DAIMLER

SUPERTRUCK

Improving Transportation Efficiency Through Integrated Vehicle, Engine, and Powertrain Research – SuperTruck II

Derek Rotz, Principal Investigator, Vehicle

Jeff Girbach, Principal Investigator, Powertrain

June 13, 2019

Daimler Trucks

Project ID: ACE100

FREIGHTLINER FUSO WESTERN STAR Thomas BUILT BUSES BHARATBENZ

Overview

Timeline

Start — January 1, 2017

End — December 31, 2021

PH1	PH2	PH3	PH4	PH5

Status 6/2019 = 50% Complete

Barriers

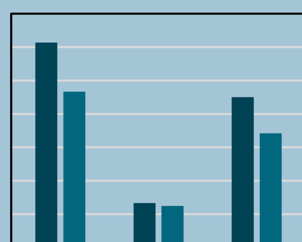
- Our first prototype component integration is underway on the A-Sample Truck, but making all the systems work together is the biggest challenge.
- Prototype controls integration on top of series controllers remains a difficult task.

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

2018 Summary

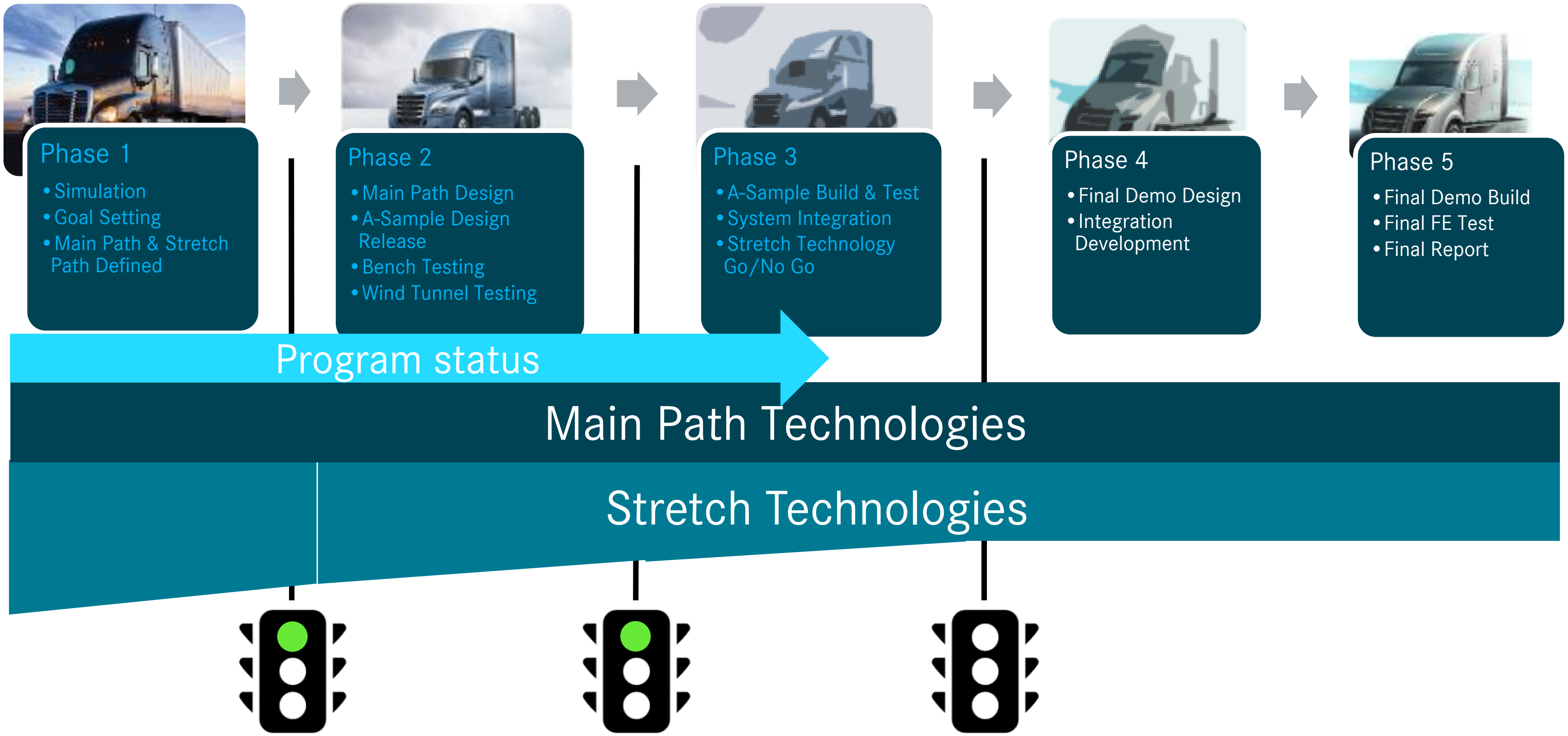


	Total	DTNA	DDC
2018 Planned	12,270,352	2,668,167	9,004,185
2018 Actual	9,334,148	2,488,671	6,845,477

Project Partners

- Schneider National
- Strick Trailer
- Michelin
- Oak Ridge National Labs
- National Research Energy Laboratory
- University of Michigan
- Clemson University

