# Navistar SuperTruck II

## Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer

***Vehicle Systems (Project ID: ACS 103)***

**DOE Contract: DE-EE0007767**
**NETL Project Manager: Siddiq Khan**
**NETL Project Officer: Ralph Nine**


**Principal Investigator: Russ Zukouski**
**Navistar, Inc.**

**DOE 2020 ANNUAL MERIT REVIEW**
June 21 – 23, 2022

Presented for Navistar by:
Russ Zukouski
Engine Chief Engineer: Jim Cigler
Vehicle Chief Engineer: Dean Oppermann

# Overview: Navistar & DOE SuperTruck II

## Timeline

| | |
|---|---|
| Start Date | October 2016 |
| End Date | June 30, 2022 |
| Percent Complete: | 100% |

## Technical Barriers and Targets

- #1 – Greater than or equal to 55% engine brake thermal efficiency (BTE) while meeting prevailing emissions
- #2 – Greater than 100% improvement in vehicle freight efficiency (FE) (on a ton-mile-per-gallon basis)
- #3 – Development of technologies that are commercially cost effective in terms of a simple payback

## Budget

Total Project Funding:

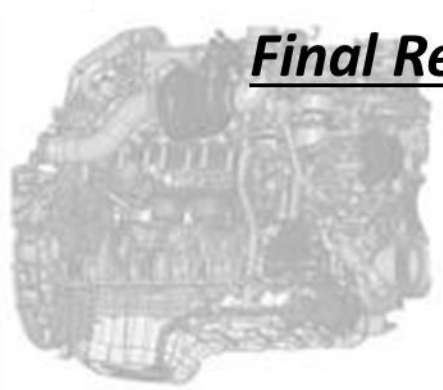
| | |
|---|---|
| DOE Share | $20M |
| Navistar Share | $35M |

## Partners and Laboratories

- Argonne National Laboratory
- Lawrence Livermore National Laboratory
- Bosch
- TPI Composites
- Dana
- J.B. Hunt Fleet Partner

***Working together to develop, evaluate, and implement technologies needed to fulfill the promise of fuel efficiency, environment protection, and operational efficiency***

# Relevance: Program Milestones and Progress



## Final Results by June 30

***Greater than 100% improvement in Vehicle Freight Efficiency***
***Stretch goal: 140%***

**Budget Period 1**
Requirements / Technology / Assessment & Initial Hardware Testing

**Budget Period 2**
Technology Development & Concept Readiness Demonstration

**Budget Period 3**
Technology Finalization & Validation

**Budget Period 4**
Tractor/Trailer Fabrication, Integration & Commissioning Demonstration

**Budget Period 5**
Fuel Economy & BTE; and Program Completion

***Demonstrated 55.2% BTE***

2017 2018 2019 2020 2021 2022

***Budget Period 4 – Tractor/Trailer Fabrication, Integration and Commissioning***

- *Final technology assessment.*
- *Engine-aftertreatment system optimization.*
- *Detail Design- Create a detailed design and analysis*
- *Commercial Viability Study- Develop a detailed cost model.*
- *Component Procurement.*
- *Powertrain Assembly and Integration-Commission.*
- *Tractor Assembly (Chassis, Powertrain, Cab) and Integration.*
- *Tractor Assembly (Chassis, Powertrain, Cab) and Integration.*

***Budget Period 5 – FE Testing and BTE Demonstration and Program Completion***

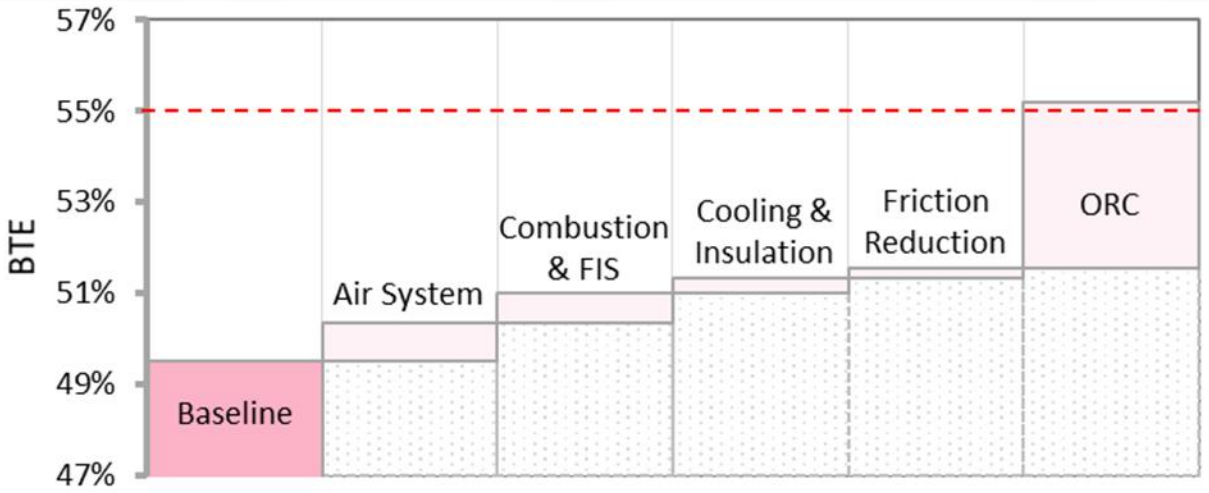
- *Engine dynamometer demonstration of 55% BTE and tailpipe emissions.*
- *Truck / trailer vehicle-level validation testing.*
- *Provide cost effective analysis focused on the technologies.*

