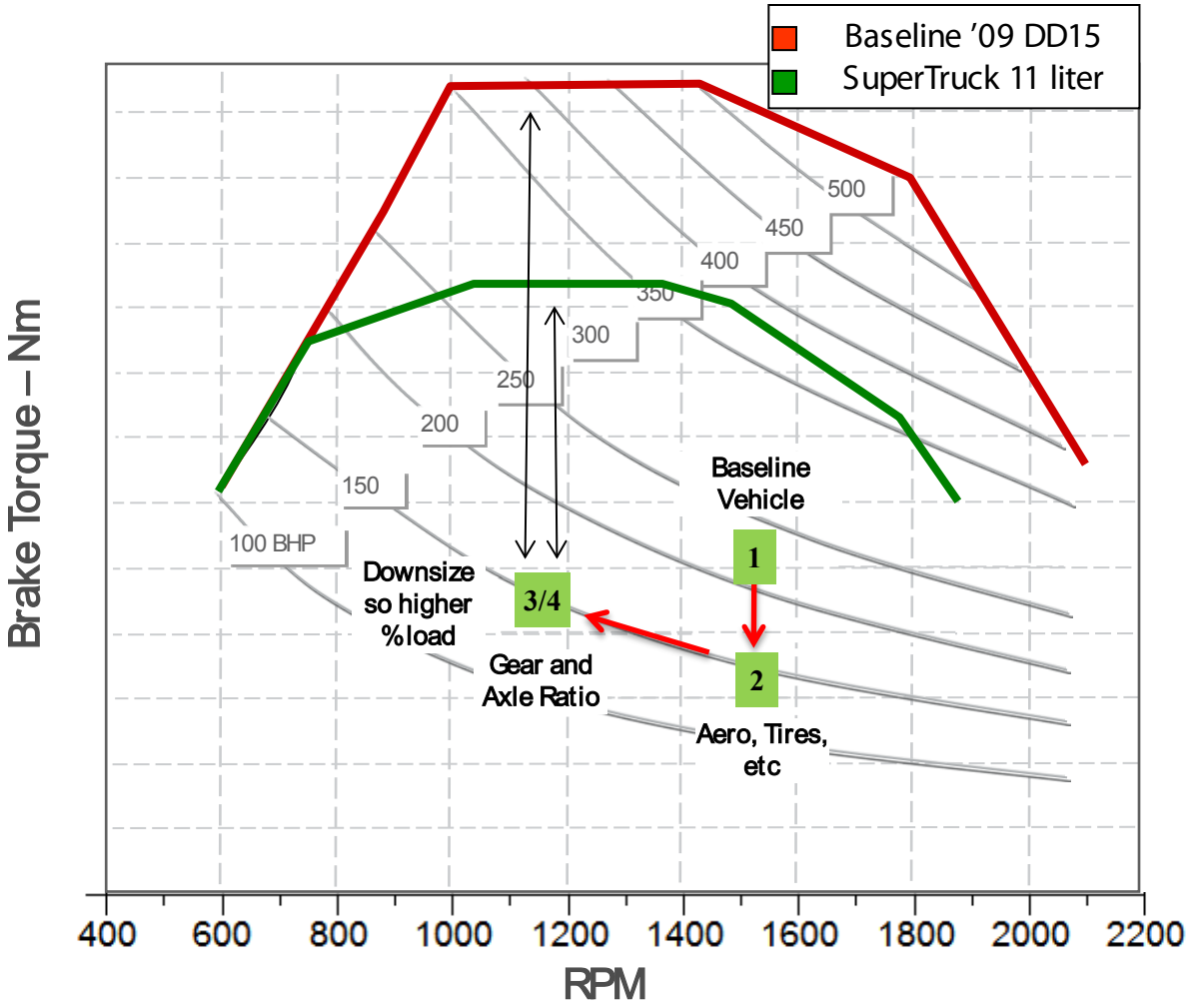
Vehicle:

- 42% measured on system level; currently implementing into demonstration vehicle.

Engine:

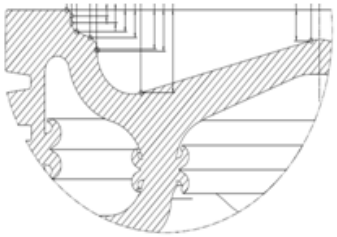
- 15% gain via engine improvements.
  - 48.1% BTE demonstrated (46.8% engine + 1.3% WHR).
  - Hardware in hand to demonstrate 50% BTE.
- Pathway to 55% BTE has been initiated (results end of year 4).

