DAIMLER

Daimler's Super Truck Program; 50% Brake Thermal Efficiency

Mercedes-Benz FREIGHTLINER FUSO WESTERN STAR Thomas BUILT BUSES BHARATBENZ

2012 Directions in Engine-Efficiency and Emissions Research (DEER) Conference

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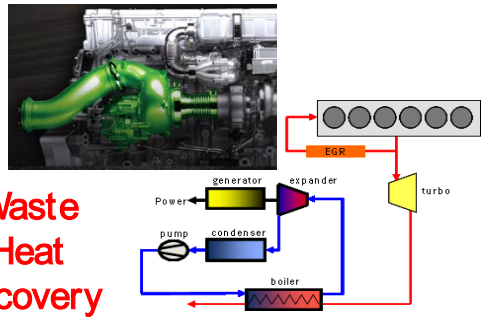
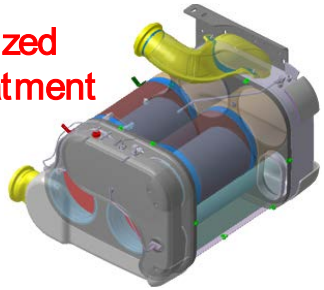
Detroit Diesel Corporation – Daimler Trucks North America

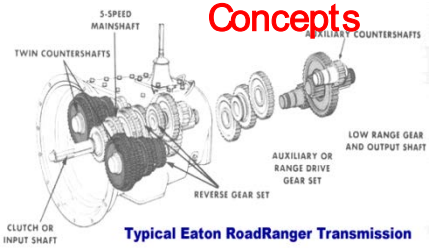
Super Truck Technology Elements



Waste Heat Recovery

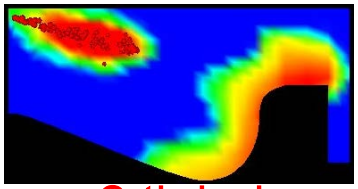


Optimized Aftertreatment



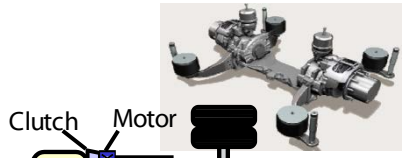
Advanced Transmission Concepts

Super Truck



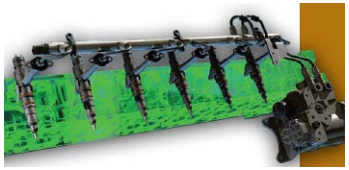
Optimized Combustion

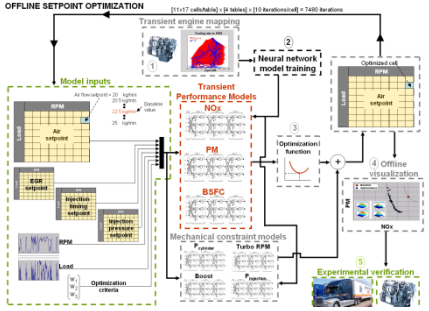
Aerodynamics



Hybrid Concepts

Enhanced High Pressure Fuel Injection System

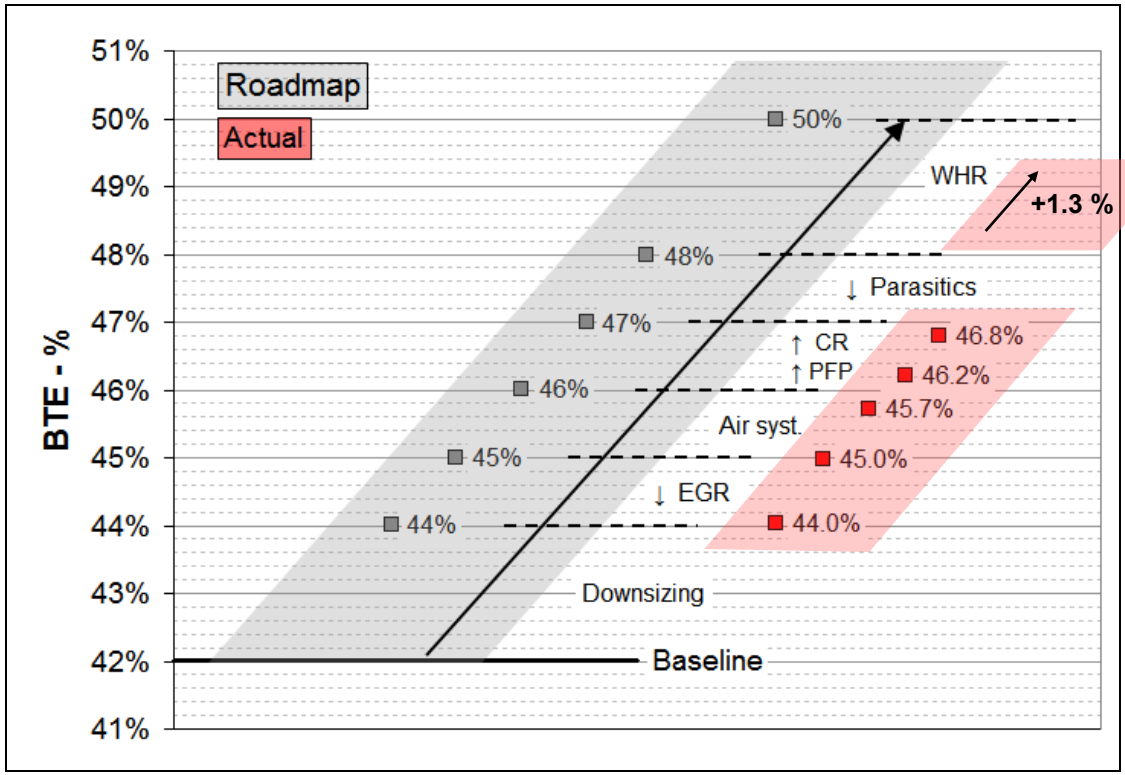




Next Generation Controller

Predictive Torque & Auxiliary Management

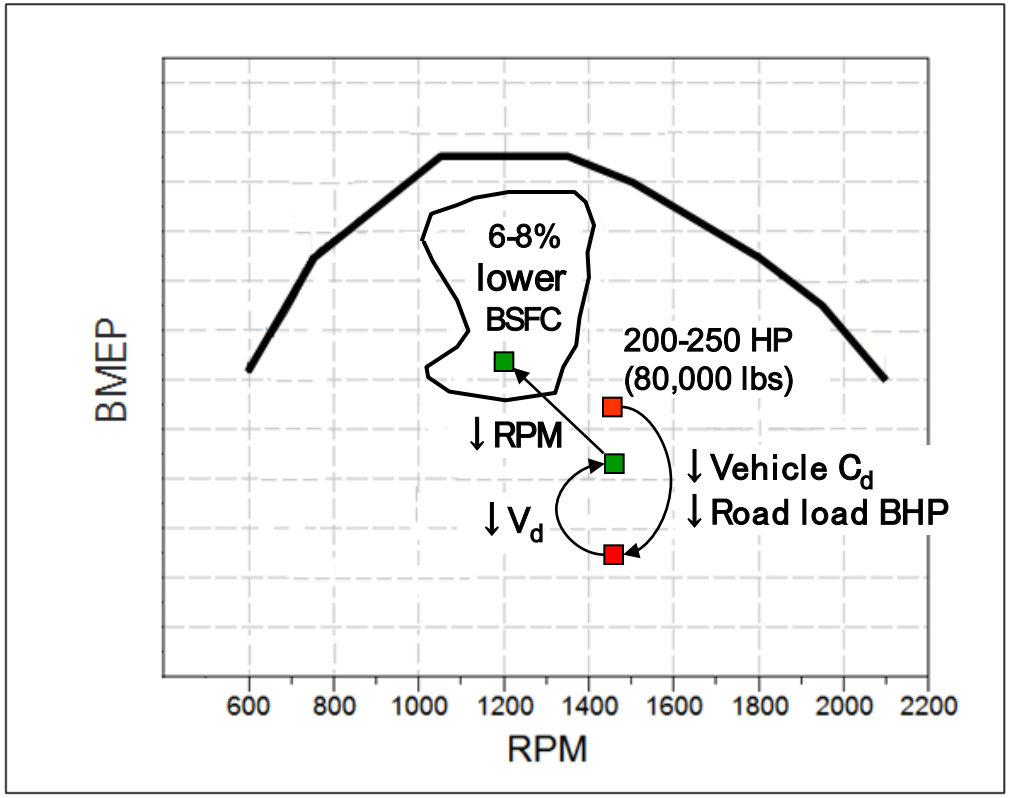