***Program End June 30, 2022***

# Engine: Technical Accomplishments & Progress

Chief Engineer
Jim Cigler

- Attain greater than or equal to 55% BTE demonstrated in an operational engine at a 65-mph cruise point on a dynamometer while meeting prevailing emissions.
- Develop engine technologies that are commercially cost effective.
- Contribute to greater than 100% improvement in vehicle freight efficiency (FE) relative to a 2009 baseline.




# Engine: Technical Accomplishments & Progress

## 55% BTE Demonstration

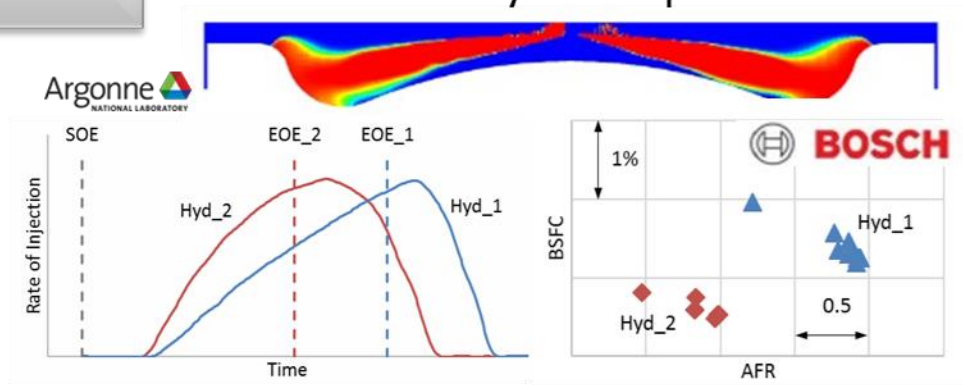
### Accomplishments

- Demonstration of 55% BTE completed
  - High efficiency turbocharger, selected for overall BTE
  - Combustion system refinement
  - Injection rate optimization
  - High compression ratio
  - High peak cylinder pressure
  - Electric water pump
    - optimized engine coolant flow and coolant temperature (reduced heat transfer)
  - Low viscosity lube oil
    - Surface treated sliding interfaces
  - Operational optimization

