DAIMLER

SUPERTRUCK

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

Darek Villeneuve, Principal Investigator, Vehicle
Jeff Girbach, Principle Investigator, Powertrain
Steve Musselman, Detroit Powertrain, Presenter
June 24, 2021

Daimler Trucks North America

Project ID: ACE100

Overview

Timeline

Start
January 1, 2017

End
December 31, 2021

PH1	PH2	PH3	PH4	PH5

June 2021 Status= 85% Complete

Technical Targets

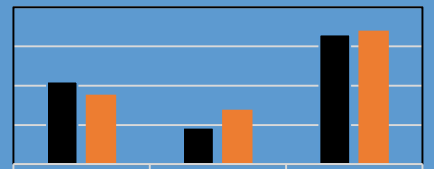
- Greater than 115% improvement in vehicle freight efficiency (on a ton-mile-per-gallon basis) relative to a 2009 baseline.
- Greater than or equal to 55% engine brake thermal efficiency demonstrated at 65 mph on a dynamometer.
- Develop technologies that are cost effective

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

2020 Summary

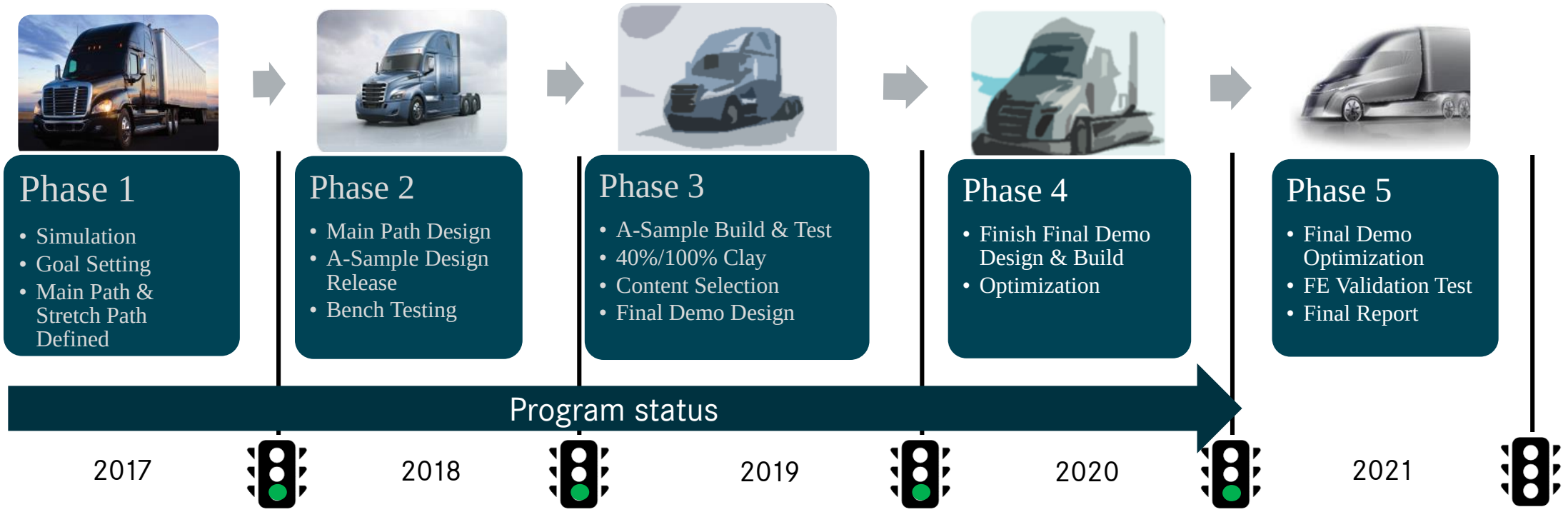


	DDC	DTNA	Total
Planned	4,206,648	1,855,282	6,613,930
Actual	3,546,715	2,783,061	6,806,991

Project Partners

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

Relevance and Objectives



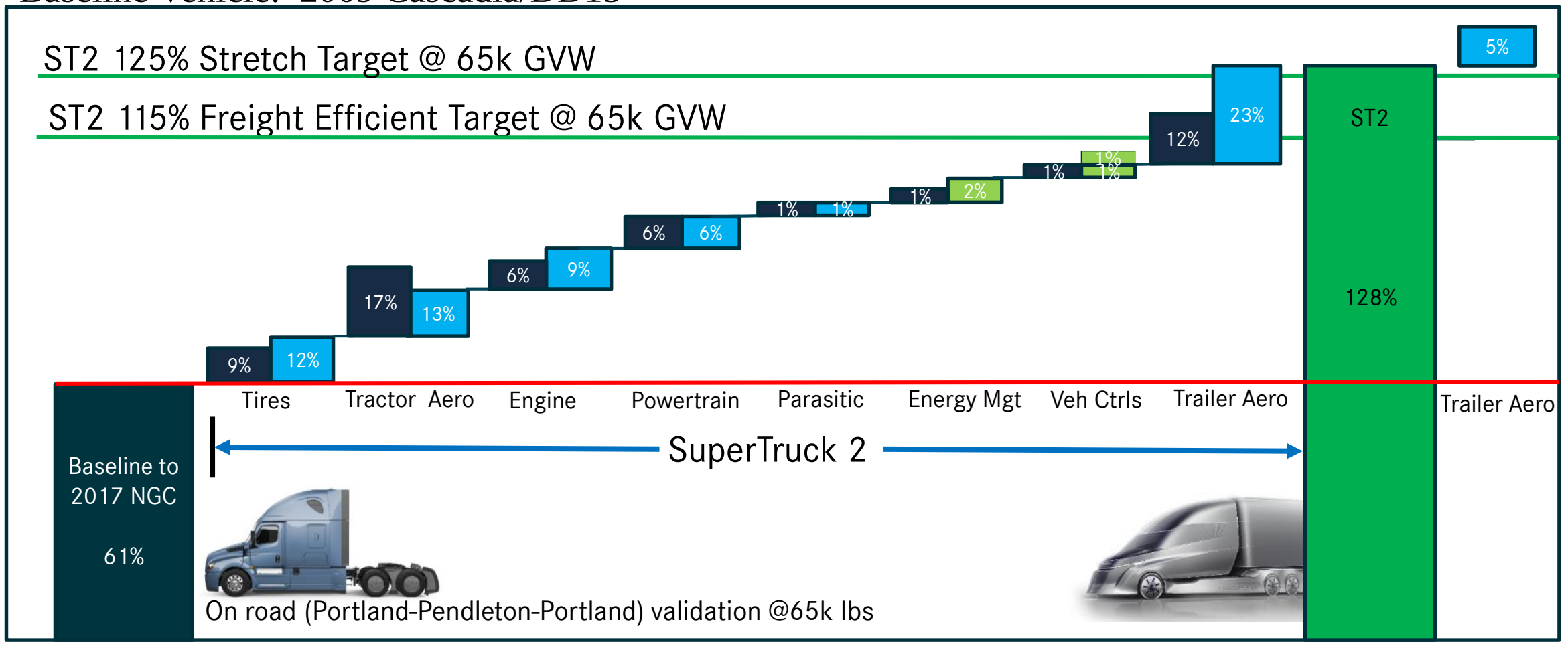
Phase	Milestone	Status	Completion Date
Phase 4	Final Demonstrator Design Released	100%	Oct 2020
	Final Demonstrator Assembled	30%	June 2021
Phase 5	Final Demonstrator FE Validation Test Complete	5%	Q4 2021
	Final ST2 Engine Bench Testing Complete	15%	Q3 2021
	Final ST2 Report Complete	5%	Q1 2022