Super Truck Core Engine Development



Demonstrate 50% brake thermal efficiency via:

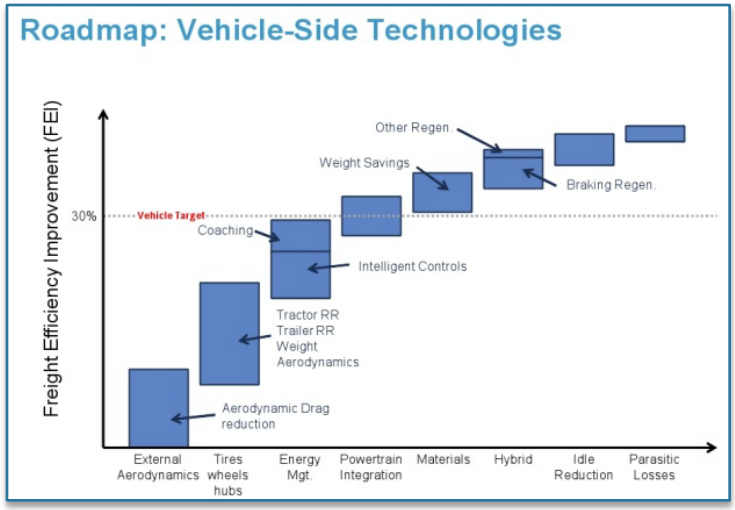
- Engine downsizing (higher BMEP)
- Higher compression ratio
- Improved combustion system
- Air system optimizations, reduced EGR
- Reduced parasitic
- Waste heat recovery

Engine Down-Sizing and Down-Speeding



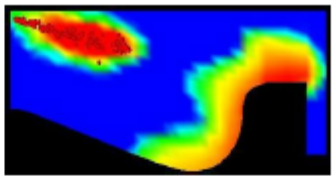
- Baseline '09 15-liter
- Super Truck 11-liter

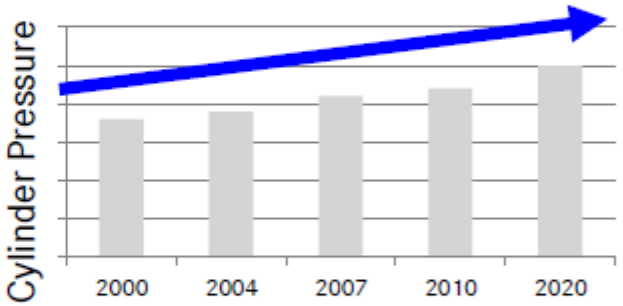
- Lower road load horsepower due to vehicle improvements
- Down-sized engine to raise road load BMEP
- Down-speeding for friction reduction
- BSFC reduction 6-8%

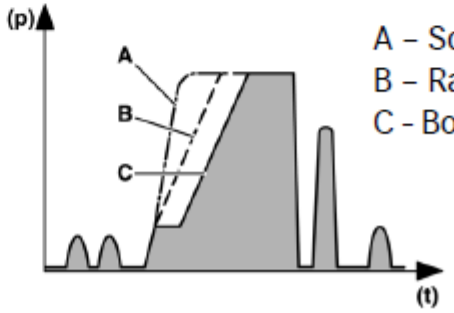


Combustion Efficiency

- Combustion Chamber
  - Piston / Head / Liner Shape & Robustness Refinement
  - Increased Compression Ratio & Cylinder Pressure
  - Thermal Coatings & Focal Point Cooling
- Injection
  - Evolutionary Nozzle Geometry
  - Optimized Hydraulic Flow
  - Dynamic Rate Shaping
  - Increased Injection Pressure
  - Multiple Injection

