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

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Jeff Girbach, Principal Investigator, Powertrain
June 4, 2020

Daimler Trucks North America

Project ID: ACE100

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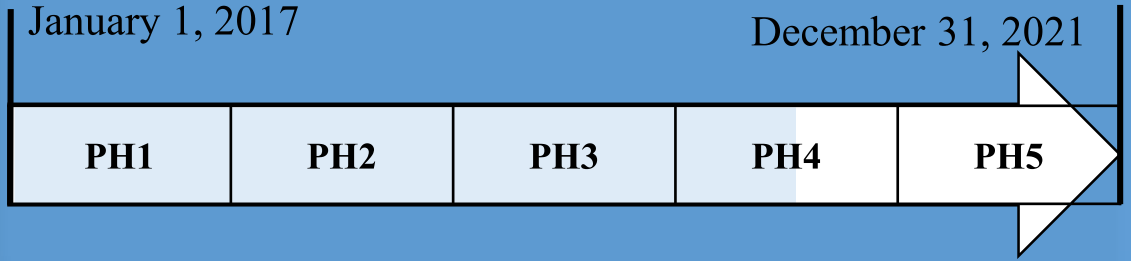
Overview

Timeline

Start
January 1, 2017

End
December 31, 2021



June 2020 Status= 70% Complete

Technical Targets

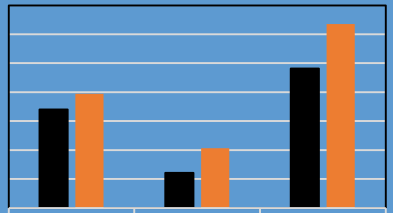
- Greater than 115% improvement in vehicle freight efficiency (on a ton-mile-per-gallon basis) relative to a 2009 baseline.
- Greater than or equal to 55% engine brake thermal efficiency demonstrated at 65 mph on a dynamometer.
- Develop technologies that are cost effective

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

2019 Summary



	DDC	DTNA	Total
Planned	$6,810,348	$2,419,797	$9,628,145
Actual	$7,883,829	$4,126,426	$12,705,008

Project Partners

- Schneider National
- Strick Trailer
- 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

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

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

Phase 4
- Finish Final Demo Design & Build
- Optimization

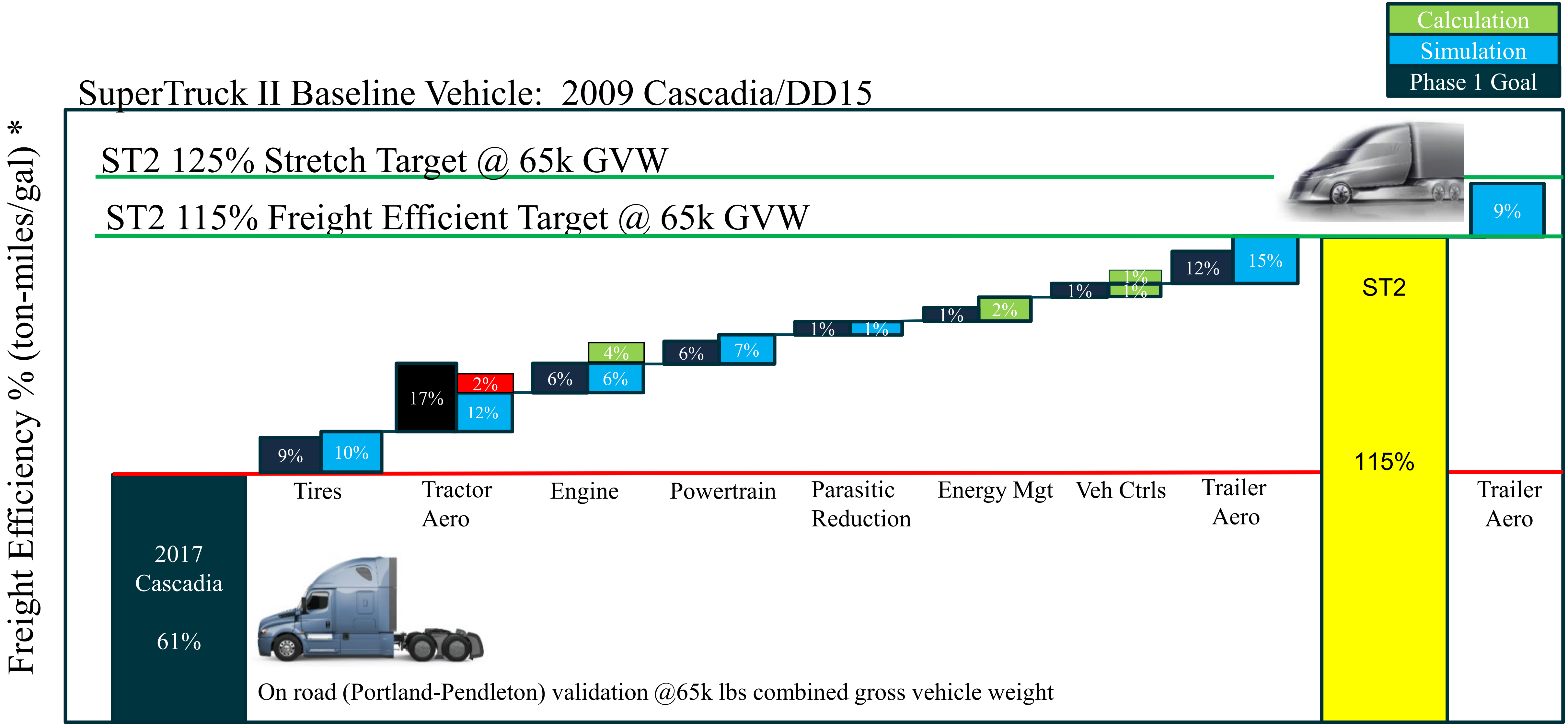
Phase 5
- Final Demo Optimization
- FE Validation Test
- Final Report

Program status

2017 2018 2019 2020 2021

Phase	Milestone	Status	Completion Date
Phase 3	A-Sample Assembled	100%	June 2019
	A-Sample Fuel Performance Test	90%	Dec 2019
	Final Demonstrator A-Surface Released	100%	Dec 2019
Phase 4	Final Demonstrator Design Released	95%	June 2020
	Final Demonstrator Assembled	10%	Dec 2020

