Volvo SuperTruck 2

Pathway to Cost-Effective Commercialized Freight Efficiency

Project ID: ACE101

Sam McLaughlin (PI)
Eric Bond (Presenter)
Jian Li (PM Powertrain)
Volvo Group North America

DOE Annual Merit Review

June 24, 2021

Project Overview

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.

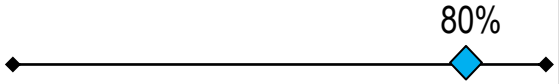
Barriers

Manage technology trade-offs during complete system integration

Develop complex systems concurrently

Push limits of laws of Thermodynamics

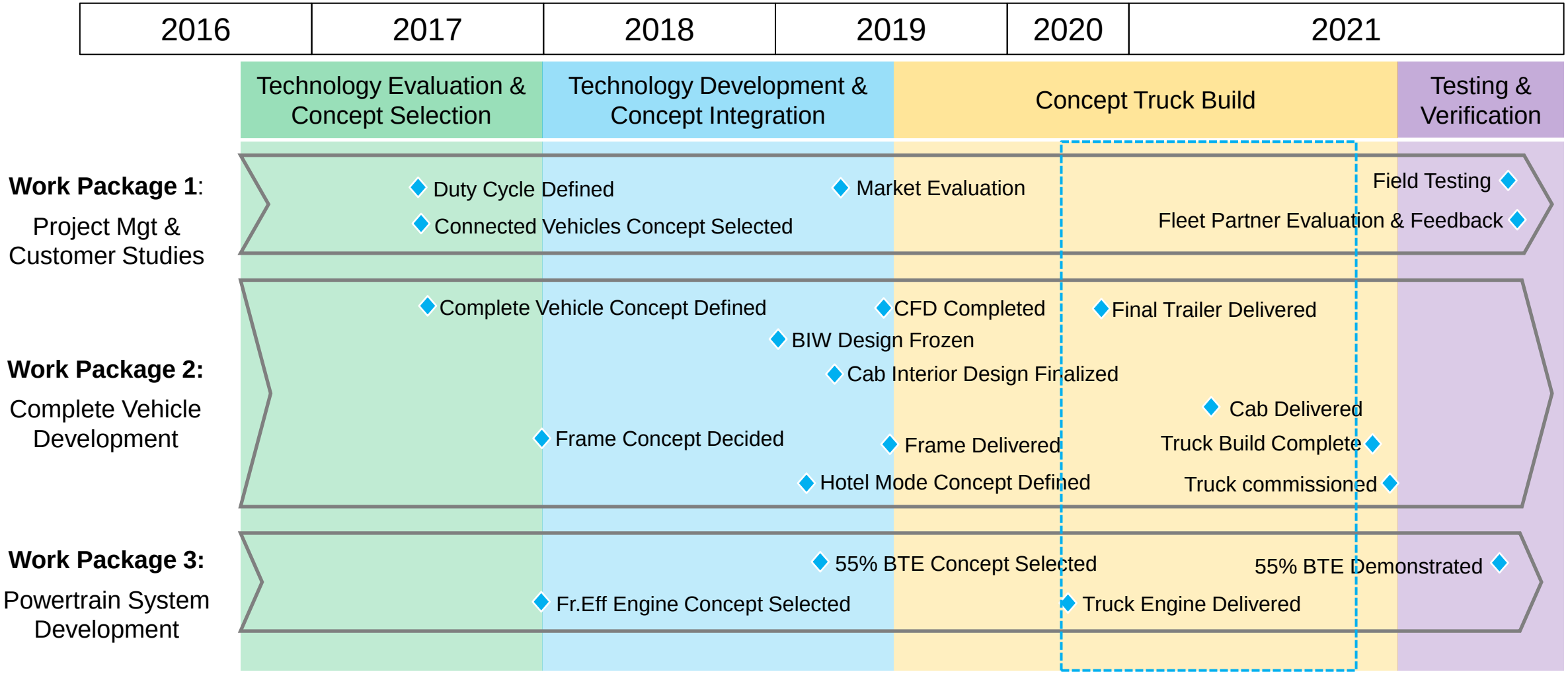
Timeline



Funding

- Total project cost > $50 M
  - DOE funds $20 M
- FY2020 funding: $2,664,756
- FY2021 funding: $3,394,387

