Volvo SuperTruck 2

Pathway to Cost-Effective Commercialized Freight Efficiency

Project ID: ACS101

Presenters: Pascal Amar (PI) & Edward Smith (PM Powertrain)

Volvo Group North America

Washington, DC

June 21st , 2018

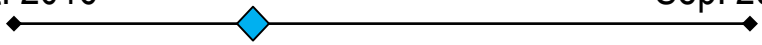
Project Overview

Cost

> $40 M Total Cost / $20 M Funding

Timeline

Oct. 2016 — Sep. 2021



35% 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

Push limits of laws of Thermodynamics

Evaluate and select multiple powertrain and vehicle technologies simultaneously

Manage trade-offs at complete vehicle level as part of concept selection

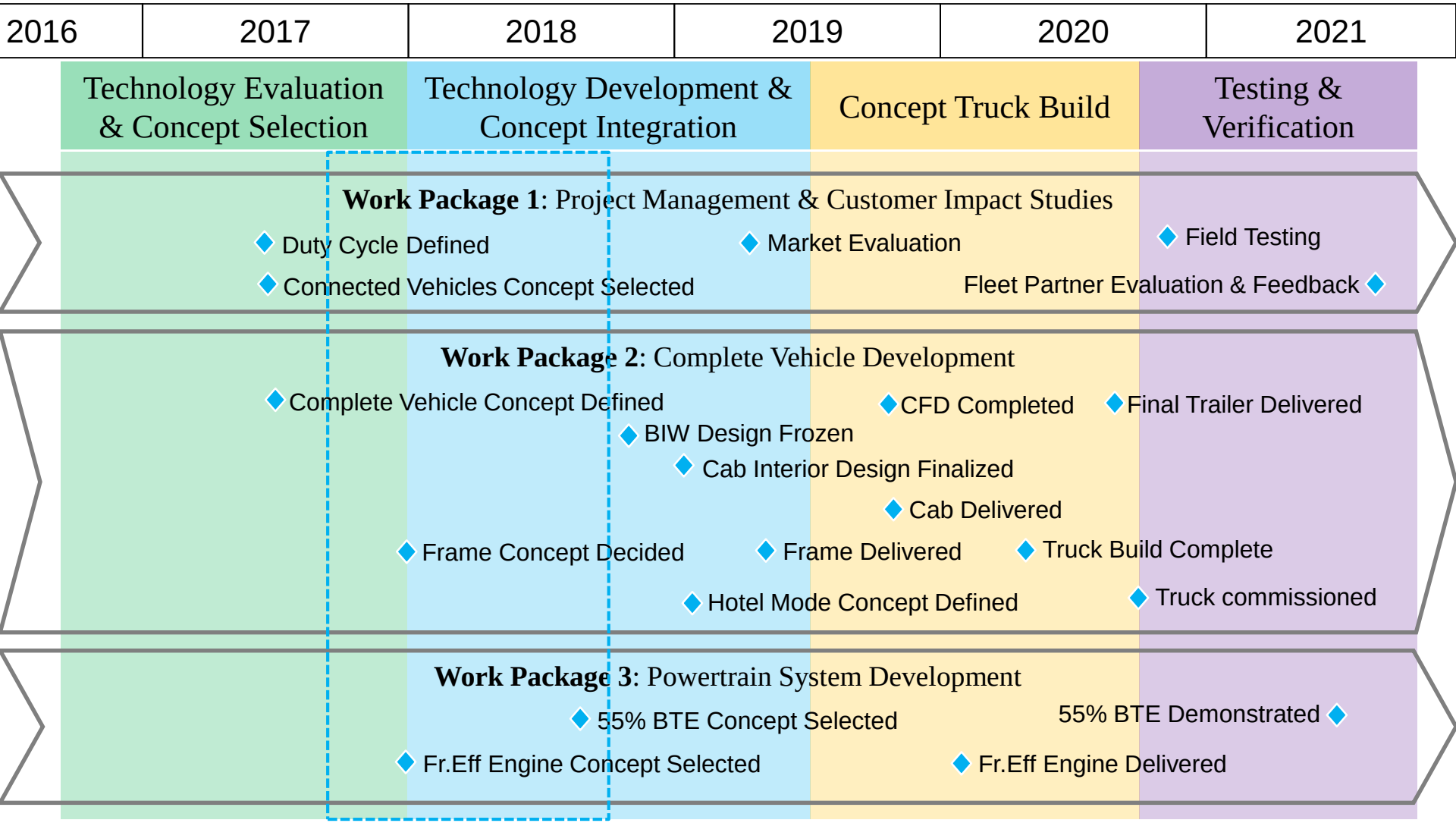
Develop complex systems concurrently

Industrialize promising technologies and concepts

Volvo SuperTruck 2 Team

Organization	Key Contributions
Volvo	Project lead, simulations, **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 X	Advanced cab climate control concept
University of Michigan	11L SCRE experiments
Peloton	Vehicle Connectivity Concepts
ORNL	Aftertreatment testing
Johnson Matthey	Aftertreatment concepts & Catalysts
Knight Transportation Wegmans	Data collection, fleet testing, driver clinics, etc

Schedule & Phasing



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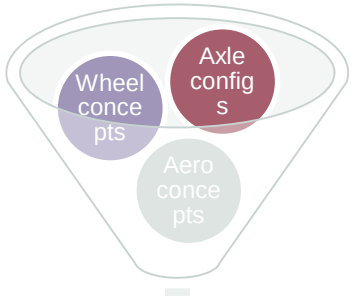
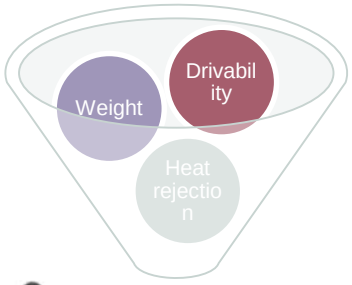
SuperTruck 2 Vision & Concept Selection