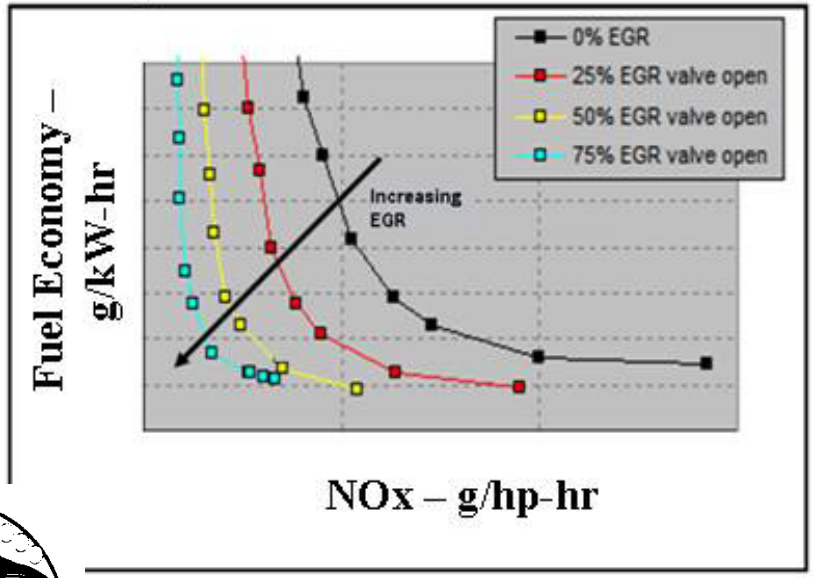


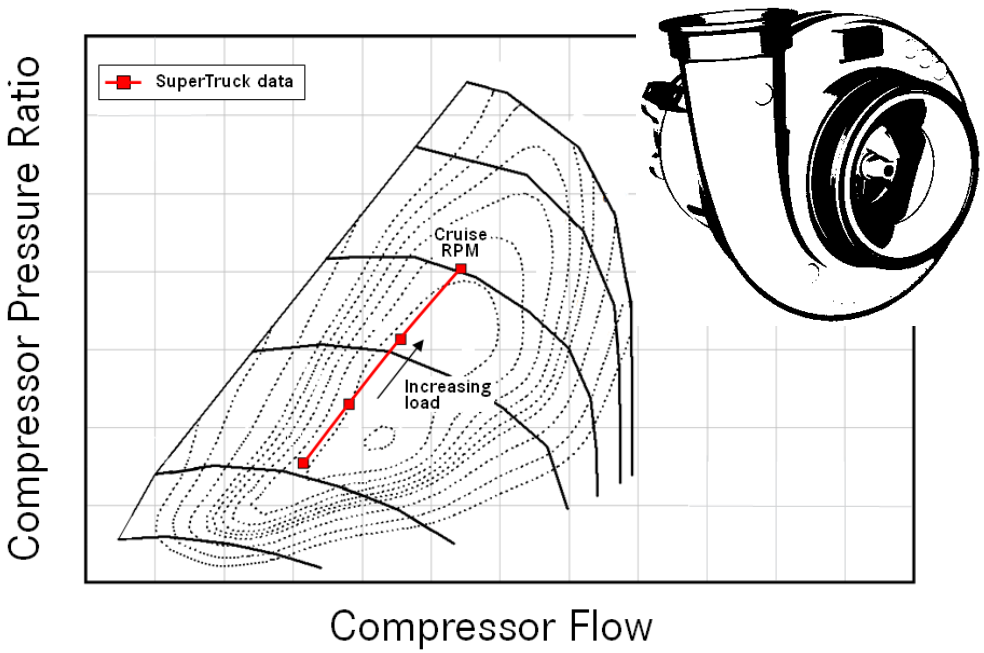




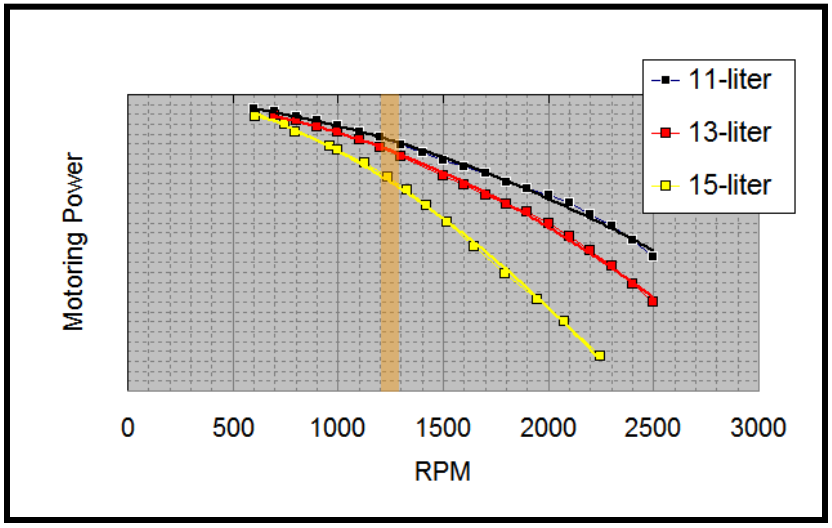
Air System Optimization

- Leveraging higher efficiency aftertreatment to reduce EGR rates
- Focus on turbocharger efficiency at cruise conditions
- Reducing pumping losses by adjusting turbine asymmetry

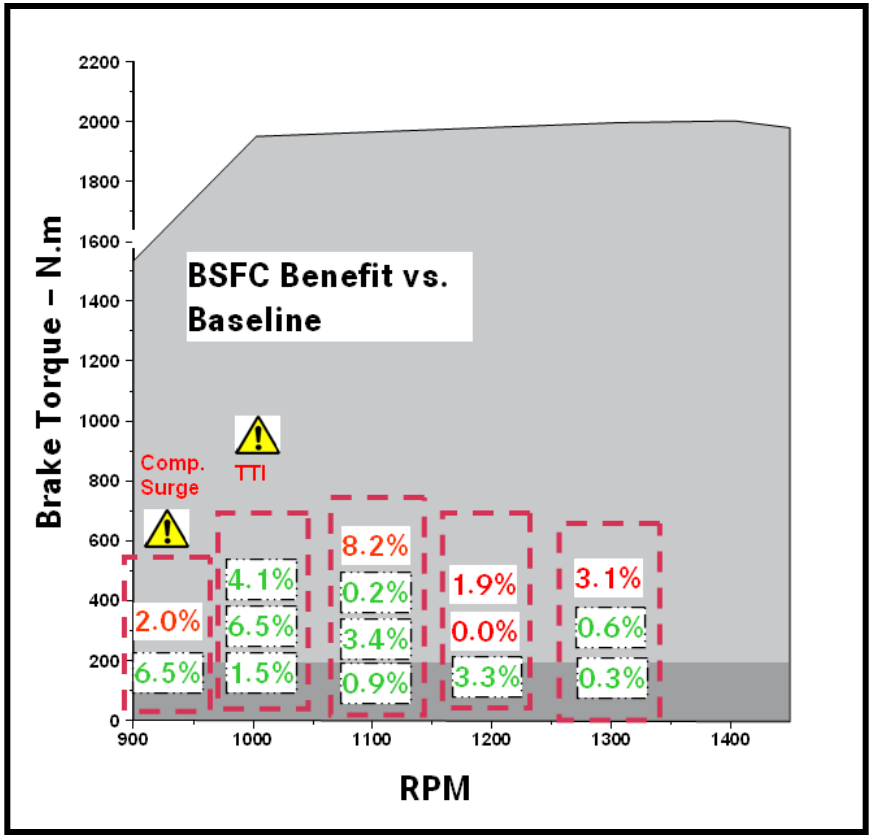




Engine Parasitic Reduction via Downsizing



- 40% motoring power reduction at cruise RPM
- Higher BMEP at road load

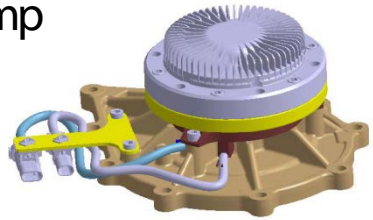


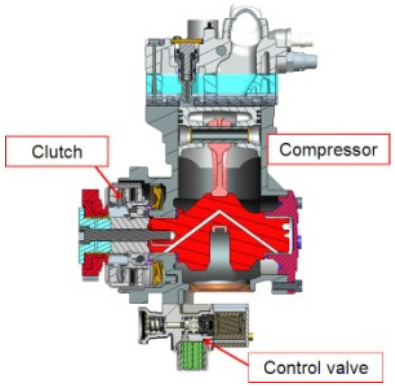
Cylinder Deactivation

- Cylinder deactivation as a way to increase BMEP
- Measurable BSFC benefit at low loads
- Limiting factors (namely exhaust temperature and airflow) necessitate turbocharger rematch.

