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SUPERTRUCK 2

Improving Transportation Efficiency Through Integrated Vehicle, Engine, and Powertrain Research - SuperTruck 2

Darek Villeneuve, Principal Investigator, Vehicle
Jeff Girbach, Principle Investigator, Powertrain
Murad Bashir, Detroit Powertrain, Presenter

June 23, 2022

Daimler Truck North America

Project ID: ACE100

FREIGHTLINER FUSO WESTERN STAR Thomas BUILT BUSES BHARATBENZ

Overview

Timeline

Start
January 1, 2017

End
September 30, 2022

PH1	PH2	PH3	PH4	PH5

June 2022 Status= 95% Complete

Technical Targets

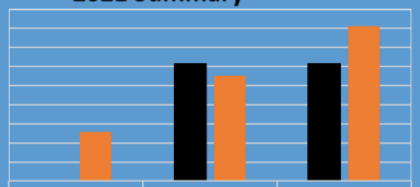
- Greater than 115% improvement in vehicle freight efficiency (on a ton-mile-per-gallon basis) relative to a 2009 baseline.
- Greater than or equal to 55% engine brake thermal efficiency demonstrated at 65 mph on a dynamometer.
- Develop technologies that are cost effective

Budget

Project Total $40Mil

DOE Share	$	20,000,000
Michelin	$	1,000,000
ORNL	$	500,000
NREL	$	203,254
Detroit Share	$	12,468,918
DTNA Share	$	5,827,829

2021 Summary



	DDC	DTNA	Total
Planned	-	1,227,880	1,227,880
Actual	513,352	1,107,462	1,620,814

Project Partners

- Schneider National
- Strick Trailers
- Michelin
- Oak Ridge National Laboratory
- National Renewable Energy Laboratory
- University of Michigan
- Clemson University

Relevance and Objectives

Phase 1
- Simulation
- Goal Setting
- Main Path & Stretch Path Defined

2017

Phase 2
- Main Path Design
- A-Sample Design Release
- Bench Testing

2018

Phase 3
- A-Sample Build & Test
- 40%/100% Clay
- Content Selection
- Final Demo Design

2019

Phase 4
- Finish Final Demo Design & Build
- Optimization

2020/2021

Phase 5
- Final Demo Optimization
- FE Validation Test
- Final Report

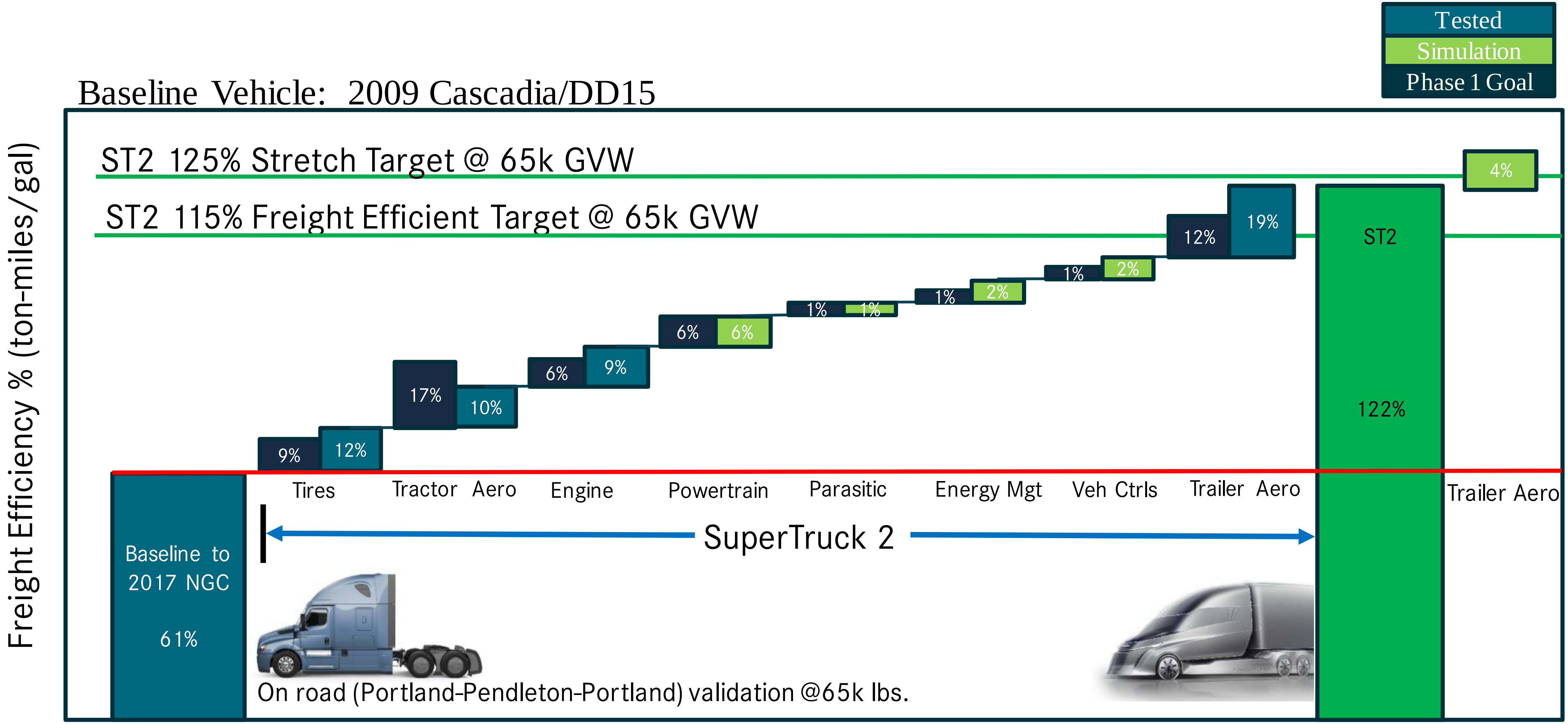
2021/2022

Program status

Phase	Milestone	Status	Completion Date
Phase 5	Final Demonstrator FE Validation Test Complete	65%	Q3 2022
	Final ST2 Engine Bench Testing Complete	97%	Q3 2022
	Final ST2 Report Complete	10%	Q4 2022

