Project ID: ACE101

Volvo SuperTruck 2

Pathway to Cost-Effective Commercialized Freight Efficiency

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Volvo Group North America

Washington, DC

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Project Overview

Timeline

Oct. 2016 — Sep. 2021

50% completion

Project Objectives

Demonstrate >**100% improvement** in vehicle ton-miles per gallon compared with a ‘best in class’ 2009 truck, with a **stretch goal of 120%.**

Demonstrate **55% Brake Thermal Efficiency** on an engine dynamometer.

Develop technologies that are commercially cost effective in terms of a simple payback.

Barriers

Manage technology trade-offs during complete system integration

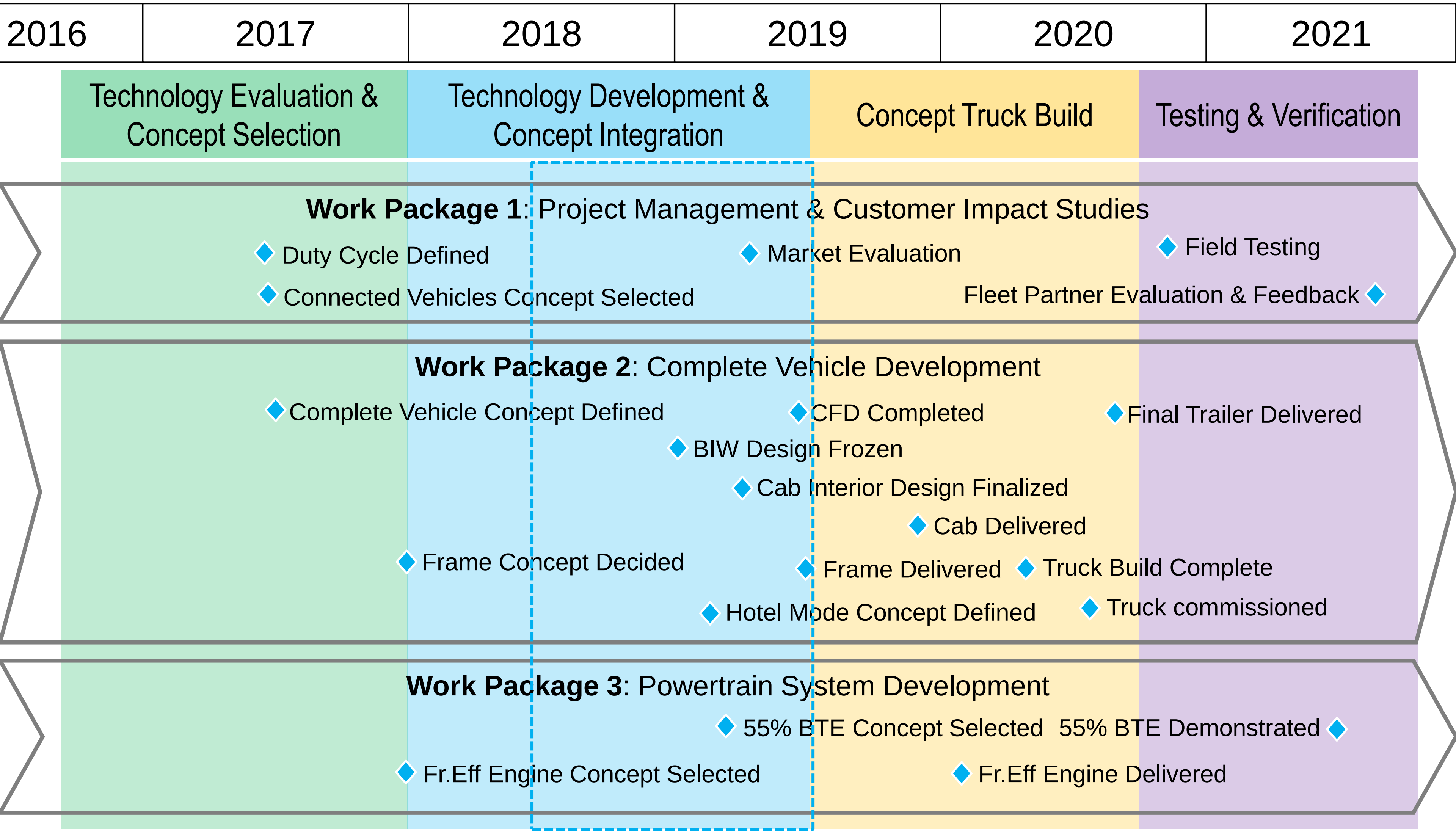
Develop complex systems concurrently

Push limits of laws of Thermodynamics

Funding

- Total project cost > $50 M
  - DOE funds $20 M
- FY2017 funding $1.7M
- FY2018 funding $6.7M