Approach – SuperTruck 2 Roadmap

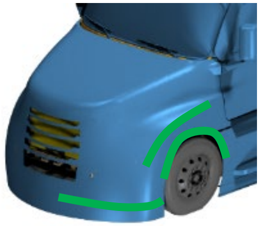


*Assumes 3,000 lbs mass reduction

Technical – Aerodynamic & Exterior Development

Exterior design cycle

Ideal aero shape



Identify key aero features

Aero inputs to Design Studio

Clay model

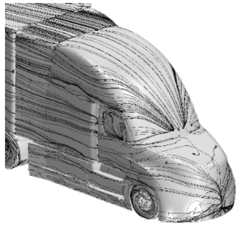
3D Scan

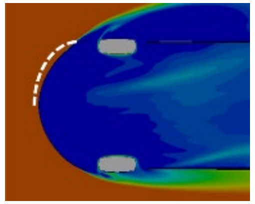
Point cloud

Resurface to CAD

Detailed CAD model

Input to CFD





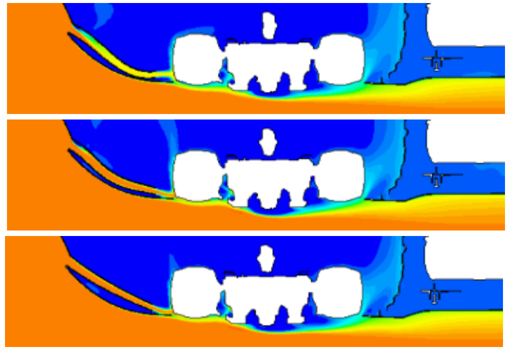
DOE in CFD

>3M CPU hr

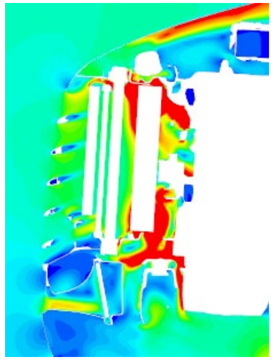
Feedback to Design Studio

About 7-10 cycles

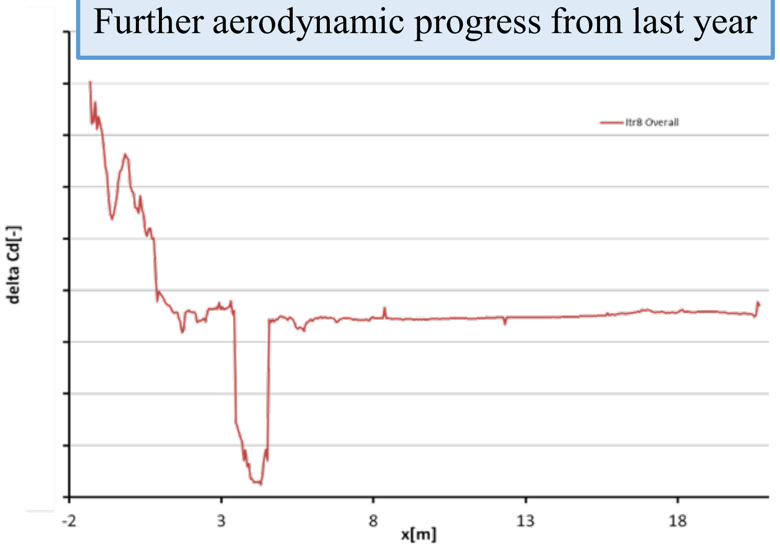
Bumper duct optimization



Cooling drag optimization



Further aerodynamic progress from last year



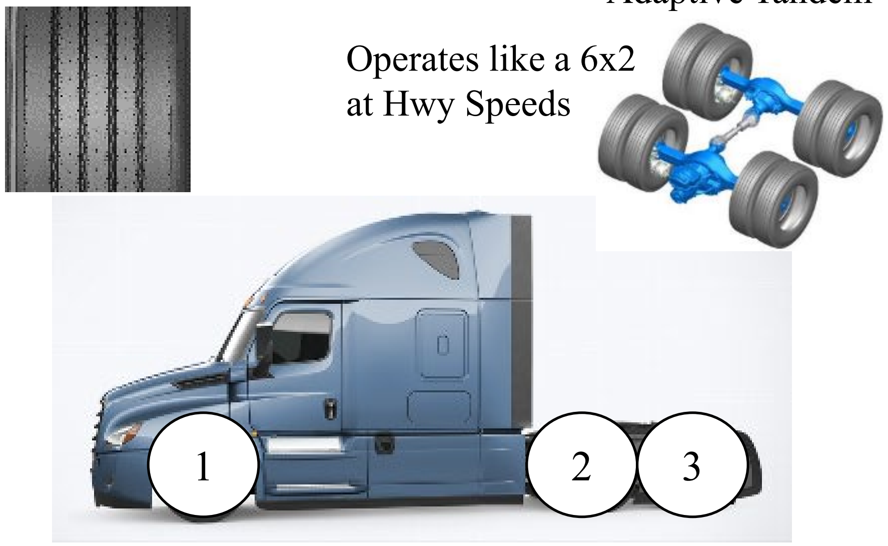
A-surface development of hood, bumper, door and chassis fairings concluded. Ready to Build.

Technical – Chassis Developments

Prototype Tires

Michelin tires optimized for Adaptive Tandem.

Adaptive Tandem



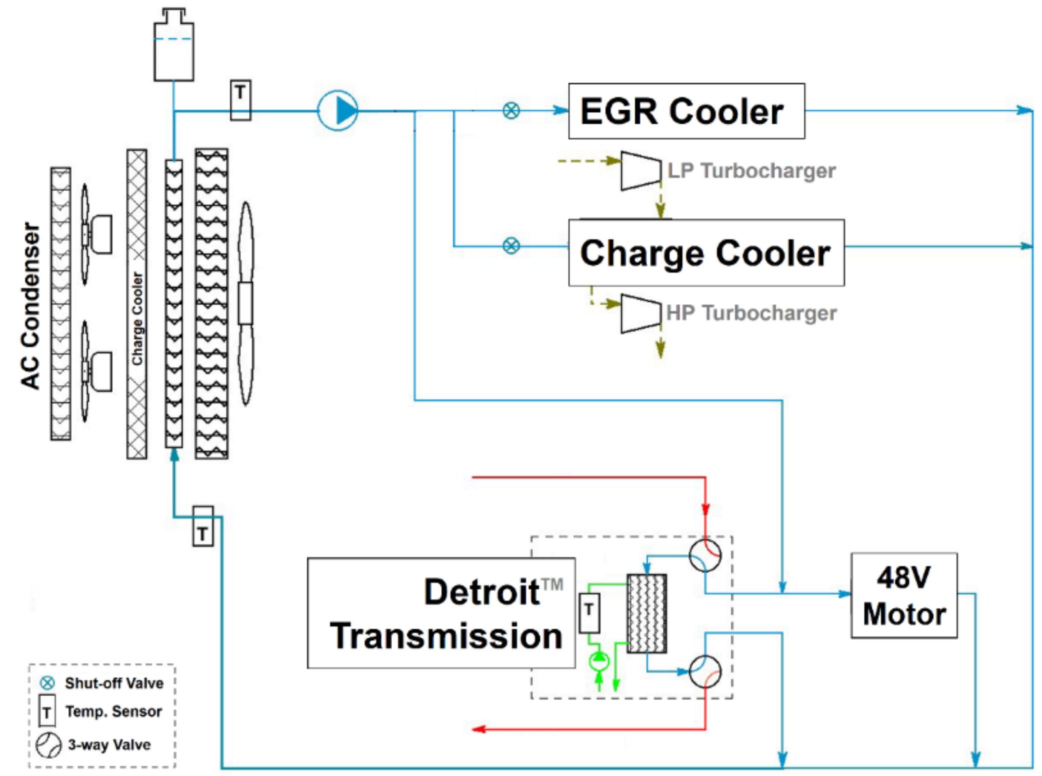
Performance improvement from last year

1. Steer Tire: 15% reduction in rolling resistance
2. Drive Tire: 30% wear improvement
3. Tag Tire: 17% reduction in rolling resistance

Thermal Configuration

Completed circuit designed for both engine & 48V system.