Reduced fuel consumption plan in HD long haul

Approach – SuperTruck 2 Roadmap



Focus on high potential workstreams

Technical Progress - Exterior Development

Aerodynamic Component Testing

- Exterior tested on road, performed better than CFD
- Tractor and trailer aero performed less than predicted
- Still on track to exceed overall program targets
- Several patents applied on vehicle exterior

Final Demonstrator Build Completed

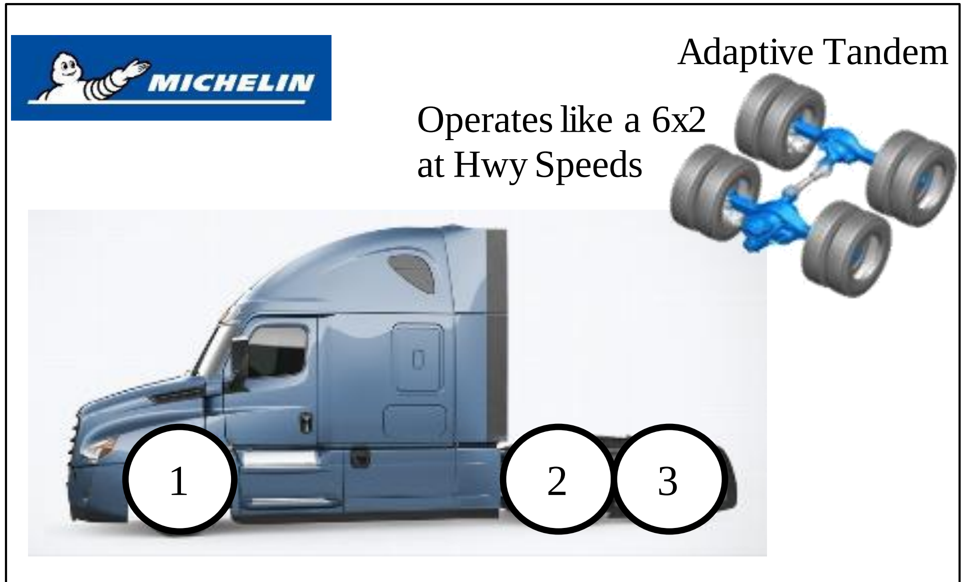
- Final demonstrator built
    - Engine installed/started in July 2021
    - First drive Sep 2021
- Upgraded software on several features
- Resolved several transients during 48v integration

~12% reduction in aerodynamic drag over SuperTruck 1

Technical Progress – Chassis Developments

Michelin Prototype Tires

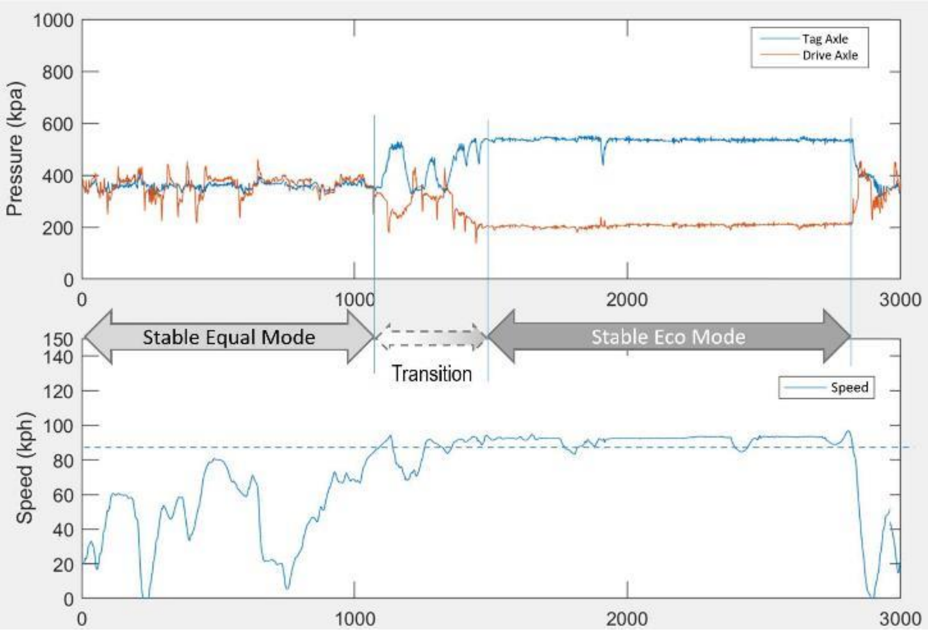
- Three new prototype tires assembled to FD
- Optimized for Adaptive Tandem



1. Steer Tire 2. Drive Tire 3. Tag/trailer tire

Dynamic Load Shift (DLS)

- Air liner suspension adjusts pressure to shift load to tag/steer tires with lowest rolling resistant tires
- Axle load determined by suspension pressure.

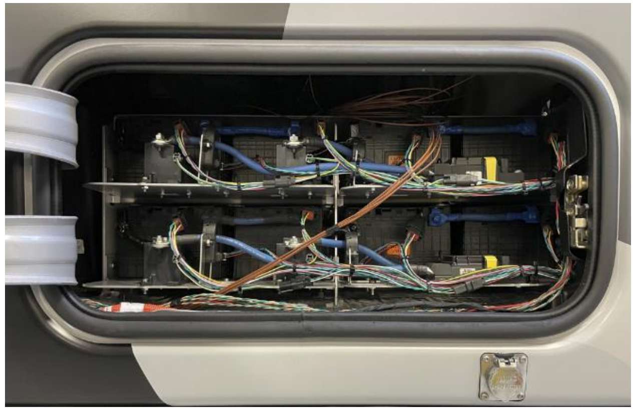


~12% reduction in tractor rolling resistance over SuperTruck 1

Technical Progress – Mechatronics & Controls

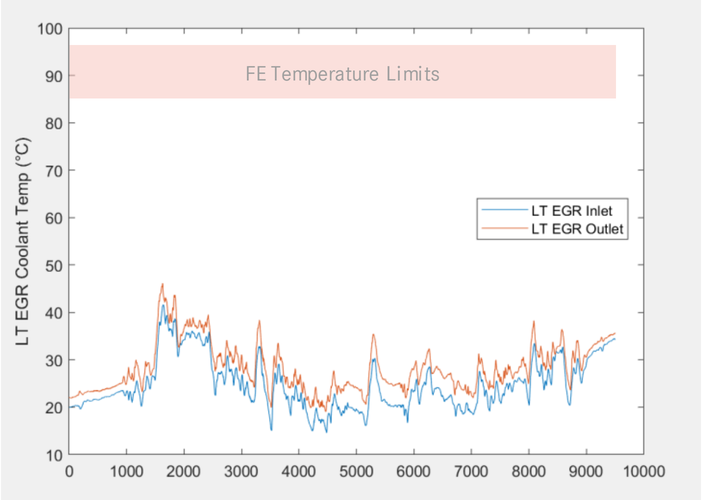
Energy Storage

- 8.4 kWh LTO battery capacity
- Commercial battery, integrated BMS
- CAN messaging integrated into vehicle