Reduced fuel consumption plan in HD long haul

Approach – SuperTruck 2 Roadmap

Calculation
Simulation
Phase 1 Goal

Baseline Vehicle: 2009 Cascadia/DD15



Focus on high potential workstreams

*Assumes 2,800 lbs mass reduction

Technical Progress - Exterior Development

Final Demonstrator

- Exterior parts received with exceptional fit to vehicle
- Active Tractor Trailer Gap (TTG) feature completed
- Aerodynamic testing confirmed performance in wind tunnel and on the track

Stowed Position

Fully deployed

Trailer Build Complete

- Standard 53’ trailer build completed with 5 enhancements
- Mass savings of ~2,000 lbs over typical trailer
- Controls for ride height and boat tail configured

Completed trailer build & test

Execution on track

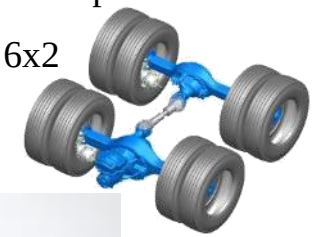
Technical Progress – Chassis Developments

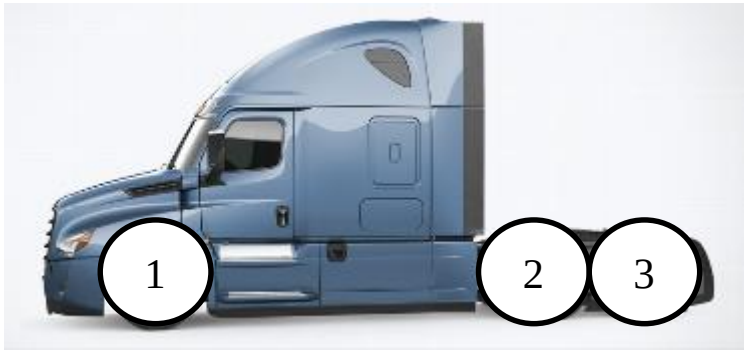
Michelin Prototype Tires

- Michelin completed tire build with testing
- Optimized for Adaptive Tandem and TCO

Adaptive Tandem

Operates like a 6x2 at Hwy Speeds



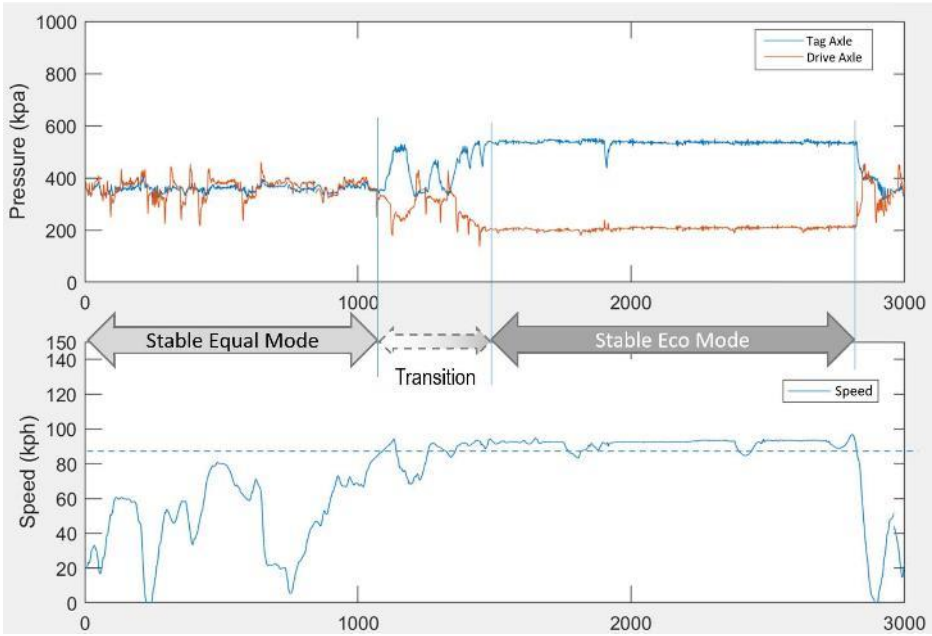


Performance improvement over 2017 NGC:

1. Steer Tire: 16% Crr reduction
2. Drive Tire: 8% Crr reduction + 30% wear improvement
3. Tag/Trailer Tire: 26% Crr reduction

Dynamic Load Shift (DLS)

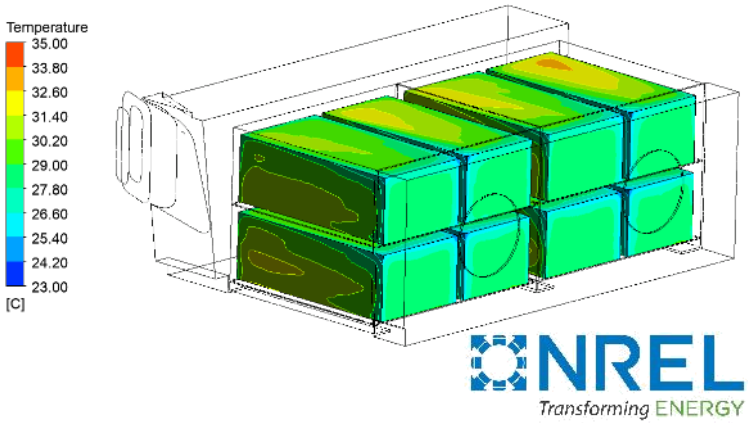
- Shifts load to take advantage of extremely low Crr tag tires
  - Traction Mode: More load on drive axle at low speeds
  - Equal Mode: Equal load on drive and tag axles
  - Eco Mode: More load on tag axle at highway speeds
- Axle load determined by suspension pressure.