Controls developed for several load cases using simulation



Technical – 48V Energy Management

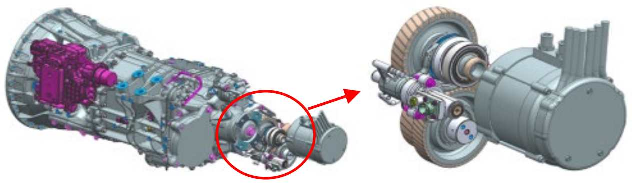
Energy Storage

A-Sample solution:
- Pack contains off the shelf lithium cells
- Packaged under step with passive cooling

Final demonstrator solution:
- Moving to 7kWh LTO battery for improved power and cycle durability
- Optimizing pack design with NREL

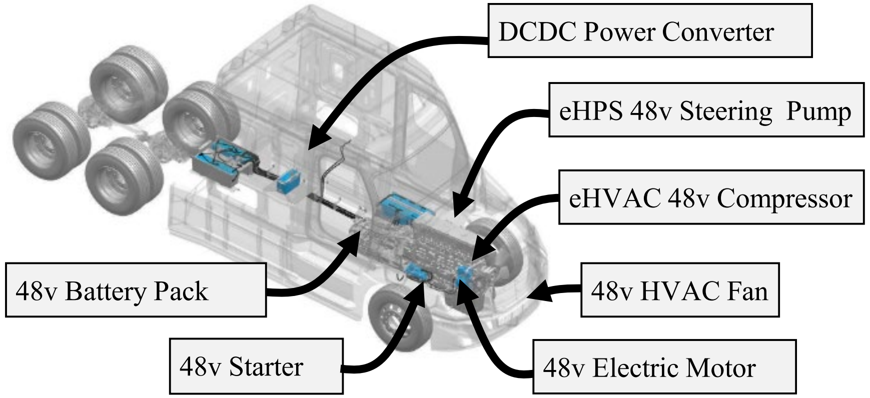
Boost Recuperation Machine

P0 Position has limited power



P2 location enables improved power

Controls



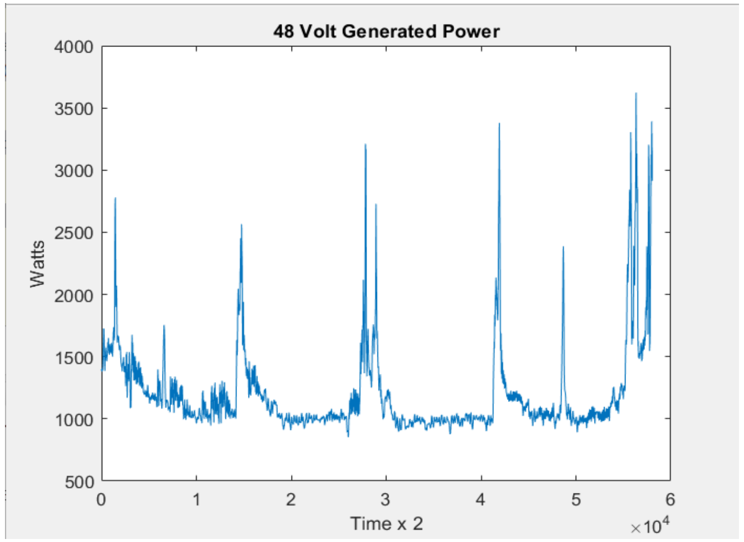
Powernet solution determined
- Accessories moved to 48v
- Optimization of energy

Architecture enabled for energy optimization

Technical – Initial A-Sample Fuel Performance Testing

Initial Road Test Results

- Achieved 15,000 test miles
- A-sample competitive style test with 2017 NGC @ 65K lbs
- Test Results:
  - Transmission lube maintained at 80 C
  - Steering Pump average consumption reduced by 540 watts
  - Air Compressor consumption reduced by 1.4 kWh
  - A-sample chassis found with higher parasitic drag



Powertrain

- 13 Speed Transmission
- Adaptive Tandem Axle
- New RAR
- Efficient Air Compressor

Split Cooling

- Low Temperature Circuit
- Transmission oil heating and cooling

Energy Management

- 48V Integration
- Electric Steering Pump
- Electric HVAC

Further A-sample testing planned in 2020 is subject to change based on funding levels

Technical – Final Demonstrator Build

Status

Further Developments ongoing with A-sample

- Improved chassis parasitic analysis
- Optimizing controls and hybrid integration
- Further hybrid power capacity

Final Demonstrator donor vehicle received April 2020

- 196 components designed and released
    - 82% ordered or on track to order
    - 18% orders on hold from spending constraints
        - Buildup of exterior components
- Coronavirus causing supply chain disruptions
    - Delivery of engine delayed from June 2020