Objectives – Project Phases

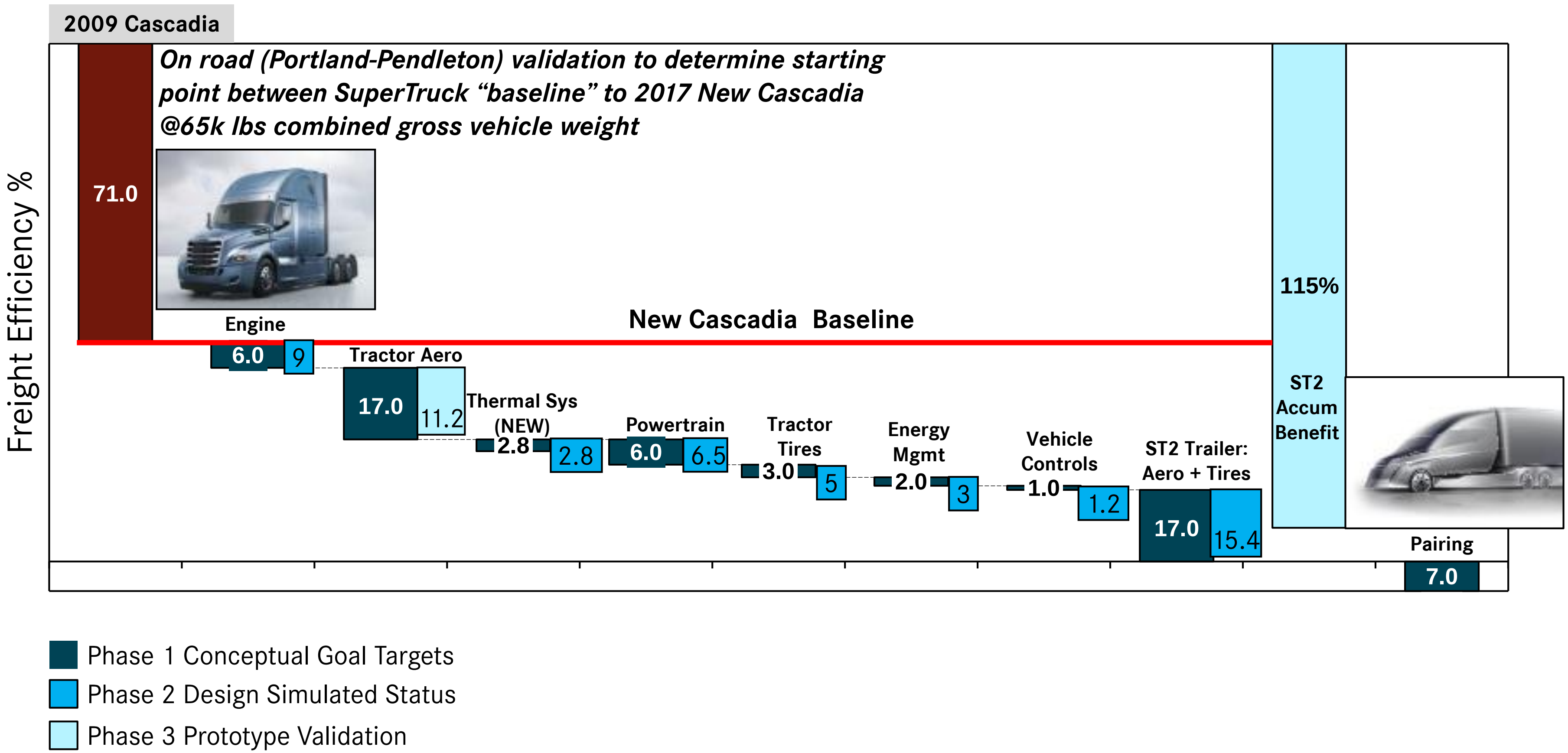


Phase 2	Aero Tinker Truck Assembled	100%	April 2018
	Prototype DD13 Engine Delivered to DTNA	100%	Sept 2018
	A-Sample Design Release	100%	Dec 2018
Phase 3	A-Sample Assembled	100%	June 2019
	A-Sample FE Validation Test Complete	30%	Dec 2019

Approach – SuperTruck 2 Roadmap Update

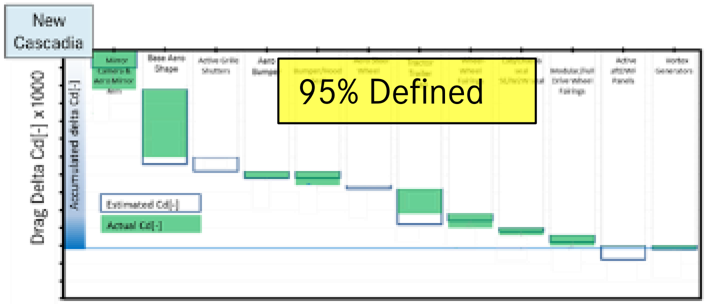
Phase 1: *Goal setting via simulated conceptual FE targets*
Phase 2: *Simulation of designed systems (ie, CFD, rolling resistance, etc..)*
Phase 3: *Validation of physical prototypes (A-Sample testing)*

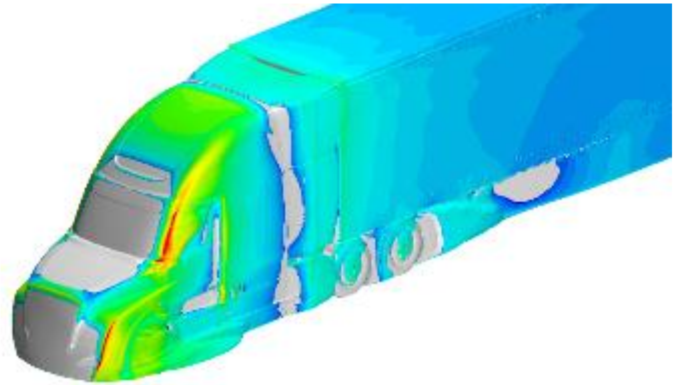
Expected reduction of FE going from conceptual to designed components



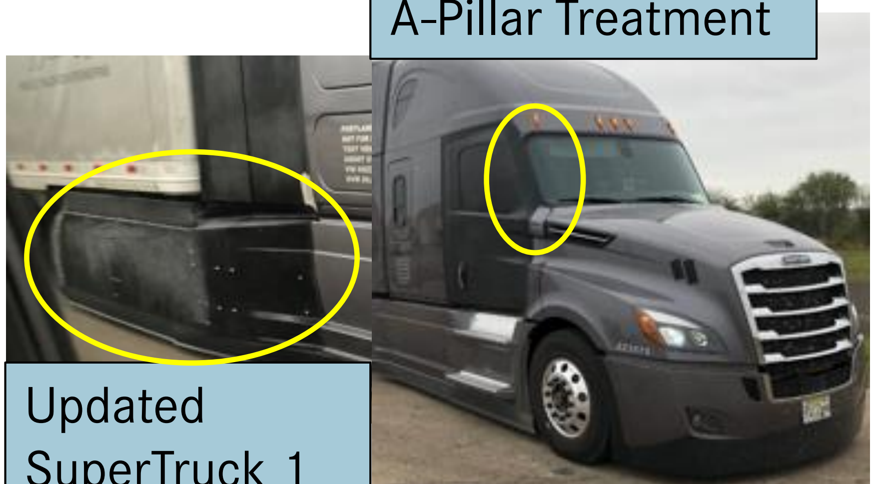
Technical – Aerodynamic & Exterior Development