Engine Auxiliary Load and Friction Reduction

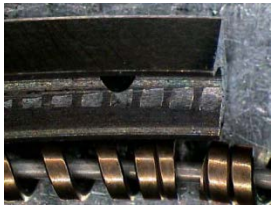
Variable speed water pump





Clutched air compressor

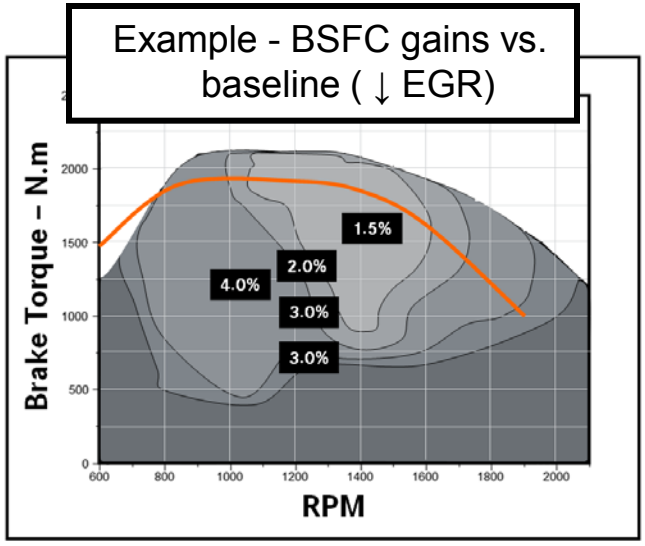
Reduced tension oil control rings



Miscellaneous related to pistons, liners, bearings

Low viscosity oil

High Efficiency Aftertreatment

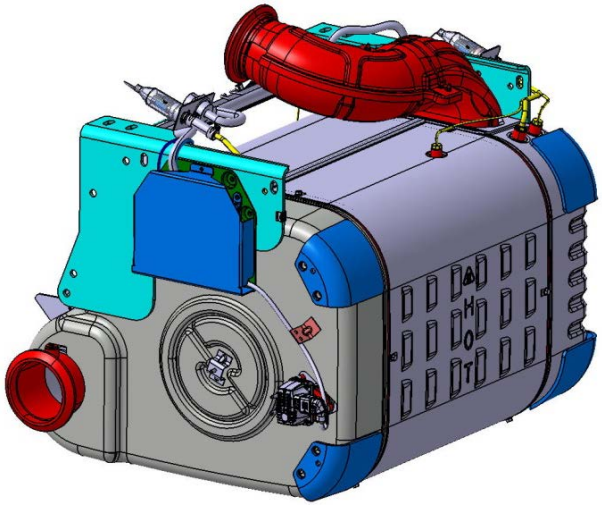


Motivation:

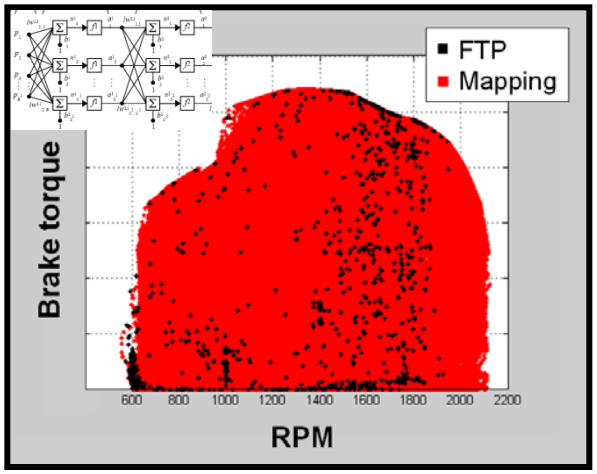
- Reduced EGR rates with turbocharger rematch enable higher thermal efficiency
- Secondary benefit – high NOx-PM ratio for DPF passive regeneration

Design Features:

- SCR w/ high efficiency for higher NOx flux – design challenges include packaging, backpressure, catalyst material
- Thin wall DPF for backpressure reduction
- Engine thermal management for good aftertreatment temperatures

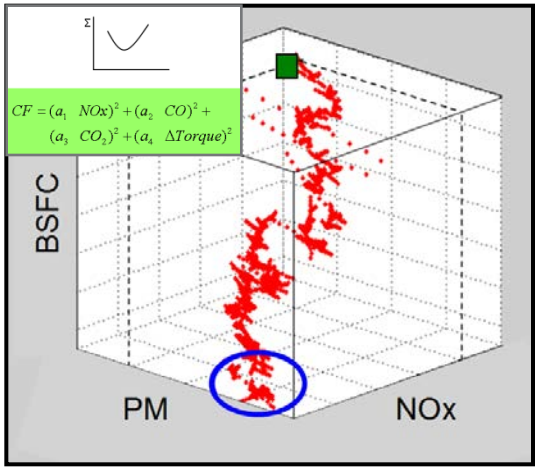


Neural Network Based Engine Controls

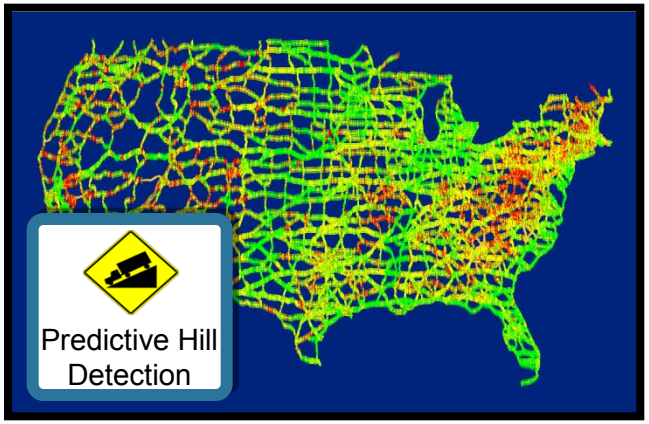


Extensive engine mapping is used in neural network model training

- Develop a predictive engine controller
- Include a fuel efficiency optimizer
- Integrate predictive vehicle information
- Reduce calibration complexity



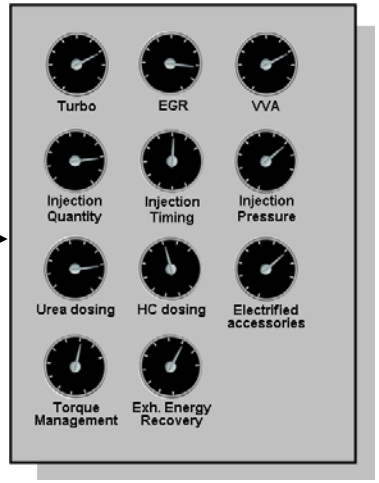
Emissions & fuel economy models enable on-board BSFC optimization



Predictive route information (GPS, terrain, traffic, etc.) to leverage the engine controller's ability to optimize the engine in real-time