Chassis performance optimized and confirmed

Technical Progress – 48V Energy Management

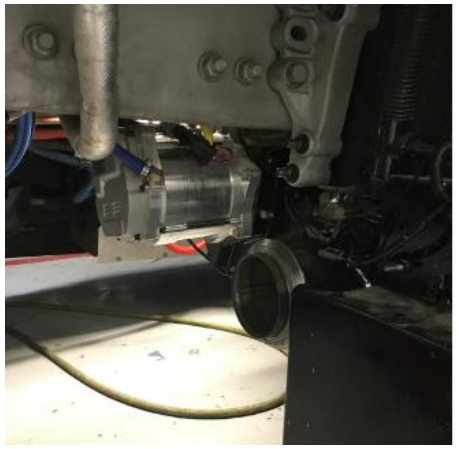
Energy Storage



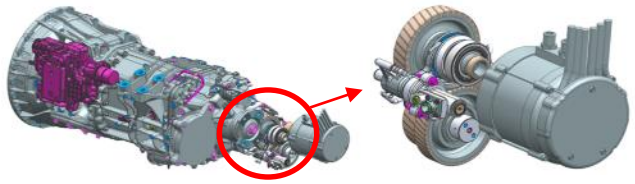
Final Demonstrator solution:

- NREL support to optimize 7kWh LTO battery with off the shelf components
- Developed cell electrothermal model based on tests at Thermal Testing Facility
- Simulation selected package arrangement and reduced order model for cooling control
- Cells remain below manufacturer imposed temperature limit

Boost Recuperation Machine

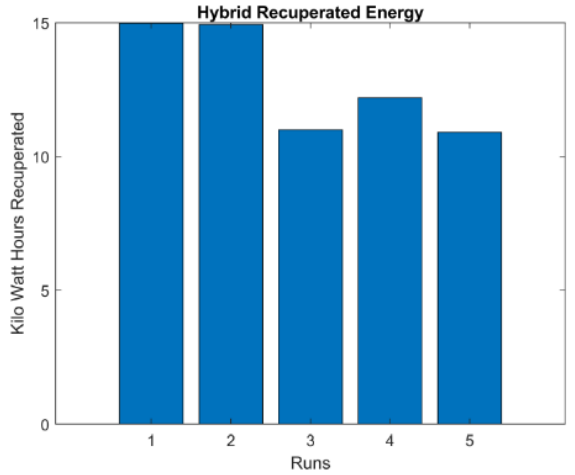


30 kW BRM in P2.5 position with 3.5:1 transfer case



P2 location enables improved power

Hybrid Energy



Hybrid Strategy with predictive cruise

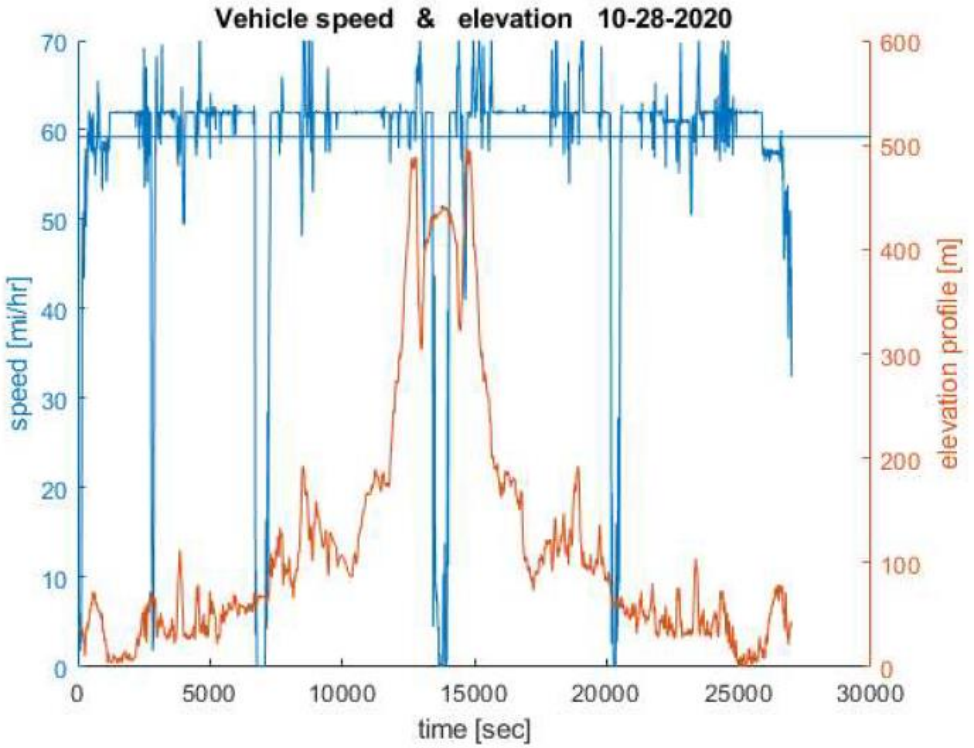
- Recuperate during negative torque events
- Long haul route minimizes recouped energy
- Finalizing balance to store or use energy

Architecture enabled for energy optimization

A-Sample Integration Results

A-Sample Component Style Testing

- Several weeks of testing reviewing integration performance
- One drive route is Portland-Pendleton-Portland (PPP)
- Route is ~7 hours (~25,000 seconds) round trip
- Significant data being captured
- Results
  - Adaptive tandem ~95% in 6x2 mode
  - Split cooling and trans temp performed well
  - DLS & height control needed further development
  - 48V accessories are stable
  - Hybrid enabled during engine braking



Powertrain/Chassis

- 13 Speed Transmission
- Adaptive Tandem Axle
- Clutched Air Compressor
- Dynamic Load Shift & AHC
- Integrated vehicle controls

Split Cooling

- Low Temperature Circuit
- Transmission oil heating and cooling

Energy Management

- 48V Integration
- 48V P0 Mild Hybrid
- 48V eHPS (Steering Pump)
- 48V eAC
- DC-DC converter to 12V
- LFP Batteries