Pathway to Reach Aerodynamic Target





- Computational Fluid Dynamics
- Physical Validation
- Input for Design (40% Clay)
- Final Check (100% Clay)



A-Pillar Treatment

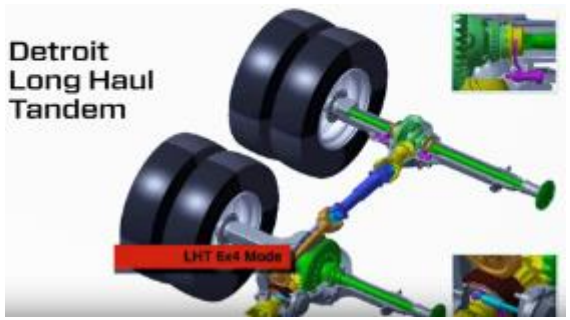
Updated SuperTruck 1 Fairings

Technical – Chassis Developments

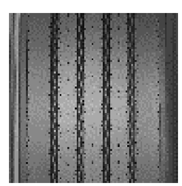
Prototype Tires

Michelin tire will be optimized for clutched rear axle – "Detroit Long Haul Tandem Concept"

Operates like a 6x2 at hwy speeds

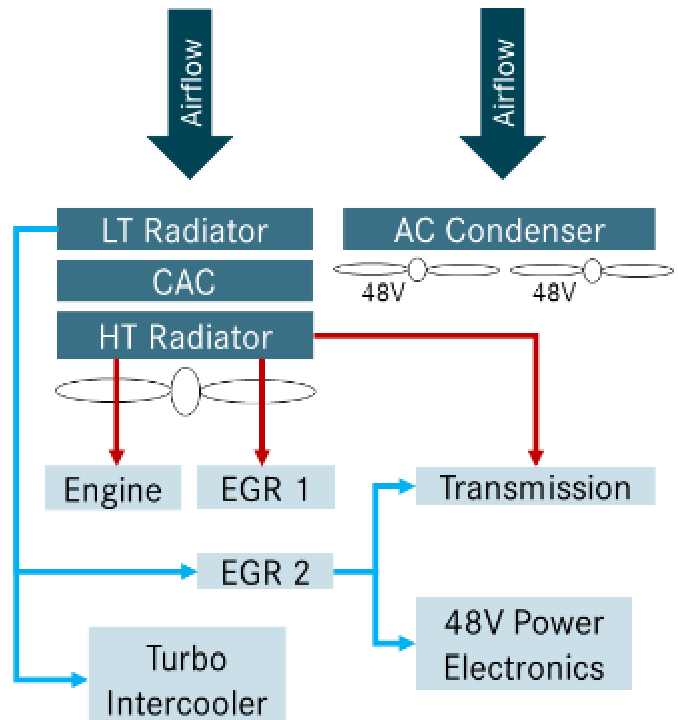


1. Low Rolling Steer Tire
2. High Mileage/Low Rolling Drive
3. Low Rolling Tag Tire



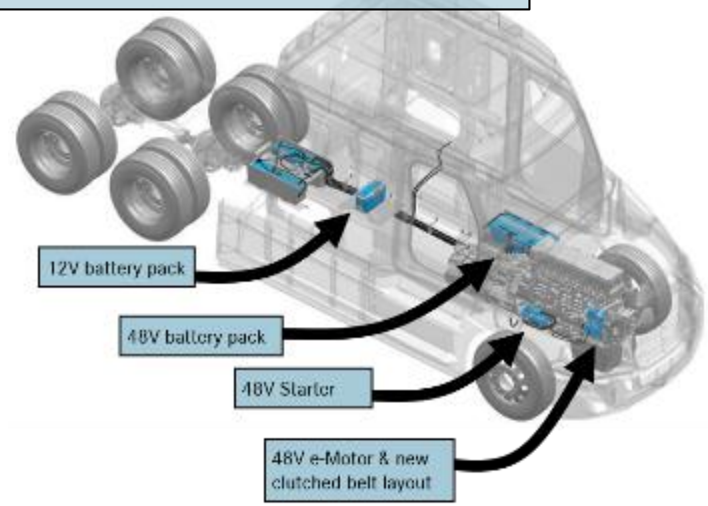
Thermal Configuration

- High efficiency engine needs new cooling concept
- Allows for 48V system cooling