Engine Down-speed and Down-size

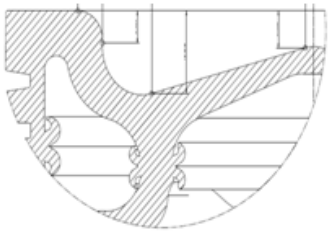


- 1 → 2
  - Impact of vehicle getting more efficient .
- 2 → 3
  - Change gear and axle ratio to drop cruise rpm toward higher BSFC points.
- 3 → 4
  - Downsize from 15L to 11L to increase BMEP at road load, giving better mpg at road load.

Piston and Compression Ratio



Step Bowl

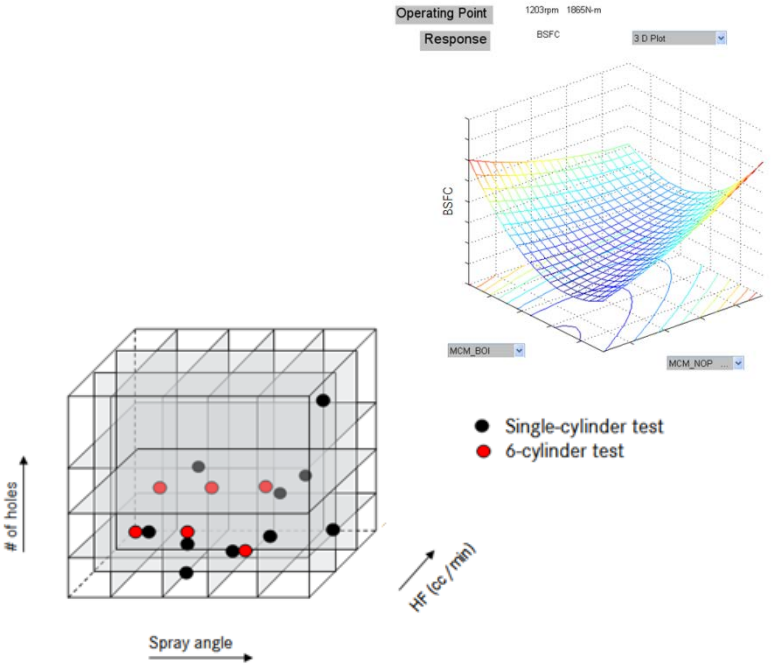


Omega Bowl

- New piston bowl shapes based on extensive single cylinder testing; engine hardware now available.
- Compression ratio being increased.
- Firing pressure will be increased up to 20% over baseline engine.

Fuel Injection System

- Best combinations of injector tip, bowl, and compression ratio determined via single cylinder testing; best combinations being engine tested.
- Design of experiments being utilized to optimize injection and engine parameters.

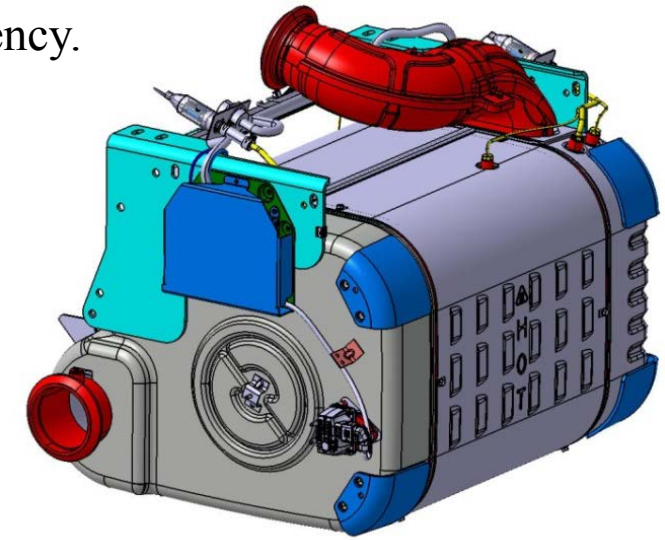


Increased Engine Out NOx

- Combustion system being optimized with engine out NOx lightly controlled (3-5 times higher than baseline engine).
- Good for thermal efficiency; increased demand on SCR system.