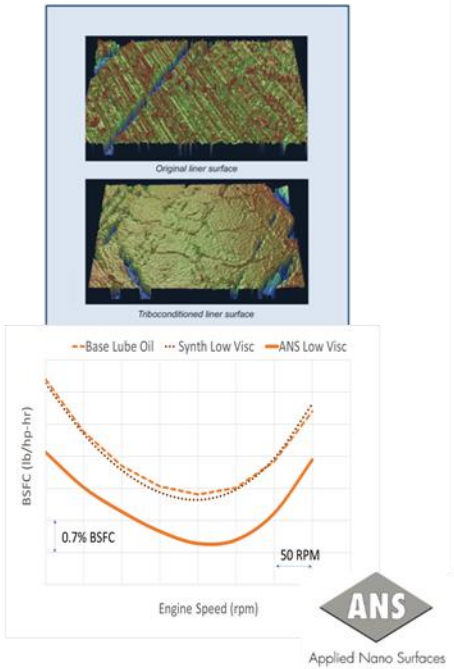
### Next Steps

- N/A

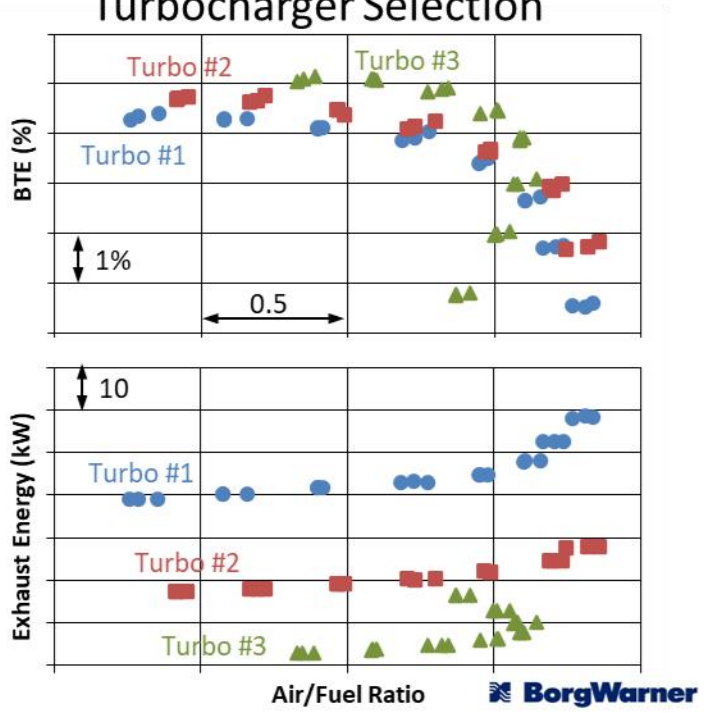
Combustion System Optimization




Parasitic Reduction




Turbocharger Selection



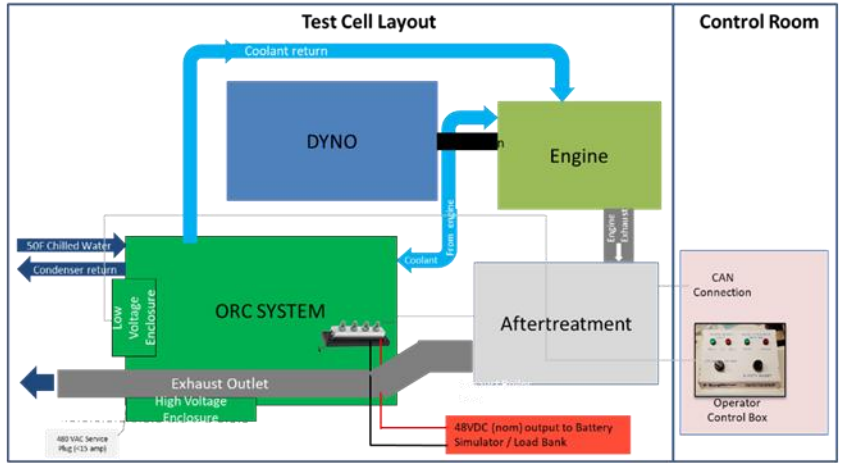
# Engine: Technical Accomplishments & Progress

## WHR & System

### Accomplishments

- Demonstrated 3.6% BTE contribution to the 55% operating point
  - High efficiency expanders and heat exchangers
  - Complex heat sources (Exhaust, coolant, multi-stage charge air)
  - LT and HT working fluid loops (phase management)
  - Robust system control
  - Minimization of system losses
    - Thermal insulation
    - Pressure drops

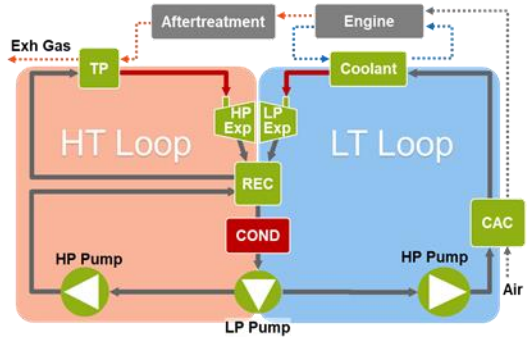
### Demonstration Test Cell Configuration