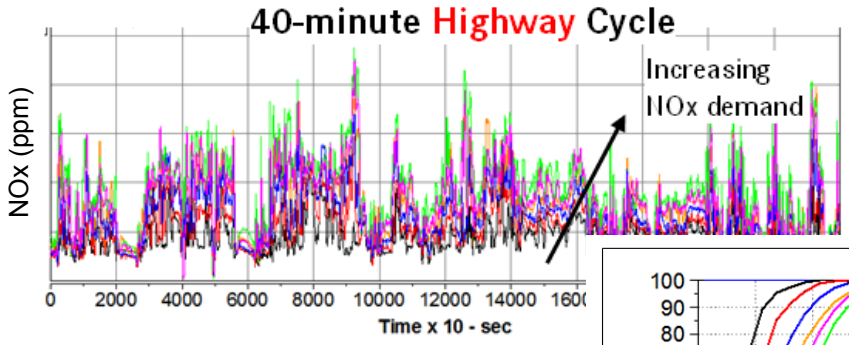
Calibration Constraints

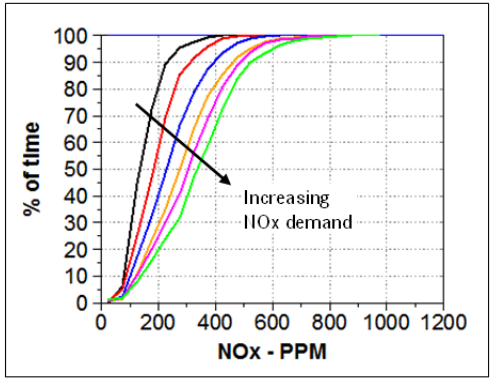
- Drivability
- Durability
- Fuel economy
- Life-cycle cost
- NOx / PM / NMHC / CO_2
- OBD
- Exhaust temperature
- GPS / Route / Traffic info.

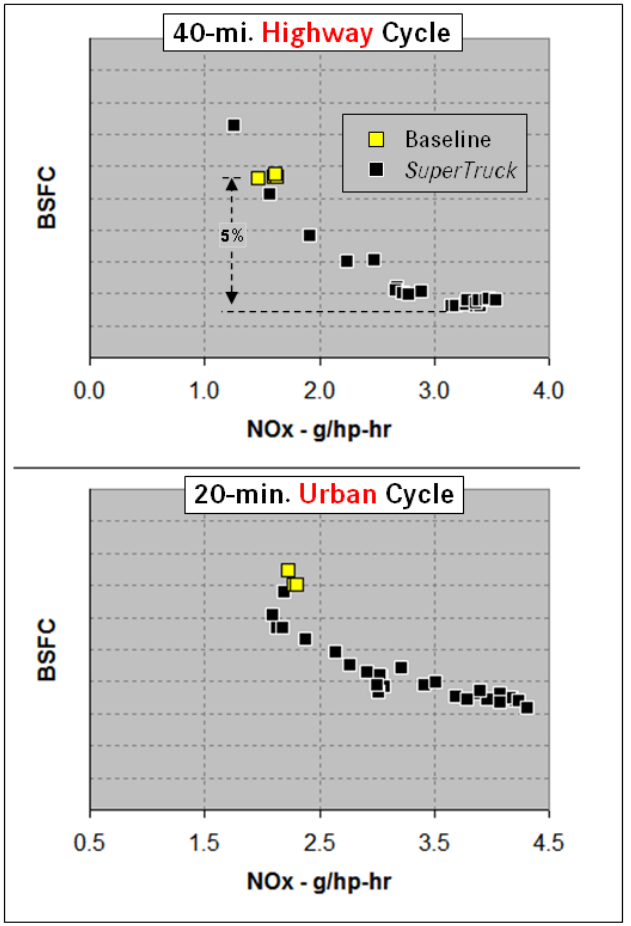


Neural Network Controller Evaluation

- Evaluated controller on Super Truck routes (20 and 40-minute dynamometer cycles)
- Demonstrated controller's ability to modulate NOx in real-time
- 5% lower BSFC over highway ST cycle
- Similar gains over urban ST cycle



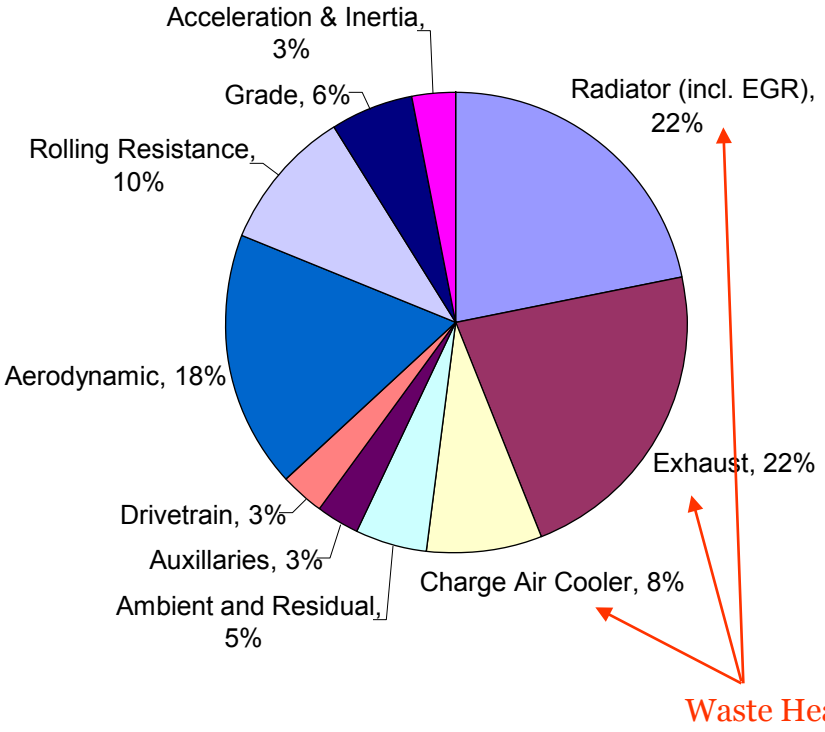


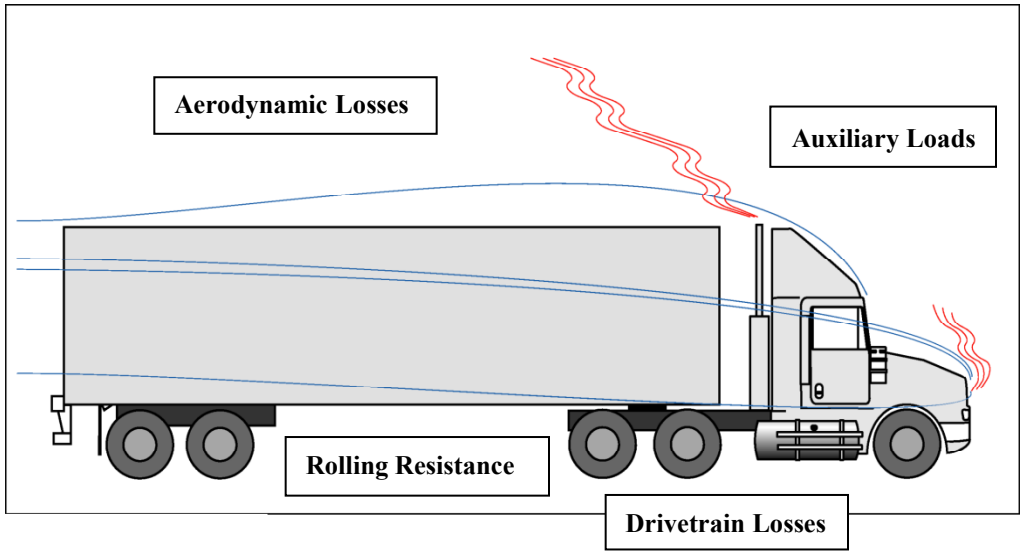


Waste Heat Recovery (WHR)