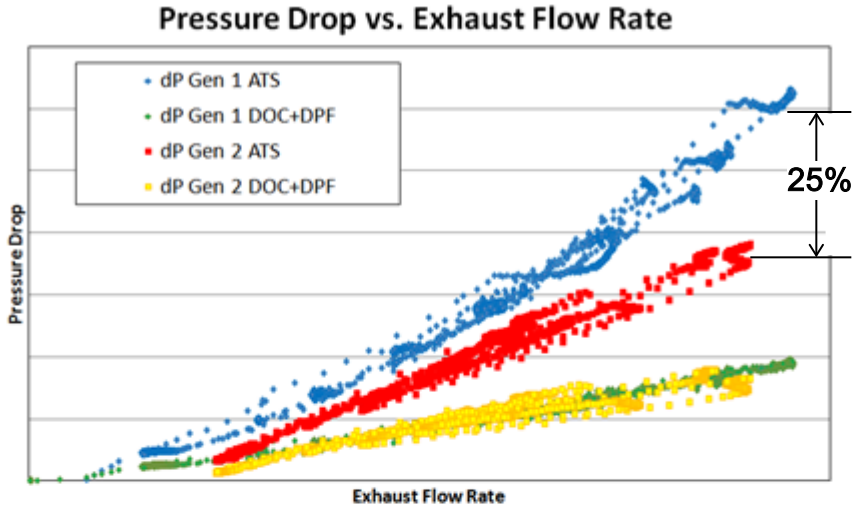
Aftertreatment

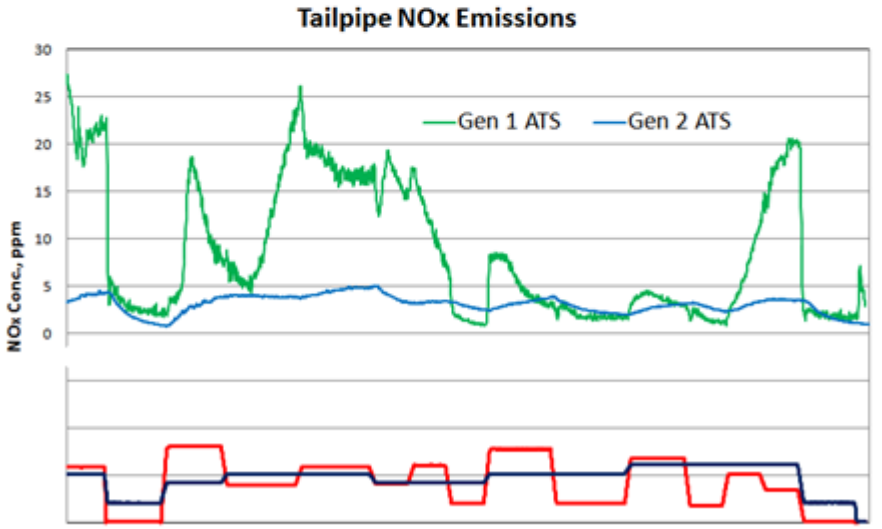
- Require very high NOx conversion efficiency.
- System resized for high NOx flux (substrates and DEF doser).
- Backpressure must be reduced for high engine efficiency.



Two Generations of Aftertreatment Hardware

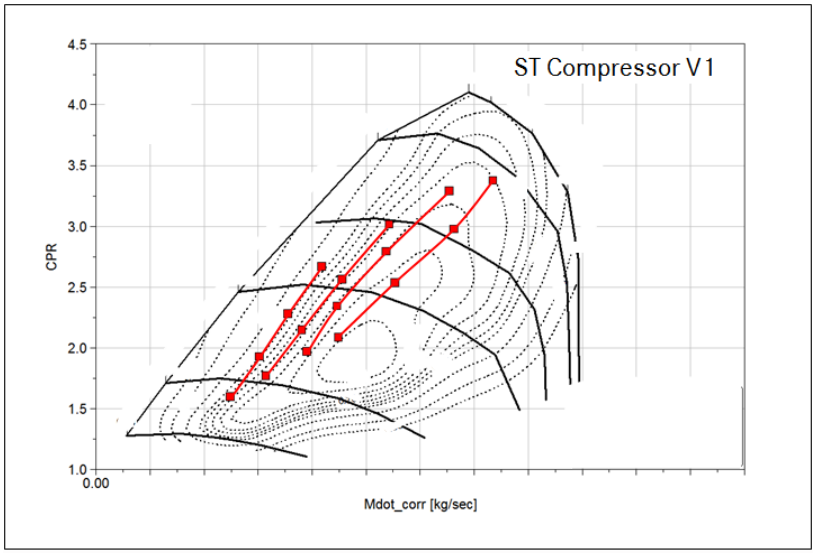
- Generation 1 has new DOC, DPF, and SCR.
  - DOC and DPF met expectations; SCR had room for improvement.
  - ΔP and NOx conversion efficiency below target.
- Generation 2 has new SCR. DOC and DPF largely unchanged.
  - Gen 2 has lower pressure drop and better SCR conversion. Performs well at high NOx flux.
- Generation 2 will be on the SuperTruck demonstration vehicle.