Schedule & Phasing

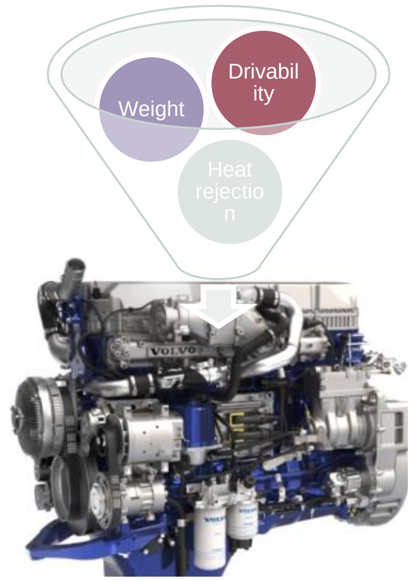


Approach & Concept Selection

A super-efficient vehicle optimized for 65,000 lbs.
and designed for the long-haul drivers of the future

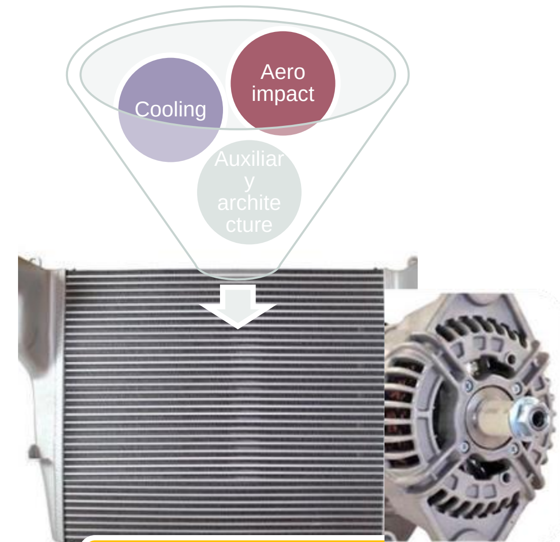
Vehicle Configuration

Confirmed requirements for vehicle & tire design



Powertrain Selection

Confirmed requirements for powertrain design



System Integration

Confirmed requirements for energy management

Tires - Approach & Technical Progress

- **Technical Challenge:** to reduce vehicle fuel consumption significantly without impacting stopping distance or tire longevity.
- **Approach & Collaborations**
  - Michelin and Volvo's ST2 team are optimizing the vehicle using a holistic system integration approach rather than an optimization of the tire as an independent sub-system. This creates new degrees of freedom for light weighting and improved aerodynamics of the vehicle.
  - A comprehensive comparison study of freight efficiency gains from rolling resistance, vehicle light weighting, and lower ride height concluded that the optimal dimension for the Volvo ST2 vehicle was a 19.5" tire.
- **Progress**
  - New technologies to lower rolling resistance (RR) were developed for the tire tread pattern, tread compounds and internal architecture.
  - These technologies were validated and confirmed that 20% RR reduction vs. best in class long haul reference tire was achievable.
  - Work is now underway to apply the technologies to the 19.5" tire

Lightweight - Approach & Technical Progress

Metalsa is leveraging new technologies like additive manufacturing & variable thickness to integrate lighter materials and reduce the number of components.

Work is on track to deliver a tractor frame assembly 40% lighter than on the reference truck.

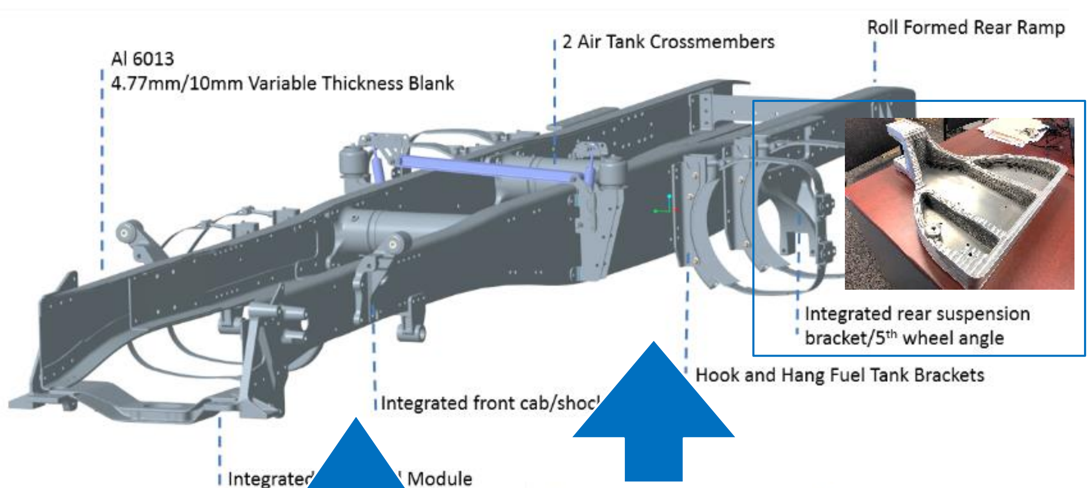
Component Optimization
Side rail thickness is focused on high-stress areas

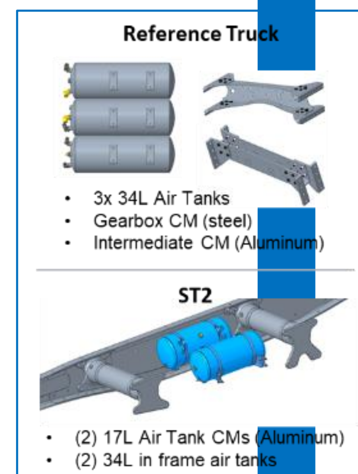
Component Integration
Cost effective way to improve packaging and reduce weight