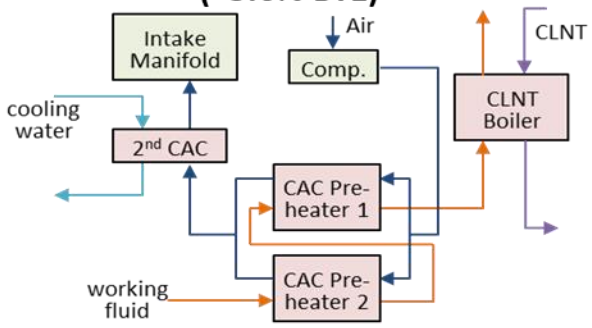

### Next Steps

- N/A

### Base System Design (+3.1% BTE)




### Final System Improvements (+3.6% BTE)



# Engine: Technical Accomplishments & Progress

## Aftertreatment System

### Accomplishments

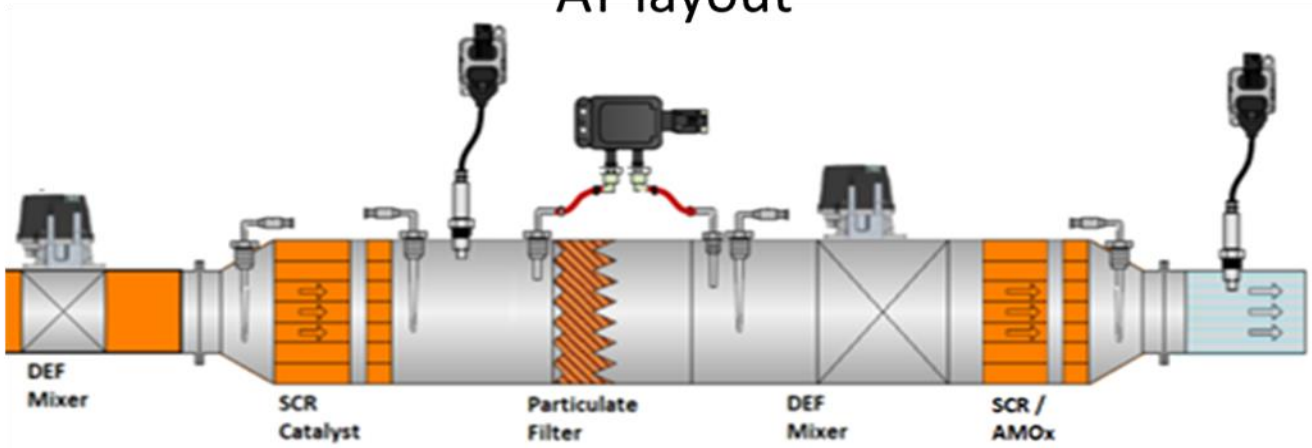
- Demonstrated Prevailing Tailpipe Emission

| | FTP cold | FTP hot | FTP comp | RMC |
|---|---|---|---|---|
| **TP NOx** | **0.22** | **0.14** | **0.15** | **0.19** |

g/hp-hr

- Installation of aftertreatment to demonstration vehicle

AT layout



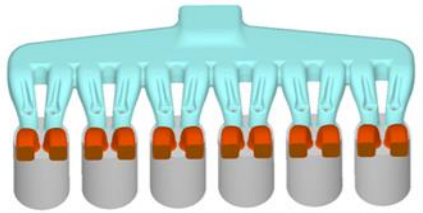

### Next Steps

- Vehicle demonstration

Upstream SCR/ASC: Cu formulation
*DOC:* *Pt/Pd formulation (only for vehicle)*
DPF: Pt/Pd formulation
Downstream SCR/ASC: Cu formulation