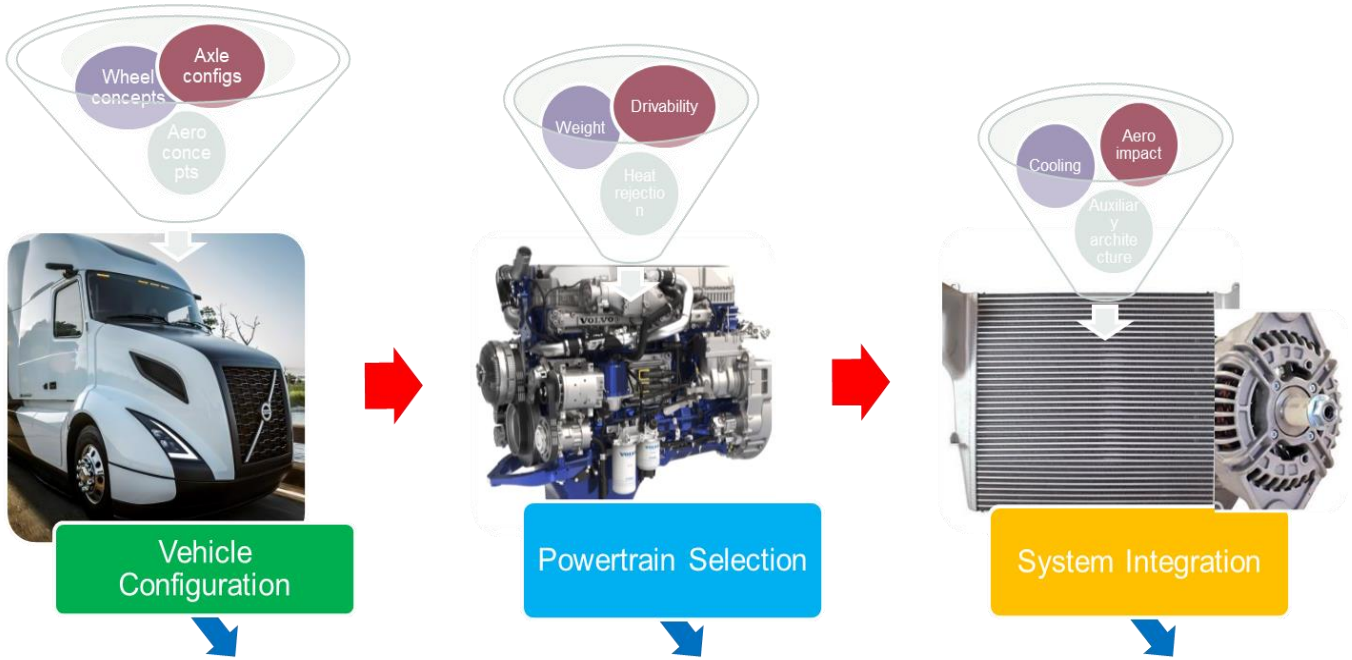
Approach & Milestones



Approach & Concept Overview

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

Design criteria for each subsystem were derived from the program goals and broken down into individual targets or requirements.