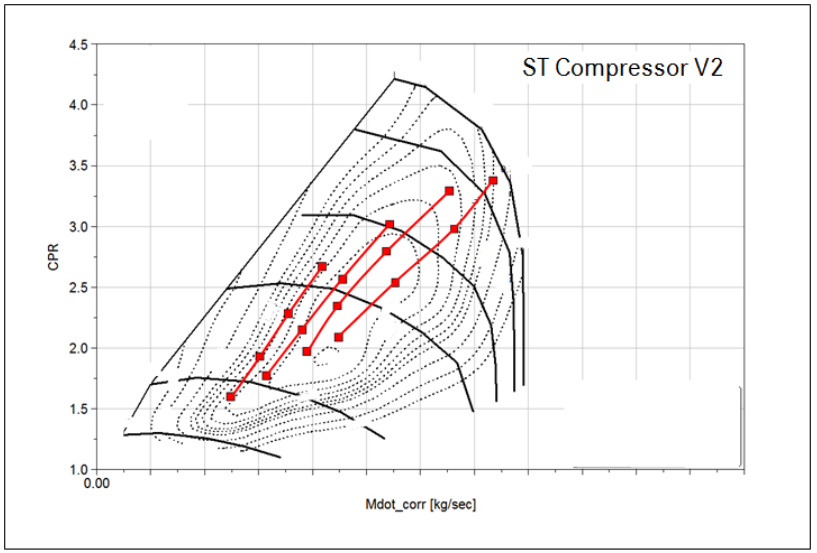




Air System Rematch

- Best BTE → higher engine out NOx → lower EGR rates → turbocharger rematch
  - Down-speed engine offers rematch opportunities.
  - Baseline turbocharger provides back pressure for high EGR rates.
- Turbocharger V2 has well matched compressor map.
  - EGR valve still partially closed to reduce EGR rates.
- Turbocharger V3 being delivered with reduced turbine backpressure.

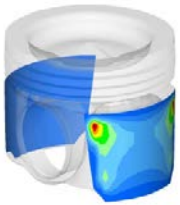


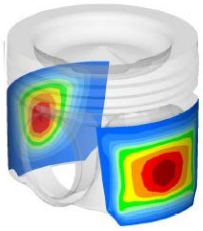


Parasitic Reductions – Implemented

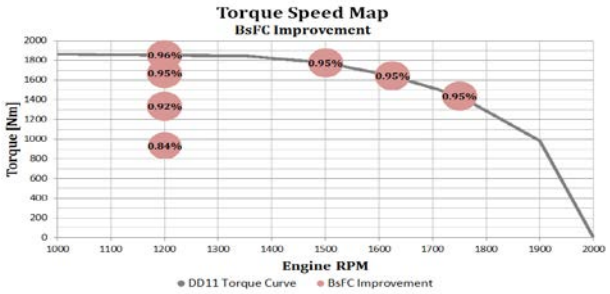
- Water pump, lower viscosity oil, and ring modification included in 48.1% BTE demonstration.

Parasitic Reduction – Planned



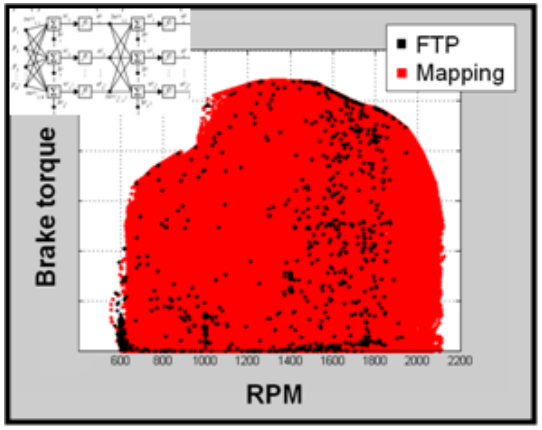


- Modifications to be tested include :
  - Altered cooling to mid-stroke area of the liner (MIT).
  - Oil circuit and pump optimizations (MIT).
  - New lubricant formulation (MIT + oil supplier).
  - Bundled cylinder kit improvements.