Anticipate approximately a 3 month delay in build and testing schedule

SuperTruck 2 Powertrain

Jeff Girbach, Principal Investigator, Powertrain
June 4, 2020

Daimler Trucks North America

Project ID: ACS100

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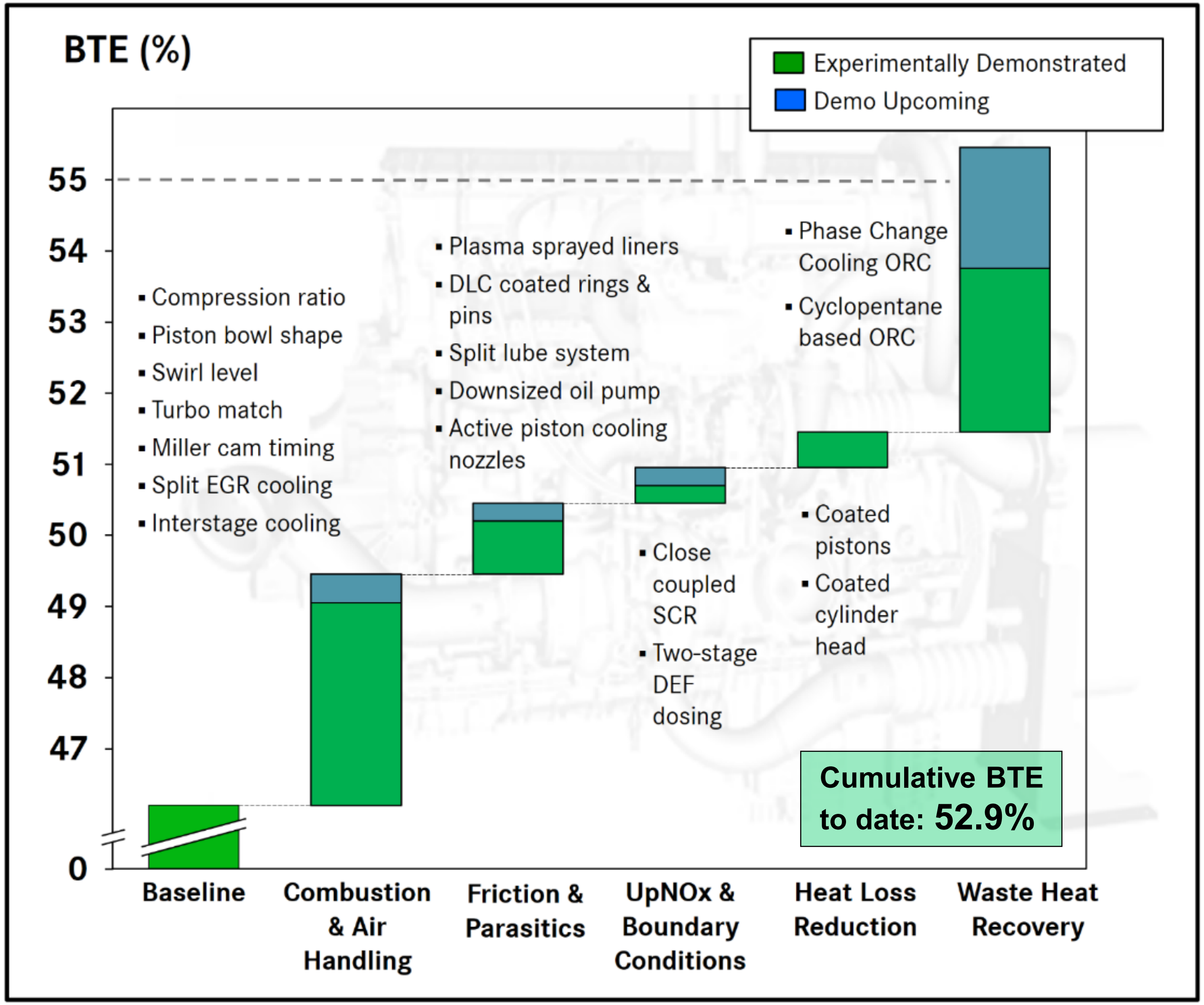
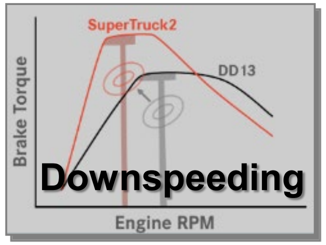
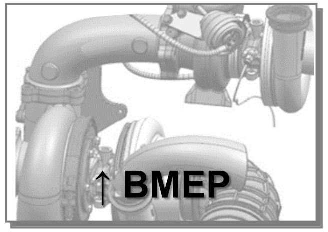
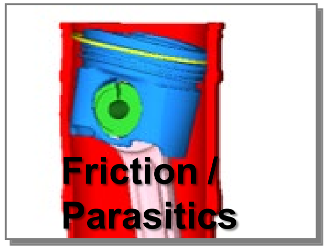
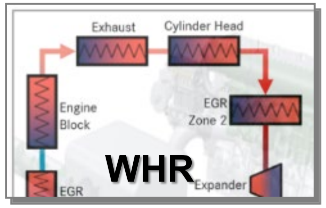
Overview











Downspeeding enablers
- Two stage turbocharging
- Interstage cooling

Faster combustion enablers
- High compression ratio
- Higher peak cylinder pressure
- Redesigned bowl shape

Air System
- Miller cycle valve timing
- Two stage EGR cooling
- Long loop EGR

Friction & Parasitics
- Liner surface conditioning
- Coated piston rings & pin
- Oil flow reduction
- Active piston cooling jets
- Low viscosity oil
- Higher oil temperature