Summary of the concept selected

4x2 axle configuration

19.5” wheels

Shorter cab w/ optimal interior configuration

<u>27,000 lbs. curb weight</u>

<u>15% better aero than ST 1</u>

325HP 11L powertrain

48V electrification & mild hybrid

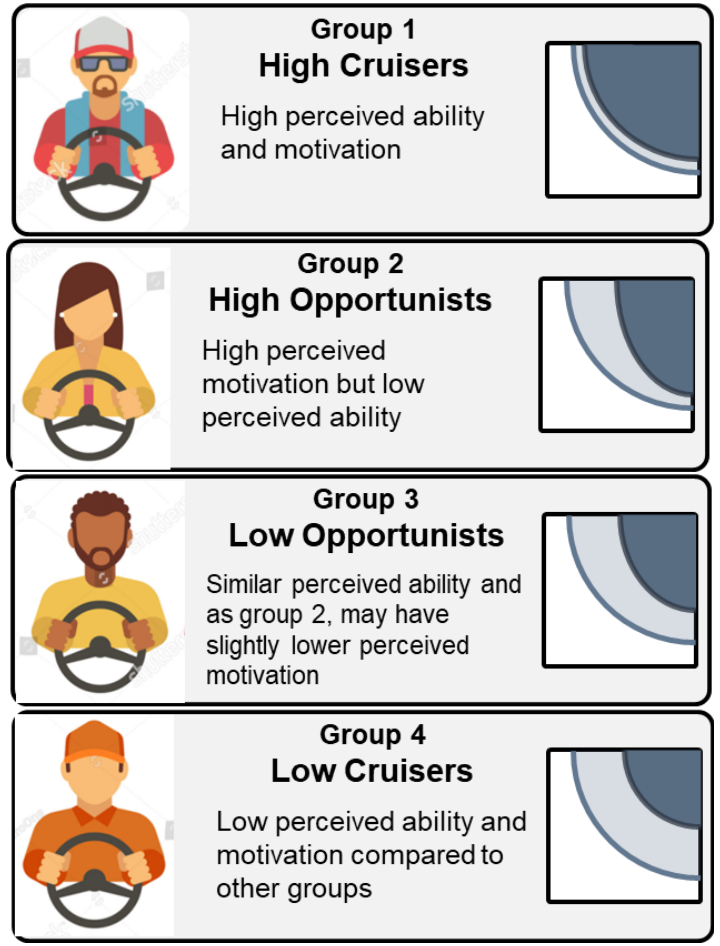
All-electric HVAC

Multiple concepts were evaluated using complete vehicle simulations over a variety of duty cycles representing highway fleet operation.

Relevance & Approach: Data Driven Design / Fleet Studies

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

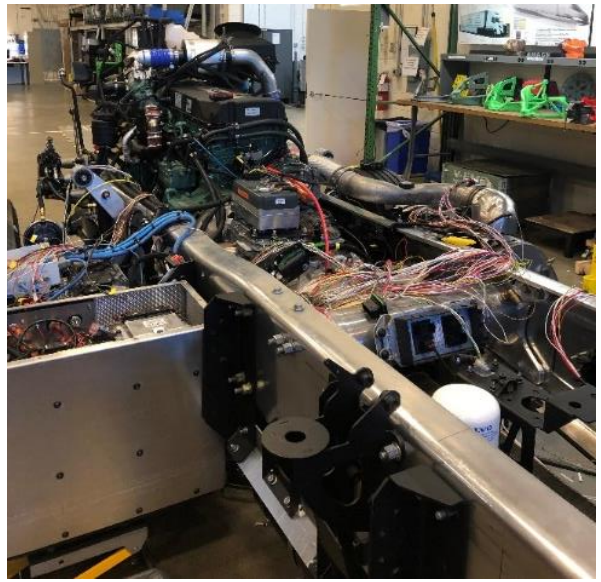
- Year long effort to collect and analyze data from driver surveys combined with operating and demographic data from a N.A. mega-fleet
- Preliminary findings that could improve cruise control usage
  - Results indicate that demographics (age, sex, seniority with fleet) do not correlate to cruise control usage
  - Drivers are aware of the type of cruise control on their vehicle' but lack understanding for when cruise control can be used safely and is beneficial to the driver
  - The study team segmented drivers into four groups based on exhibited cruise control behavior when the truck is in and out of top gear (Groups 1 to 4)
  - A behavior modeling framework is applied to the segments to understand what is missing when cruise control is not used by drivers
    - Motivation is perceived benefits for driver
    - Ability is understanding of when cruise control is safe to use
    - Both must be perceived to be present at the same time for cruise control to be engaged



VOLVO
VOLVO GROUP

Accomplishment: Complete Vehicle Build

- Engine installed.
- Complete drivetrain installed.
- Fuel system complete.
- Brake system complete.
- 48 V battery box installed.
- Cab and chassis fairings delivered to GSO.
- Wiring and pneumatics complete.
- Complete vehicle commissioning under way.



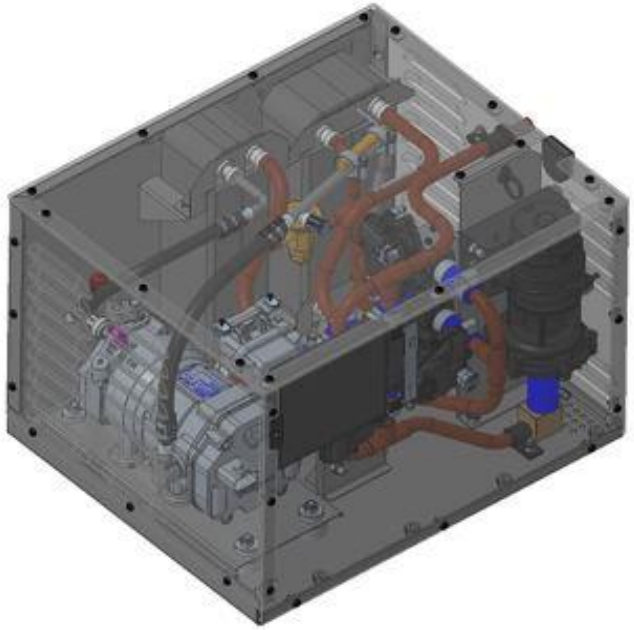
Next Steps:

- Cab modifications and installation.
- Final commissioning.
- Road worthiness and freight efficiency testing.