6013-T4 Blanks

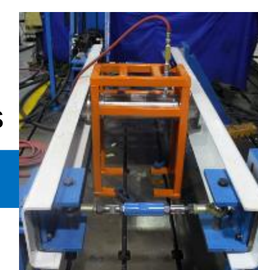
Variable Thickness Roll forming

Al 6013 aged to T6
5mm channel gauge
9.5mm top/bottom plates





19x torsional stiffness
1.3x parallelogram stiffness
150 psi rated air pressure
26% Weight reduction



Fatigue rig testing

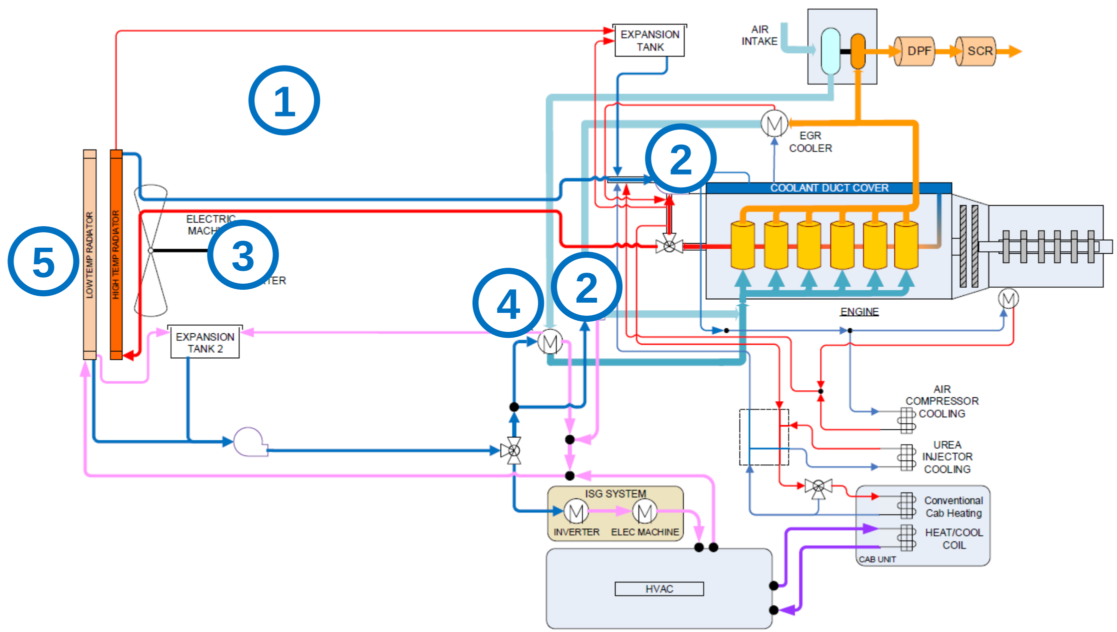
Cooling System – Approach & Technical Progress

Significant improvements in parasitic drag forces and combustion efficiency result in lower power demand and heat rejection. This provides new design freedom for the cooling system.

Multiple concepts were evaluated with regards to their impact on weight / cost / efficiency / packaging of the complete vehicle.

The solution chosen for integration in the ST2 demonstrator features:

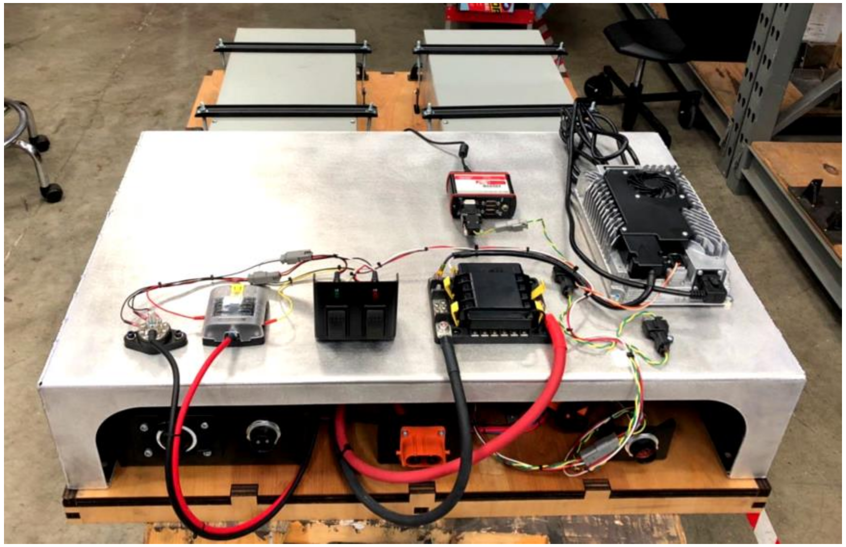
1. High & low temperature loops
2. Electric pumps
3. 28” fan with electric drive
4. Liquid/Air charge air cooler
5. Low-restriction radiators



Detailed design is complete and component fabrication/testing has begun, on track to deliver a complete system for chassis installation by end of the year.