Heat Loss Reduction
- Thermal barrier coatings

Waste Heat Recovery
- Phase Change Cooling WHR

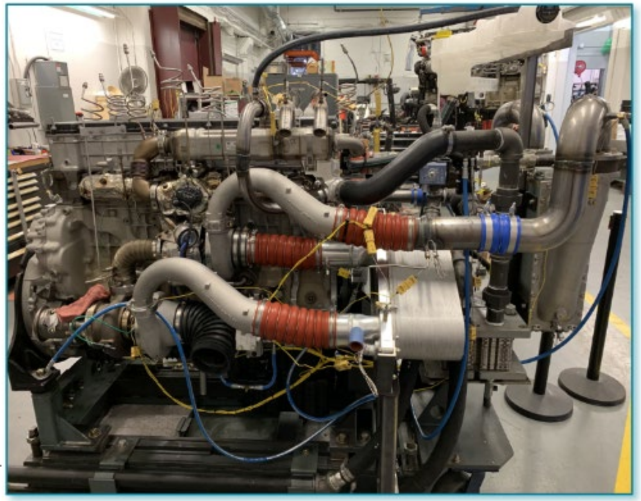
Controls
- Model predictive controls

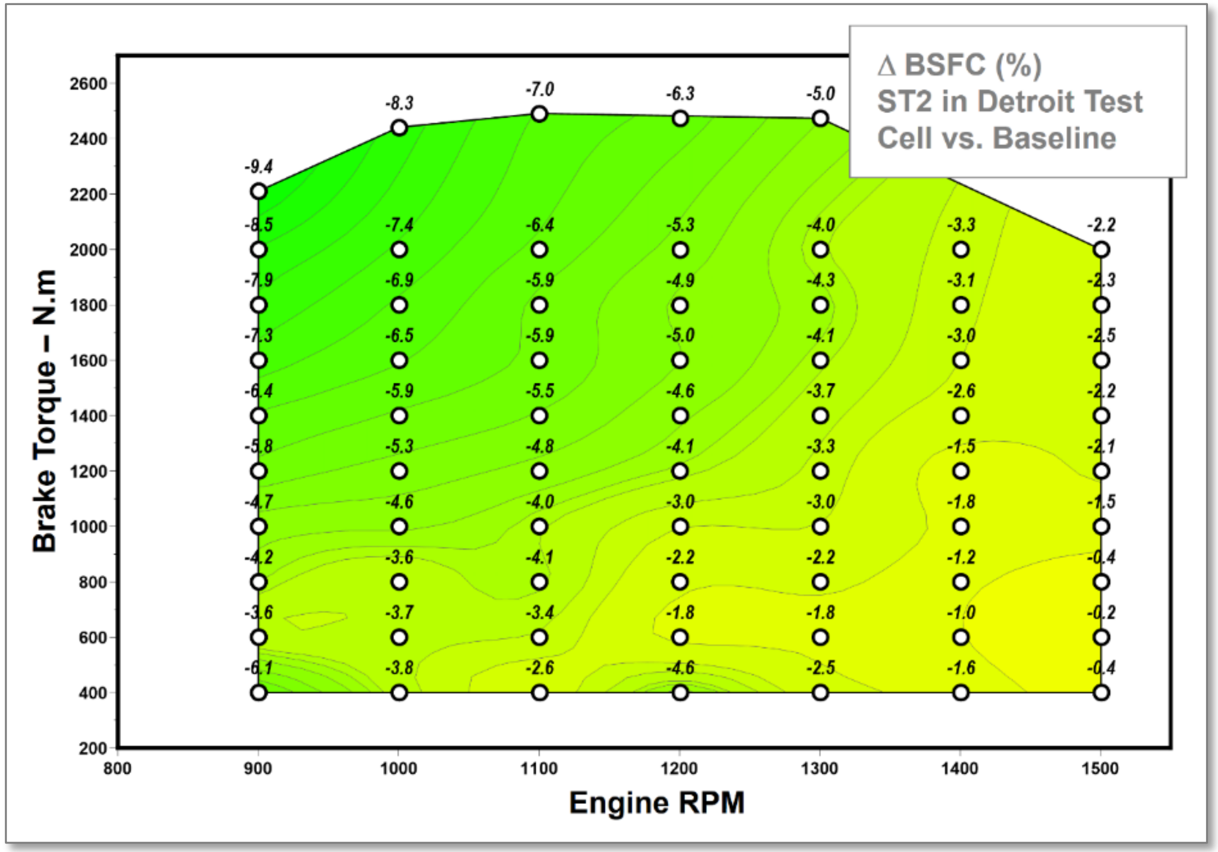
Aftertreatment
- Close-coupled SCR

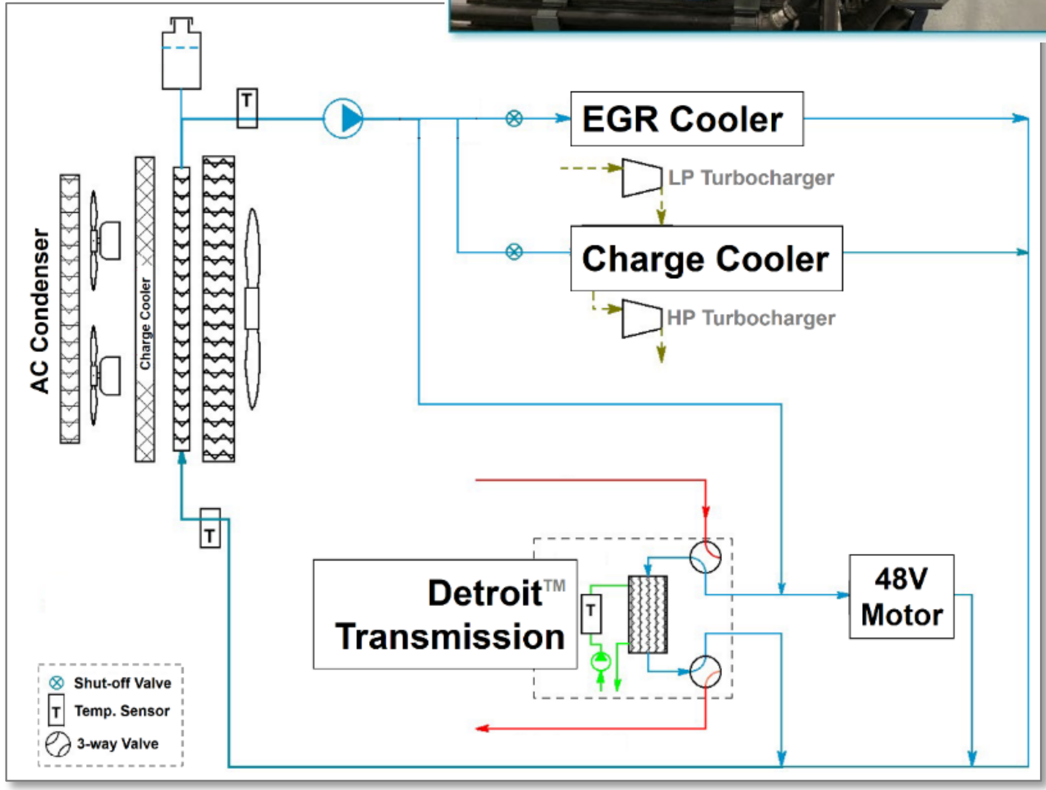
Fluid Temperature Management
- Split Cooling System
- Transmission temp. management

Technical – Air/EGR & Split Cooling Systems

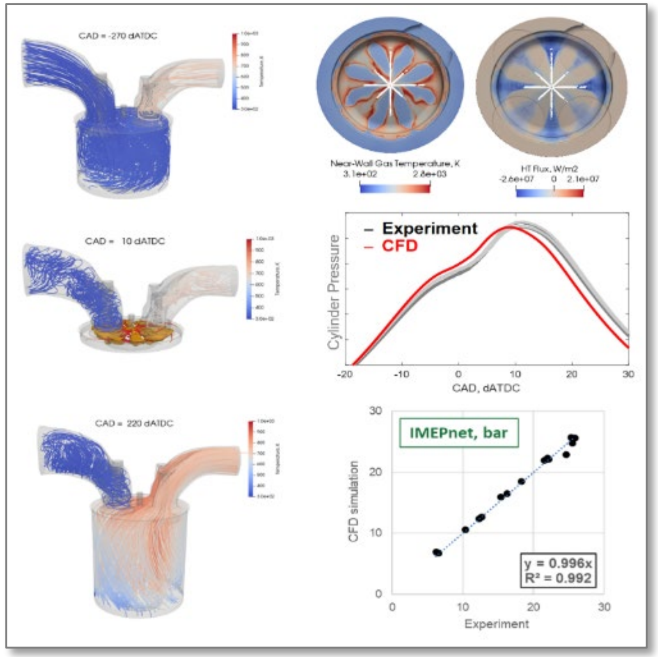
- DD13 Engine
- Two stage turbocharging
- Low temperature (LT) cooling circuit
  - Efficient interstage cooling
  - Split EGR cooler (HT/LT)
- Late Miller timing camshafts
- Potential up to 30-bar BMEP
- Downsped PT configuration
- Close-coupled SCR
- 9.5% BSFC improvement over best available engine at peak torque