Accomplishment: Complete Vehicle Items

- HVAC (Bergstrom)
  - Redesigned compressor box to accommodate 48V compressor
  - Will be installed on vehicle after bench test and validation
  - Touchscreen HMI developed (Motivo)

- Tires (Michelin)
  - Low Rolling Resistance (LRR) tires delivered, to be tested against conventional baseline
  - ~5% fuel economy improvement expected for LRR tires



New design with straighter and clean tube routing

Accomplishment – Trailer Weight Reduction Wabash National

- VEV4 test trailer was built in May 2020
  - Weighs 15% less than a base Wabash dry van
  - Custom aero devices, suspension adjustments and electrical interface installed at the Wabash R&D Test Lab.
- Trailer delivered to Volvo in June 2020
- February 2021, updates to landing gear assembly.

Upcoming Activities

- Support Volvo in VEV4 road testing should any issues or questions arise with regards to the trailer.

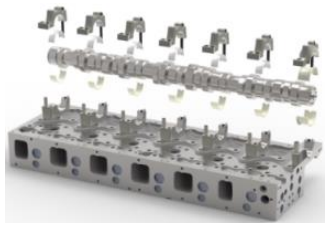
Approach – Freight Efficiency Optimized Powertrain

48V hybrid system recovers kinetic energy

- Integrated starter / generator on rear PTO
- 2-speed gearbox for optimal torque/RPM
- 14 kWh Li-Ion battery system for energy storage

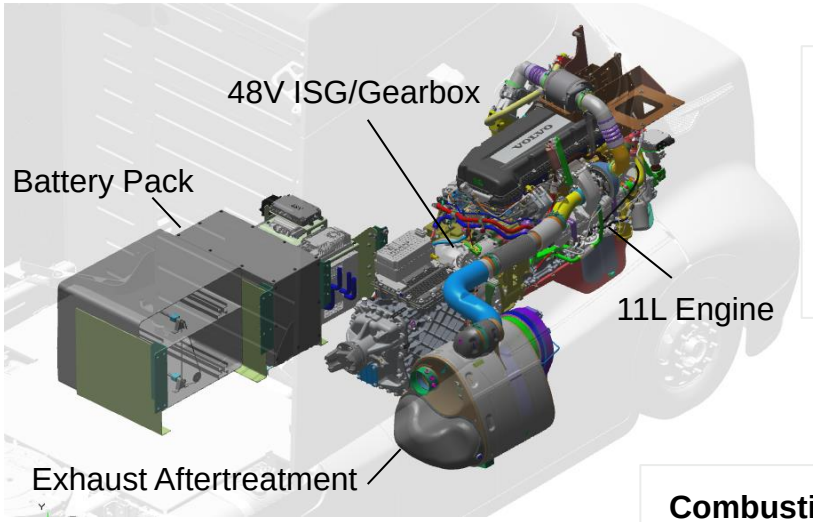
Improved air handling system

- EGR pump maximizes expansion
- Re-optimized fixed turbo system
- Miller camshaft enables more pumping reduction



Parasitic loss reduction with improved base engine

- Synthetic overlay Bearings
- Long Con rod
- Short CH piston
- Low friction ring pack
- Variable oil pump



Redesigned Aftertreatment system

- low back pressure with short DPF/SCR
- Low restriction exhaust diffuser design
- Electrically heated catalyst