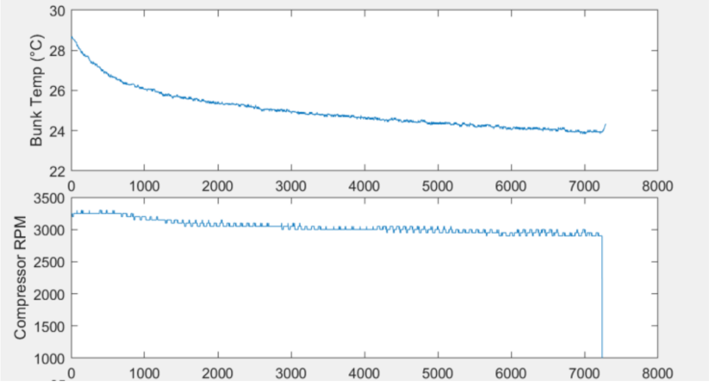
Low Temp Cooling System

- 48v pump (CAN interface)
- Additional engine cooling circuits
- More powerful BRM / location
- LT radiator position change



Stationary eAC Testing

- 100°F, 600 W/m2 Solar and 50% RH
- 4 kWh consumption in simulation
- Several tests ran for calibration
- Confirmed operational and system reliability



Architecture enabled for energy optimization

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SUPERTRUCK

SuperTruck 2 Powertrain

Jeff Girbach, Principle Investigator, Powertrain
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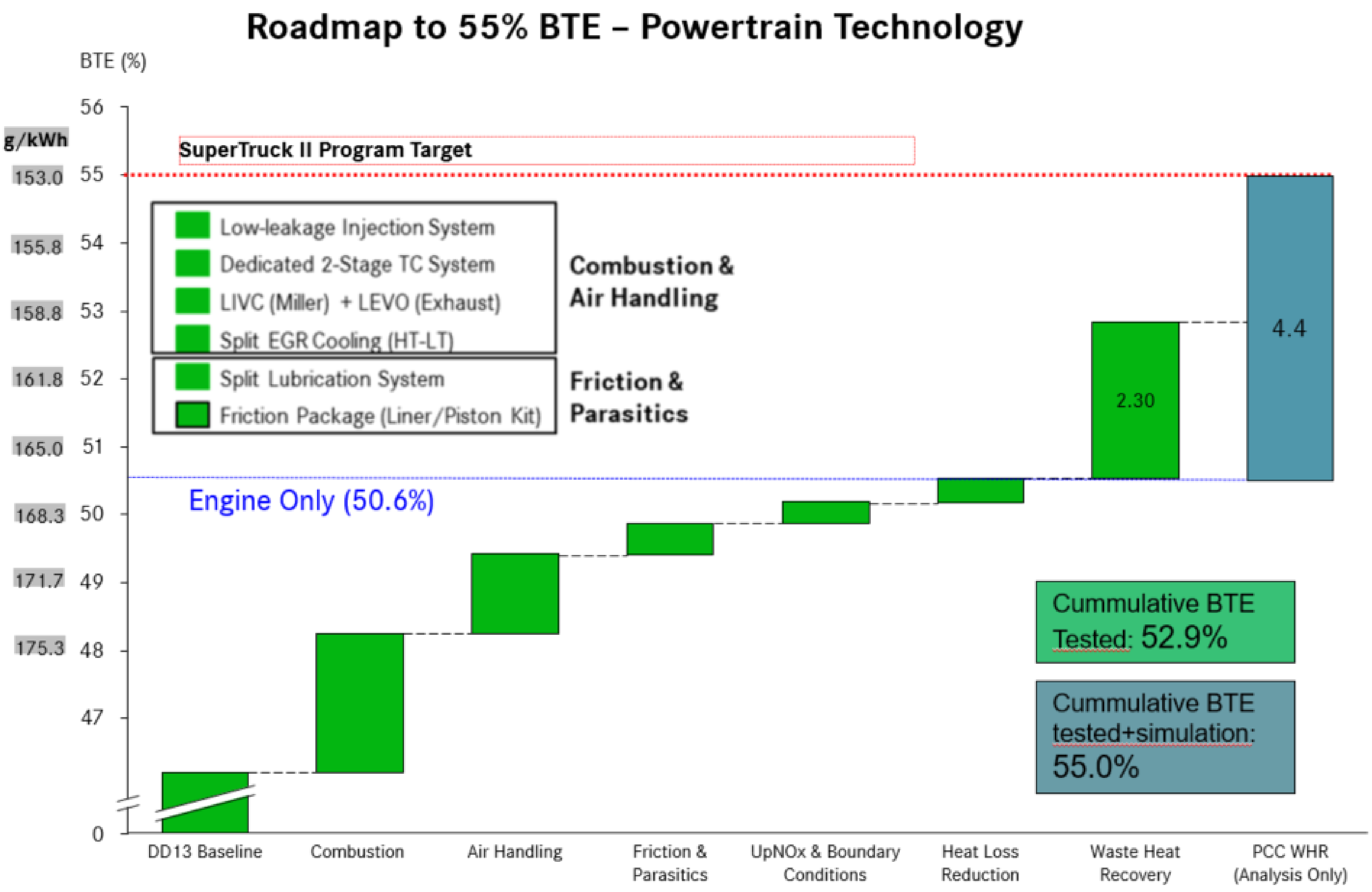
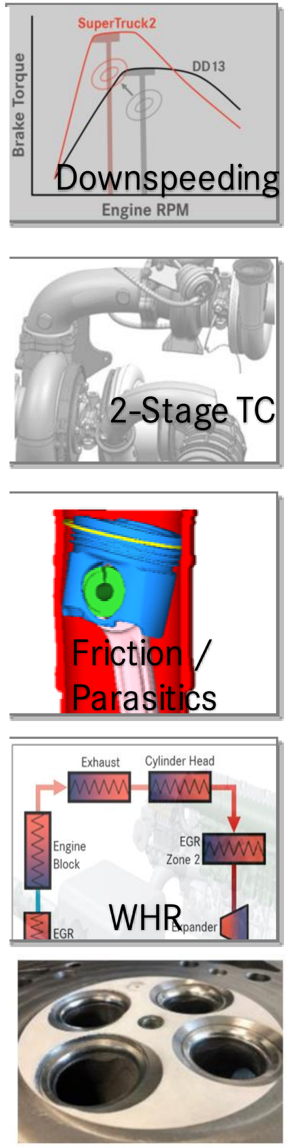
June 23, 2022