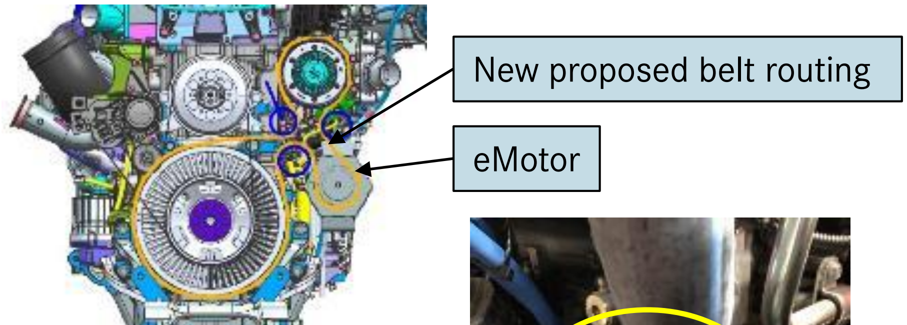
48V Configuration

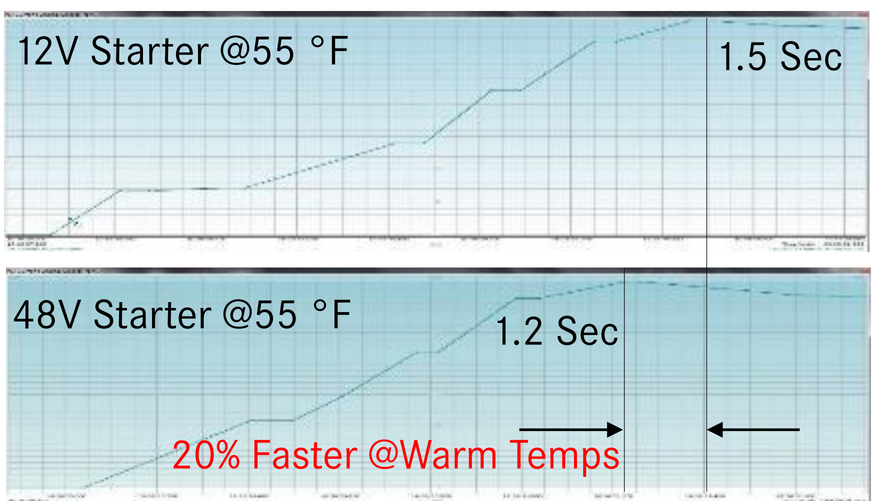
A-Sample System Layout



Replace alternator with 48V motor generator:

- Pull power off the engine in place of the alternator.
- Consume battery power as an e-motor to assist powertrain.
- Allows for energy recovery “mild hybrid”.

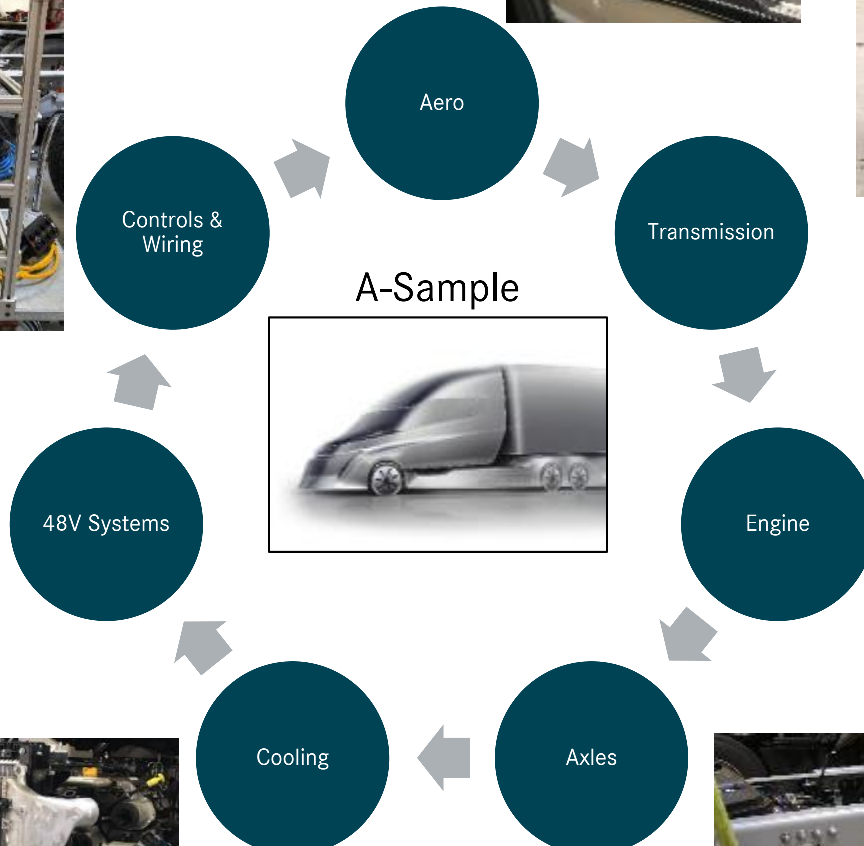




48V Starter

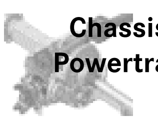
48V Motor

Collaboration: First Prototype Integration A-Sample Truck



Summary of Technical Investigations

- Phase 2 Simulated & Design Status
- Phase 3 Prototype Validation

	Main Path	Stretch Items	Investigation Topics
 Aero	• Aero front • Improved tractor-trailer gap mgmt • Improved wheel treatments • Aero windshield • Mirror cameras • Improved aero seals	• Under hood airflow	• Roofcap shape changes
 Engine	• Down-sped, high BMEP DD13 engine • High peak firing pressure • Heat loss & friction reduction measures • Active drivetrain fluid temperature control	• In-cylinder thermal barrier coatings • Additional WHR heat sources • Real-time predictive powertrain control	
 Chassis & Powertrain	• High FE Tires (Michelin) • Thermal system • Advanced axle system	• High FE gear oil • AC Condenser w/electric fan	• Axle temp management
 Energy Management	• 48V Mild Hybrid • 48V Power Steering • Improved pHVAC system (NREL)	• 48V Water Pump • 48V HVAC Compressor	• Higher capacity battery systems • Clutched Air Compressor
 Vehicle Controls	• Pairing • Eco Roll 2.0 • Mechatronics System Integration	• Intelligent Controls • HMI for new systems	