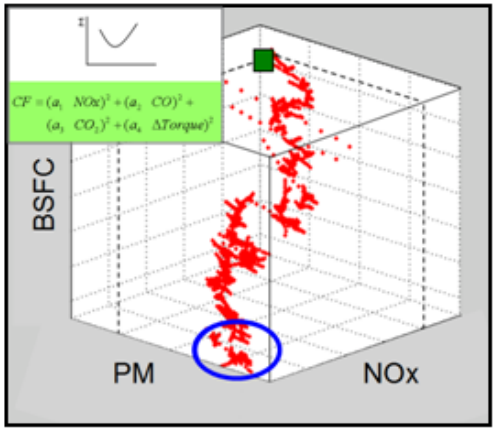
Massachusetts Institute of Technology

SuperTruck Engine Controls – Objective

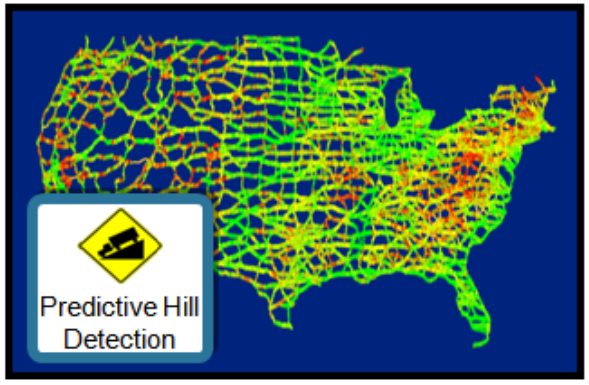


Extensive engine mapping is used in neural network model training

- Developed a predictive engine controller.
- Includes a fuel efficiency optimizer.
- Integrates predictive vehicle information.
- Reduced calibration complexity.



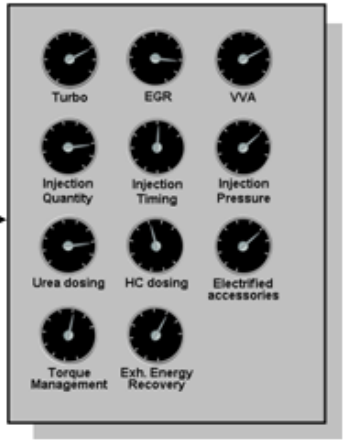
Emissions & fuel economy models enable on-board BSFC optimization



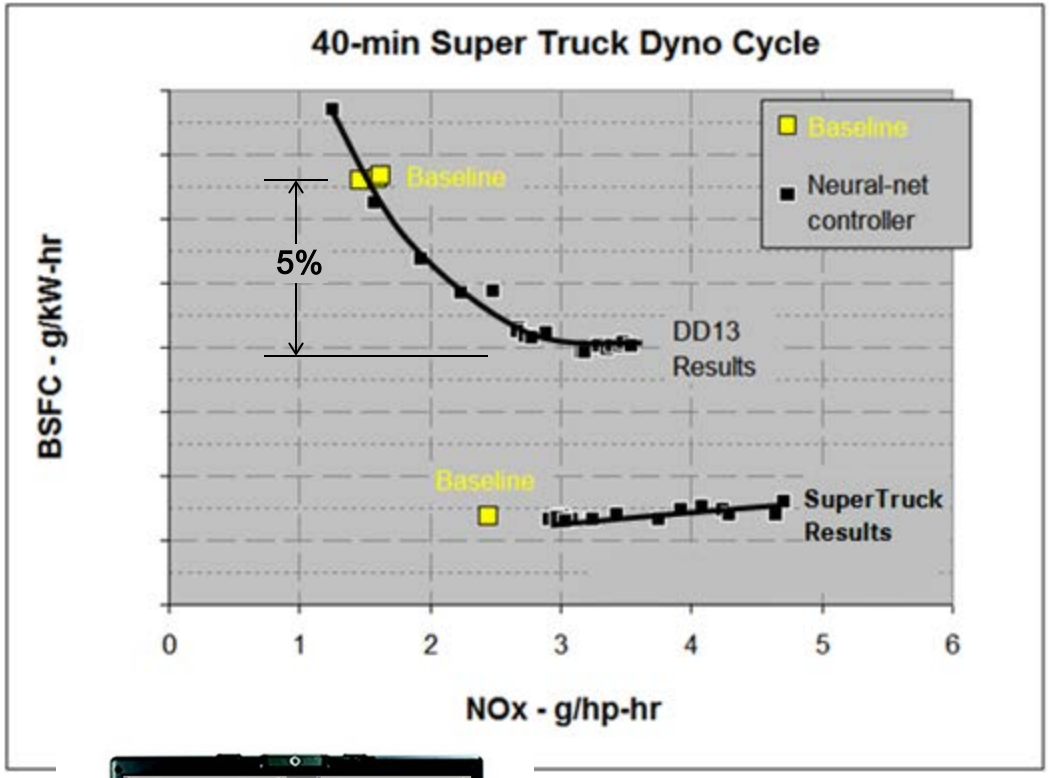
Predictive route information enables enhanced use of engine optimization.