Daimler Truck North America

Project ID: ACS100

Overview





Technologies included in final tested configuration:

Downspeeding + Air Handling

- Two stage turbocharging
- Interstage cooling

Air Handling

- Miller cycle intake valve timing & late exhaust valve opening
- Two stage EGR cooling

More Efficient FIS / Combustion

- Low loss FIS
- High peak firing pressure
- New combustion design

Friction & Parasitics

- Liner surface conditioning
- Coated piston rings & pin
- Twin drilled crank and oil flow reduction
- Active piston cooling jets
- Low viscosity oil

Heat Loss Reduction

- 'Dynamic' thermal barrier coatings

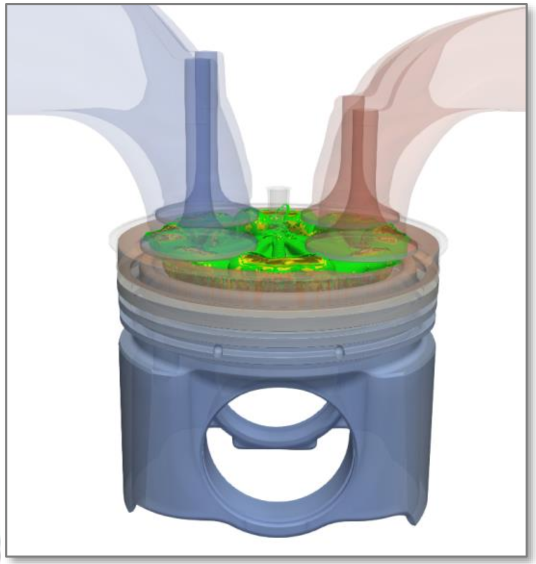
Waste Heat Recovery

- Cyclopentane WHR (tested)
- Phase Change Cooling WHR (pending)

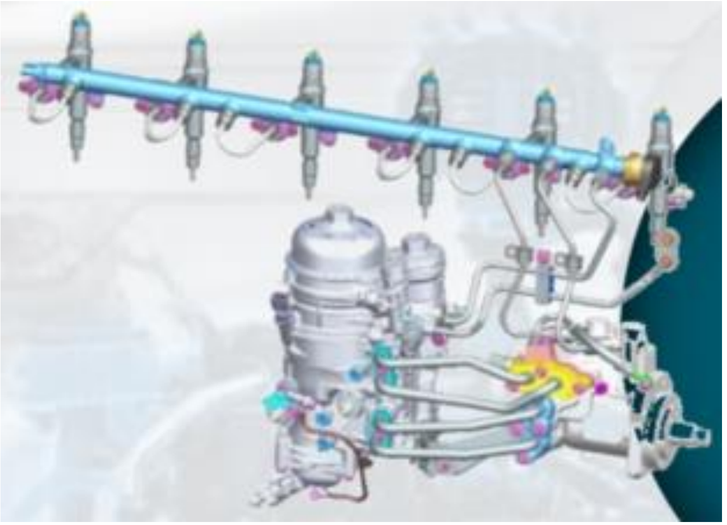
Aftertreatment

- Close-coupled SCR

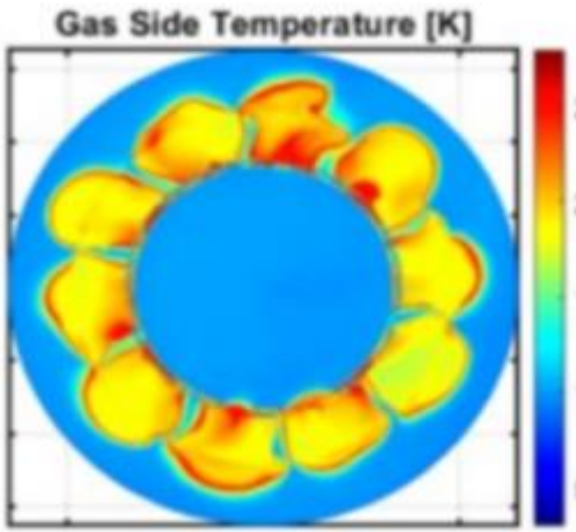
Combustion & Fuel Injection System

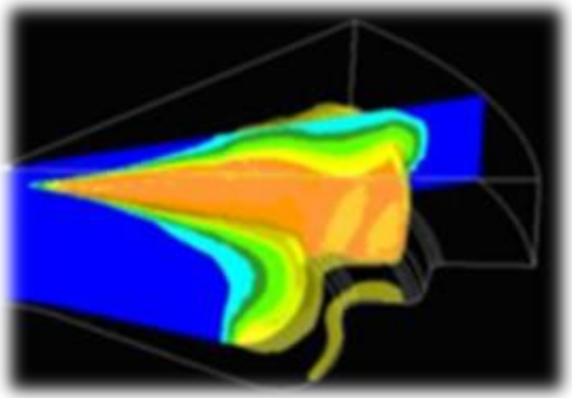


Combustion and FIS Approach:
- All new combustion approach, plus all new FIS
- Largest contribution total to core engine BTE improvement