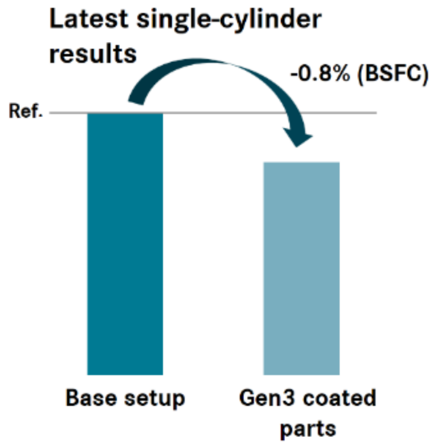


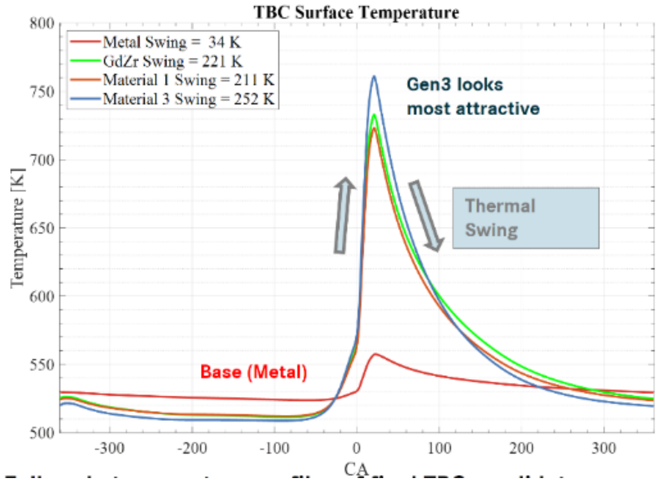


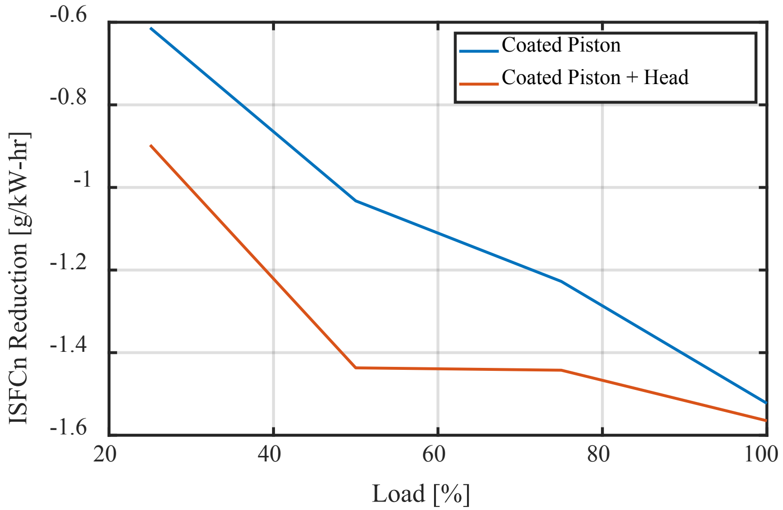
Technical - ST2 Thermal Barrier Coating

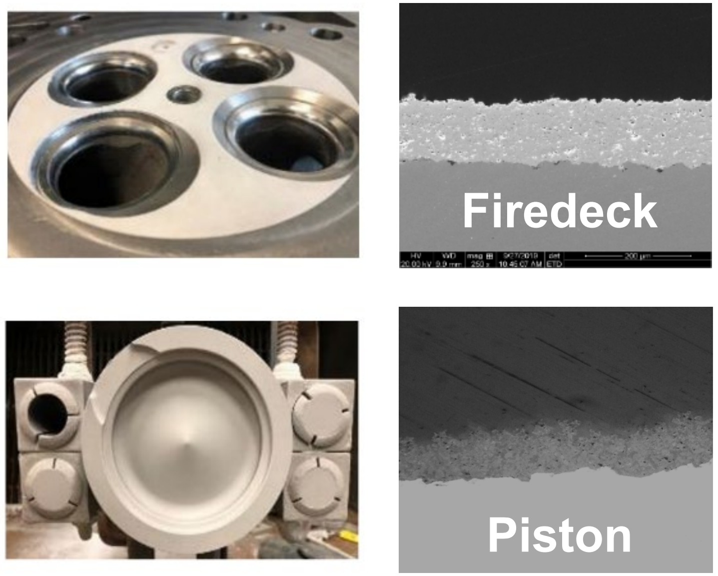


- CFD & FEA Models used to evaluate several TBC formulations
- ISFC Potential based on CFD and cycle simulation shows 1% BSFC improvement
- Single cylinder experimental test showed 0.8% BSFC potential (reference load)
- 100 hour durability test completed
- Multi-cylinder engine testing in the final 55% BTE demonstration engine





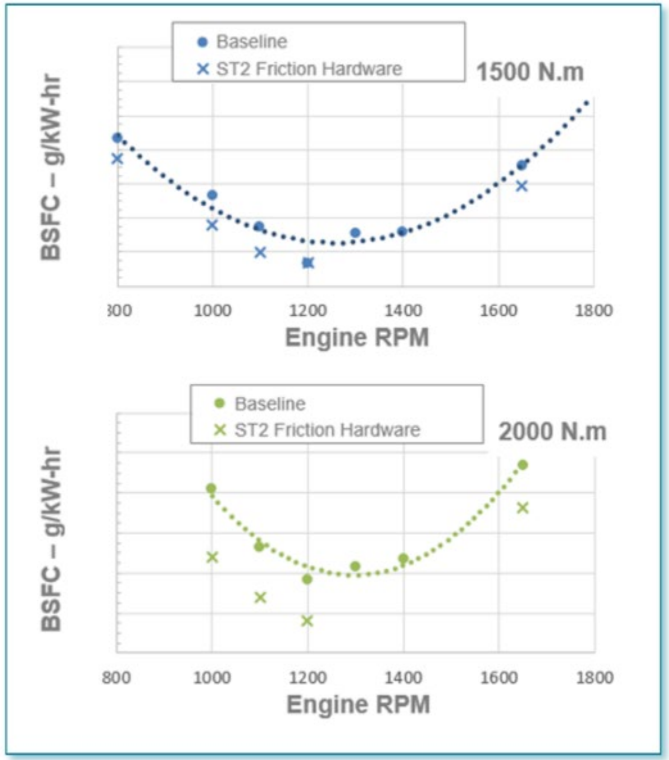




Technical - Engine Friction Reduction

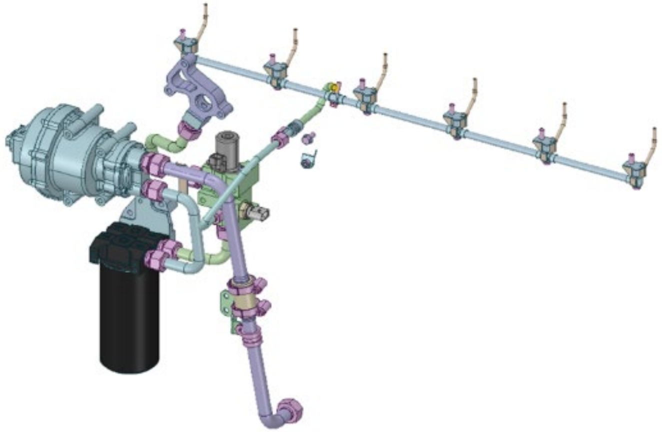
Friction and Parasitic Reduction Testing