# Engine: Technical Accomplishments & Progress

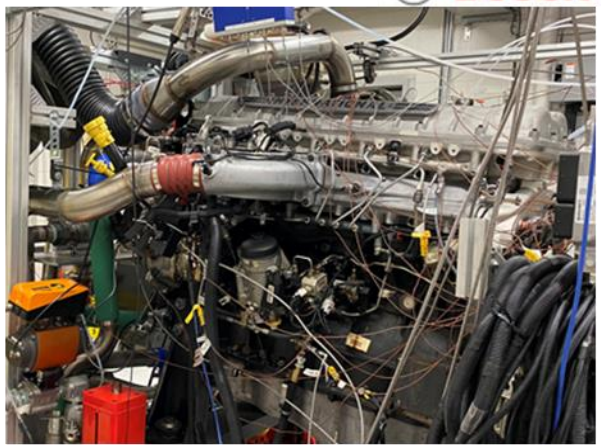
## Beyond 55% - High Flow Cylinder Head



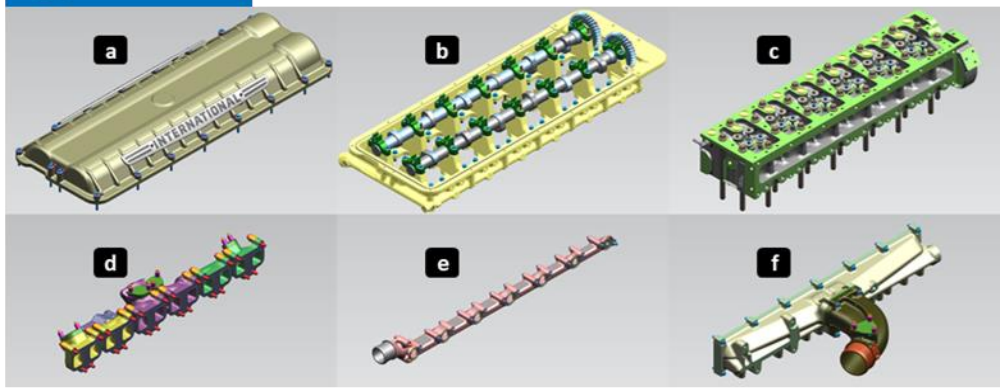
### Accomplishments

- High flow cylinder head demonstrated
- Analysis led design
- Thermal and structural analyses
- Procured new subsystems
  - Additive manufactured components
- Final testing at Bosch
- 0.0-0.15% improvement in BTE

BOSCH



GE Additive

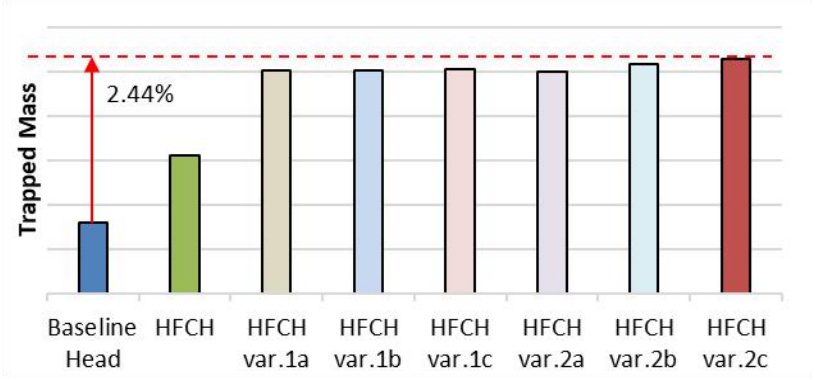


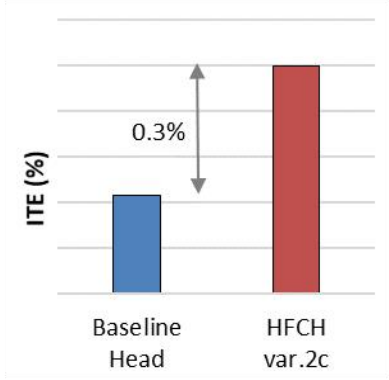

(a) valve cover, (b) dual overhead camshafts with the support frame, (c) high flow cylinder head, (d) exhaust manifold, (e) coolant inlet manifold for the head, (f) intake manifold with coolant return and EGR mixer.