Results driving Final Demonstrator development

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SuperTruck 2 Powertrain

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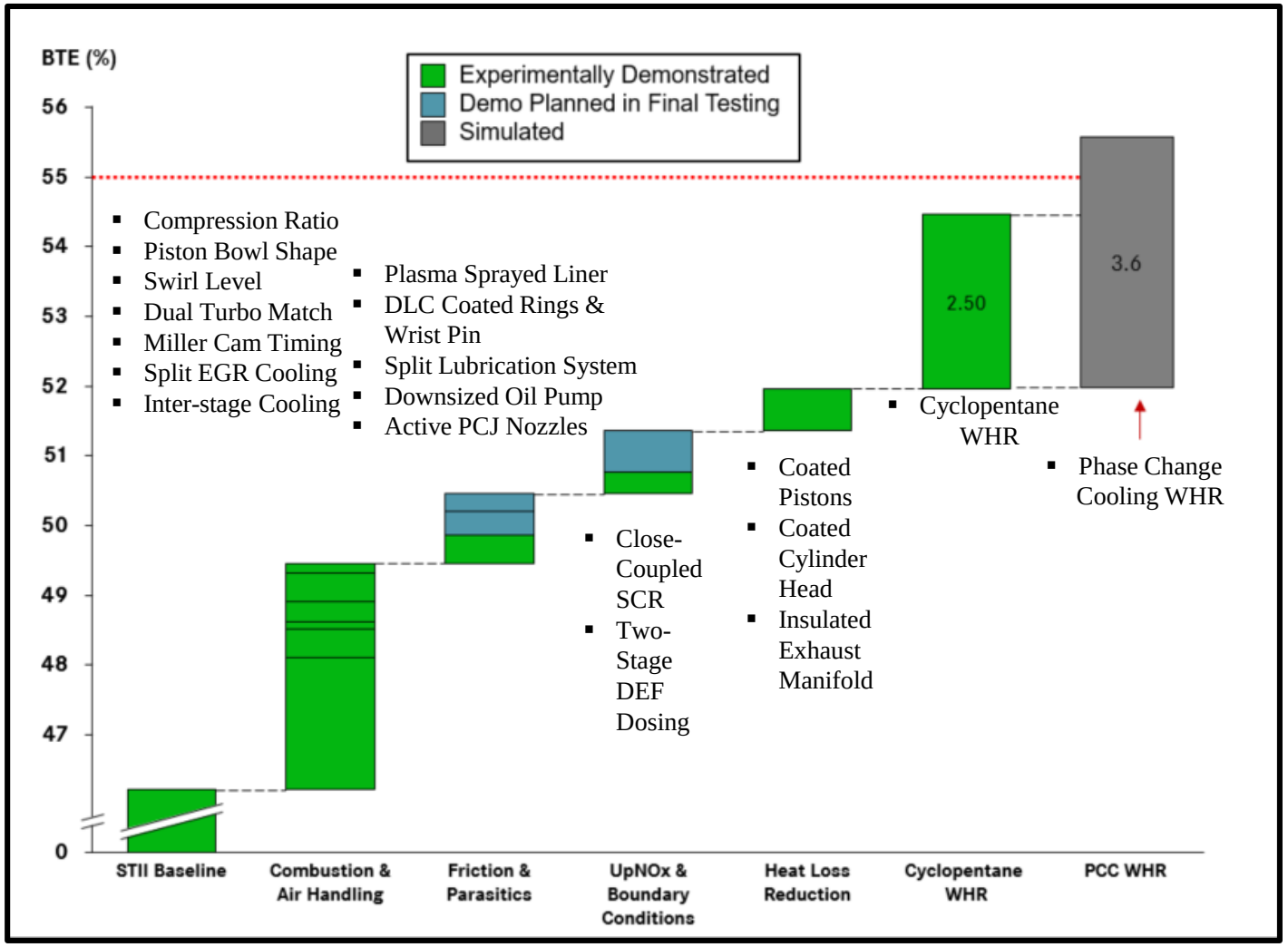
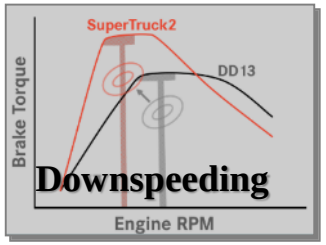
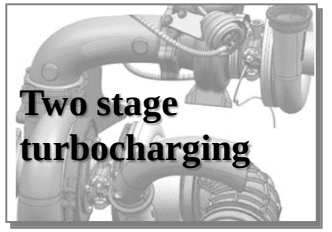
Daimler Trucks North America

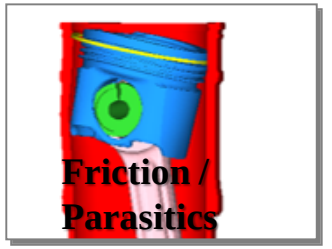
Project ID: ACS100

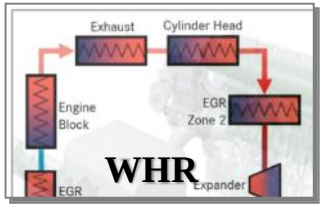
ST2 Engine Overview











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
- Late exhaust valve opening
- Two stage EGR cooling
- Long loop EGR

Friction & Parasitics
- Liner surface conditioning
- Coated piston rings & pin
- Oil flow reduction (crankshaft)
- Closed-loop oil pressure control
- Active piston cooling jets
- Low viscosity oil / higher oil temperature

Heat Loss Reduction
- Thermal Barrier Coatings on piston and cylinder head.
- Insulated exhaust manifolds

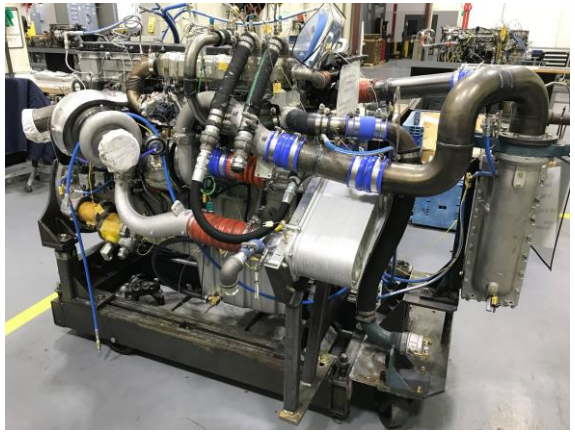
Waste Heat Recovery
- Phase Change Cooling WHR

Aftertreatment
- Close-coupled SCR

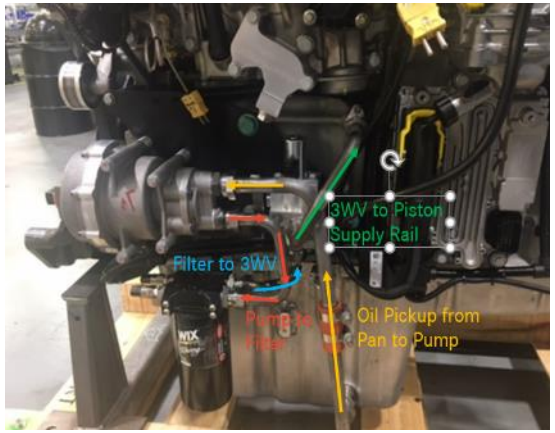
Fluid Temperature Management
- Split Cooling System