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



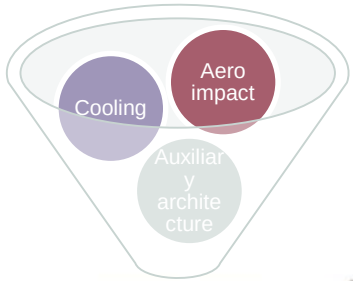
Vehicle Configuration

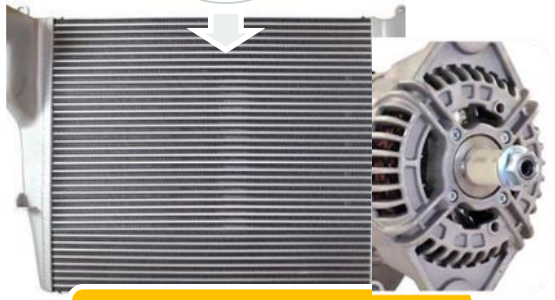
Confirmed requirements for vehicle & tire design



Powertrain Selection

Confirmed requirements for powertrain design





System Integration

Confirmed requirements for energy management

SuperTruck (1) evolves into SuperTruck 2

Program	Vehicle Name	Picture	Vehicle Description
SuperTruck 1 *Completed*	VEV1		Mule truck used for concept selection and development of technologies for SuperTruck 1
	VEV2		Final SuperTruck 1 (ST1) Demonstrator
SuperTruck 2 *In Process*	VEV3		ST1 rebuilt with improved technologies Mule truck used for concept selection and development of technologies for SuperTruck 2
	VEV4		Final SuperTruck 2 Demonstrator New, custom built concept truck

Milestones

Milestones & Go/No-Go Decisions	Date	Status
Connected vehicle concepts chosen	Nov. 2017	Complete
Initial vehicle simulation model available	Apr. 2017	Complete
Customer duty cycle defined	Aug.2017	Complete
Complete vehicle concept selected	Dec. 2017	Complete
Freight efficiency powertrain concept selected	Jan. 2018	Complete
Final tests of VEV3 for completed	Jun. 2018	On track
55% BTE concept selected	Aug. 2018	On track
All component & technologies identified for integration	Sep. 2018	On track
Concept design for new cab interior complete	Dec. 2018	On track
Component & sub-system studies completed	Feb.2019	On track
Technologies integrated and planned for installation	Aug.2019	On track
Completed CAD of VEV4	Sep.2019	On track

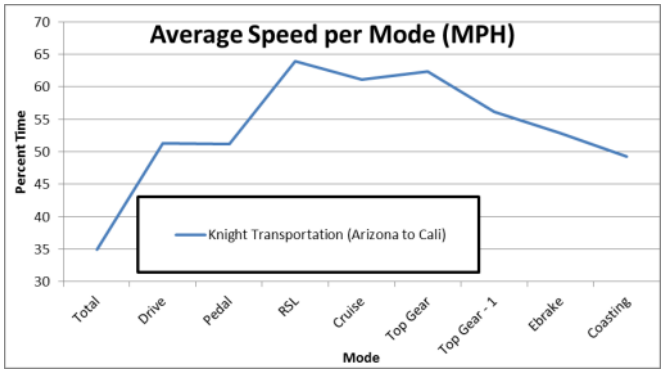
Approach – Fleet Duty Cycle Creation

- Data Gathering:

Trucks collects & transmits data while driving

Telematics Data

Logged Vehicle Data



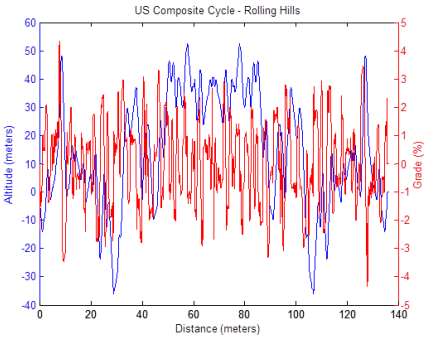
Data is analyzed using engineering tools to define vehicle usage profiles

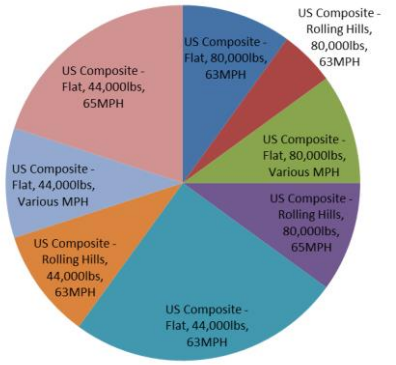
- Detailed data about specific operating parameters and performance statistics are downloaded when the vehicle is connected to a service computer.

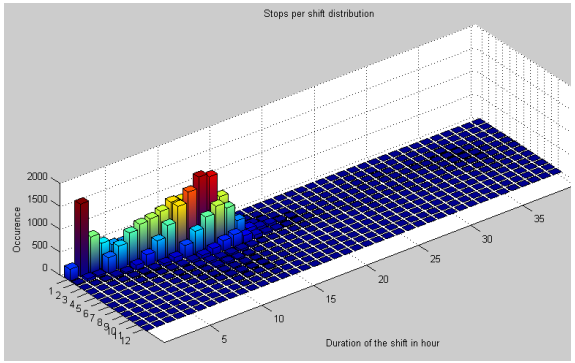
- Live streaming data helps fill the knowledge gaps regarding non-highway operational characteristics e.g. stop duration/frequency, route.

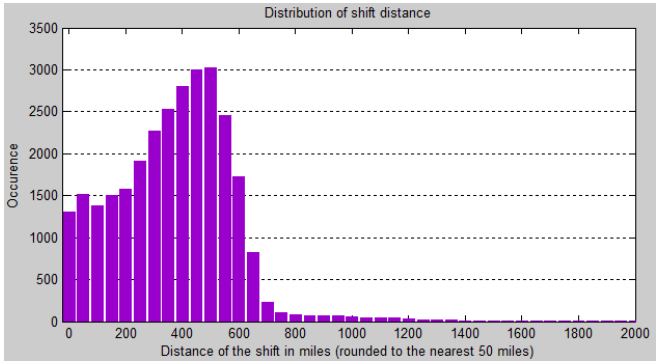
Technical Progress – Duty Cycle Creation

- Duty cycles were created which match the fleet partners' usage in terms of speed distribution, weight distribution and road grade.
- Complete vehicle simulations and road tests can now be performed to evaluate the impact of technologies on these duty cycles.
- Next Step: Mine telematics data to capture all parts of fleet operations ex. idling, hotel loads









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Technical Progress – Tires

- The Michelin team has identified the key technologies that will be used to contribute to the freight efficiency objectives of the project:
  - New light weight/low rolling resistance carcass
  - New tread design to improve wear / rolling resistance trade-off
  - New tread compound to improve tire wear.