DAIMLER

SUPERTRUCK

SuperTruck 2 Powertrain

Jeff Girbach, Principal Investigator, Powertrain

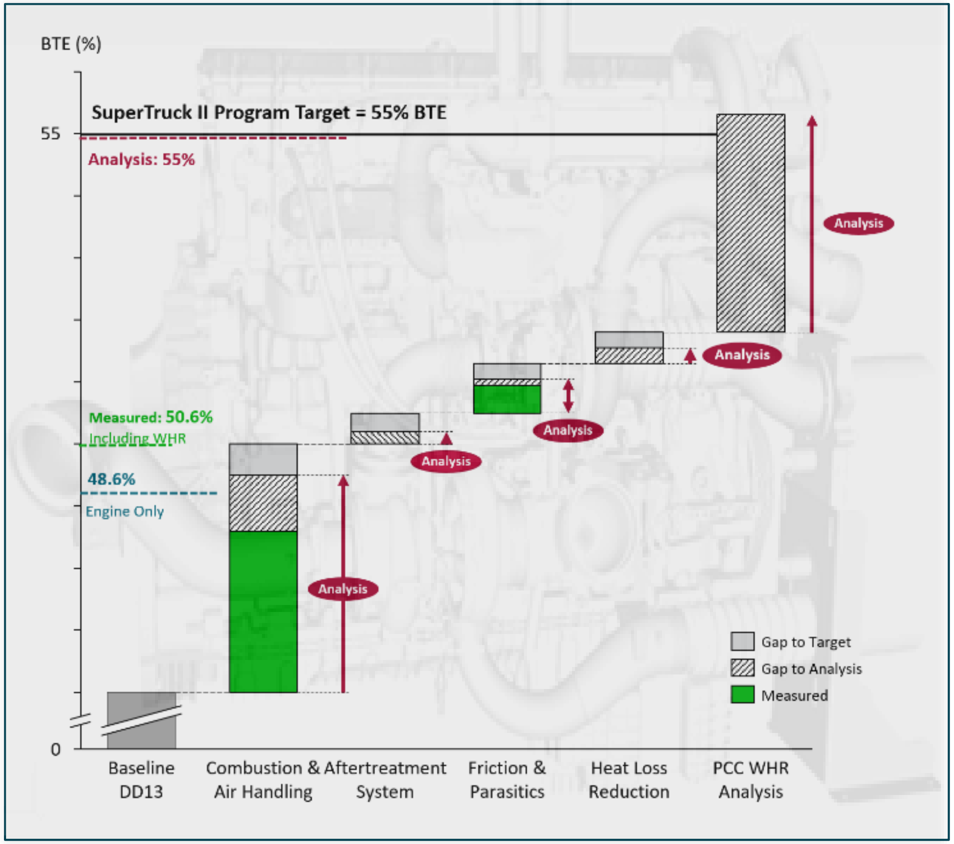
June 13, 2019

Daimler Trucks

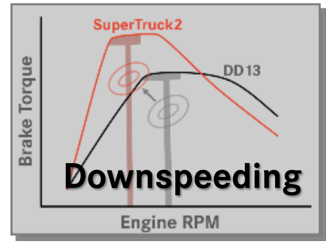
Project ID: ACS100

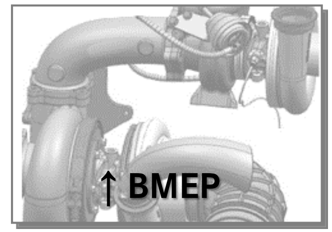
FREIGHTLINER FUSO WESTERN STAR Thomas BUILT BUSES BHARATBENZ

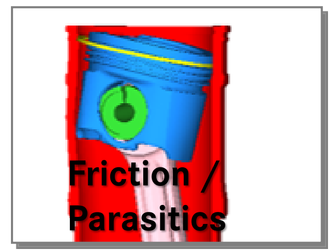
Approach – Powertrain Research Components

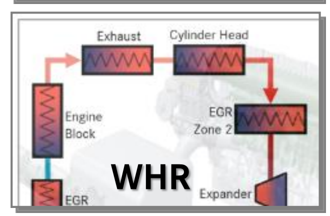


- Designed and analyzed a number of BTE improvement measures
- Experimental evaluation on-going
- Two primary test platforms in Detroit
  - Dedicated Tinker Truck vehicle
  - Engine test cell









Downspeeding enablers
- Two stage turbocharging
- Interstage cooling
- High hydraulic flow injectors

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

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

Controls
- Model predictive controls
- Transient calibration optimization

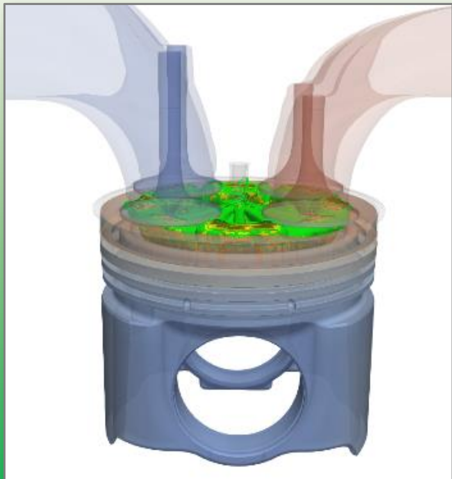
Parasitics
- Oil flow reduction
- Low viscosity oil
- Higher oil temperature
- Active piston cooling jets
- Liner surface conditioning
- Variable speed water pump

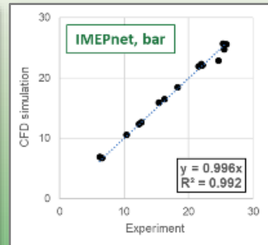
Waste Heat Recovery
- Phase Change Cooling WHR

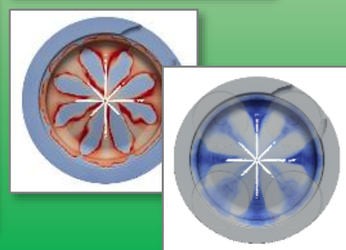
Aftertreatment
- Close-coupled SCR

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

Technical – Collaboration with ORNL







- Developped ST2 DD13 Combustion & conjugate heat transfer (CHT) CFD model
- 3-D CHT on piston, 1-D CHT on liner
- Technical investigations
  - Miller Cycle (late IVC) with low-pressure EGR
  - Thermal barrier coating (TBC)
- CFD is coupled with Daimler's cycle simulation model
- Analysis results
  - Demonstrated reduced pumping losses/lower BSFC (1% at road load)
  - Demonstrated TBC's potential for reduced heat loss

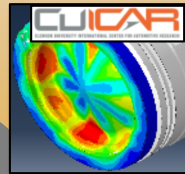
- New engine installed at ORNL
- Initial firing and baseline planned for April
- Full performance and emissions evaluation capabilities
- Proposed efforts include
  - Friction pack evaluation
  - Intake conditioning studies

- Power pack testing at ORNL's Vehicle System Integration (VSI) laboratory
- Hardware-in-the-loop drive-cycle testing
- Component level to full HD powertrain
- Repeatability typically within 0.3% CoV
- Advanced transmission design evaluation
- Efforts planned for summer 2019