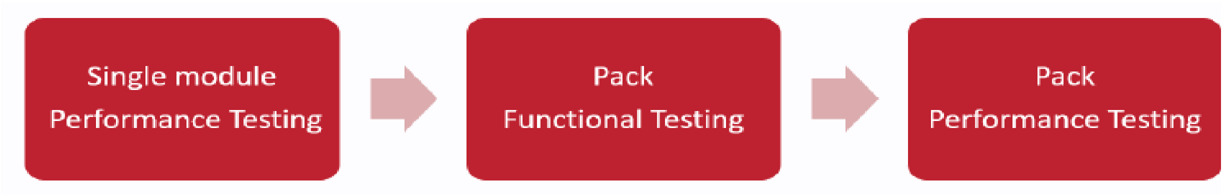
Energy Storage System – Approach & Progress

Complete vehicle requirements on energy storage were previoulsy developed and frozen, which allowed the team to select battery size, cell chemistry, system architecture, etc.



Achievements to date include:

- 24V & 48V circuits design complete
- Component selection complete
- Component procurement 80% complete
- System packaging & design complete
- Bench testing ongoing



Next steps:

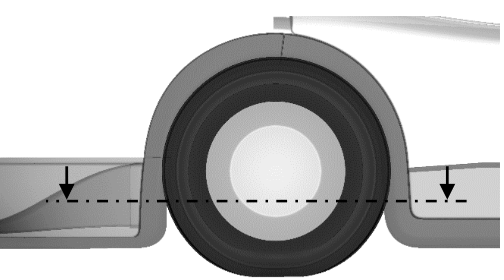
- Complete battery pack functional & performance testing
- Integrate charger, DC/DC and ISG to bench test rig for complete system evaluation

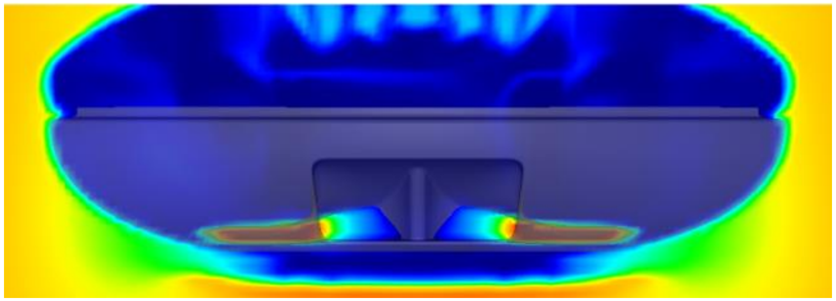
Technical Progress – Tractor Aero

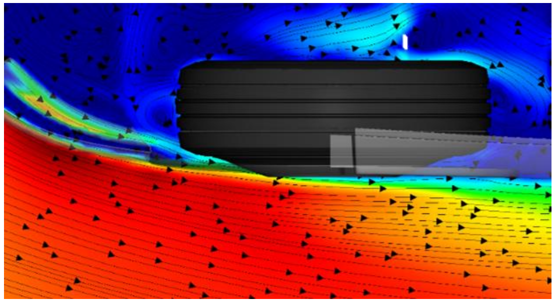
- Tractor A-surface design frozen
  - Driving area interior packaging (Impact on greenhouse ➔ A-pillar width)
  - Wiping feasibility (Impact on greenhouse ➔ Windshield curvature)
  - Trailer swing clearance (Impact on fairings, 5th wheel height ➔ Tractor-Trailer Gap)
  - Camera (CMS) position and mounting optimization
  - Bumper duct and air curtain designed to minimize front wheel wake

- Cooling package design & fan installation finalized
  - Minimized impact on front end design and cooling drag

- Status: 60+ complete vehicle aero design iterations completed (~2M CPU-hrs of CFD)
  - Exceeding target of 50% drag reduction vs. baseline (>15% over SuperTruck 1)