FIS
- New FIS with reduced system losses
- Equal engine-out NOx emissions



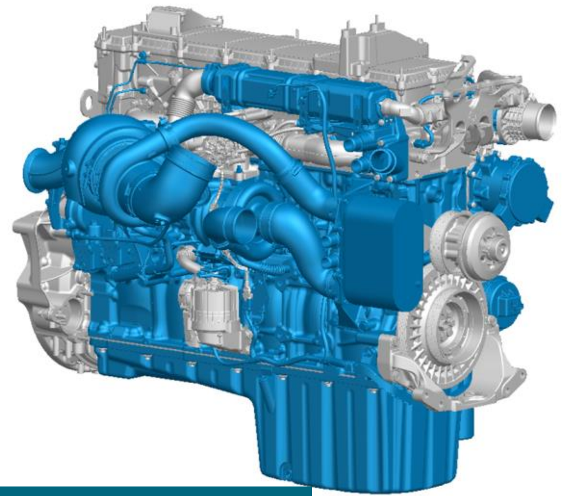


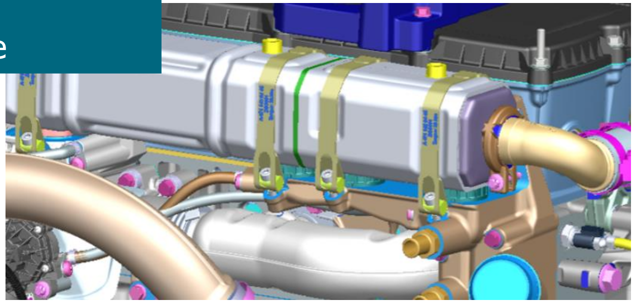
New Combustion System
- Optimized Piston Bowl Shape and Spray Pattern to maximize combustion efficiency and improve soot/NOX trade-off
- Faster combustion and better air utilization resulting in less smoke
- High peak firing pressure, high compression ratio

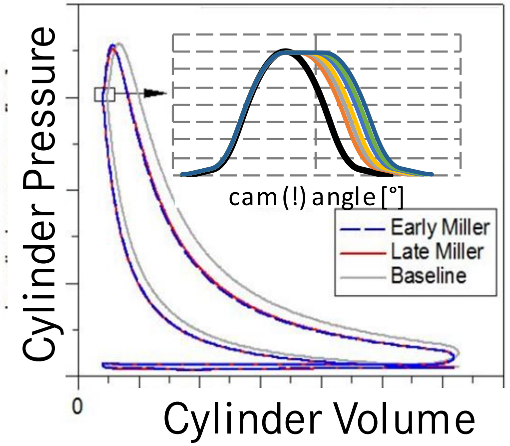
Air Handling System

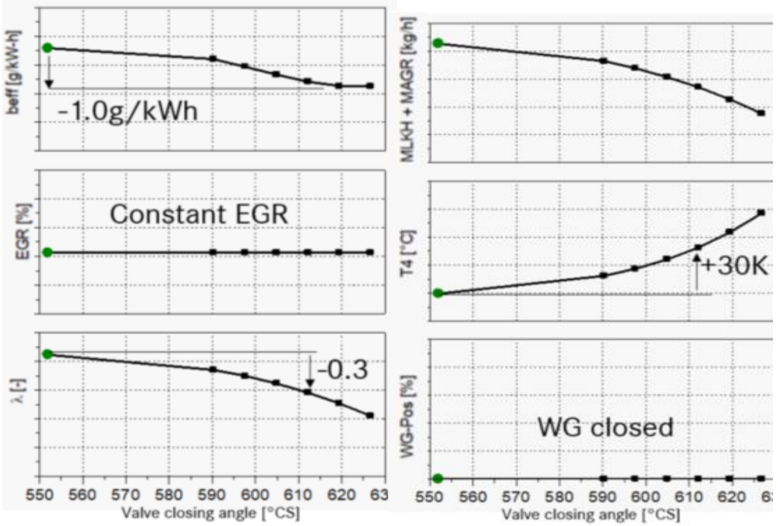
Air Handling System Approach:

- Two stage turbocharging with low temperature interstage cooling
- Two stage EGR cooling, with low temperature final stage
- Miller cycle cam timing
- Integrated with low temperature cooling circuit on vehicle







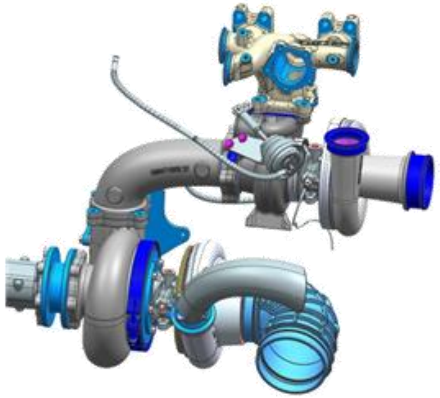


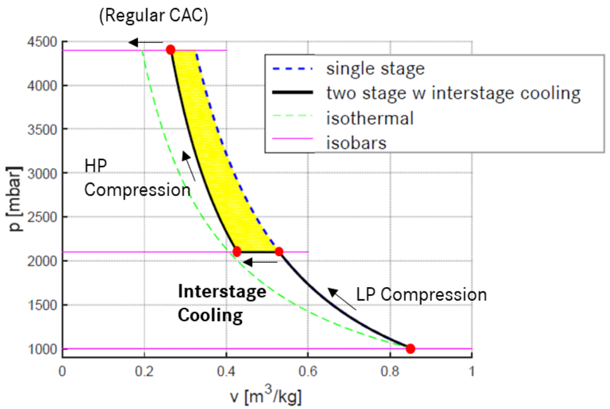
2-Stage EGR Cooler

- Lower charge temperature for Increased fuel efficiency and reduced engine out NOx emissions

Inter-stage Cooling

- Uses water from vehicle low temperature cooling circuit
- Very low interstage temperatures lead to more efficient compression work, and colder air charge