Technical – Thermal Barrier Coating Development

High Fidelity Single Cylinder CFD Model

Composite TBC/Piston FEA



Cycle Simulation

Performance variables

- IMEP
- Thermal Efficiency
- Emissions Estimates
- Surface Heat Flux
- Surface Temperature
- Heat Release Rate
- Heat Flux

Analysis

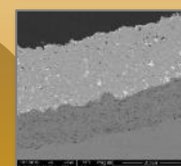
Three major enablers

- Analysis
- Plasma spray
- On-engine validation

CLEMSON UNIVERSITY

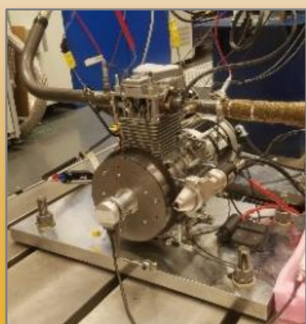
SOLUTION SPRAY TECHNOLOGIES

OAK RIDGE National Laboratory



- SST developing advanced plasma spraying process for thermal spray of advanced oxide TBC onto steel piston
- Plasma spray process optimized for complex geometry
- Coatings demonstrate uniform, smooth coverage over entire piston crown
- Initial durability assessment of coatings in progress

Spray Technology



Single Cylinder Engine

Multi Cylinder Engine

Experimental Evaluation

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

Objectives

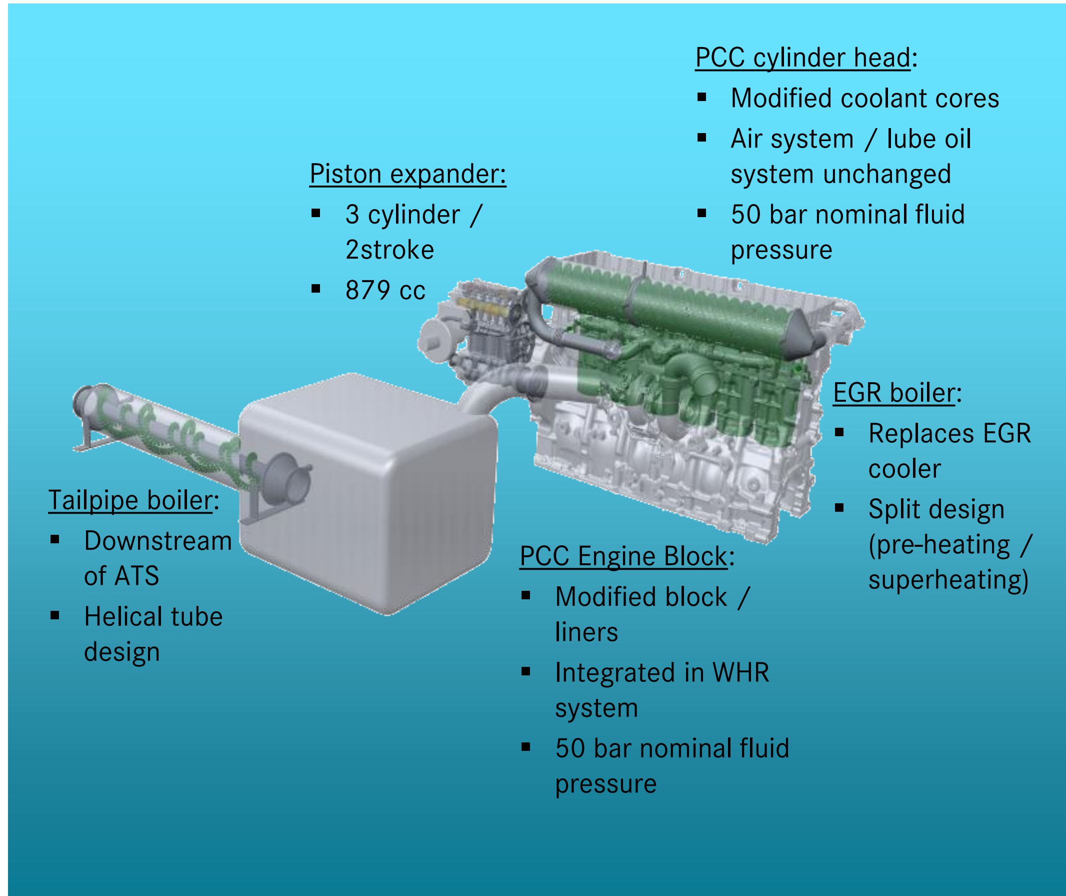
- Recover high quality waste heat in the cylinder head and engine block
- Deliver on 3.5% BTE potential

System description

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

Status

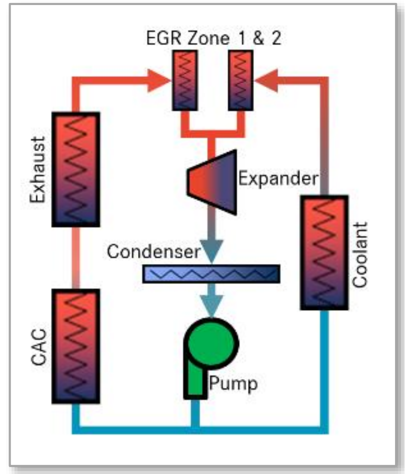
- Finalizing coolant core design
- Experimental evaluation scheduled to start Q4 2019

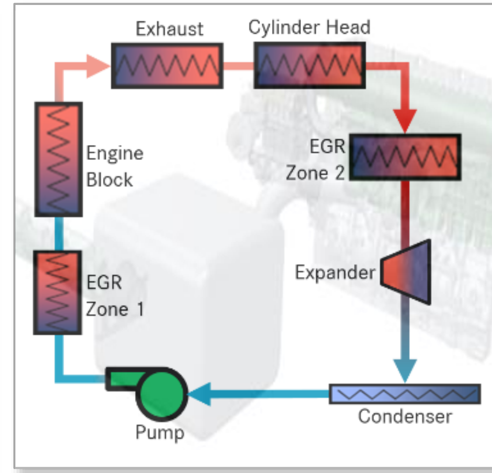


Technical –Waste Heat Recovery (WHR)