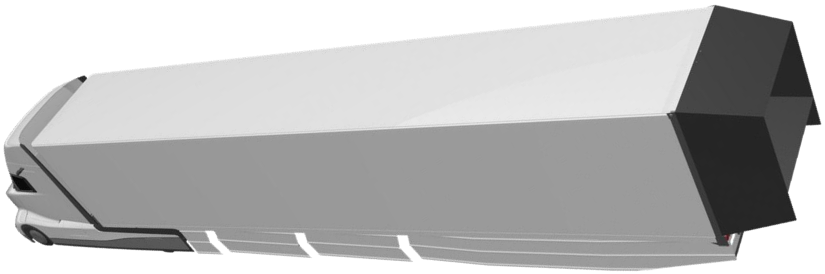


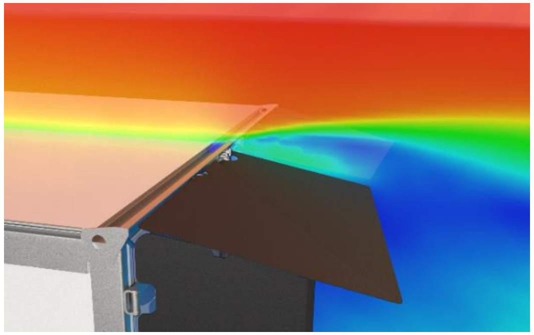




Technical Progress – Complete Vehicle Aero

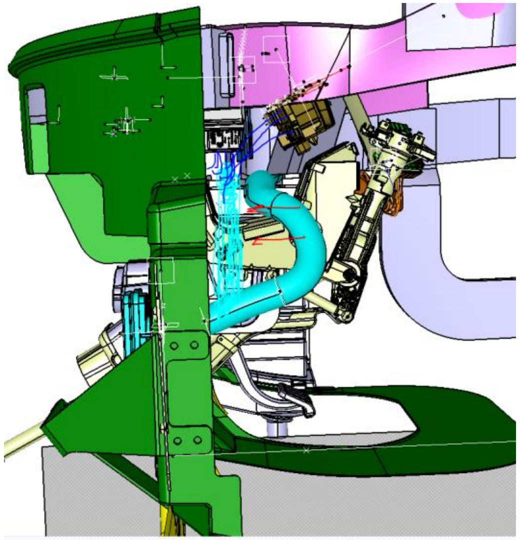
- Trailer design frozen
  - Designed a customized gap fairing
  - Finalized dry van box dimensions & suspension details
  - Balanced trailer skirt design for aerodynamic performance and brand identity
  - Completed optimization of boat tail with finalized tractor and trailer

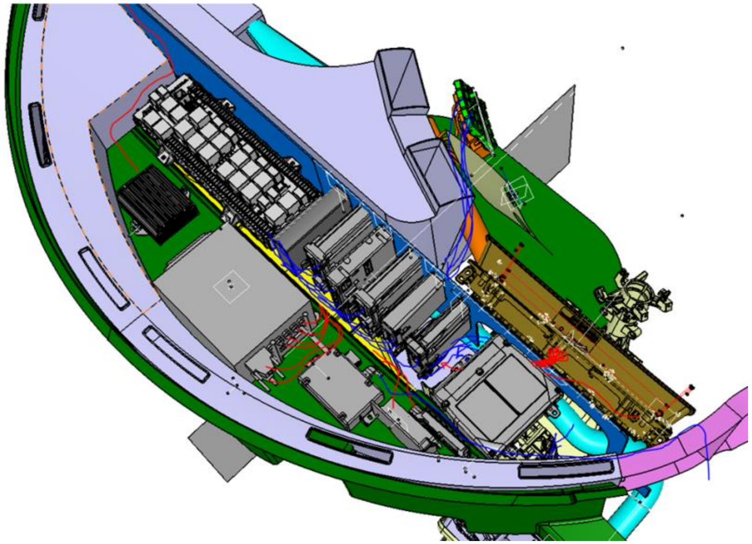




Technical Progress – Demonstrator Build!

- With design frozen in all critical areas, focus has shifted to detailed packaging / routing / plumbing / etc
- Manufacture is well underway for key sub-systems (chassis / cab / powertrain / ...)
- All partners have begun fabrication of long leadtime components
- Demonstrator build is on track for first road test within 18 months





ST2 Powertrain – Technical Description

In alignment with the concept vision of a super-efficient vehicle optimized for 65,000 lbs. the powertrain Work Package will deliver:

Freight efficiency demonstrator

- Weight reduction
- **Friction reduction**
- **Insulation improvement**
- **Electrification**
- **Combustion efficiency improvement**

55% BTE demonstrator

- Downsizing
- **Friction reduction**
- **Insulation improvement**
- **Electrification**
- **Combustion efficiency improvement**
- Waste heat recovery