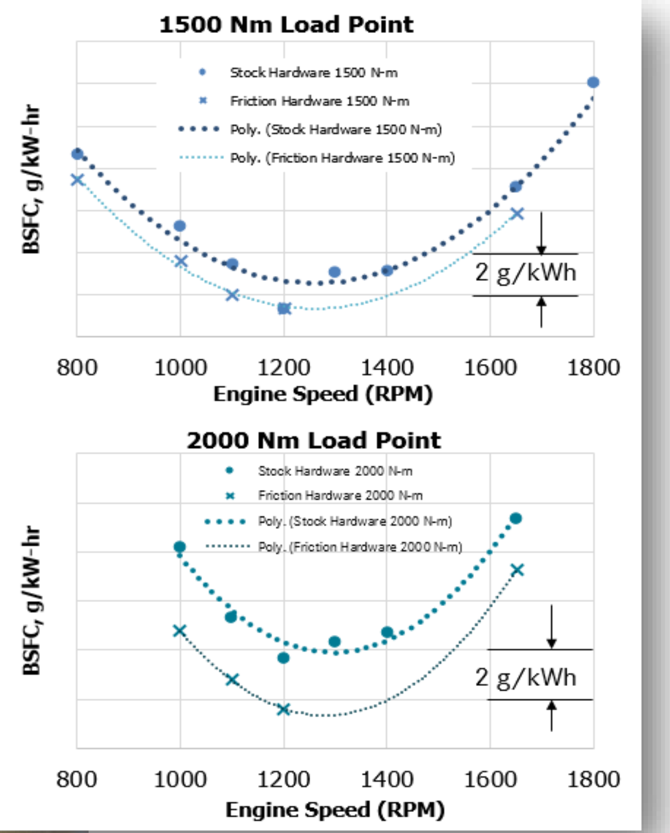
Miller Cam Timing:

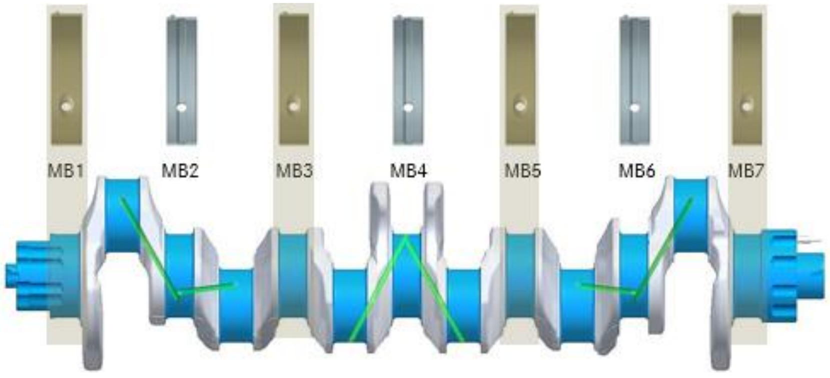
- Improved expansion / compression ratio
- Two stage turbocharger can compensate for reduced filling
- Shifts the compressor work from crank / piston to the turbocharger system

Engine Friction and Parasitics Reduction

Friction Approach:
- Focus on highest friction losses – slider/crank mechanism
- Plasma sprayed low friction liner surface
- Low friction, high hardness piston pin coating
- Low friction, high hardness piston ring coating
- Low viscosity / HTHS oil selection

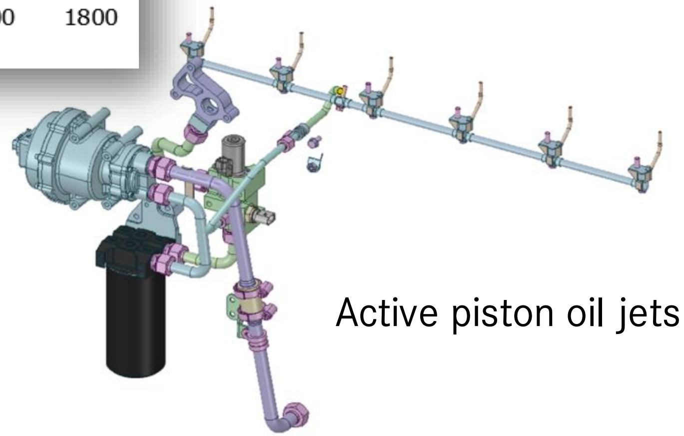
Parasitic Reduction Approach:
- Reduction in oil flow rates with downsized oil pump to reduce parasitic load on engine
- Twin-drilled crankshaft, reduce angle oil grooves, reduced overhead oil use.
- Controllable piston oil jets