- Baseline tire performance tests were performed at Laurens Proving Grounds
- Finite element simulations ongoing to optimize the tire technologies identified with respect to its overall performance and predict final impact on ST2 concept
- Next steps: Finalize the tire design and mold drawings

Technical Progress - Lightweight

- Metalsa is pursuing multiple approaches in parallel to reduce the weight of the tractor frame assembly
  - Alternative material for frame and components that attach to the frame.
  - Packaging of multiple components together
  - Reduce number of components by using new technologies like additive manufacturing and variable thickness.
- Testing of a representative Class 8 truck at Volvo's Proving ground is underway in order to collect data which will be used as input to finite element simulations of the proposed chassis in order to generate stress results for each proving ground event.
- Next Step: perform fatigue calculations update the design to achieve durability targets

Technical Progress – Technology Mule Testing

- Multiple on-road test campaigns of the technology mule VEV3 were completed
  - Hotel Load energy consumption analysis and baselining
  - Duty Cycle validation
    - 4 overnight stays & 4,372 miles accumulated on VEV3

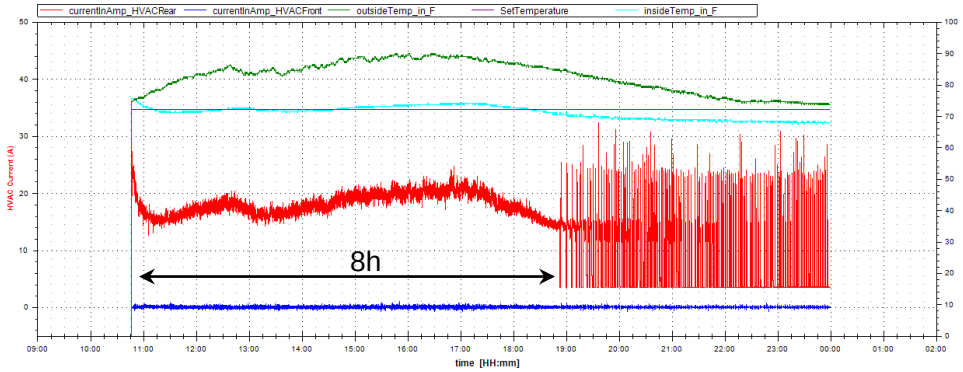
Baseline MY2009 vehicle (left, same truck as ST1 project) and VEV3 test mule (right) at rest stop during testing

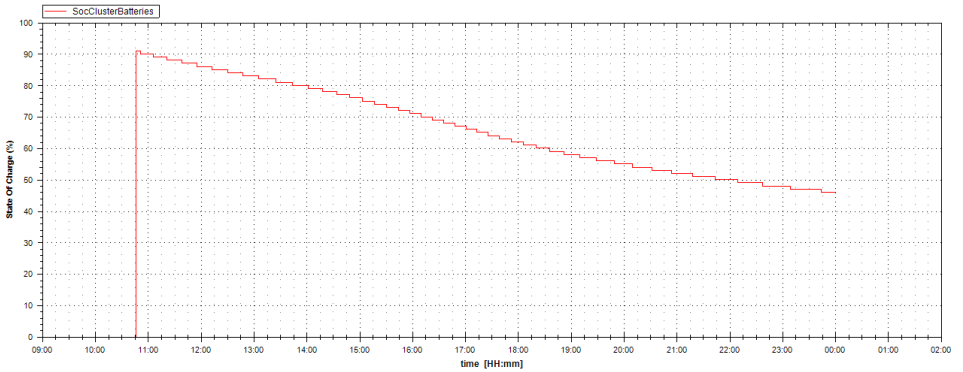
- On track to complete VEV3 road tests this budget period as planned

Technical Progress – Hotel Load Testing

- VEV3 testing has provided crucial input to the ST2 concept selection studies.

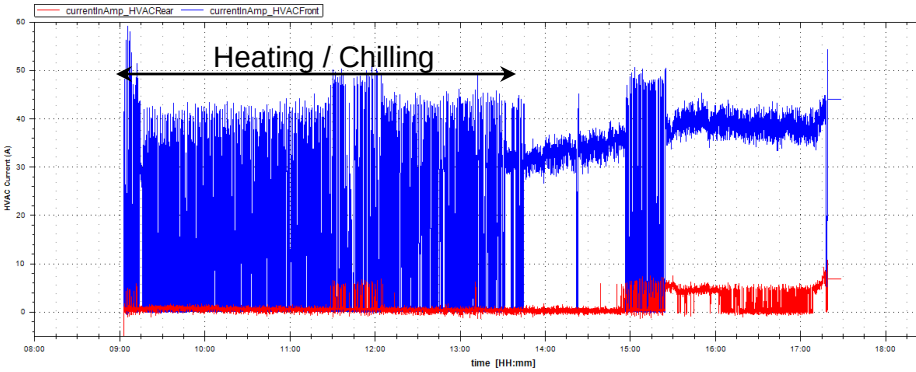
Hotel

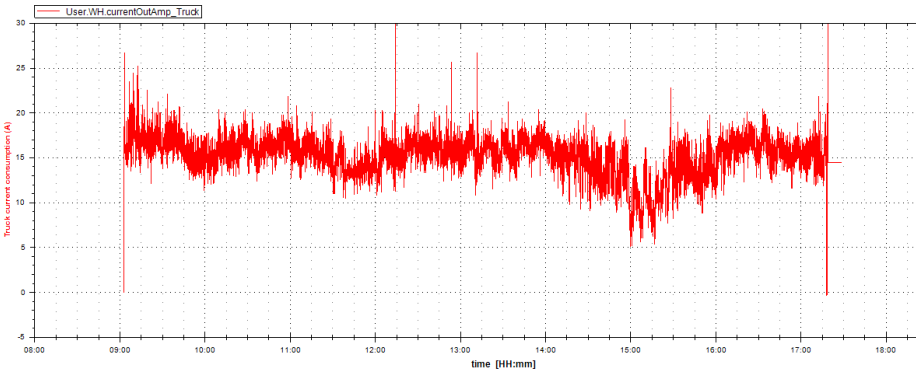




Hotel mode test at 83°F average daily temp.
Average consumption 345W, peak at 540W.
Battery SOC drop from 91% to 39%.

Driving





Driving from Greensboro (NC) to Dublin (GA).
2 distincts HVAC operating phases (heating / cooling). Average consumption ~ 450W.