Thermal Efficiency Demonstration – 55% BTE Engine System Tested at ORNL

Engine ready for testing at ORNL

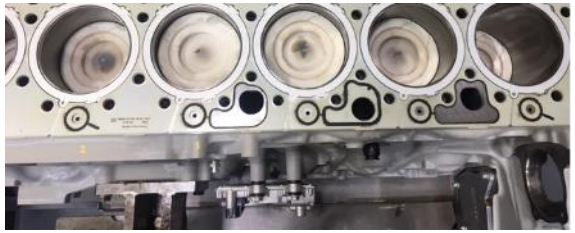


PCJ Split Lube System (e.g. 48V pump)



High-Pressure Turbo Stage with two waste-gates

Set of Pistons with Thermal Barrier Coatings

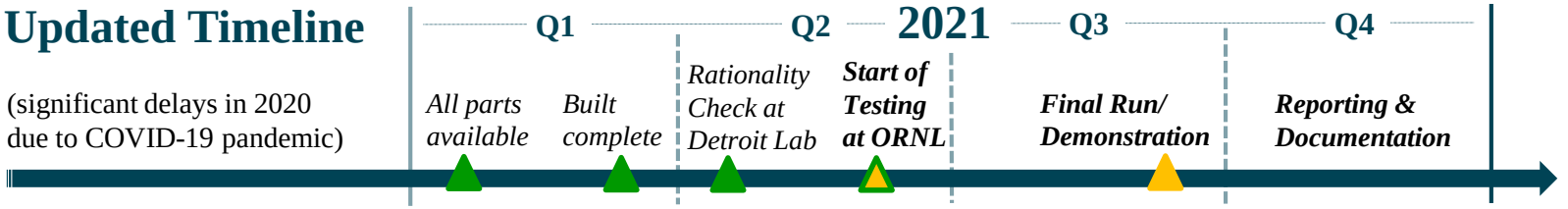


'Twin-Feed Crankshaft' for reduced oil flow

Insulated exhaust manifold

Updated Timeline

(significant delays in 2020 due to COVID-19 pandemic)



Downspeeding enablers
- Two stage turbocharging
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Faster combustion enablers
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Air System
- Miller cycle valve timing
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Friction & Parasitics
- Liner surface conditioning
- Coated piston rings & pin
- Oil flow reduction (crankshaft)
- Closed-loop oil pressure control
- Active piston cooling jets
- Low viscosity oil / higher oil temperature

Heat Loss Reduction
- Thermal Barrier Coatings on piston, cylinder head in process.
- Insulated exhaust manifolds

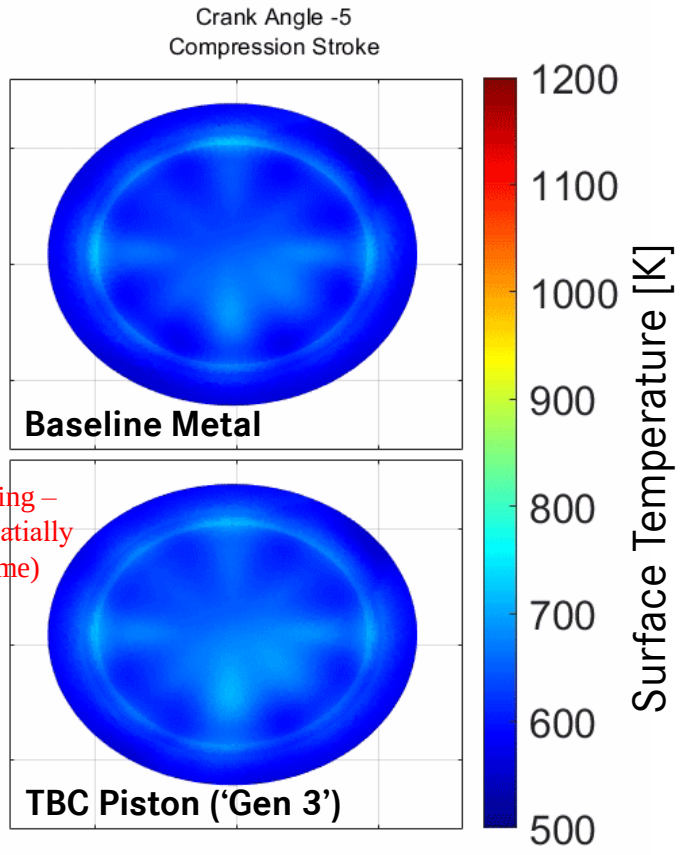
Waste Heat Recovery
- Phase Change Cooling System placed on hold, testing to be finished with EGR & Exhaust WHR.

Aftertreatment
- Close-coupled SCR

Fluid Temperature Management
- Split Cooling System

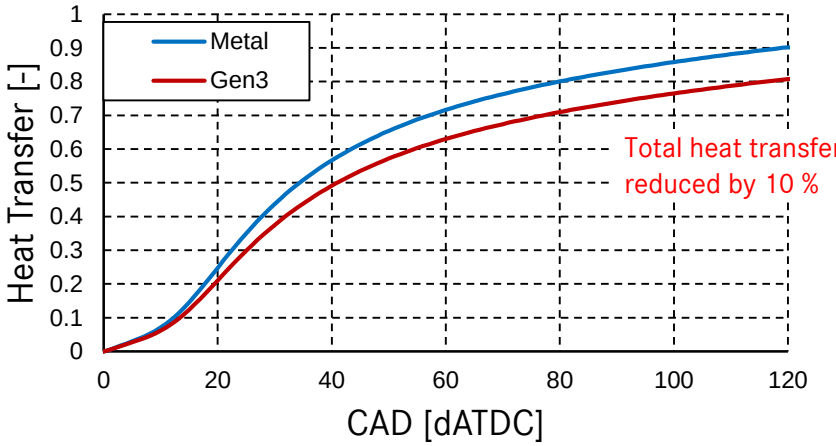
Thermal Barrier Coating Development – Simulation Loop and Engine Validation

Coupled CFD and FEA simulation to predict piston surface temperature (baseline vs. coated)