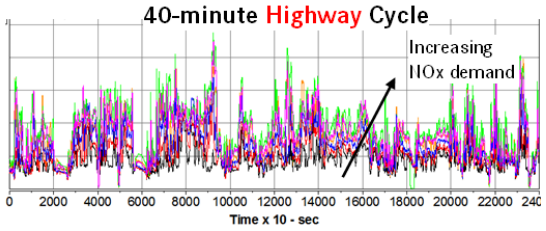
Calibration Constraints

- Drivability
- Durability
- Fuel economy
- Life-cycle cost
- NOx / PM / NMHC / CO_2
- OBD
- Exhaust temperature
- GPS / Route / Traffic info.



SuperTruck Engine Controller Results





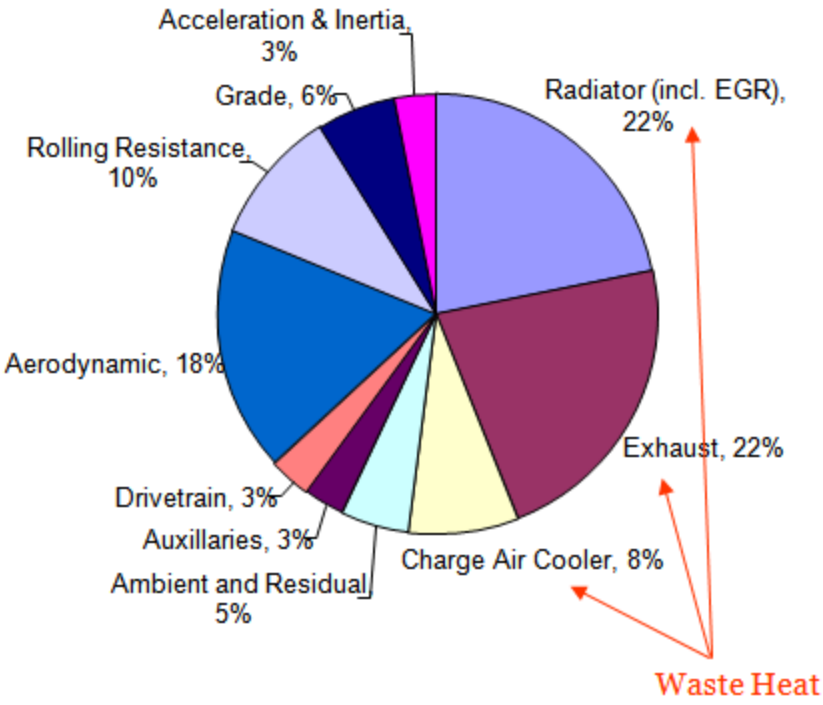
- Controller continues to performed well on DD13.
- System prepared for vehicle implementation.
- Recalibrated for SuperTruck engine in late 2012.
  - Controller showed no NOx vs. BSFC trade-off.
  - Table based calibrations did improve BSFC at high NOx.
  - Lesson learned: model was not trained over a wide enough range of actuator positions.
- Will re-train controller with finalized set of engine hardware (pistons, turbo, etc.).

Waste Heat Recovery (WHR)

- Waste heat recovery has significant potential for meeting efficiency goals.
  - Rankine cycle has the most potential among available options.
- Will recover energy from exhaust and EGR.

- SuperTruck objective: demonstrate 2% BTE improvement via WHR.
- Current Status: demonstrated 1.3% BTE with exhaust heat only. EGR boiler on engine and will be evaluated for BTE shortly.

Waste Heat Sources	Quality	Quantity
Exhaust	High	High
EGR	High	Low
CAC	Low	Low
Coolant	Low	High

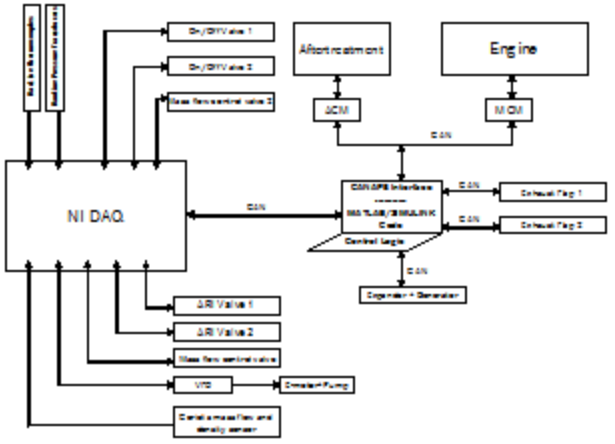


WHR -- Test Bed

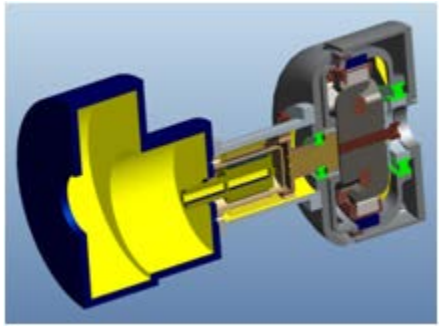
- Test stand functional with ethanol as the working fluid.
- Initial system characterization complete.
- EGR energy recovery now added to engine.
  - Targeting > 2% BTE with this configuration.