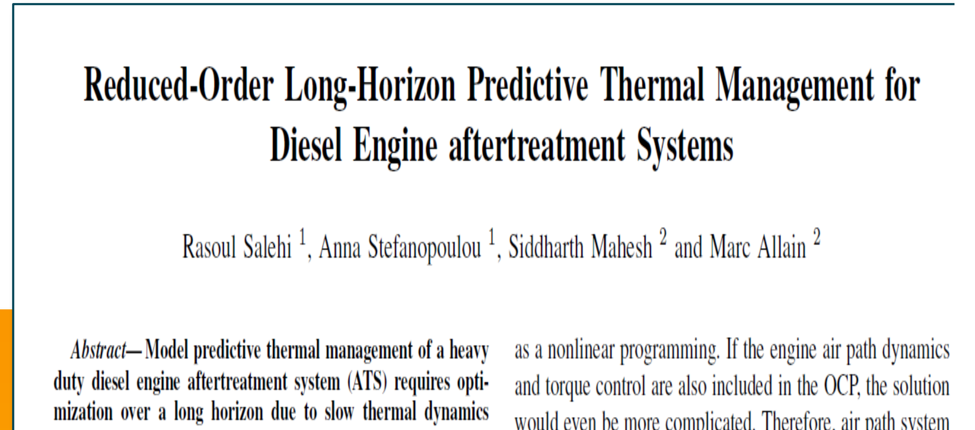
	Refrigerant Based System	Ethanol Based PCC System
Complexity	👎 👎	👎
Performance	👎	👍
Condenser Requirements	👎	👍
System Cost	👎 👎	👍
Development Challenges	👎	👎 👎

- Significant added complexity in both cases
- PCC system eliminates the need for a coolant circuit
- PCC requires extensive engine re-design
- Refrigerant based system poses significant heat rejection challenge



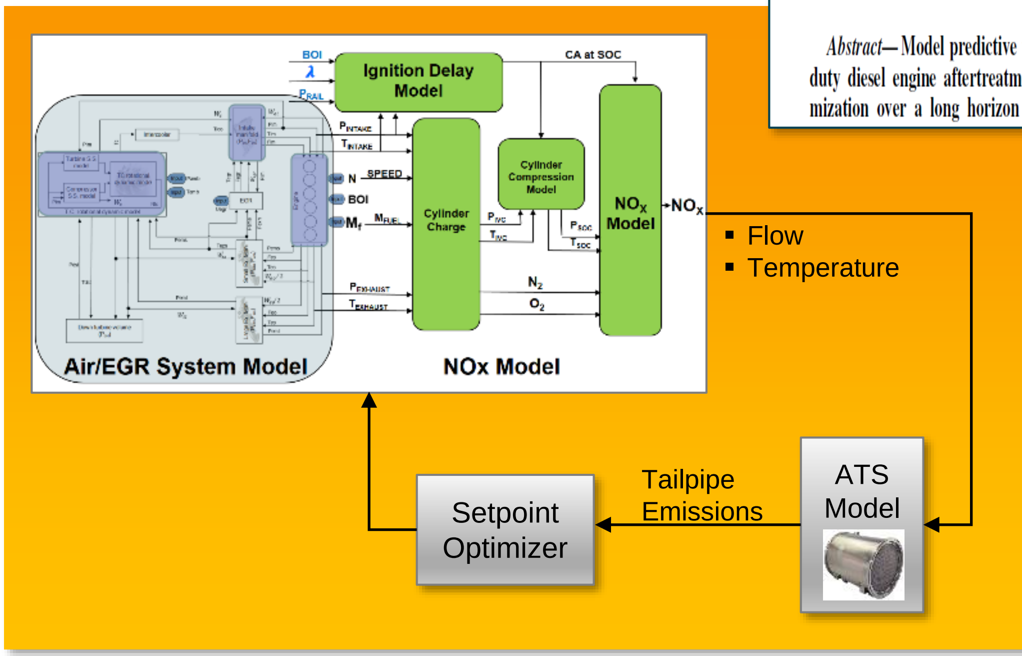


Technical – Model-Predictive Powertrain Controls


Reduced-Order Long-Horizon Predictive Thermal Management for Diesel Engine aftertreatment Systems

Rasoul Salehi [1], Anna Stefanopoulou [1], Siddharth Mahesh [2] and Marc Allain [2]

Abstract— Model predictive thermal management of a heavy duty diesel engine aftertreatment system (ATS) requires optimization over a long horizon due to slow thermal dynamics as a nonlinear programming. If the engine air path dynamics and torque control are also included in the OCP, the solution would even be more complicated. Therefore, air path system

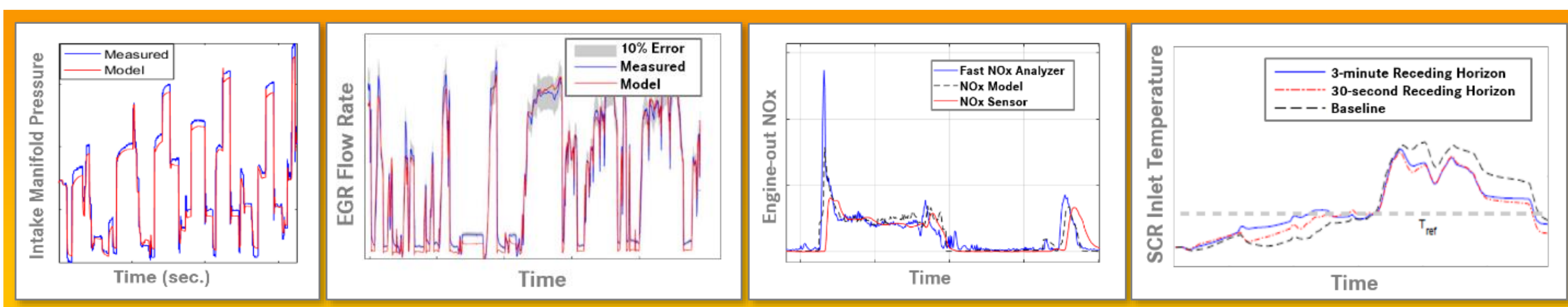


Objectives

- **Real-time engine & aftertreatment control optimization with high fidelity on-board models exercised over a receding horizon**