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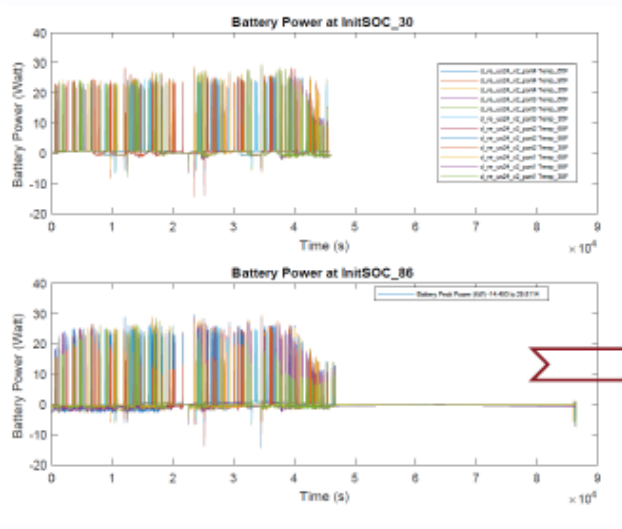
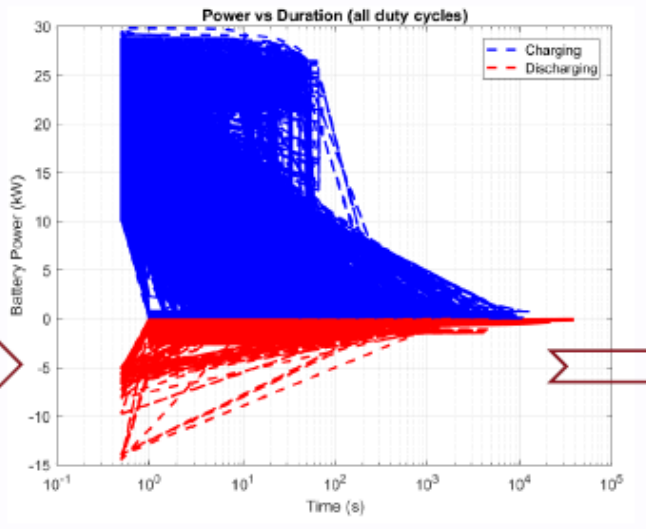
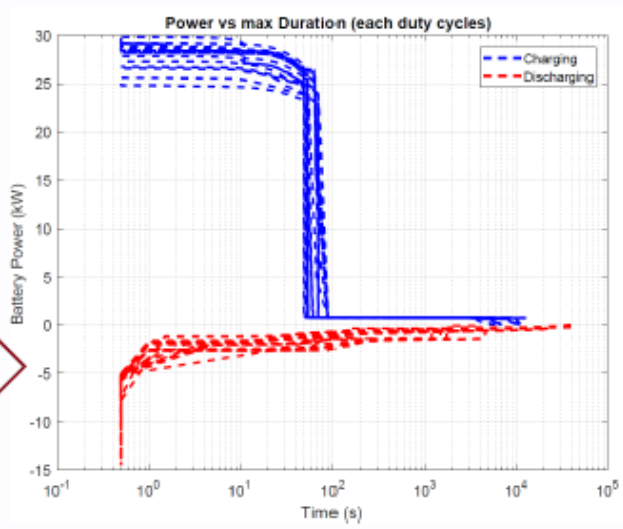
Achievements – Energy Storage System

- *Goal: develop complete vehicle requirements on energy storage system and identify leading technologies for down selection*
- Status
  - Completed tests & simulations to quantify electrical load requirements:







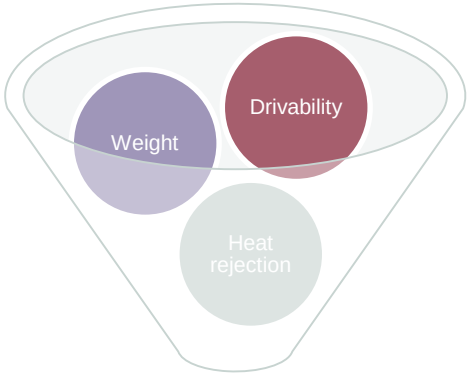
  - Energy storage system requirements frozen
  - Collected information from cell vendors for benchmark
- Next Step: Select cell chemistry and kick-off system design

Technical Progress - Aerodynamics

- Complete vehicle aerodynamic modeling and simulation during this reporting period has considered multiple variations in vehicle and powertrain concepts
  - Wheels openings / enclosures
  - Trailer gap distance / aero devices
  - Fixed / dynamic aerodynamic devices
  - Tractor & trailer ride height
  - Split / enclosed cooling package
  - ...
- Road testing was performed to support trailer simulation and design work, with the goal to achieve ST1 trailer performance using commercially viable devices

- Status: complete vehicle aero design 15 iterations complete, currently exceeding target of 15% improvement vs. SuperTruck 1