Twin drill crankshaft

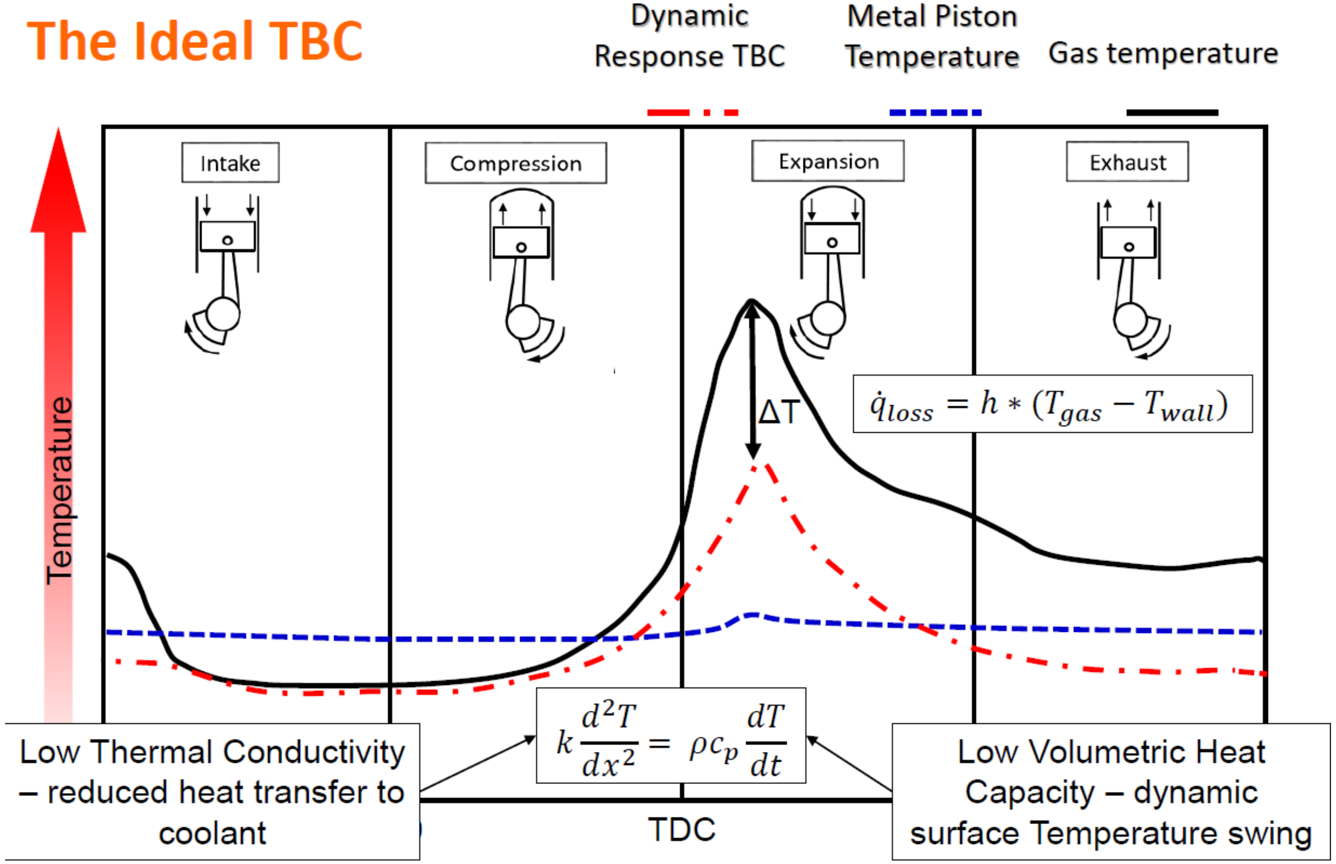
Narrow angle bearing grooves



Active piston oil jets

Thermal Barrier Coatings

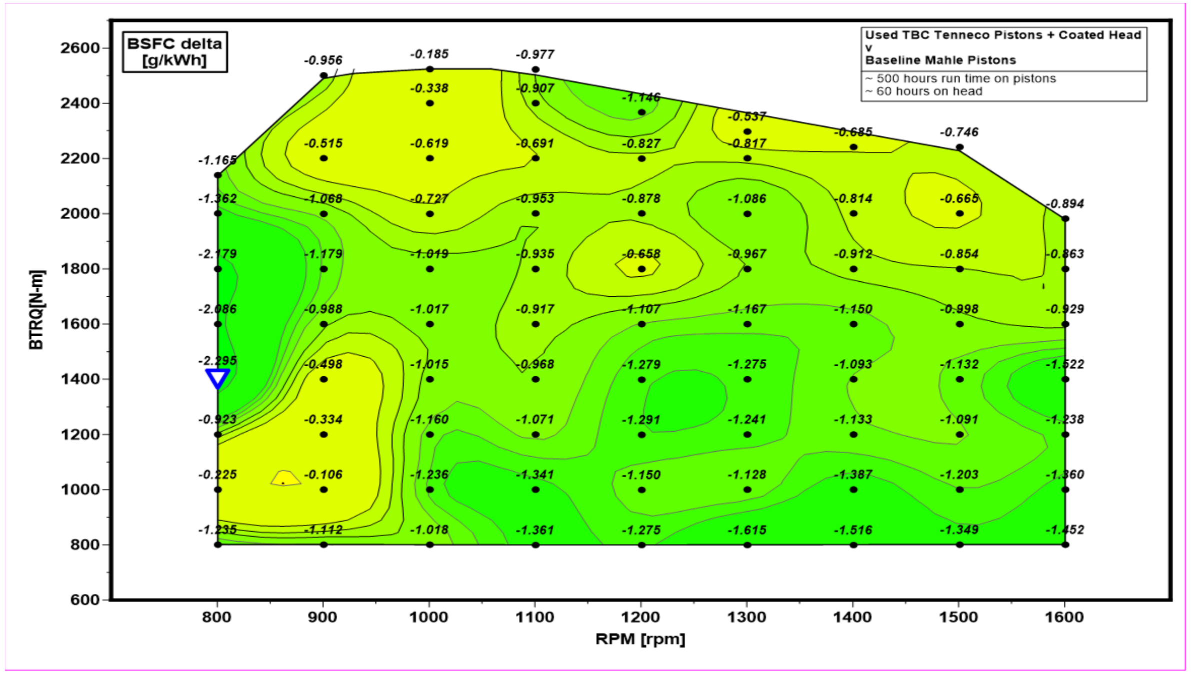
Thermal Barrier Approach:
- Low mass thermal barrier coatings with thermal 'swing' retain combustion heat while reducing cylinder temperature during intake stroke
- Dedicated, low mass coating developed for piston bowls (Worth ~70% of BTE improvement)
- Different coating applied to cylinder head fire deck and valve faces (Worth ~30% of BTE improvement)



'Gen 3' coating on piston (example shown here)

GdZr coating on cylinder head (example shown here)

Thermal Barrier Coatings



- Combustion phasing and heat release are improved due to thermal isolation from the coatings
- There is also a small increased compression ratio due to the thickness of the coating.
- There is ~0.3g BSFC benefit thanks to the coated head alone and a further ~0.7g from the pistons giving an overall 1g benefit at best point for Thermal Barrier Coatings
- Effects are broad based across most of the engine operating range.

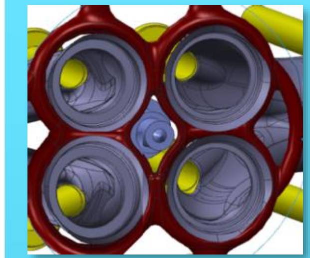
Noticed discoloration and loss of coating on the intake valves and seat- which maybe caused due to the temp shock caused by cold intake air interacting with the coated fire deck.