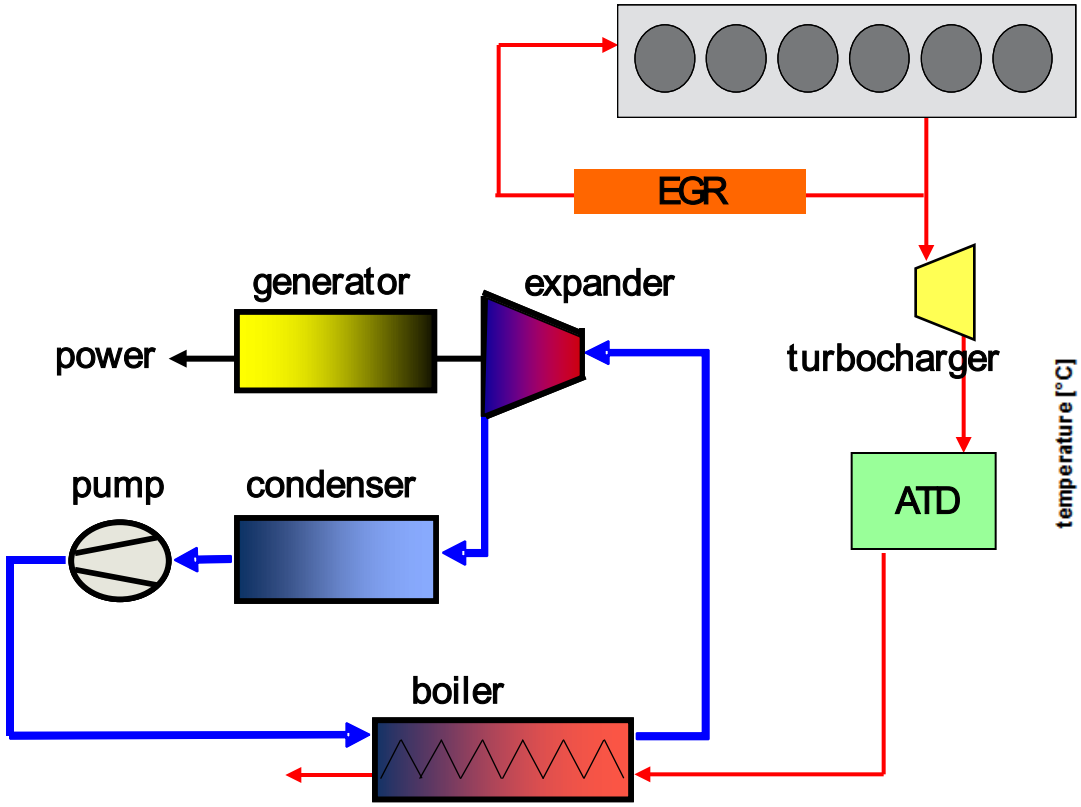
- Waste heat recovery on a heavy duty truck may become essential to meet long term efficiency goals
- Rankine cycle has the most potential among available options
- FE improvement targets in the range of 5 to 10%to make it a viable technology

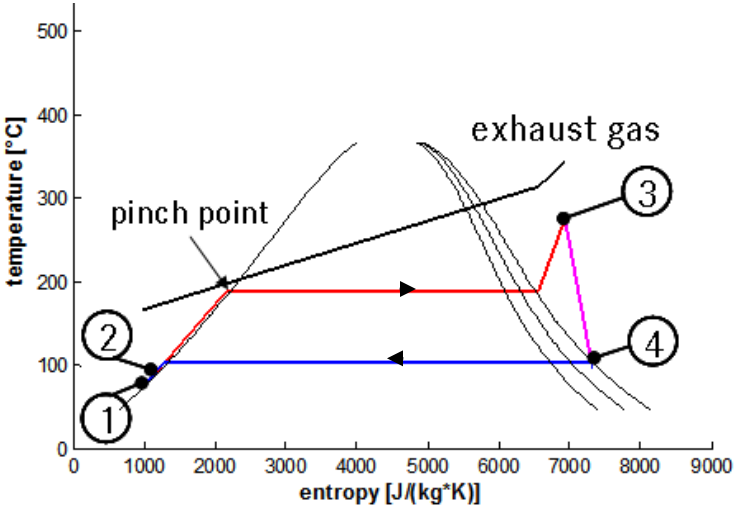
Waste Heat Sources	Quality	Quantity
Exhaust	High	High
EGR	High	Low
CAC	Low	Low
Coolant	Low	High





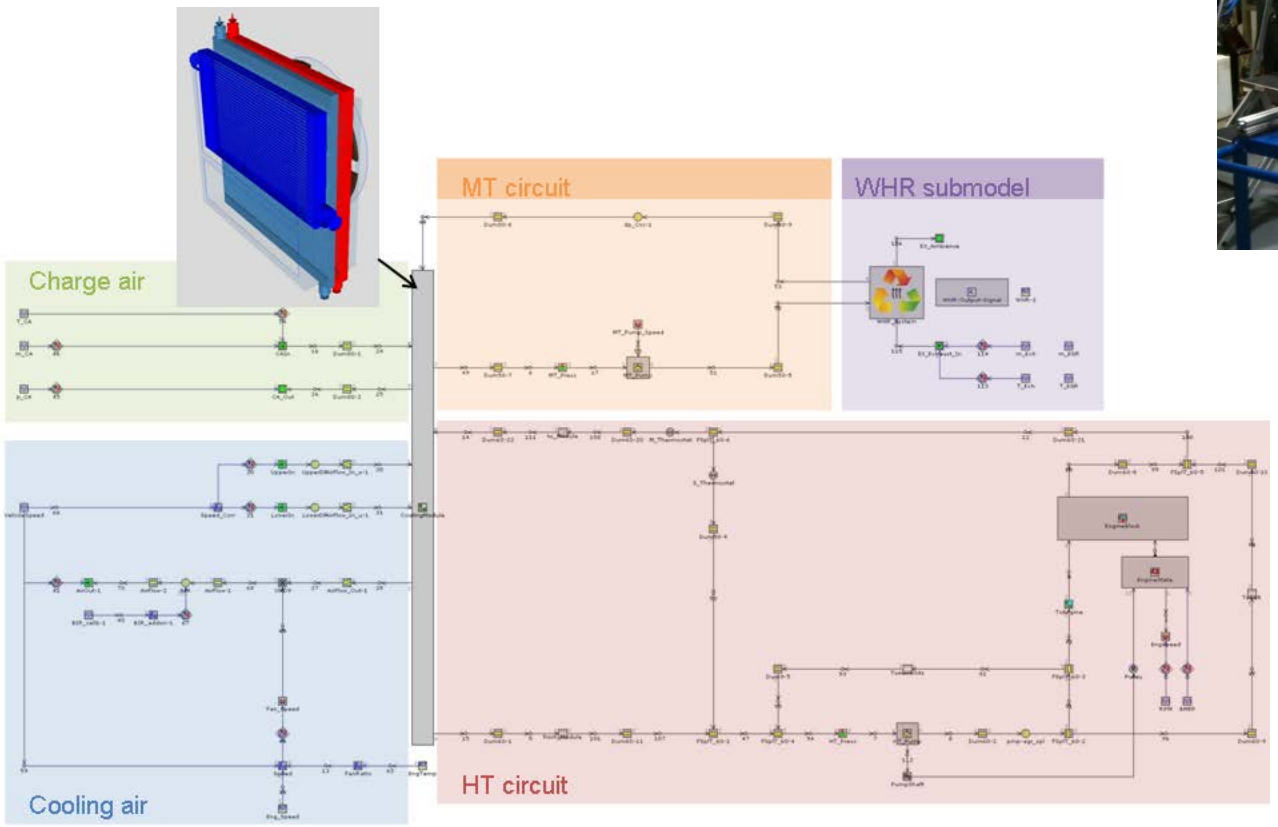
WHR Heat Engine – Organic Rankine Cycle (ORC)