System Approach to Concept Selection



Vehicle Configuration

Powertrain Selection

System Integration

Confirmed requirements for vehicle & tire design

Confirmed requirements for powertrain design

Confirmed requirements for energy management

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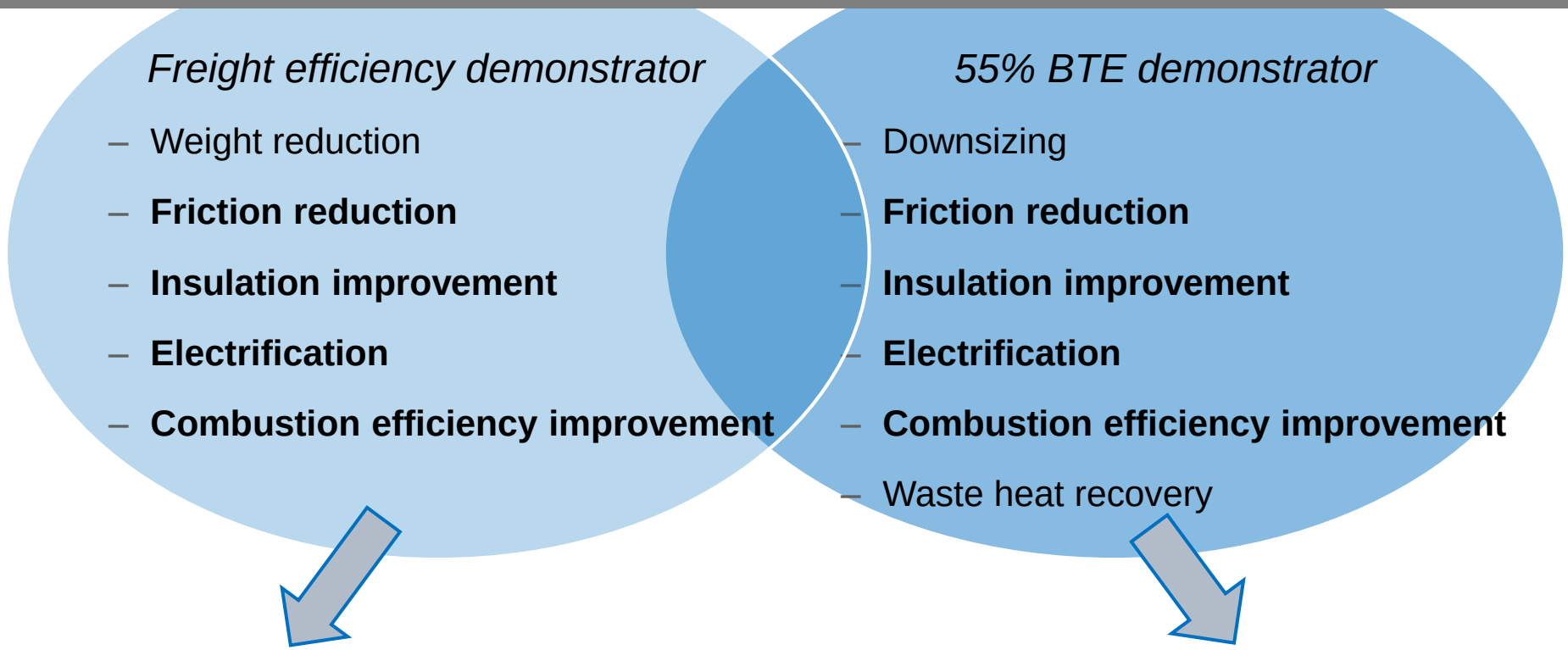
ST2 Powertrain – Concept Selection Approach

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



Short term value stream

Long term applied research

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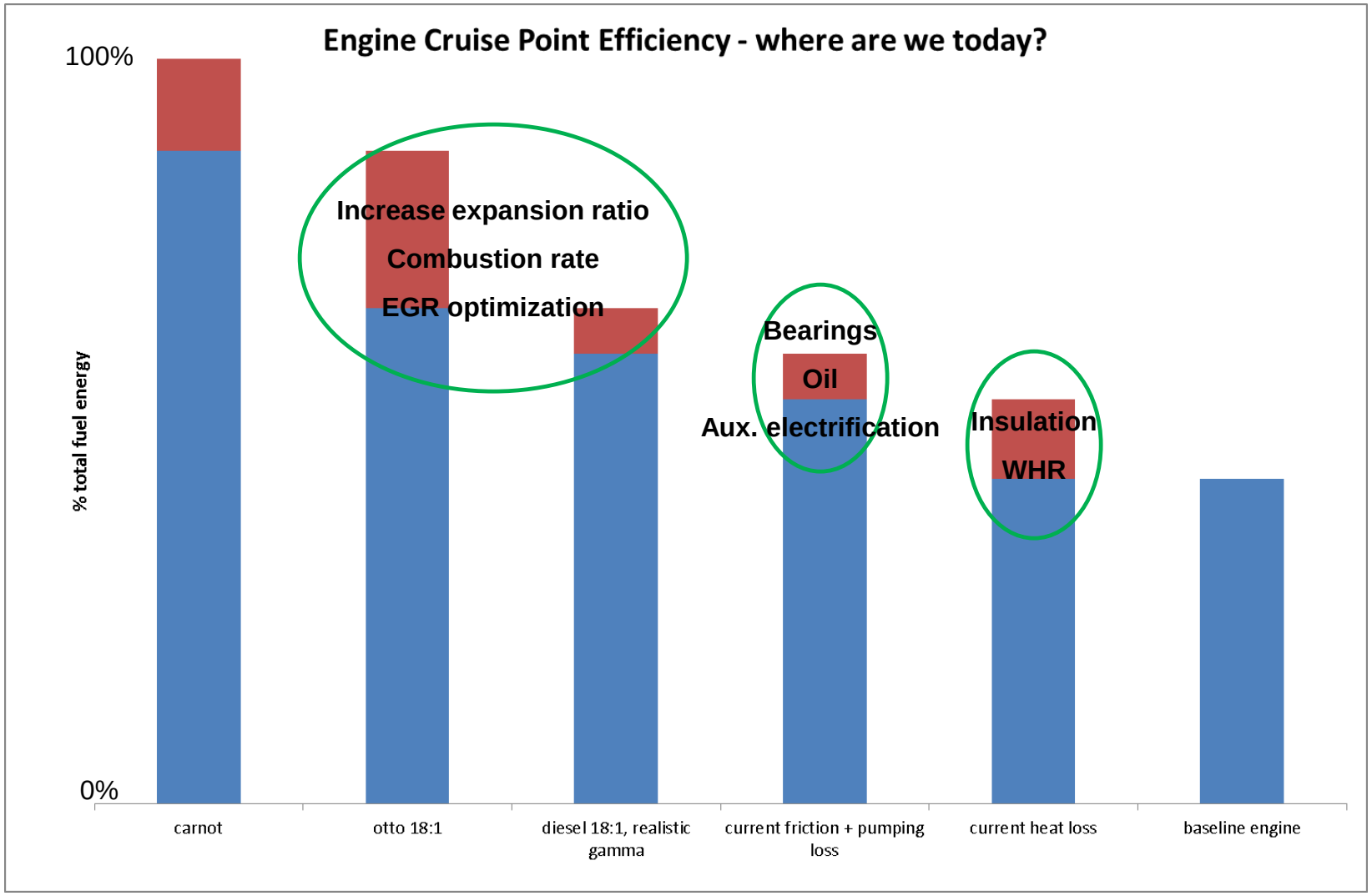
Approach – Engine Efficiency Optimization