- Testing at Oak Ridge National Lab
- Friction package
  - Plasma-sprayed liner surface, piston kit with DLC coated rings and DLC coated wrist pin
  - Use of dedicated low-viscosity oil /scuff resistant for reference
- Friction hardware shows significant improvements in BSFC over stock hardware
- Improvement most consistent at high load



Split Lubrication System

- Downsized main oil pump/system and supplemental oil circuit for piston cooling jet supply
- Potential for 0.5% BSFC Improvement
- Engine testing in the final 55% BTE demonstration engine



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

Objectives

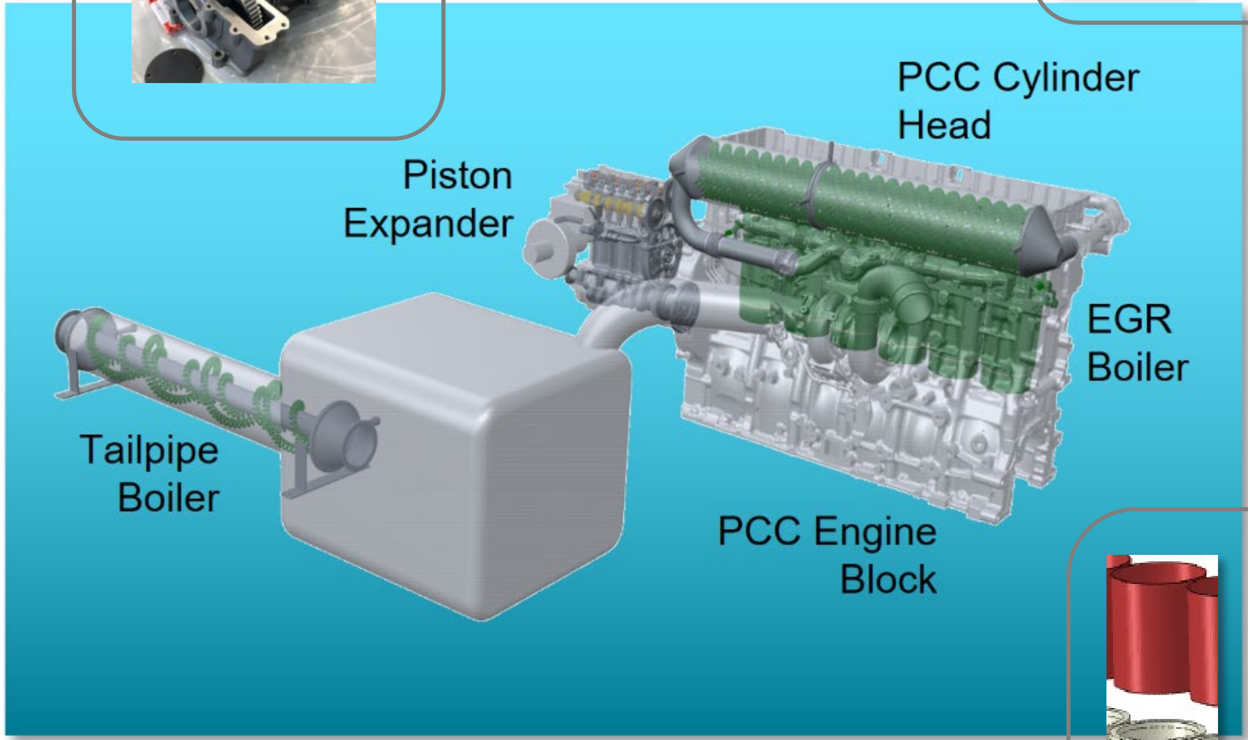
- Recover high quality waste heat in the cylinder head and engine block
- Deliver on 3.5% BTE potential

System description

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

Status

- Experimental evaluation in 2020



Addressed a number of casting issues that required several casting parameters to be modified

Technical – Model Predictive Control (MPC)

Optimal Control Problem

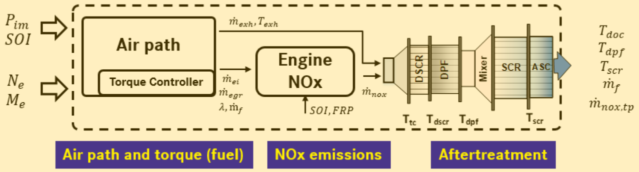
Adjust engine calibration … to minimize cost function

$$[P_{im}, SOI]^*\Big|_{t0} = \underset{P_{im},SOI}{\operatorname{argmin}} \sum_{k=t_0}^{t_0+T_h-1} J\Big|_k \longrightarrow J_k = f(e_{dscr}, e_{dpf}, e_{scr})\Big|_k + \alpha_1 \dot{m}_{fuel}\Big|_k + \alpha_2 e_{NOx} u(e_{NOx})\Big|_k$$

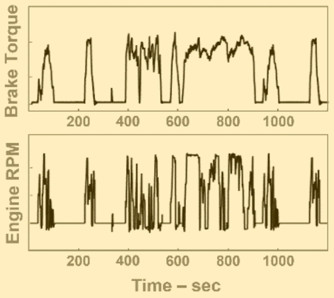
Exhaust Temperature Cost | Fuel Economy Cost | NOx Cost

Model Development

$$X|_{k+1} = F_{AFT}(X, \dot{m}_{exh}, T_{exh})|_k$$
$$[\dot{m}_{exh}, T_{exh}, P_{ems}, P_{tbl}]|_k = F_{AP}(\dot{m}_f, U)|_k$$
$$\dot{m}_f = F_{Me}(M_{e,ref}, P_{ems}, P_{tbl}, U, N_e)|_k$$
$$\dot{m}_{NOx}|_k = F_{NOx}(X, U, N_e, M_e, \dots)|_k$$
$$X = [T_{tc}, T_{dscr}, T_{dpf}, T_{scr}]$$
$$m_{nox_{tp}}(t_0 + T_h) \le m_{nox_{ref}}(t_0 + T_h)$$



Real-time Implementation



- Real-time engine & aftertreatment control
- Optimized with high fidelity on-board models
- Models are exercised over a receding horizon