### Next Steps

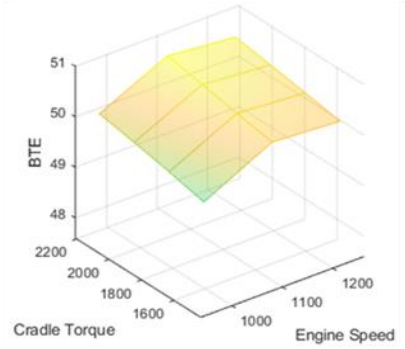
- N/A

### Simulation

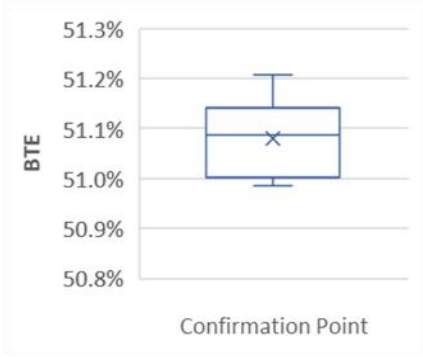



### Optimization




### Validation



# Engine: Technical Accomplishments & Progress

## Cylinder Deactivation

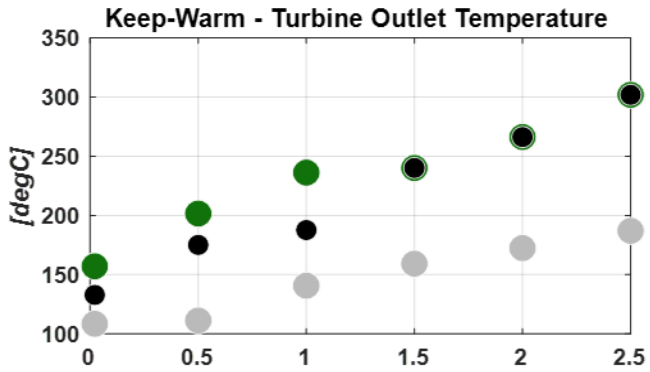
### Accomplishments

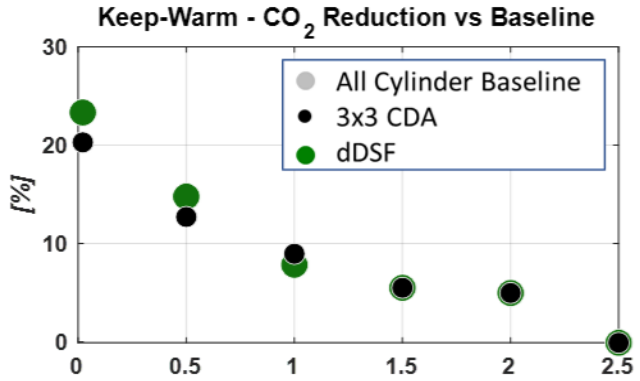
- Implemented individual cylinder deactivation control hardware
- Implemented control system to enable dynamic control of firing configurations - Tula Diesel Dynamic Skip Fire (dDSF)
- Demonstrated benefits to exhaust temp, CO2 and heating power at low loads
  - Vehicle FE and cycle emissions reduction (2027+)

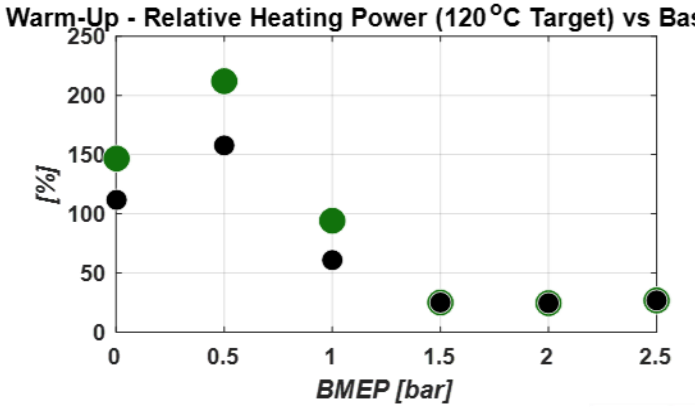
### Next Steps

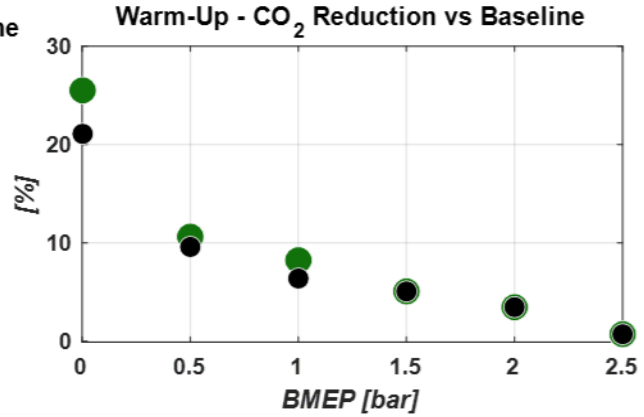
- FTE and LL emissions cycles and vehicle demonstration (outside SuperTruck 2 project)