WHR -- Control System

- Test bed control system fully functional.
- Model refinements, diagnostics, and integration with other control systems ongoing.

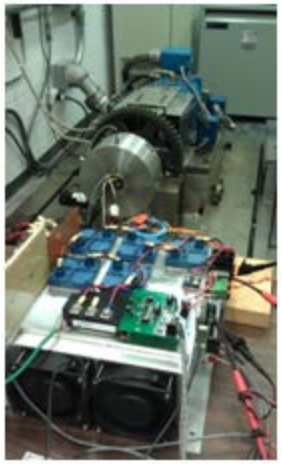


Generator Development



- ORNL developing new design generator for WHR.
  - Low cost wound field generator.
  - No inverter required, simple controls for voltage regulation, brushless, air cooled.
- Iteration 1 could only generate 20% of desired power.
- Iteration 2 generates desired power; mapping in process.

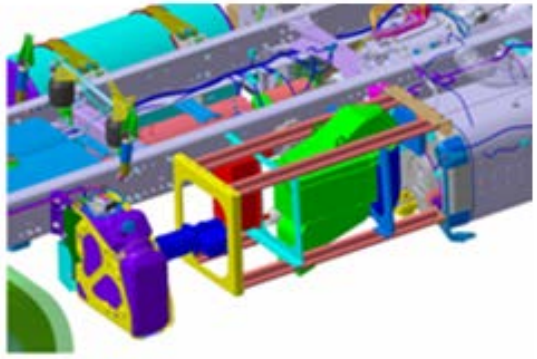
Generator Controls

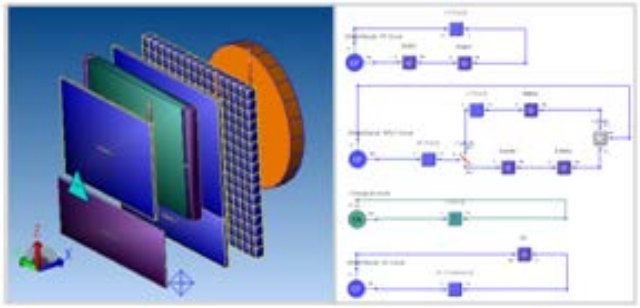


- Controls development and performance testing of the integrated expander and generator ongoing at ORNL.
- Demonstrated expander speed control and load dumping.

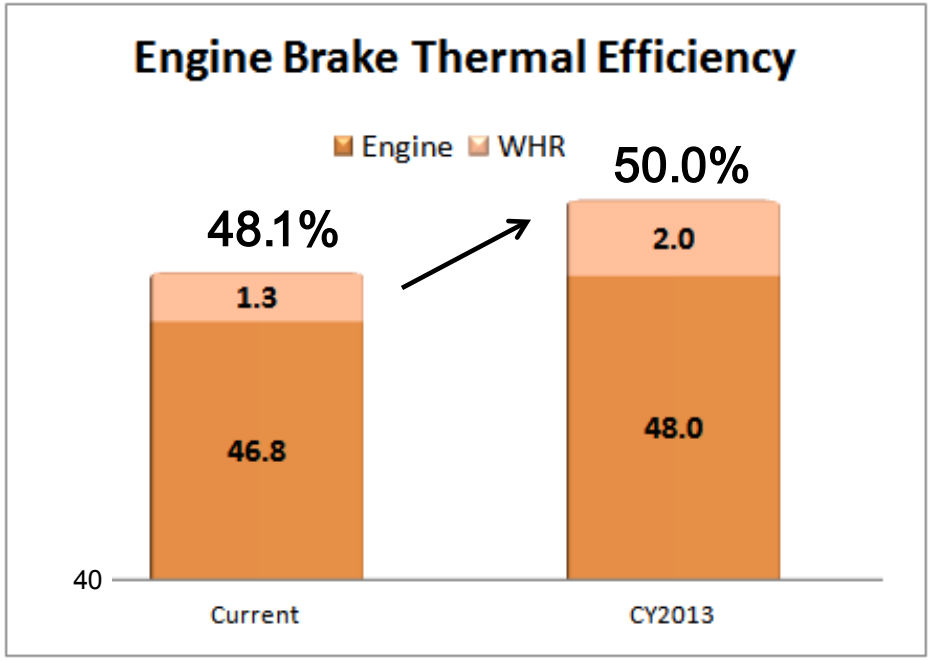
Waste Heat in Vehicle

- Vehicle packaging of Rankine components complete; system assembly in process.
- Build and test in 2013.