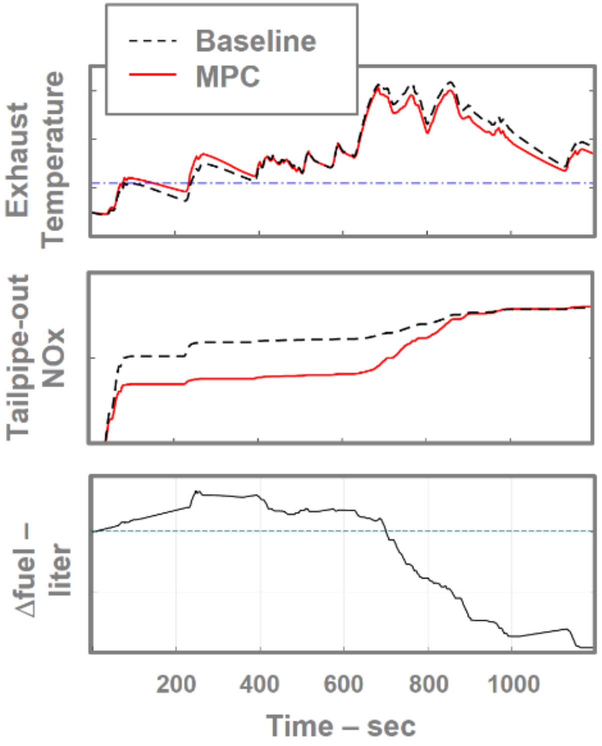


Illustration of exhaust temperature, NOx and fuel economy management over a transient drive cycle.

Remaining Challenges & Barriers

Technical

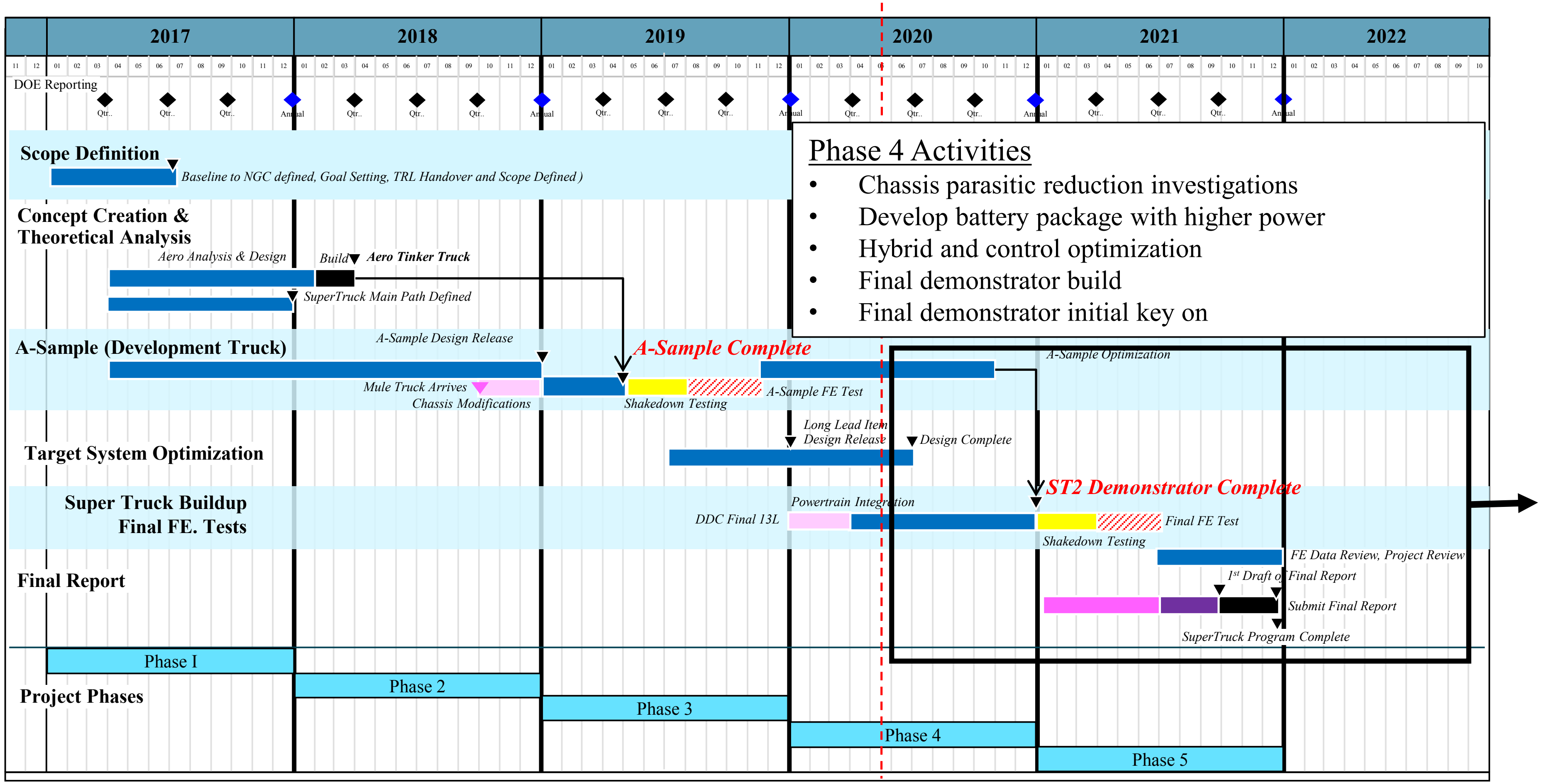
- Resolve casting process challenges for phase-change cooling WHR cylinder head.
- Evaluate chassis parasitic reductions during a drive cycle.
- Optimization and evaluation of hybrid and control strategies during a drive cycle.

Resources

- Starting late in March, with the Coronavirus shutting down worldwide supply chains and with measures to preserve capital, significant spending outside Daimler has been minimized impacting program timing. Anticipating a 3 month delay.

Summary and Future Work

Anticipate a 3 Month Delay from Coronavirus



Potential FE test complete by Oct 2021

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

Responses to Previous Year Reviewers' Comments

Comment	Response
Little progress made on model predictive powertrain controls since last year... It was unclear how this model control approach can help achieve the program goal, and how this program would be integrated with the vehicle and the engine control unit (ECU). The reviewer stated that this is more like a research and development (R&D) program without tangible return, and suggested that more description would be helpful.	Tangible results are in the form of optimized real world engine and emissions optimization on transient cycles over a receding horizon. The engine can be optimized to shifting real world situations. This approach will improve the freight efficiency performance but is not relevant to the steady-state BTE target. As was the case in ST1, the team plans to demonstrate the advanced controls on the running final demonstrator, exhibiting how this can function in real world vehicles beyond the test cell.
What role the National Renewable Energy laboratory (NREL) has on the vehicle side	NREL has been supporting the hvac control development. NREL will be moving to help with battery pack thermal development.
On the engine side, it was again disappointing to the reviewer to see that there is no report on the BTE progress with a specific BTE number, making the reviewer wonder about the exact status. Although some progress has been made on thermal barrier coating and combustion, it was not clear to the reviewer how much these technologies can really help the BTE goal.	Demonstrated BTE numbers often come from different test resources as we are working with several partners on ST2. For 2020 we will roll up the demonstrated results, but until the main engine technologies are run together in a single test cell in Q4 2020 this remains a composite.

Questions?