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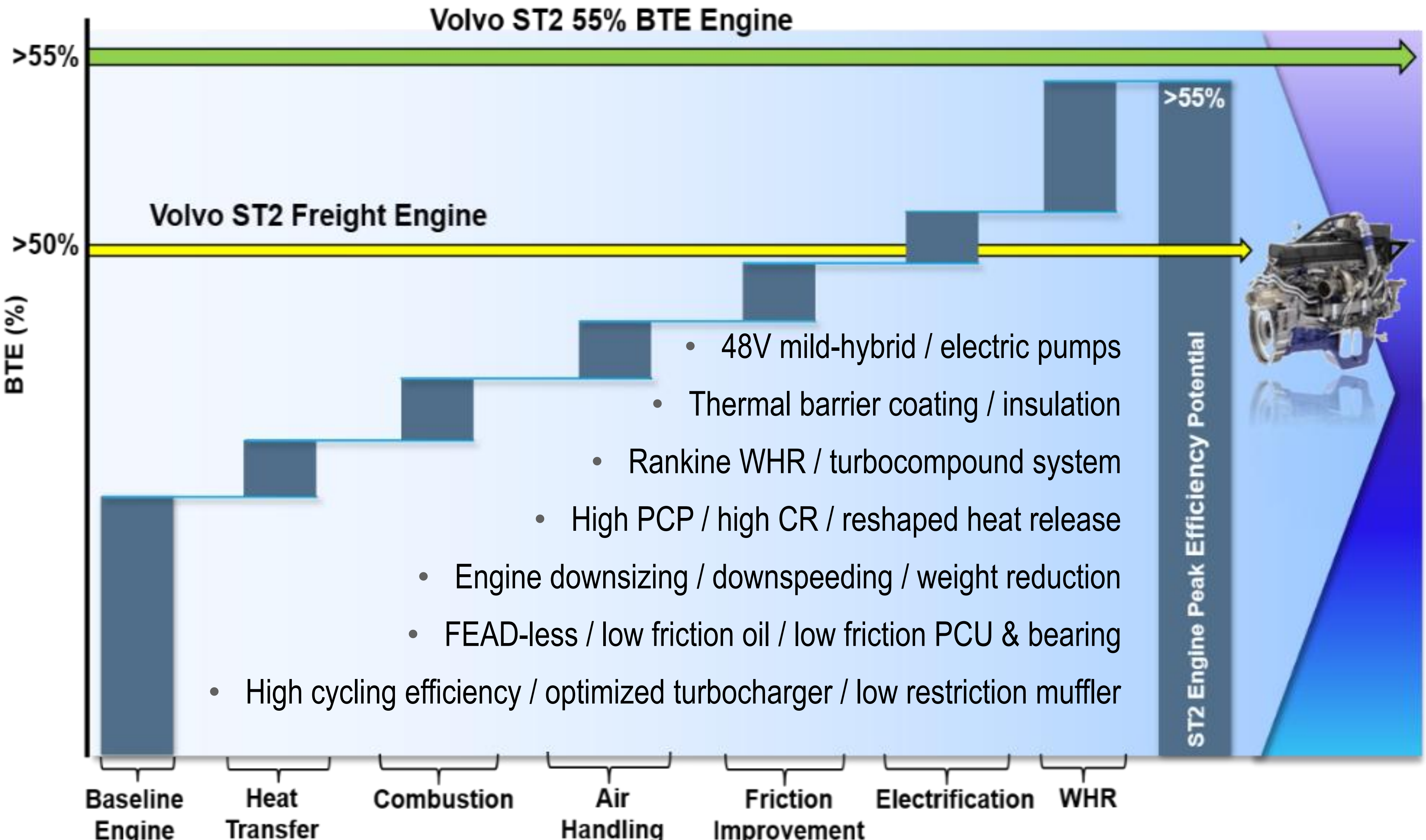
Approach - ST2 Powertrain Development



Combustion Efficiency Improvement – Approach & Progress

Methods and Approach

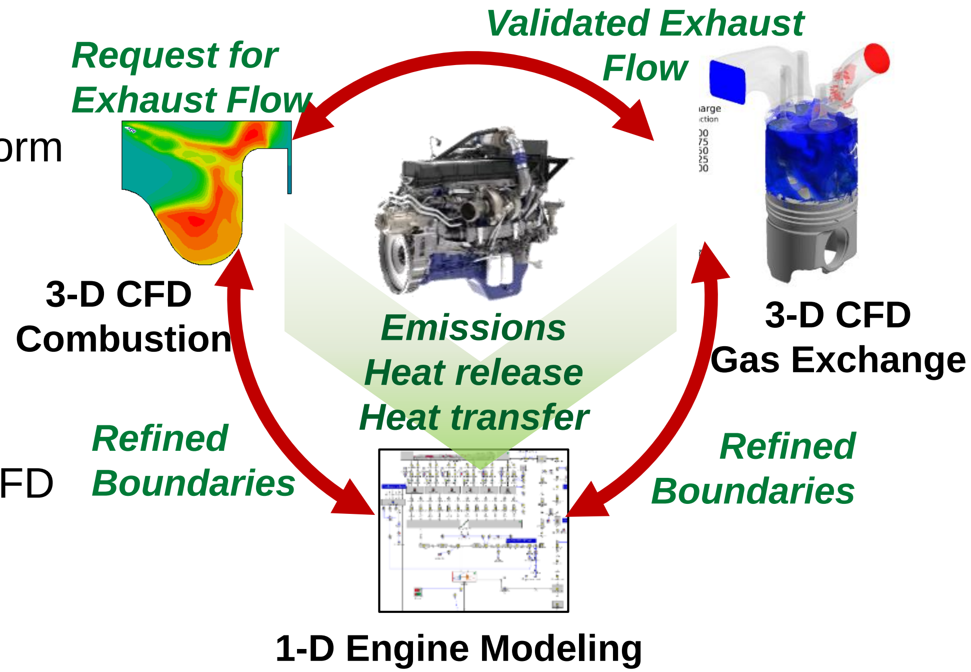
- Multi-cylinder research engine as test platform
- Analysis oriented design
  - 1-D engine modeling
  - 3-D combustion / gas exchange CFD
- Engine performance evaluation
  - Coupled 1-D engine modeling / 3-D CFD