More parasitic loss reduction enabled by 48V hybridization

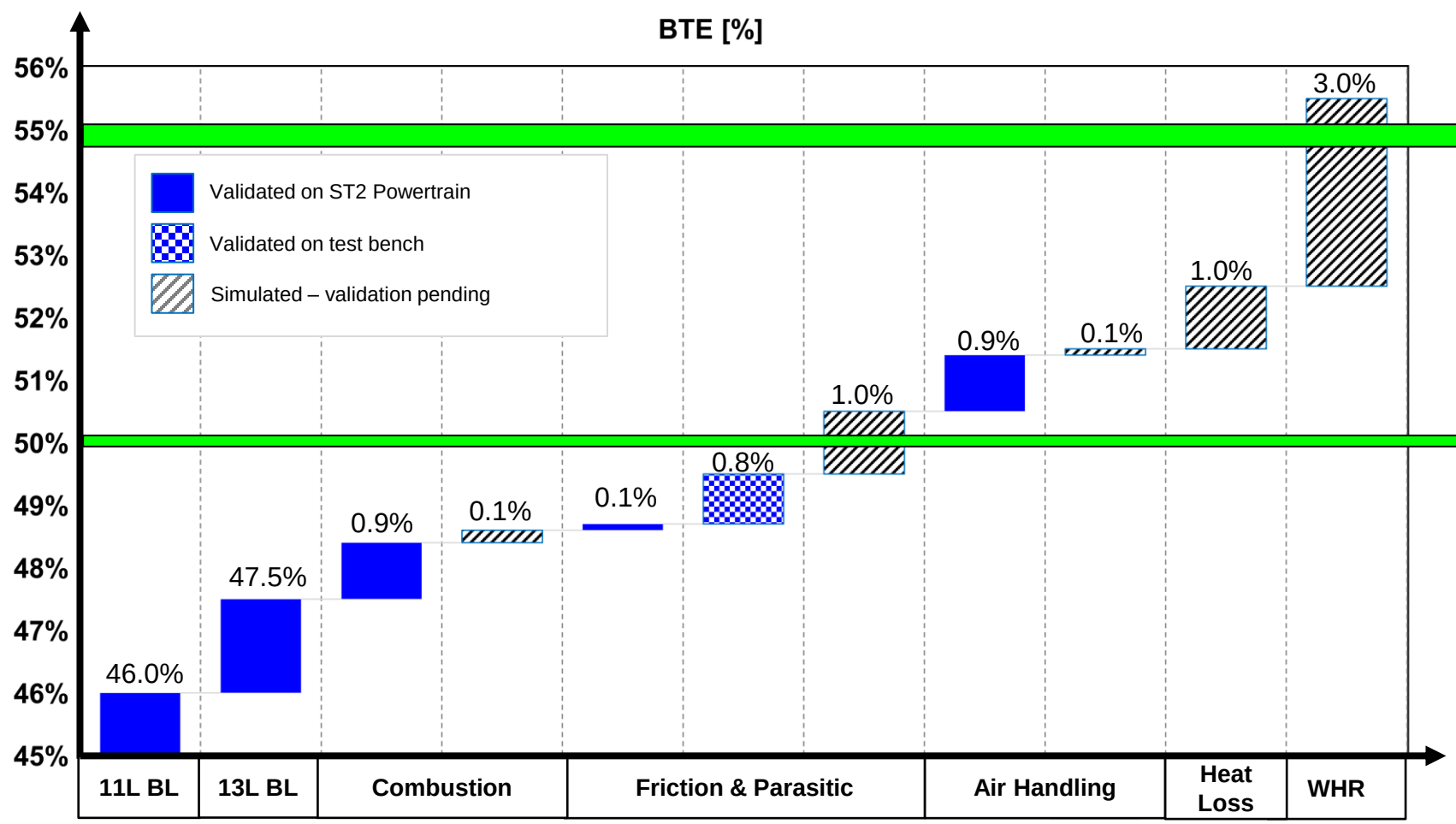
- Front Engine Accessory Belt removal
- Electric coolant pumps
- Electric radiator fan
- Electric EGR pump

Combustion efficiency improvement

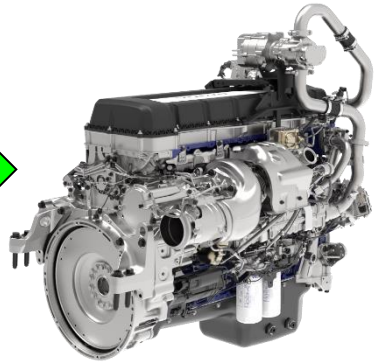
- 20:1 compression ratio wave bowl
- 250 bar peak cylinder pressure
- Optimized heat release w/ improved common rail
- Thermal barrier coated pistons & liners

VOLVO
VOLVO GROUP

Progress – Validation of Powertrain Technologies



- US23 11L VGT
- US24 13L TC
- Low friction rings
- Improved bearings
- Variable oil pump
- CR 23:1 Wave
- PCP 250 bar
- Miller Cam
- Remote CRS
- Reshaped HR
- Electrical EGR pump
- Electrical coolant pumps
- Low friction liners
- Reduced piston cool.
- Low viscosity oil
- Optimized turbo
- EGR pumping
- DST
- EGR cooler
- New EATS
- TBC bowl
- TBC cyl. head
- TBC exh. Port
- High therm piston
- Tailpipe WHR
- Coolant WHR