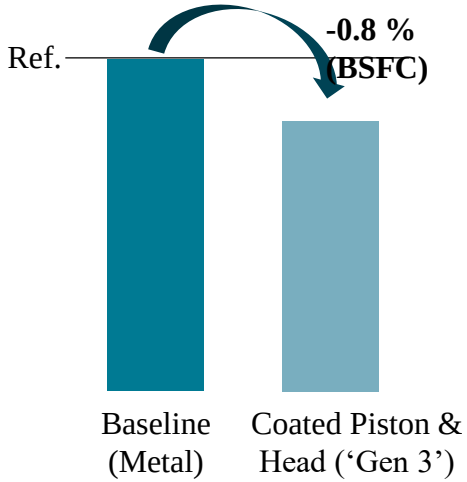


Thermal Barrier Coating – ≤ 500 K difference spatially (same increment of time)

1-D Cycle Simulation (GT POWER) – Combustion chamber heat transfer

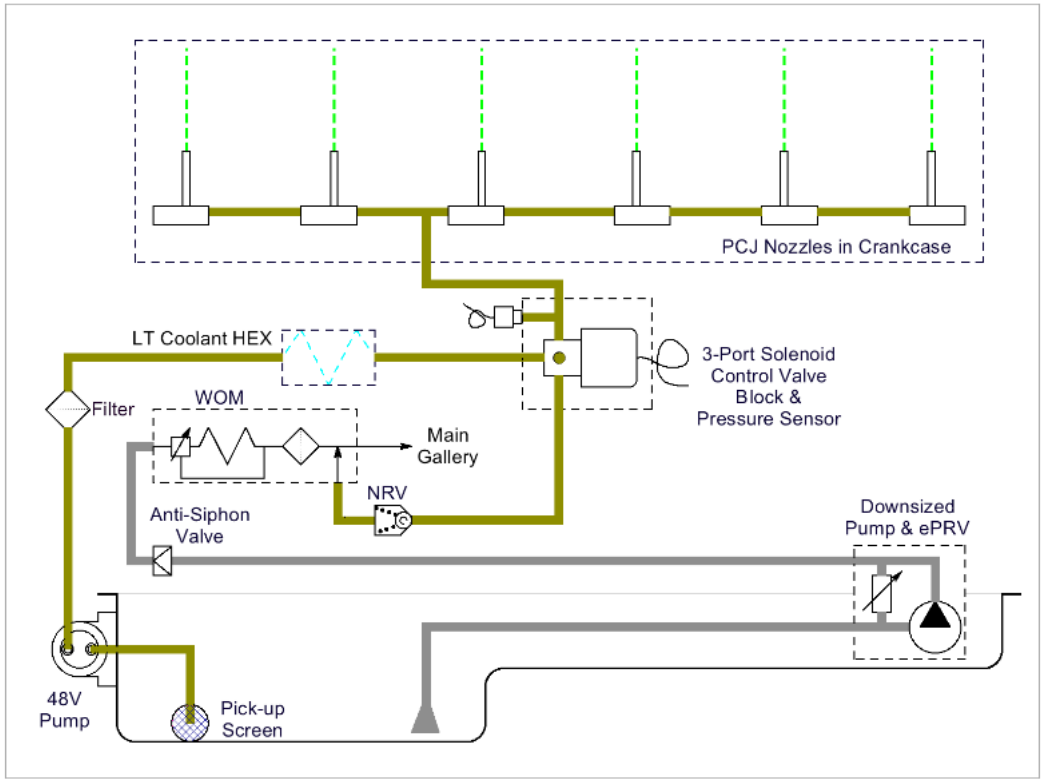


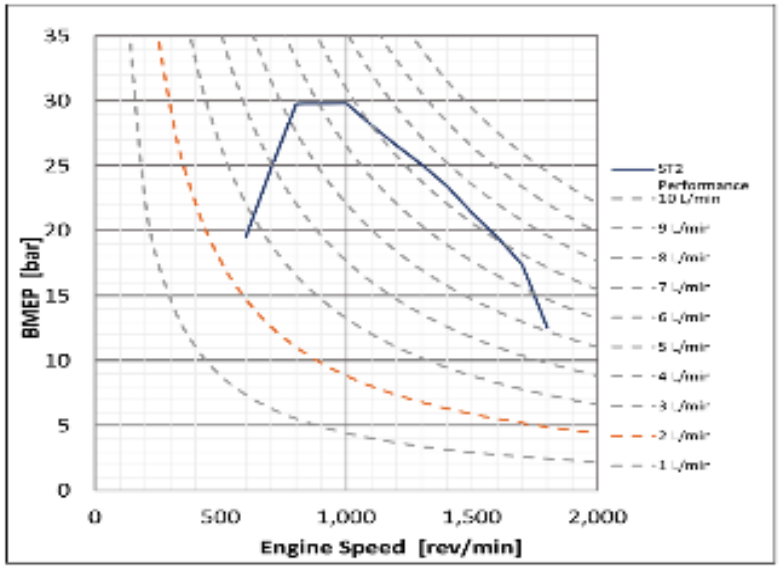
Single-Cylinder Engine



- CFD (ORNL) & FEA (Clemson) models used to evaluate several TBC formulations → 'Gen 3' coating was downselected for best thermal swing and thermal stability.
- Up to 1% BSFC improvement based on CFD and 1-D cycle simulation
- Single-cylinder experimental test showed 0.8% BSFC potential (reference load)
- 100 hour durability test successfully completed on single-cylinder engine
- Multi-cylinder testing in the final 55% BTE demonstration engine at ORNL