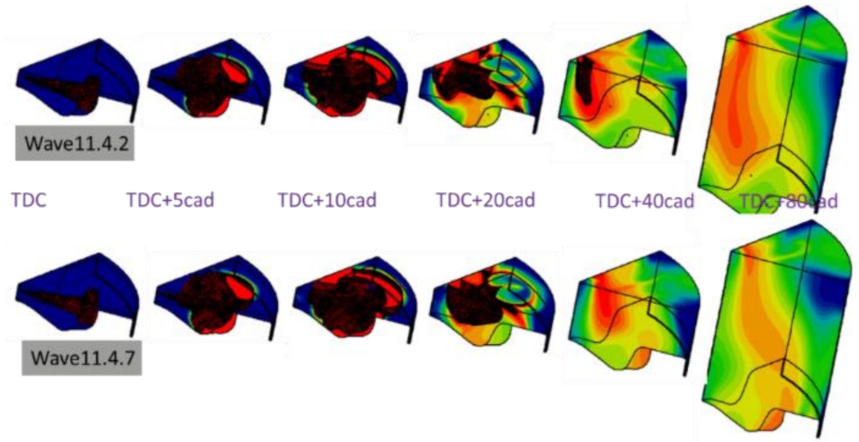
Progress

- Complete engine system modeling
- High compression ratio Wave piston designs
- High peak cylinder pressure operation
- Multiple injection strategy
- Optimized camshaft profile/Miller timing
- Optimized turbo and turbocompound system

Challenges

- Long lead time for prototyping pistons





Thermal Barrier Coating – Approach & Technical Progress

Objective

- Low specific heat / Low thermal conductivity
- High porosity / Low surface roughness
- High strength and durability

Approach

- Thermal barrier coating on power cylinder units
- MCE and SCE tests
- 3-D CHT CFD
- 1-D engine modeling

Progress

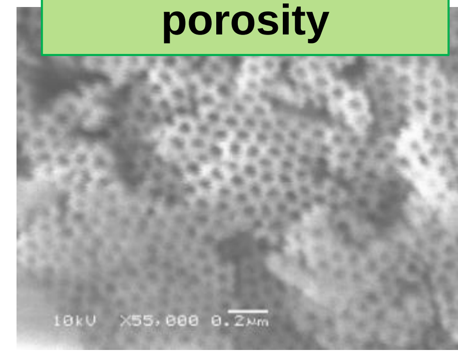
- Analysis oriented
- Multiple TBC approaches
- More TBC engine testing

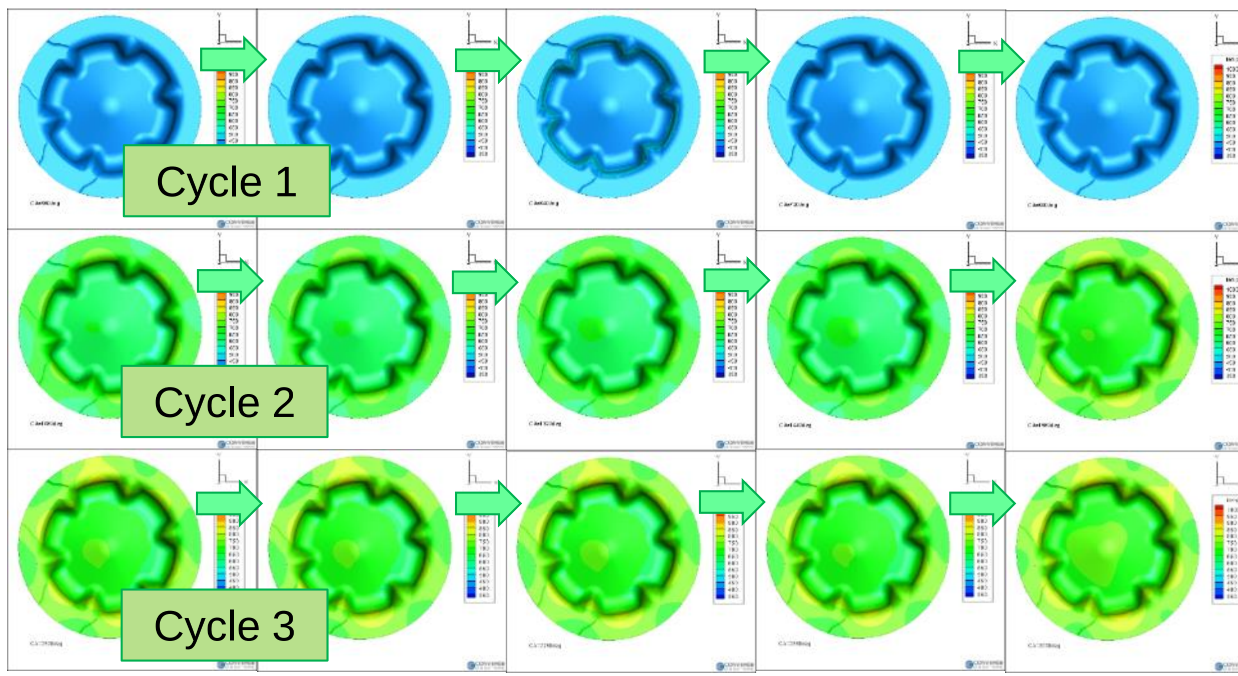
Challenges

- "Surface Temperature Swing"

Exhaust Ports Insulation

Nanostructured porosity





Single Cylinder Engine Test at University of Michigan

Technical Barriers

- Limitations in engine efficiency and challenges with reducing lost work
- Practical and durable engine system modifications that enable higher efficiency
- Trade-offs between reducing heat loss in the power cylinder, and adverse impacts on volumetric efficiency