55.5%

Powertrain optimized for thermal efficiency
Engine Dyno Demo

50.0%

Powertrain optimized for freight efficiency
Truck Demo

Technical – TBC and Miller Cycle on Single Cylinder Engine

Objective

- Thermal barrier coating and Miller cycle for engine efficiency improvements

Approach

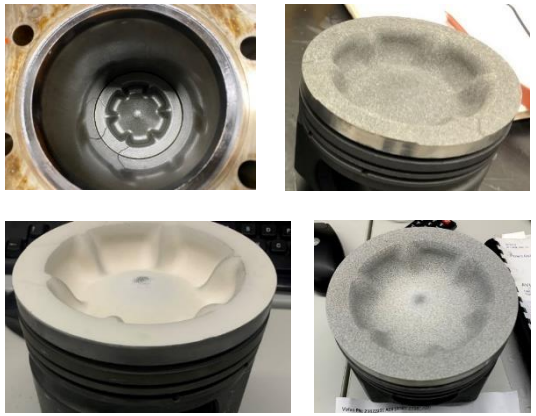
- Wave pistons tested with varying TBC formulation/thickness by reducing heat loss from cylinder, thereby improving engine efficiency
- Extreme IVC timings against the conventional IVC timing at fixed turbocharger efficiency by Lotus AVT system

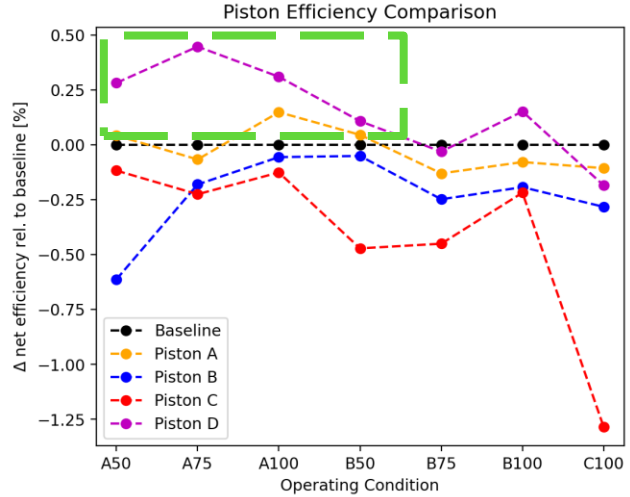
Progress

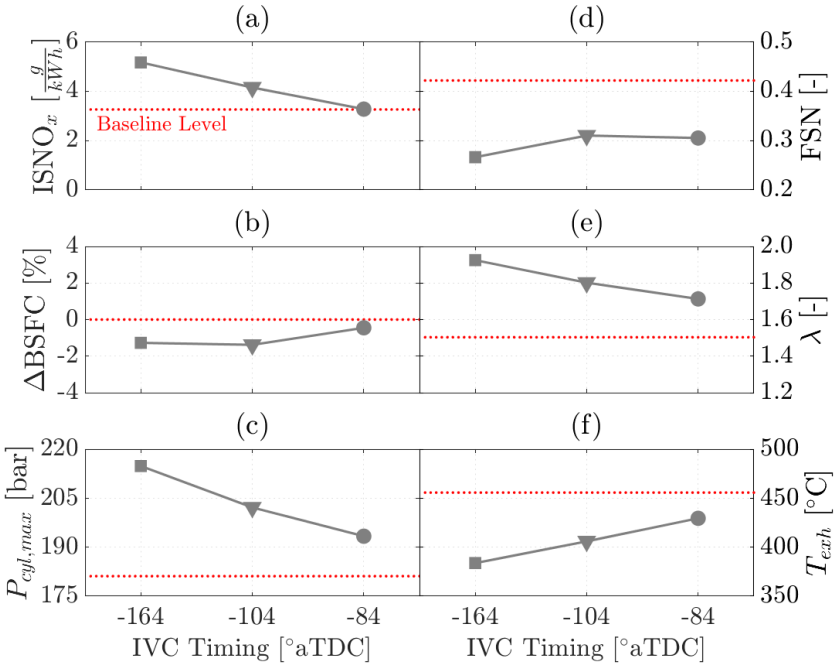
- **Outperformed baseline non-TBC piston** by up to 0.45% improvement, 0.15% on average, increased exhaust temperatures
- Optimum LIVC timing up to **1.4% BSFC improvement over baseline with 20% less NO_x than high boost CIVC case**