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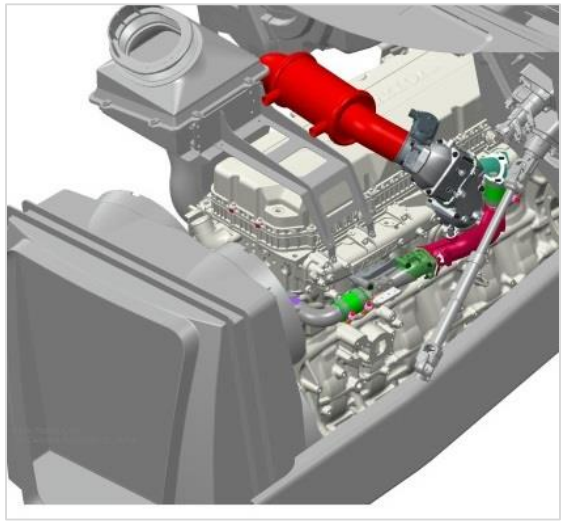
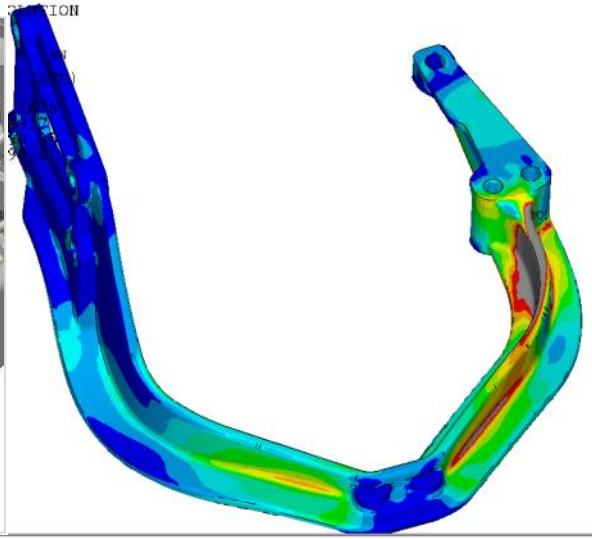
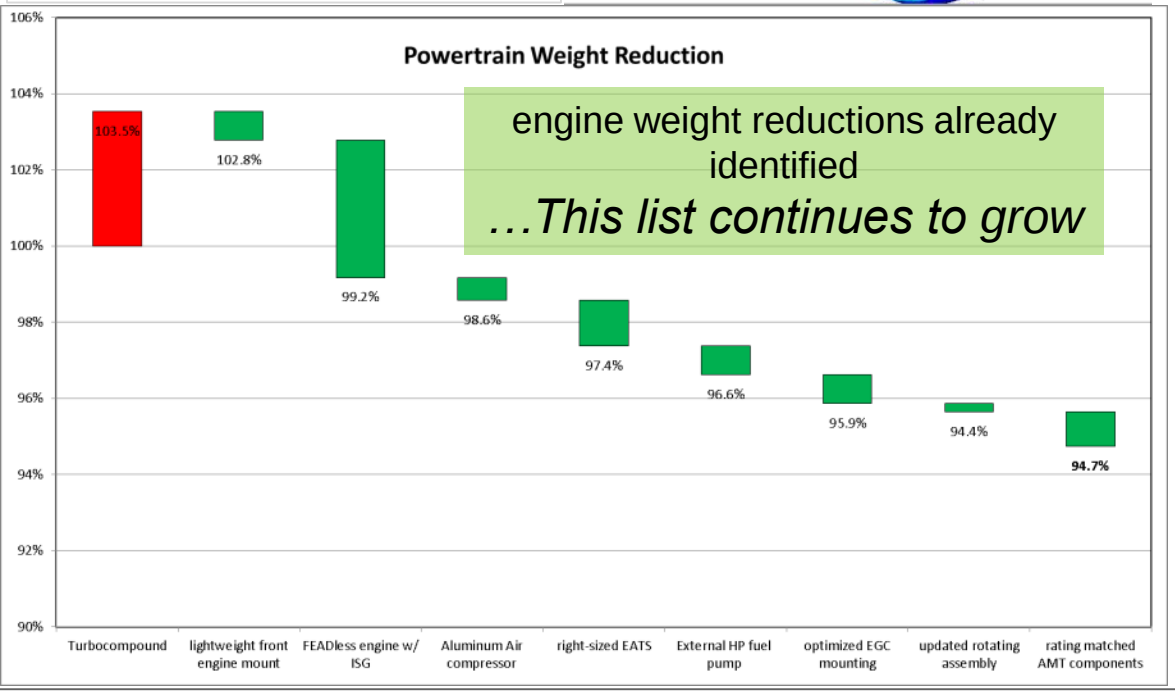
Technical Progress - Weight reduction







- Intelligent material choices
- Innovative application of advanced manufacturing processes
  - Integrated component mounting using additive manufacturing processes
- Tradeoff analysis to inform design choices
- Optimized component spec'ing in multiple loops
  - Lower vehicle weight & drag leads to lower power and torque requirements, which lead to lighter driveline components which lead to a further lightened vehicle, which…
  - *Take full advantage of the virtuous cycle!*

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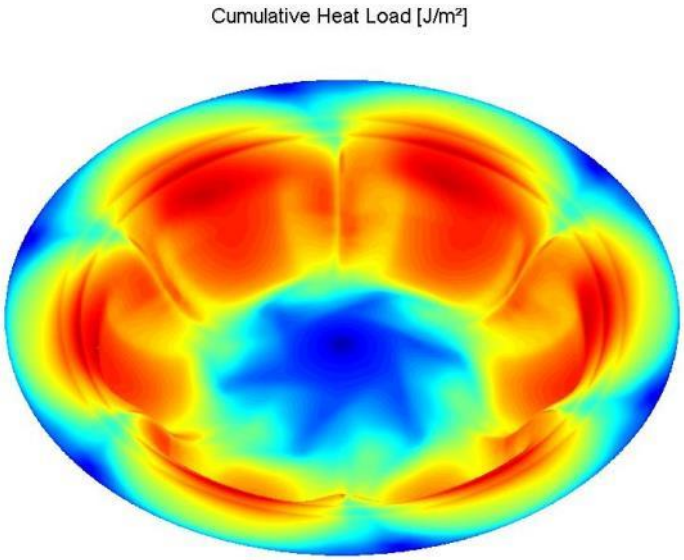
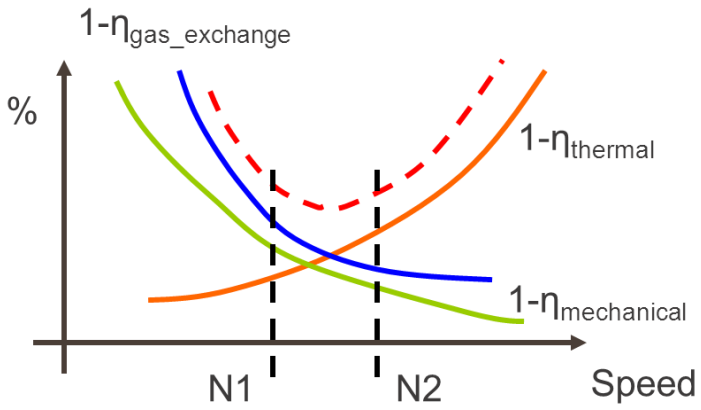
Approach - Insulated combustion chamber