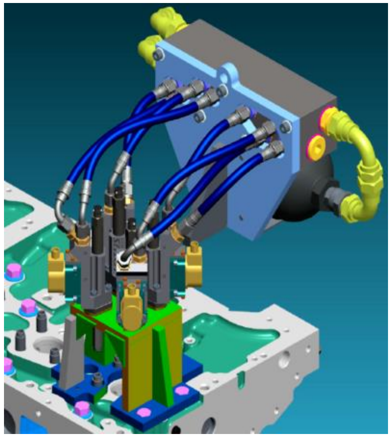
Methods and Approach

- Single cylinder research engine as test platform
- Advanced piston designs to improve thermal efficiency
- High pressure and multi-shot fuel injection
- Advanced thermodynamic cycles via Variable Valve Actuation

Progress

- Additional piston designs and configurations
- Installation and commissioning of VVA system on the MD11 single cylinder engine
- Ready to begin studying novel combinations of pistons and valve timing strategies

VVA System



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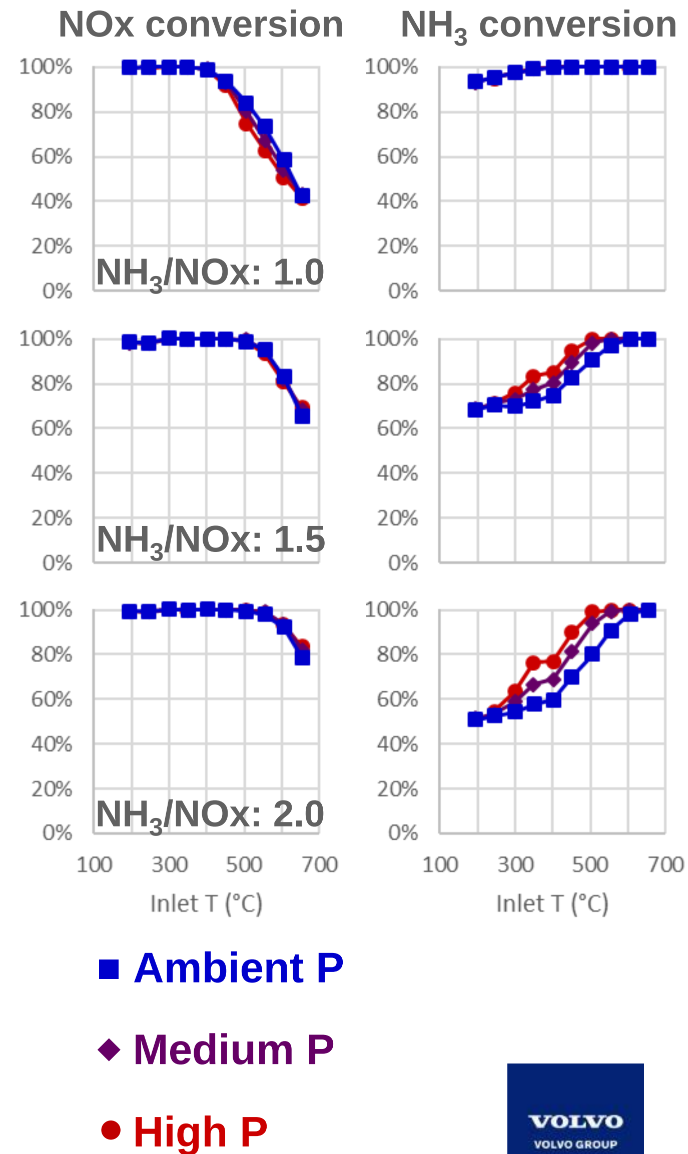
ORNL: Evaluating performance impacts of placing emission control catalysts pre-turbo

- **Challenge**
  - 55% BTE engine will generate lower temperature exhaust, making emissions compliance more difficult
  - Placing catalysts upstream of the turbo would increase operating temperatures
  - Impacts of elevated pressure operation on catalyst performance are largely unknown
- **Approach & Collaborations**
  - Run elevated pressure synthetic exhaust flow reactor experiments on catalysts from **Johnson Matthey**
  - Use relevant exhaust compositions, flows, and temperatures provided by **Volvo**
- **Progress**
  - Baseline SCR catalyst shows minimal impact on NOx conversion & reduced NH_3 slip at elevated pressures
  - High temperature SCR formulation next



Aftertreatment System – Approach & Progress Johnson Matthey

Challenges

- Maintain tailpipe emissions while reducing the volume / weight of the aftertreatment system to support the complete vehicle transport efficiency improvements.

Approach

- Higher cell density substrate to increase geometric surface area of the catalyst
- Electrically heated catalyst to increase exhaust temperature
- Thin wall substrates to reduce thermal inertia and enable faster heat up of the system

Progress

- High cell density SCR catalysts and thin wall filters are coated and ready for test
- Electrically heated catalysts are coated and ready to ship to Volvo test facility
- Thin wall DOC substrates are being coated

Collaborations

- Worked closely with Volvo and ORNL over the past year that enabled the introduction of innovative aftertreatment concepts for the freight efficiency program

Thank you