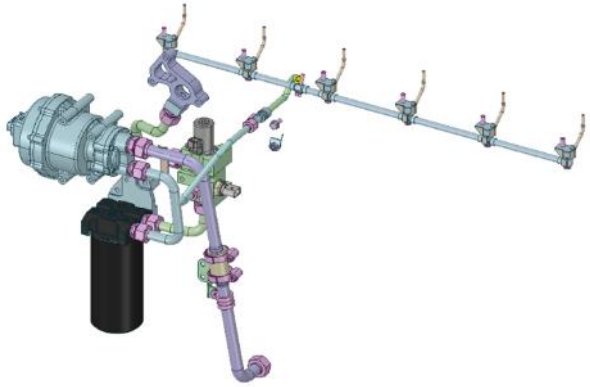
Split Lubrication System

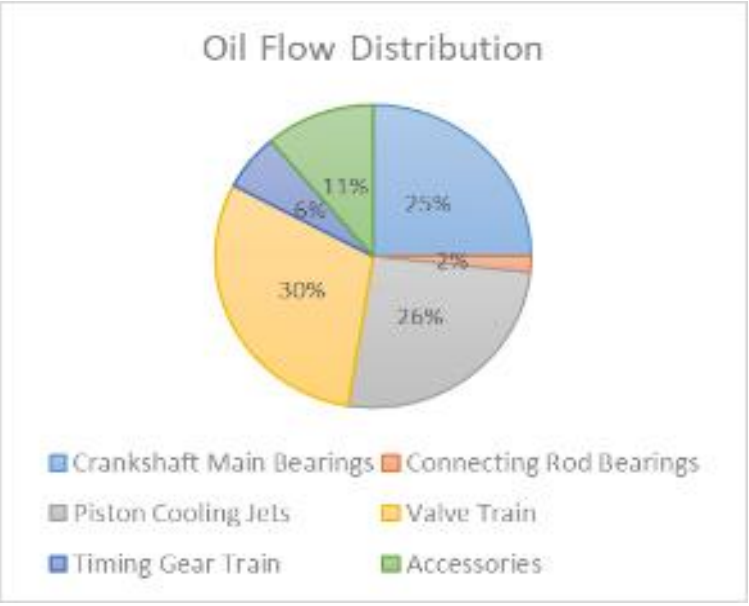




Cooling oil flow requirement per piston

Piston Cooling Jets – Fixture Test





Standard Oil Circuit – Flow Distribution

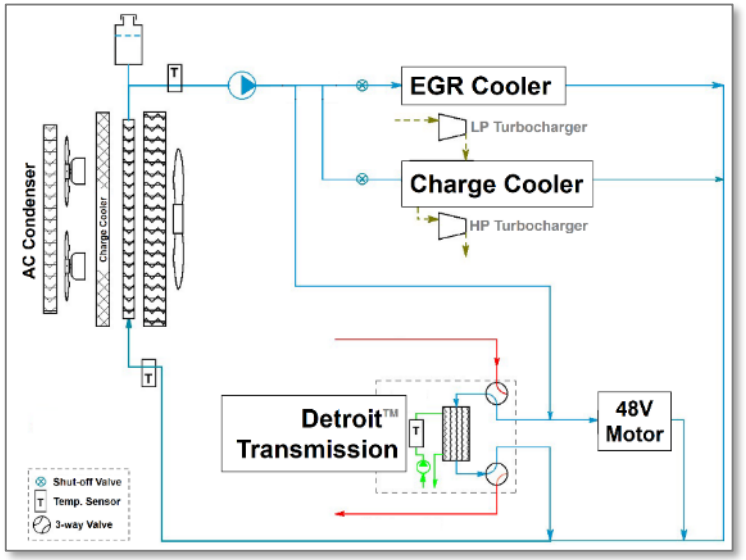
- Downsized main oil pump/system and supplemental oil circuit for piston cooling jet supply
- Fixture testing validated flow targeting at piston cooling gallery.
- Flow Rate Testing confirmed maximum flow rate capability and nozzle-to-nozzle flow variation within acceptable level
- Simulated potential for 0.5% BSFC Improvement, will be confirmed on 55% BTE Engine

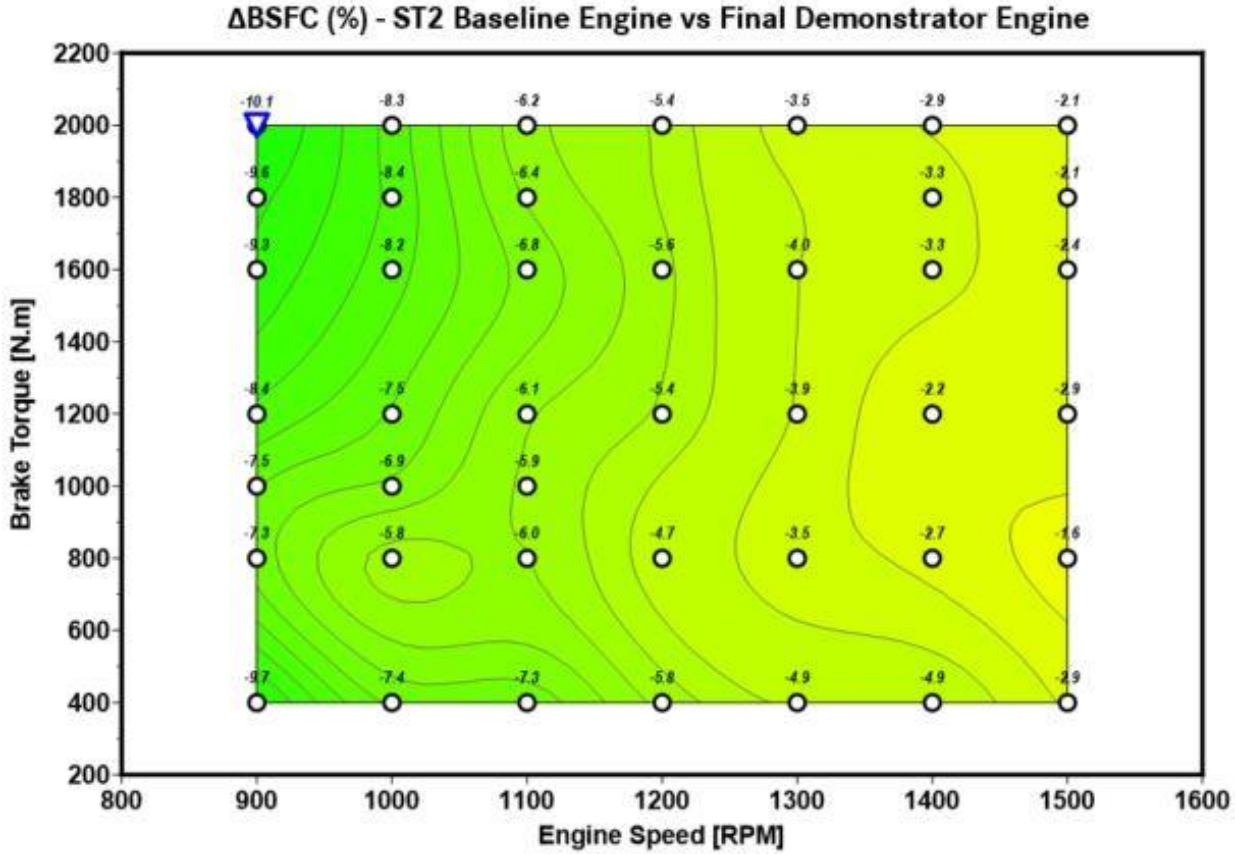
Final Demonstrator Vehicle Engine and Transmission

- DD13 engine
- Two stage turbocharging
- Late Miller timing camshaft
- Late exhaust valve opening camshaft
- High BMEP potential for down-sped PT configuration

- Low temperature (LT) cooling circuit
  - Efficient Interstage cooling
  - Split EGR cooler (HT/LT)

- Significant BSFC improvement over best available engine, especially at lower engine speeds