Wave Piston Heat Load





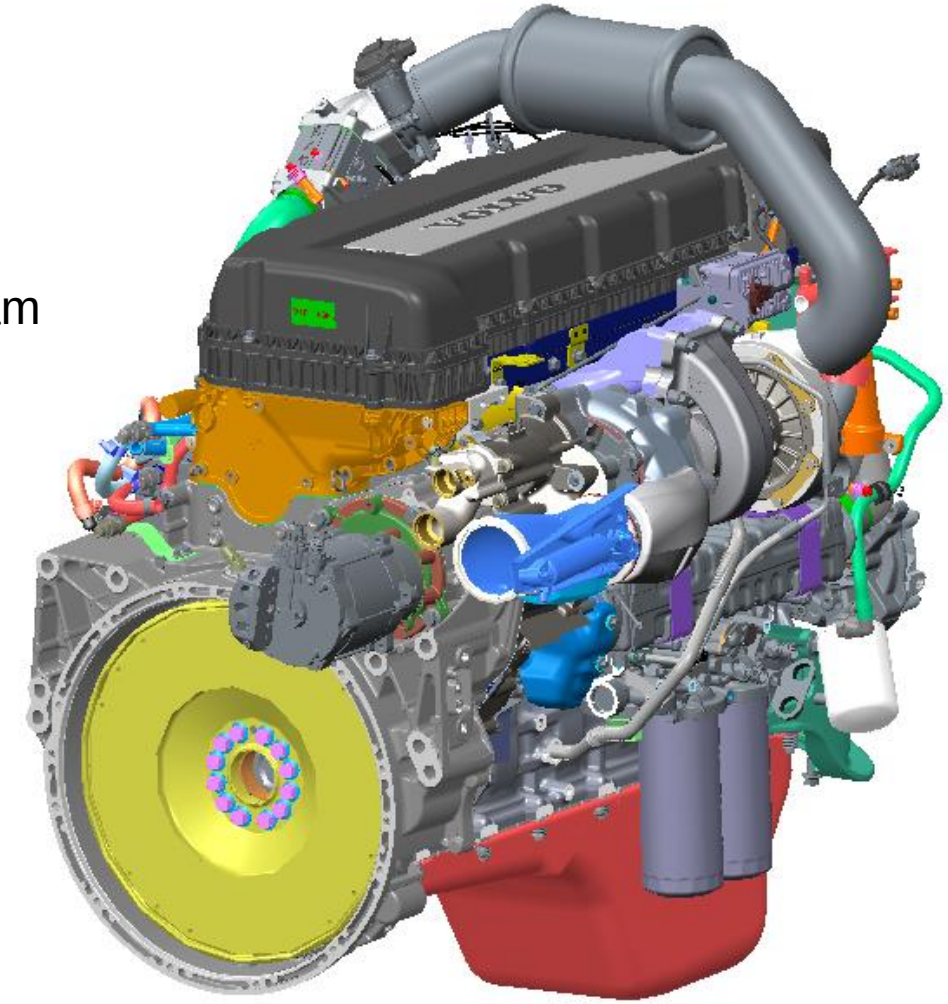
Thermal Barrier Coated Piston & Firedeck

- Thermal barrier coating
  - Low thermal conductivity / heat capacity
- Higher bowl surface temperature
  - Reduced bowl heat loss
    - Indicated thermal efficiency gains
    - More exhaust energy
    - Reduced UBHC, CO
- Insulation - key technology to enable further friction reduction via downspeeding conventional 4 stroke engines
- Simulations are of limited utility – more empirical testing!
- Lessons learned – it's a journey – need flexibility to iterate based on experimental findings

Approach – Powertrain Electrification

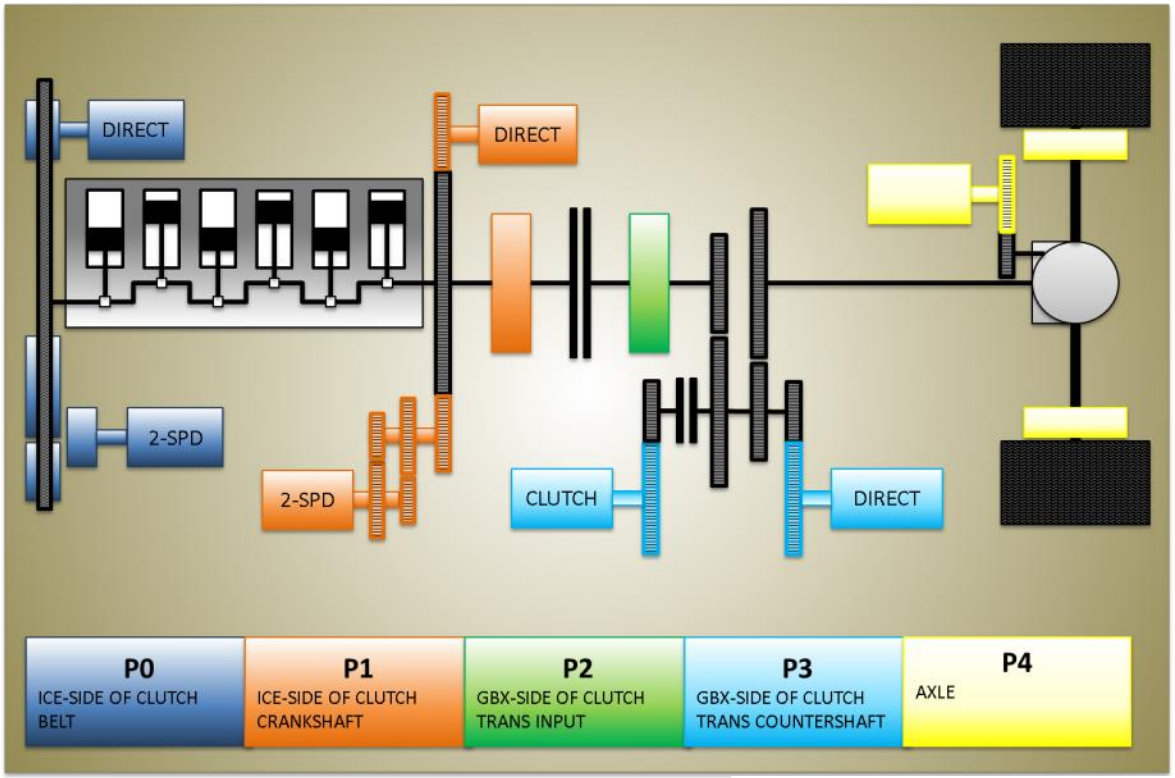
- FEADless concept
  - Electrified cooling system
  - Remote AC compressor
  - No brackets, tensioners, ad nauseam
- Integrated Starter Generator
  - 25 kW class machine
  - Replaces starter and alternator
  - Power for electrified auxiliaries
  - Brake energy recuperation