Status

- **Engine systems fully characterized**
- **Aftertreatment system modeling on-going**
- **Experimental evaluation in progress**



Daimler Trucks

Remaining Challenges & Barriers

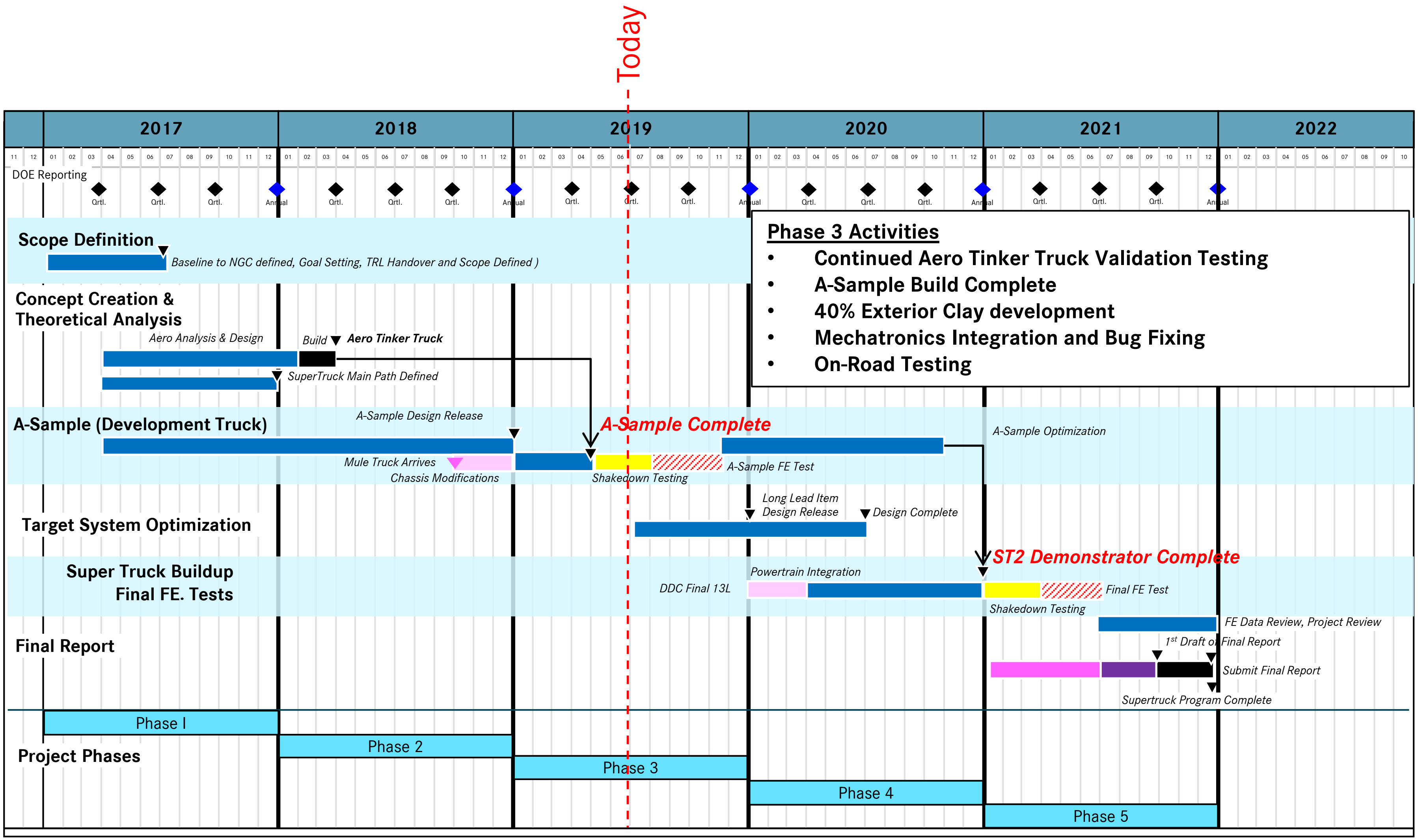
Technical

- We are now beginning to receive updated heat loads for the final demonstrator engine based off of test cell data. We need to re-run the thermal simulation data to check that we have enough heat rejection without raising the charge air cooler temperature.
- We are beginning the packaging studies for the ST2 Final Demonstrator, the twin turbo charger setup is large and due to proximity, could present a heat issue for the HVAC air intake system.
- First engine prototypes with the new technology are being installed in test bays. Validation of the designs and optimization of the new technologies will begin.

Resources

- In April, our Mechatronics Integration person left the company, right before A-Sample key on. We are shifting controls resources to cover the immediate need, getting A-Sample up and running

Summary and Future Work



Responses to Previous Year Reviewer's Comments

Comment	Response
Start-Stop was not in the primary pathway. Predictive engine and drive systems seem to also have been removed.	We evaluated start-stop from a 48V perspective, but since ST2 is an on-road, long haul vehicle, the benefits to the program would be negligible. DTNA continues to develop predictive systems, and the latest updates will be in the final ST2 demonstrator, but there was no need for additional ST2 funds to be used to develop this topic.
There are still big gaps to achieve the program goal of a 55% BTE demonstrator engine. It casts doubts if this can be achieved	New simulation results on engine technologies are now showing that we should be on a good path to reach the 55% BTE. Next steps is building and validating the performance to hit the program goal.
Questioned why single wide based tires would be abandoned at such an early stage when there is a clear advantage	Yes, wide based single tires have a rolling resistance advantage, but most of the market uses duals, so we wanted to tackle the tougher problem. Improving the dual solution in both rolling resistance and tire life.

SuperTruck 2 Partnerships and Collaborations

SUPERTRUCK 2

US National Labs

- Oak Ridge National Laboratory
- NREL

Universities

- University of Michigan
- Clemson University

Industry

- Michelin
- iav automotive engineering
- Johnson Matthey
- Solution Spray Technologies
- Yinlun TDI LLC Thermal Dynamics
- Strick
- Gates
- Atkinson LLC

Fleet

- Schneider

Questions?