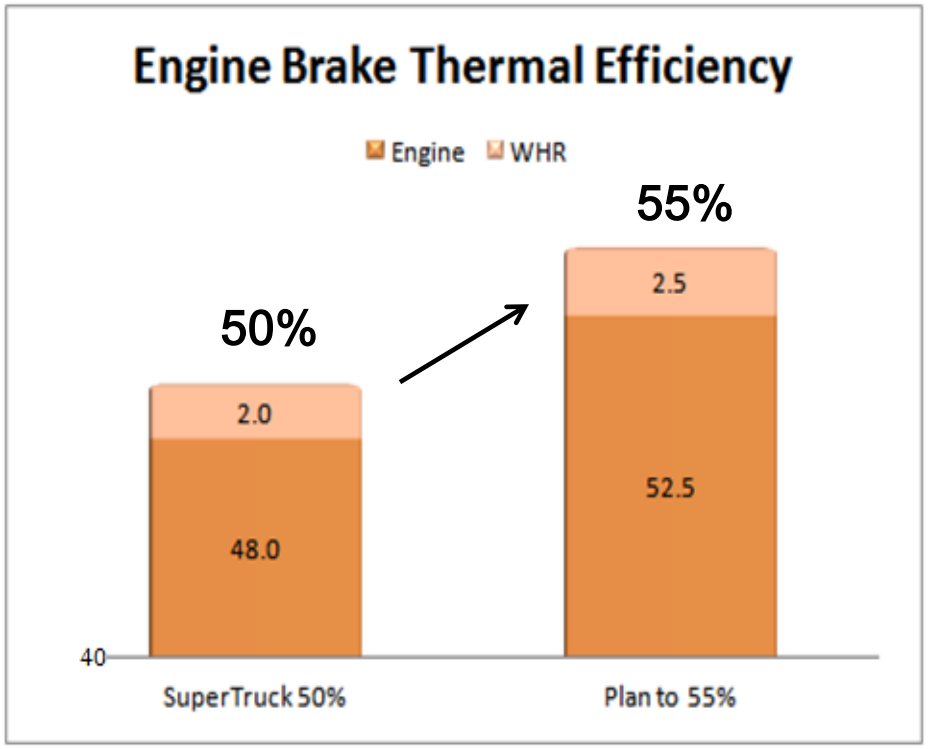


Plan to 50% BTE → Need 1.9%



- Engine → need +1.2%
  - Combustion system: new bowl shape, higher CR, higher PFP, fuel system optimized via DOE.
  - Turbo with reduced back pressure.
  - Parasitic reductions: liner cooling, cylinder kit improvements, oil system improvements, new oil.
- WHR → need +0.7%
  - Addition of EGR boiler.
  - Minor component optimizations (plumbing, etc.).

Plan to 55% BTE → Need 5.0%



- Engine → need +4.5%
  - Baseline model calibrated, will be refined for latest and greatest hardware when data is available (summer 2013).
  - Turbocompound will be engine tested.
  - Over 15 engine improvement items will be evaluated.
- WHR → need > +0.5%
  - System refinements.
  - Potential for coolant and/or charge cooler WHR.
    - WHR >> 2.5% BTE
- Results at end of year 4

SuperTruck Partnerships and Collaborations

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

Engine

- Massachusetts Institute of Technology
- Atkinson LLC
- BOSCH
- DAIMLER
- MAHLE Driven by performance
- Oak Ridge National Laboratory, Managed by UT-Battelle for the Department of Energy

Aftertreatment

- CORNING
- Eberspächer
- Johnson Matthey

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

- Achieved significant increase in performance; baseline 42% BTE, currently 48.1% BTE.
- Remaining 2 years of SuperTruck.
  - In the next 6 months, demonstrate 50% BTE.
    - Combustion system (pistons, CR ratio, fuel injection, etc.), new turbocharger, further reduced parasitics (liner cooling, cylinder kit modification, etc.) and WHR including from the EGR system.
  - Move to final engine validations and implementation into SuperTruck vehicle.
  - Define building blocks for 55% BTE.
  - Continued system refinements (controls, WHR including generator, etc.).