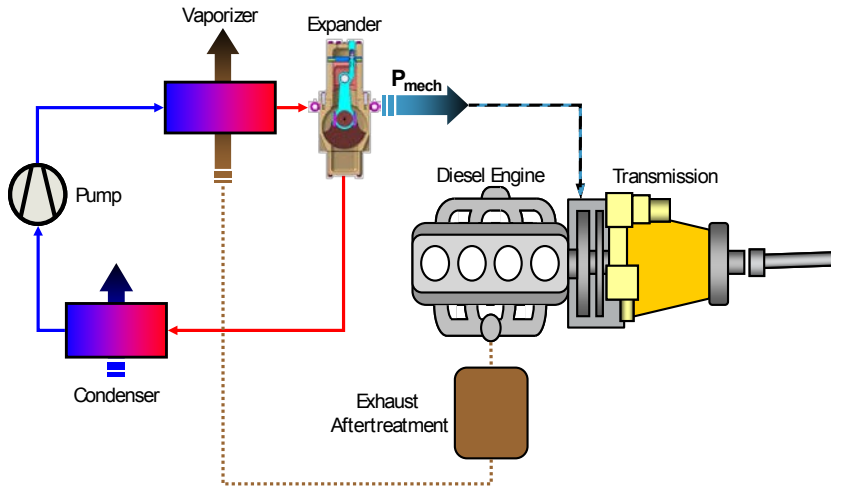
WHR Modeling & Testing for System Optimization

- Modeling of ORC at system level for both component sizing and overall system optimization
- Test bed representative of vehicle implementation in development



WHR Power Feedback

Mechanical



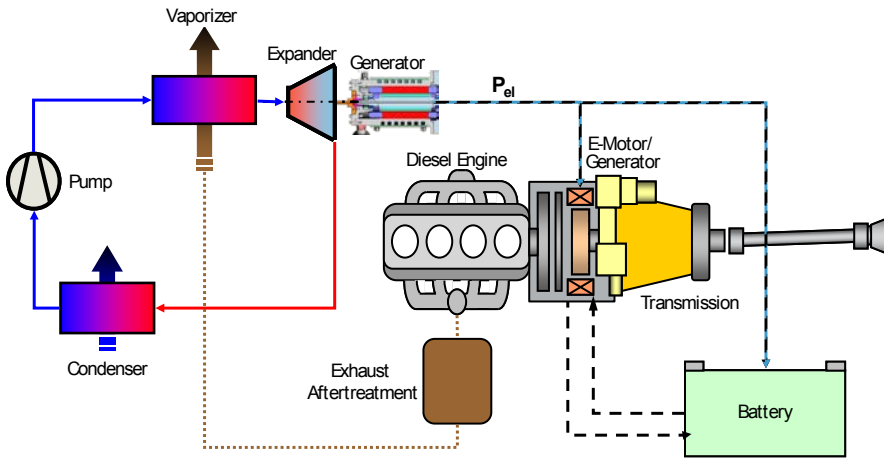
Pros:

- Low power loss by direct mechanical connection
- No batteries or e-motor required

Cons:

- No energy storage method
- Energy produced may not match power demand
- Slower expander or transmission required

Electrical



Pros:

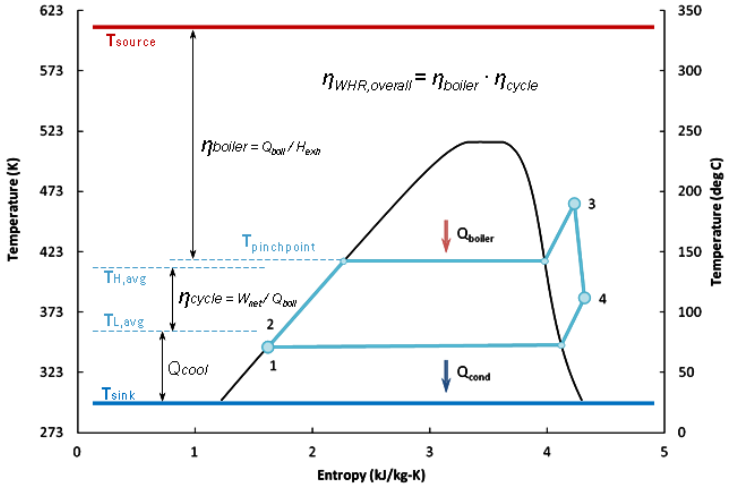
- Energy storage possible (with battery)
- Energy feedback according to vehicle power demand (if energy storage is possible)

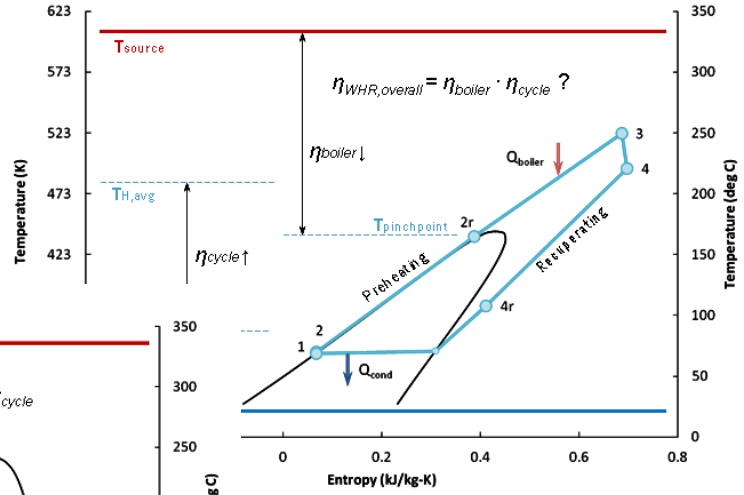
Cons:

- Losses converting mechanical power to electrical and back.
- Requires e-motor

ORC Working Fluid Selection

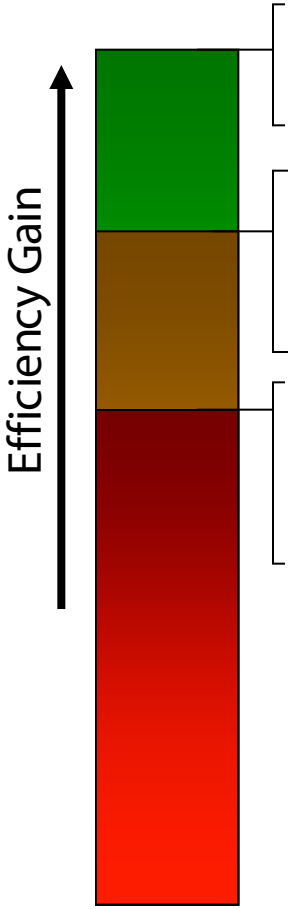
- ORC fluid selection is the primary step – other design factors cascade from it
- Ethanol is a good candidate. Other choices include – R245fa, water, Novec 649
- Definition of desired ideal ORC fluid and collaboration with chemical industry
- Selection criteria…
  - Thermodynamic efficiency
  - Fluid & system cost
  - GWP, ODP
  - Thermal Stability
  - Toxicity





Wet Vs. Dry Fluid

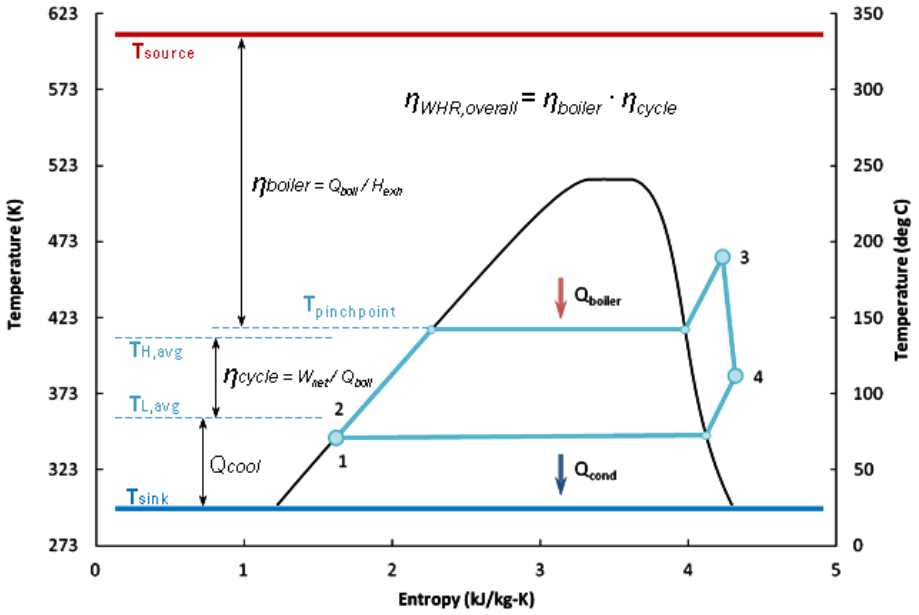
WHR Vehicle Integration



System & component design and efficiency
Working fluid choice

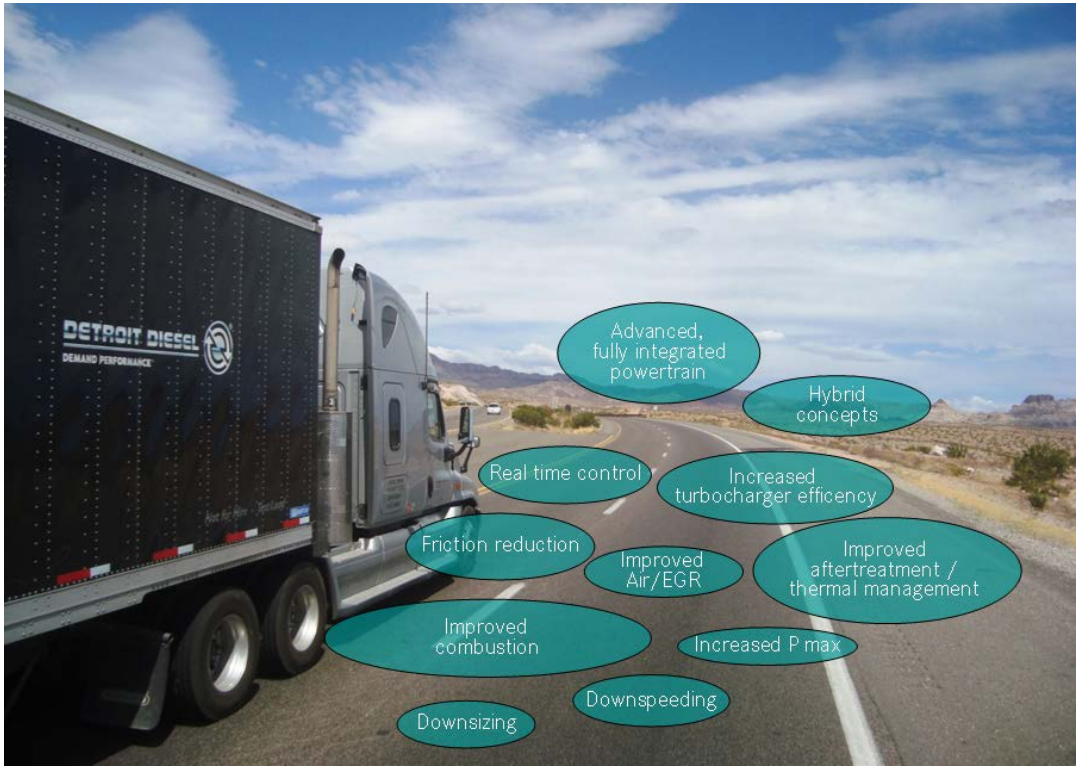
Vehicle tradeoffs -
Cooling burden, aero penalty
Optimization and operating parameters

Freight efficiency –
Component weight & packaging



Summary

- Engine technologies which translate to over the road freight efficiency improvements are crucial for future customer and regulatory demands
- Freight efficiency improvements require advancements in engine, power train, vehicle, and optimized system integration – put together this yields a Super Truck.



Collaboration and Support

Department of Energy Head Quarters

- Gurpreet Singh
- Roland Gravel

National Energy Technology Laboratory

- Carl Maronde

Oak Ridge National Laboratory

- Waste heat recovery system

Massachusetts Institute of Technology

- Low friction technologies

Atkinson LLC

- Advanced engine controls