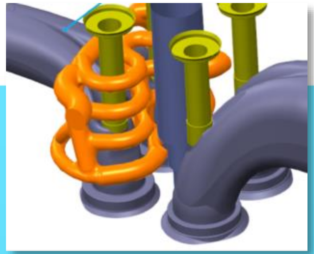
Phase Change Cooling (PCC) Waste Heat Recovery (WHR)

Key Concepts:
- WHR system recovers waste heat directly from the engine.
- WHR replaces traditional coolant system, WHR fluid changes to vapor phase in the head, and superheats in the in EGR cooler
- Simulation predicts +4.4% BTE gain, to reach a total of 55% BTE for engine + WHR

Fluid	Water – ethanol mix (60%/40%)
Pressure	50 bar
Temperature	305°C
Vapor Power	159 kW

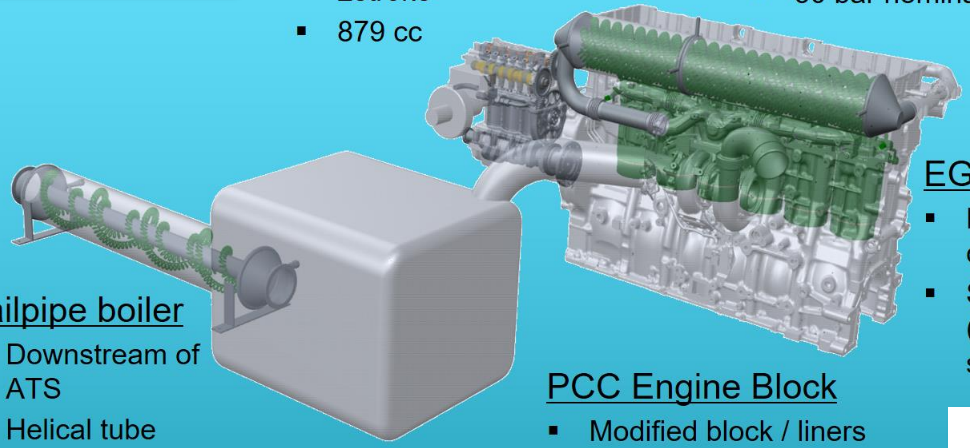
Status
- Updated ST1 based WHR tested to demonstrate a combined 52.9% BTE
- PCC WHR demo engine is built and ready for testing
- PCC WHR testing is pending, but not scheduled.





Piston expander
- 3 cylinder / 2stroke
- 879 cc

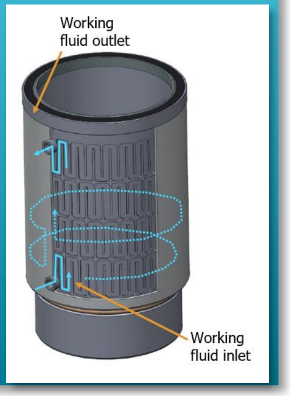
PCC cylinder head
- Modified coolant cores
- Air system / lube oil system unchanged
- 50 bar nominal fluid pressure



Tailpipe boiler
- Downstream of ATS
- Helical tube design

PCC Engine Block
- Modified block / liners
- Integrated in WHR system
- 50 bar nominal fluid pressure

EGR boiler
- Replaces EGR cooler
- Split design (pre-heating / superheating)



Responses to Previous Year Reviewers' Comments

Comment	Response
It is not clear what final version of the engine would be used for the final vehicle demonstration. The engine size due to twin turbo seems to be big, and it is not sure whether the engine that is targeted to 55% BTE can fit the vehicle under hood compartment,	The final demonstrator engine has many components from the 55% BTE engine including the dual turbocharger concept. The turbocharger and CAC pieces are moved to fit under the hood. Some engine content was removed such as the Thermal Barrier Coating as it is not been fully tested for a long term vehicle environment. See slide 11 for picture.
The pathway to 55% BTE on slide 10 was a little more difficult to understand. It would have been helpful to identify the pieces of the bar chart (particularly for the combustion and air handling) regarding which technology each portion came from	Engine testing is mostly complete with 52.9% BTE demonstrated using the Exhaust + EGR cyclopentane WHR. The PCC WHR engine has been assembled and is ready for its final testing. Slide 9 has improved component performance definition in performance roll up.
The project team should also include in the final review an estimate comparison of performance against a comparable current model year product because investment in SuperTruck 2 technologies is against current competing production products, not MY2009 ones which are several generations behinds in emission levels and technical capability	SuperTruck 2 foundation is based upon a comparison to 2009 Model Year vehicle. In addition, we have compared the performance to our SuperTruck 1 project. Comparing to a current model year is a moving target and is based upon the vehicle content/configuration and would vary.

Collaboration and Coordination

- Schneider National
  - Project scoping
- Strick Trailers
  - Low mass trailer with production available aerodynamic features
- Michelin
  - Low rolling resistant tires balanced with fleet TCO
- Solution Spray Technologies
  - TBC coating development
- Oak Ridge National Laboratory
  - Engine friction and parasitics, testing
- National Renewable Energy Laboratory
  - Thermal development/management and testing
- University of Michigan
  - Model based controls and testing
- Clemson University
  - Engine TBC analysis and development

Remaining Challenges

Technical

- Optimization of hybrid with new battery system
- Evaluation and optimization of hybrid during multiple drive cycles.
- Demonstration of combined fuel efficiency for SuperTruck 2 engine with extreme downspeeding and efficient overdrive transmission

Resources

- Final engine testing with PCC WHR remains unfunded work but planned to be completed.

Any proposed future work is subject to change based on funding levels

Project on schedule to complete on time

Proposed Future Research

- Vehicle
  - Ground aerodynamics need further study
  - Trailer aerodynamics need further study
  - Hybrid optimization and powernet management strategy with route
- Powertrain
  - Further work on thermal barrier coatings to extend durability and performance
  - Continued development of advanced combustion approaches, including new directions like multi-cylinder development of ducted flame combustion

Any proposed future work is subject to change based on funding levels

Summary

Accomplishments

A-Sample Integration Vehicle
- Completed development on features used in Final Demonstrator

Engine Development
- 55% engine completed testing at ORNL and Detroit. 50.6% BTE demonstrated for core engine alone
- 52.9% BTE demonstrated with exhaust+EGR cyclopentane WHR included.
- A clear path to 55% BTE simulated with the PCC WHR included. PCC engine awaiting WHR opening in test cell.

Final Demonstrator build completed
- Engine, new exterior and all major features installed
- Longer test drives with optimization has started

Testing completion expected end of Q3 2022

Questions?