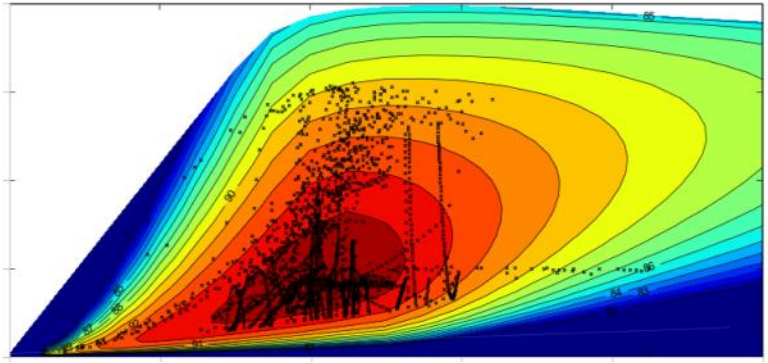
Smart spec'ing – *electrification leads to net system weight reduction*

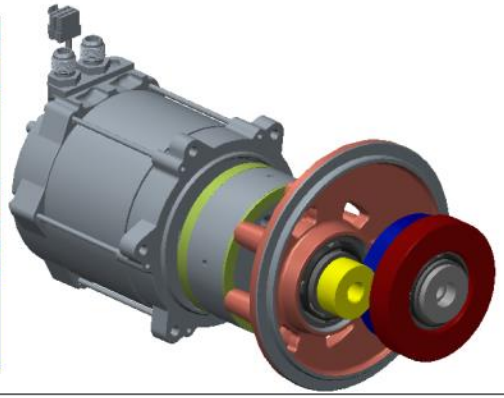


Technical Progress - Microhybrid Studies

- Multiple architectures studied to select best tradeoff between cost, weight, and efficiency improvement
- Off-axis P1 identified as primary path based on technology maturity and robustness of enabled features
- Synergy with light duty technologies enables advanced features at acceptable cost
- Packaging feasibility secured for highway products







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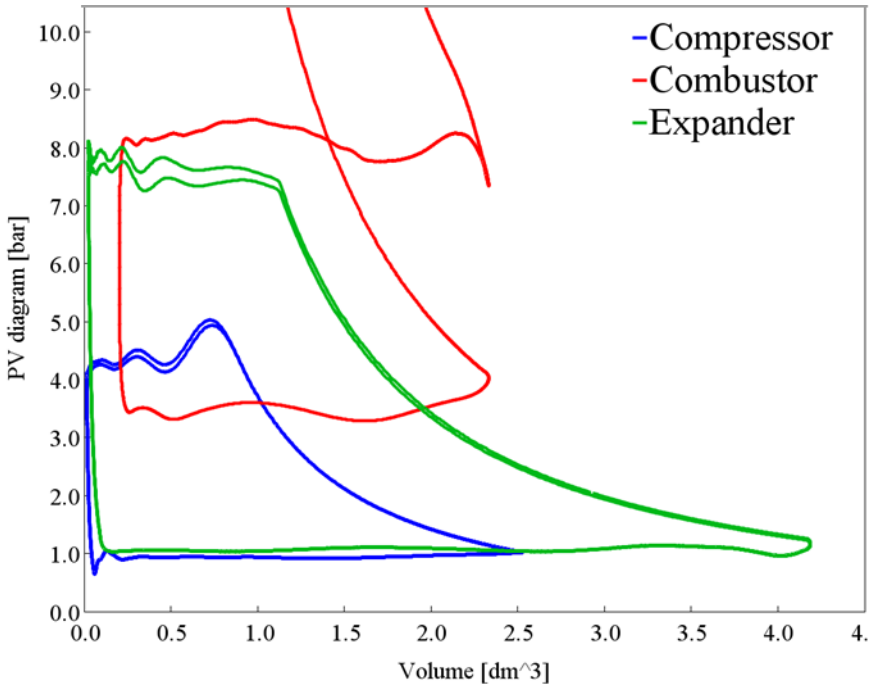
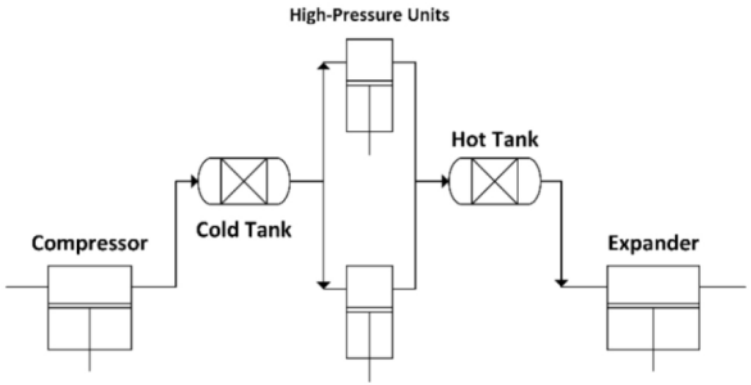
Technical Progress - Advanced Engine





Work on Dual Compression / Expansion (DCEE) engine continues

- Combustor cylinder tested using several combustion regimes
- Compressor/expander test results to be available Q4 2018

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Penn State
MICHELIN
Oak Ridge
Peloton
Metalsa
Wegmans
KNIGHT
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Thank you