Future Work

- Combine TBC piston with Miller cycle valve strategies

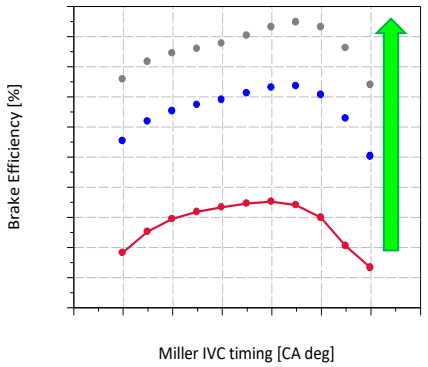


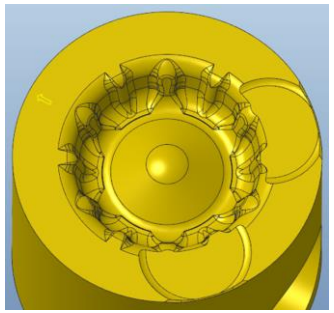


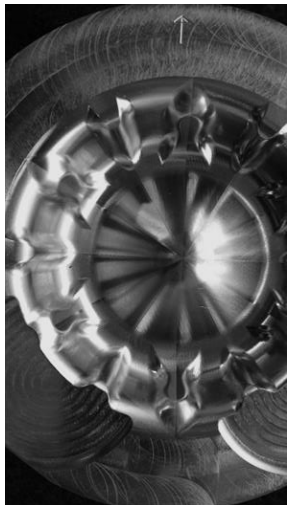


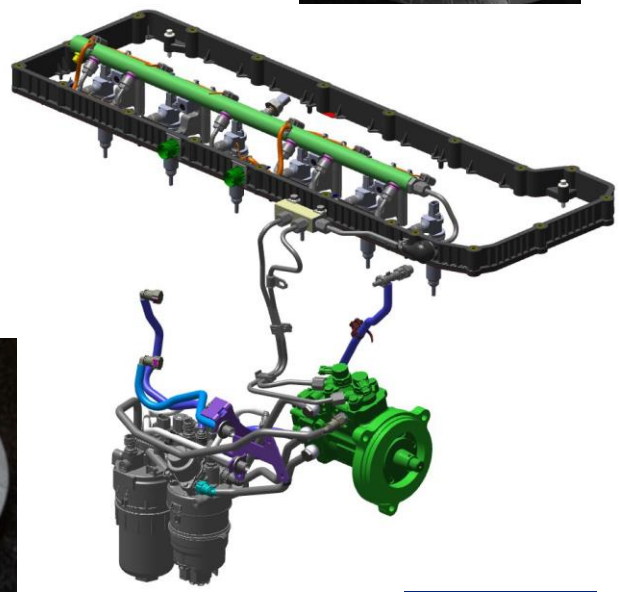
Technical – 55% BTE Base Engine Development

- **Advanced Combustion System**
  - Verified advanced combustion system on freight efficiency engine: CR20:1 piston + 48V EGR Pump + Miller Cam + Optimized Turbo
  - Estimated up to 2.3% BTE gains from 55% BTE 13L demo engine with CR23:1 piston + 48V EGR Pump + Miller Cam + Optimized Turbo
- **Thermal Barrier Coating**
  - TBC bowl and TBC liner for demo
- **HP CRS Remote Fuel Pump**
  - 2700 bar HP Common Rail system
  - Next generation high efficiency/speed remote HP pump
  - Estimated up to 0.3% BTE gains
- **Progress**
  - Dividing/Colliding-12wave pistons for demo
  - HP remote fuel pump system delivered by Q3, 2021