Responses to Previous Year Reviewers' Comments

Comment	Response
Little or no discussion of trailer and trailer partner efforts in the project yet significant savings identified in the FE plan. No discussion of trailer tire Crr improvement.	With limited time and presentation slides available, not all work is highlighted during the AMR. Strick Trailers has been an integral part of SuperTruck 2 development. Strick has produced a 53' trailer that is about 2,000 lbs. lighter than typical with innovative aero components that could be adapted to the approximately 2 million trailers found on the road today.
Friction hardware shows significant improvements in BSFC over stock hardware implies it will be a big part of the final demonstrator package, but the data shown is a combined effect of these coatings, along with lower viscosity oil, so a lower pumping loss. With no numbers on the graph, I have doubts that the benefit will be worth the cost and risk involved with these coating (long term durability and effect on oil consumption).	Referring to friction & parasitics slides from the 2020 AMR, we demonstrated approximately 0.5% fuel consumption reduction for the friction reduction package in the stand-alone test of the friction package. A 0.5% fuel consumption reduction is significant for a friction package and would be worth consideration on a business case basis.
Optimizing tire Crr differently between tag and pusher tires did not consider TCO ramifications to fleet operations and replacement rates, retreading, etc.	TCO was considered throughout tire development. The tag tire can also be used on the trailer axle since it is not a tag specific tire. As a consequence, the fleets will not have additional inventory for replacement (Tractor + Trailer still has to deal with three tire types: steer, drive, tag/trailer). The tag tire can be retreaded with the appropriate tread on either the drive/tag/trailer axles.

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

- Integration of new engine into Final Demonstrator
- Evaluation and optimization of hybrid during multiple drive cycles.
- Integration of new smaller 48v battery system.

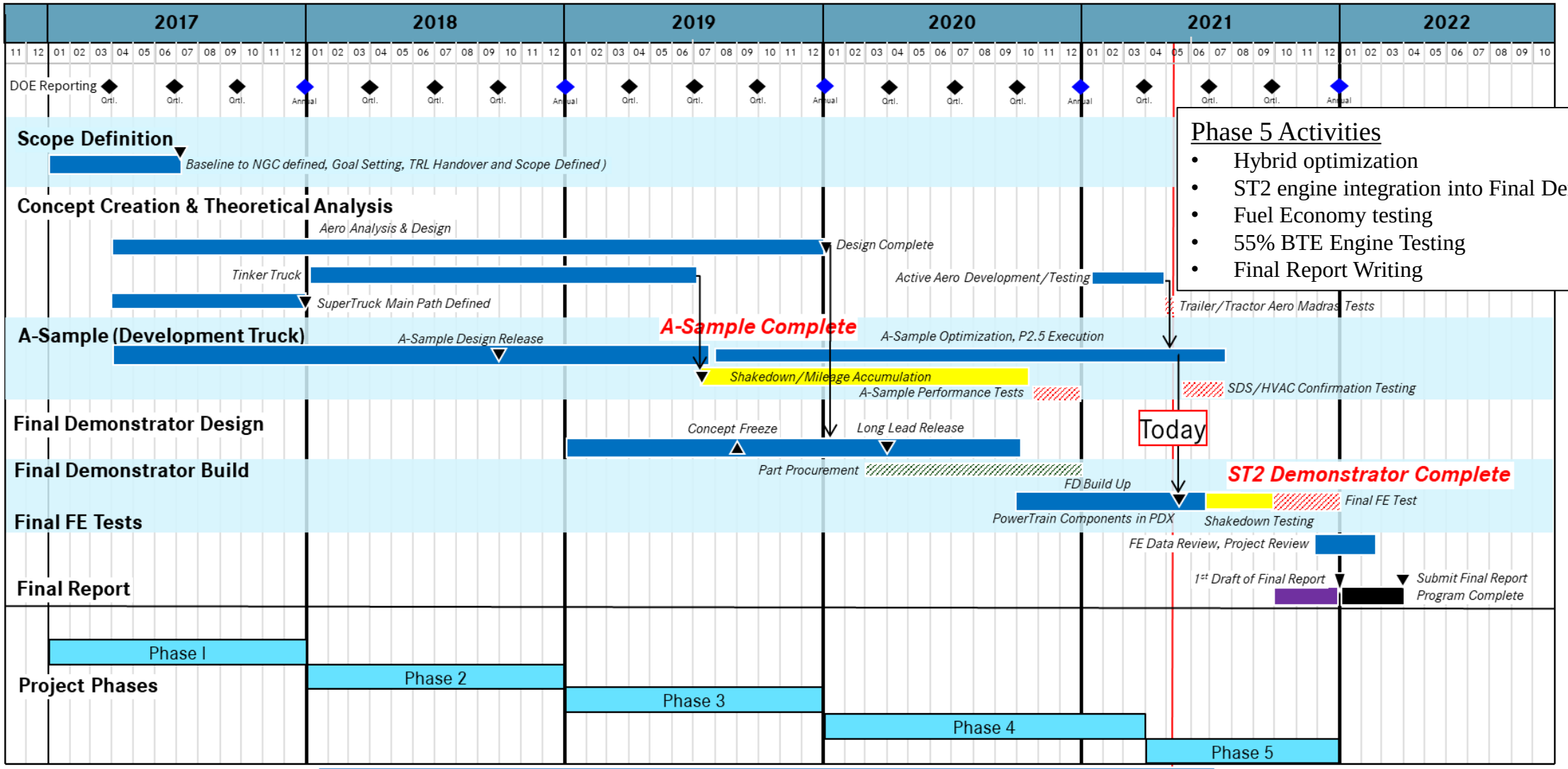
Resources

- Starting late in March 2020, supply chain disruptions and work arrangements changed delaying critical part delivery such as the engine about 8 months. Recovery plans are in place, but have risk to finish all testing before end of 2021.

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

Plans in place to address challenges

Summary and Future Work



Phase 5 Activities

- Hybrid optimization
- ST2 engine integration into Final Demonstrator
- Fuel Economy testing
- 55% BTE Engine Testing
- Final Report Writing

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

Summary

Accomplishments

A-Sample Integration Vehicle
- Completed several weeks of testing in Fall 2020
- Continued through 2021 to integrate most new features

Engine Development
- 55% engine completed build and shipped to ORNL for final testing
- Final demonstrator engine completed dynamometer calibration

Final Demonstrator donor vehicle received April 2020
- Chassis torn down and rebuilt awaiting engine expected in May 2021
  - Michelin built and tested tires exceeding original Crr reduction goals
- Completed exterior build including trailer with testing
- Testing and simulation show good path towards >115% freight efficiency
- Coronavirus caused supply chain disruptions
  - Have aggressive plan to complete testing in 2021 with increasing risk

Questions?