Technical – Waste Heat Recovery Systems

Objective

- Electrical Waste Heat Recovery system for engine efficiency improvements

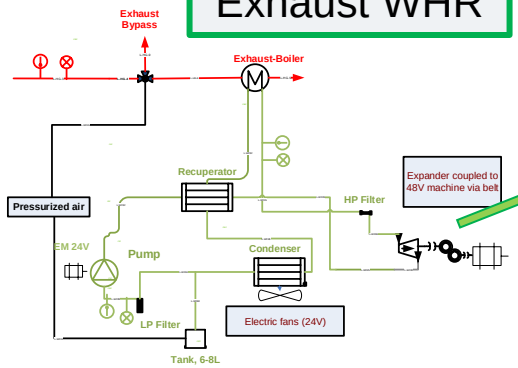
Approach

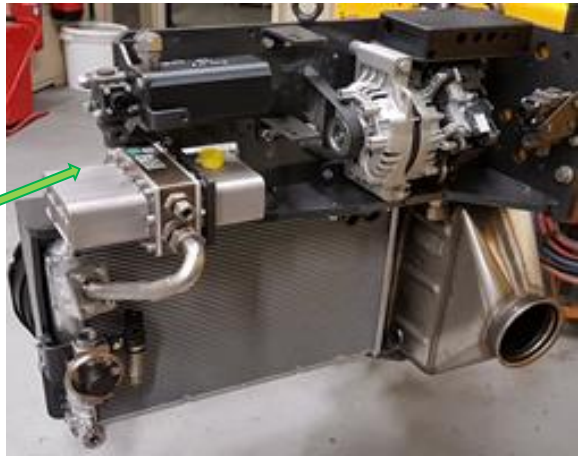
- Exhaust recovery system
  - ~2% estimated BTE gain
  - Working fluid: Cyclopentane
- Coolant recovery system
  - ~1% BTE gain
  - Working fluid: Refrigerant
- 48V electrical power system
- Compact design

Progress

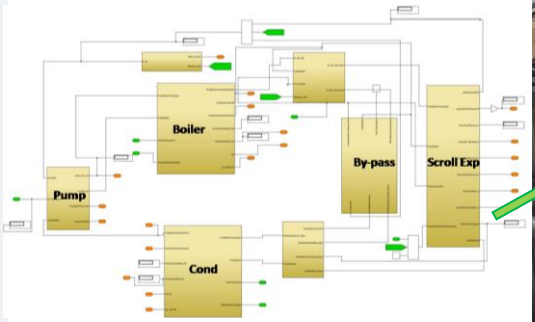
- Tailpipe WHR system rebuilt and to be tested in Q3/Q4 2021
- Coolant WHR system being built, to be tested in Q1 2022
  - Test rig built and expander in test

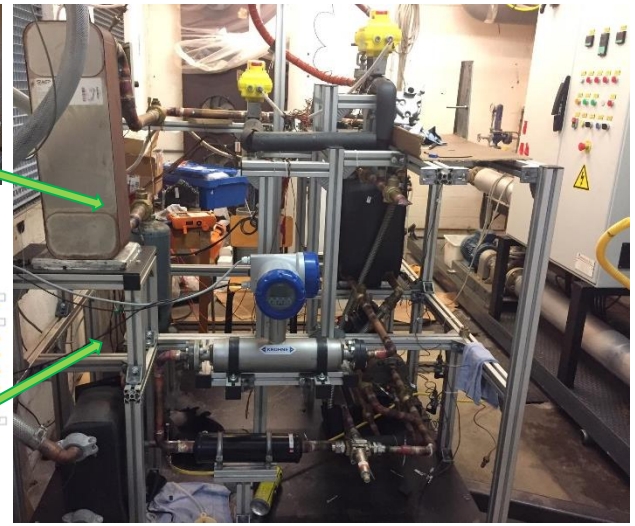
Exhaust WHR





Coolant WHR





Project Summary

- **Relevance**

  The goals of this project are aligned with the key barriers to higher fuel efficiency of highway transportation. Each task in the project scope addresses a specific technical challenge e.g., aerodynamic improvement, friction reduction.

- **Approach**

  Volvo's SuperTruck 2 program is currently finishing the third phase, which focuses on integrating the technologies. As we near completion of the concept truck build and commissioning, we will move into the fourth and final phase of testing and verification.

- **Milestones & Technical Accomplishments**

  In this reporting period, we continued progress in the complete vehicle and powertrain areas. The complete cab and aerodynamic components have been delivered. Major vehicle subsystems are installed. Build and commissioning are nearing completion for the vehicle demonstrator. Testing and development continue for the technologies selected to achieve the engine BTE goal. Despite the challenges of the last year, we are well on our way to demonstrating >120% freight efficiency improvement for the complete vehicle, plus achieving the 55% BTE engine goal.

- **Future Work**

  Complete build & commissioning of the ST2 demonstrator to begin testing and verification. Optimize the performance of the vehicle sub-systems. Continue to develop and integrate the technologies selected for the 55% BTE engine demonstration.

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

VOLVO
VOLVO GROUP

Team Members

Organization	Main Responsibility
Volvo Group	Project lead, powertrain development, complete vehicle integration, testing
Metalsa	Lightweight Chassis Frame Concepts
Michelin	Advanced low-friction tires (steer, drive, tag, trailer)
Wabash	Trailer Technologies (weight & aero)
Bergstrom	Advanced cab climate control concept
University of Michigan	11L SCRE experiments
ORNL	Aftertreatment testing
Motivo Engineering	48V system rapid development & testing
Johnson Matthey	Aftertreatment concepts & Catalysts
Knight Transportation & Wegmans	TCO discussion, driver clinics, etc

Thank you

See You Soon!

VOLVO
VOLVO GROUP

Technical Backup Slides