***Performance Comparison for Keep-Warm and Warm-Up Modes at 1000 RPM***




Jacobs Vehicle Systems®

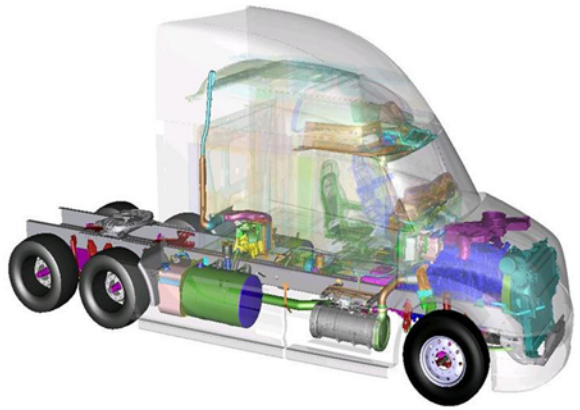
TULA

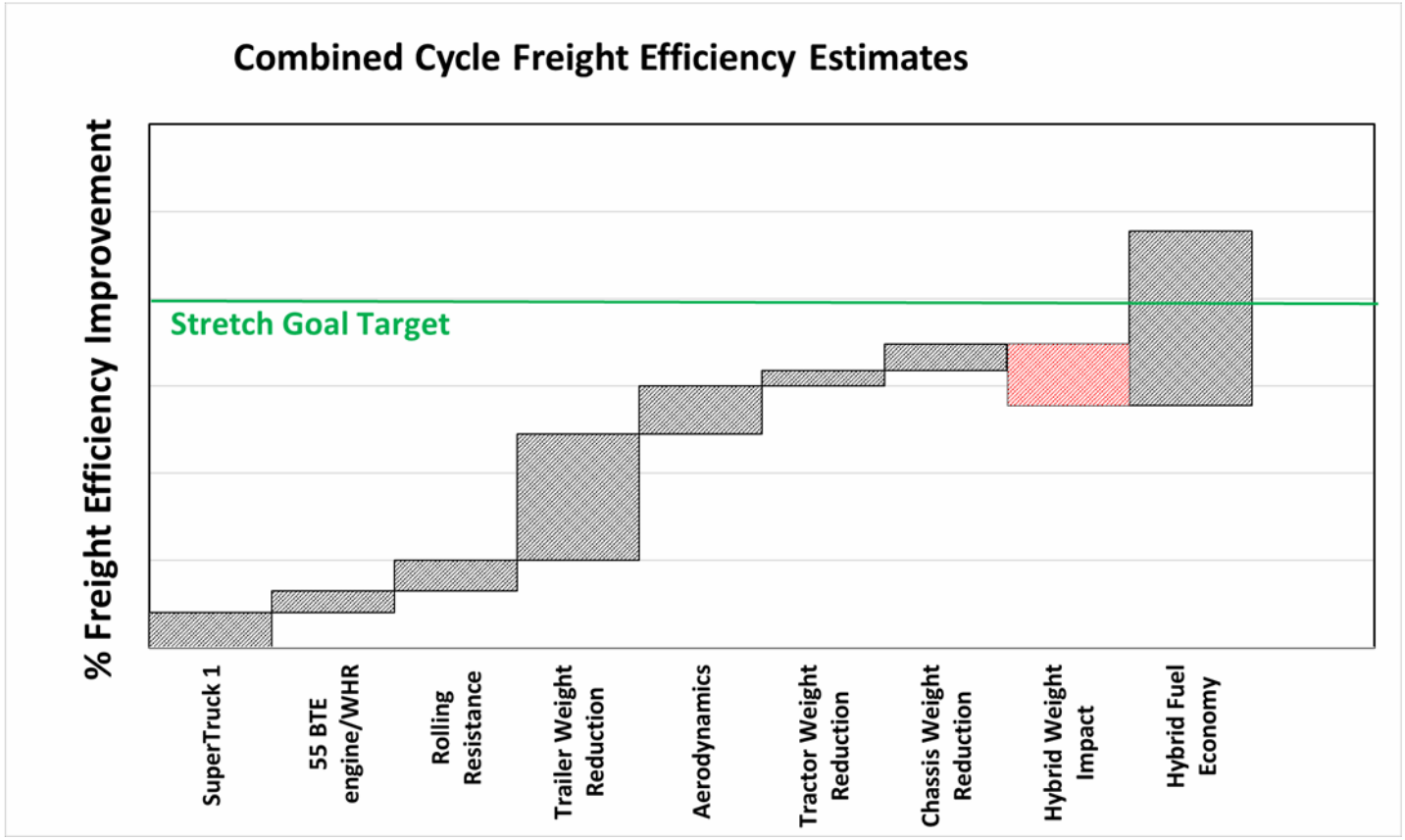
# Vehicle: Objective and Approach

Chief Engineer
Dean Oppermann

Research, develop, and demonstrate a vehicle that achieves the following goals:

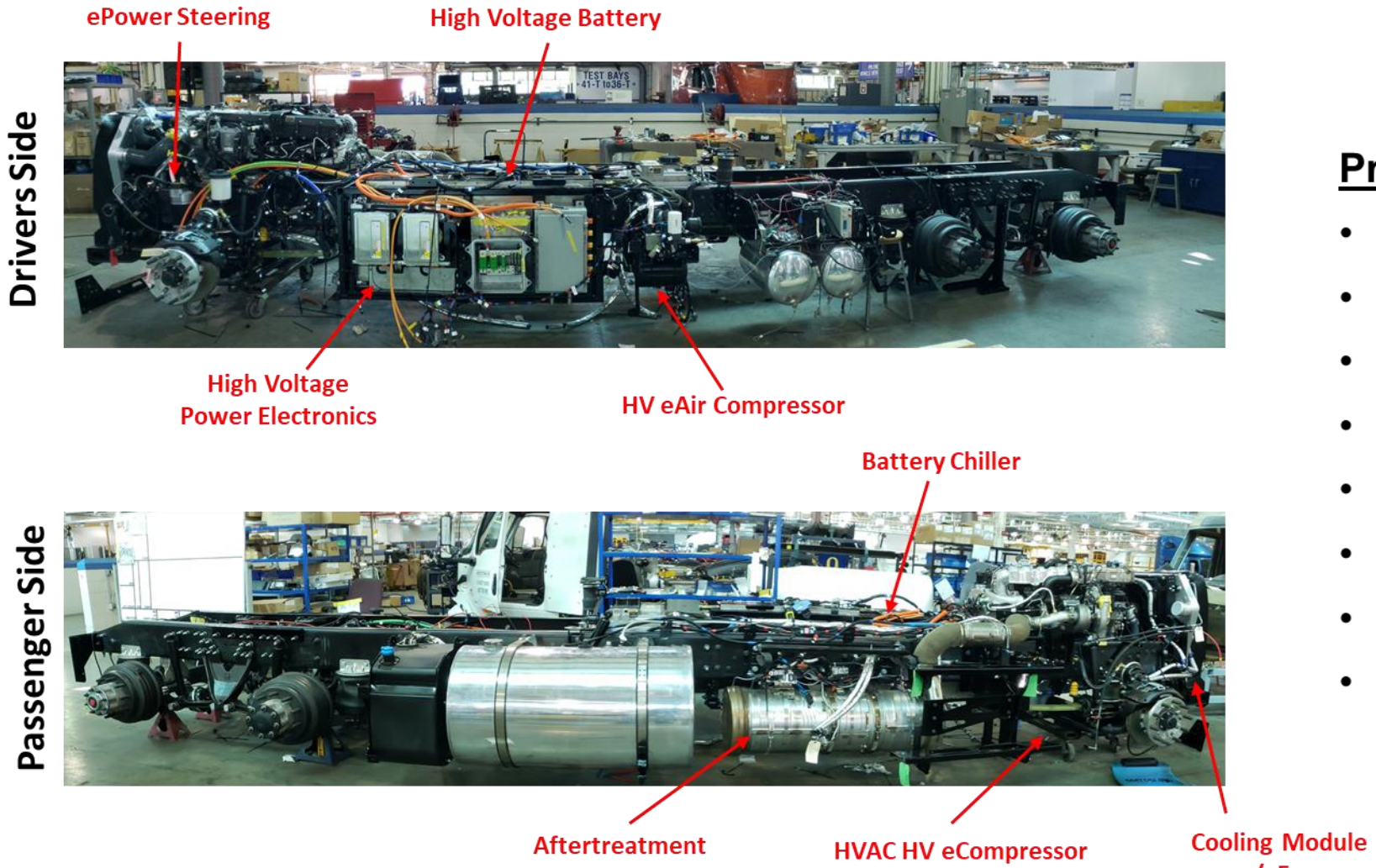
- Greater than 100% improvement in vehicle freight efficiency (FE) (on a ton-mile-per-gallon basis) relative to a 2009 baseline
- Stretch goal of >140% improvement
- Development of technologies that are commercially cost effective in terms of a simple payback





# Vehicle: Technical Accomplishments and Progress

## Vehicle: Build Process




**Prototype Subsystems Installed:**

- HV Battery
- HV Battery cooling (chiller)
- HV Power Electronics
- eAir Compressor
- ePower Steering
- Multi-stage AfterTreatment
- HVAC eCompressor
- eCooling Module

# Vehicle: Technical Accomplishments and Progress

## Tractor Aero Features

**Aerodynamic Subsystems Installed:**

- Hood
- Grill
- Bumper with Air Curtain ducts
- Skirts
- Rear Bumper assembly
- Polycarbonate Windshield
- Tractor Belly pan
- Cab Side Extenders and Skirt Closeouts

# Vehicle: Technical Accomplishments and Progress

## Trailer

Primary Belly Pan

Axle Pan

Base Trailer

Trailer Rear Diffuser and Axle Skirts

Fixed Boat Tail

### Trailer Build

Base Trailer:

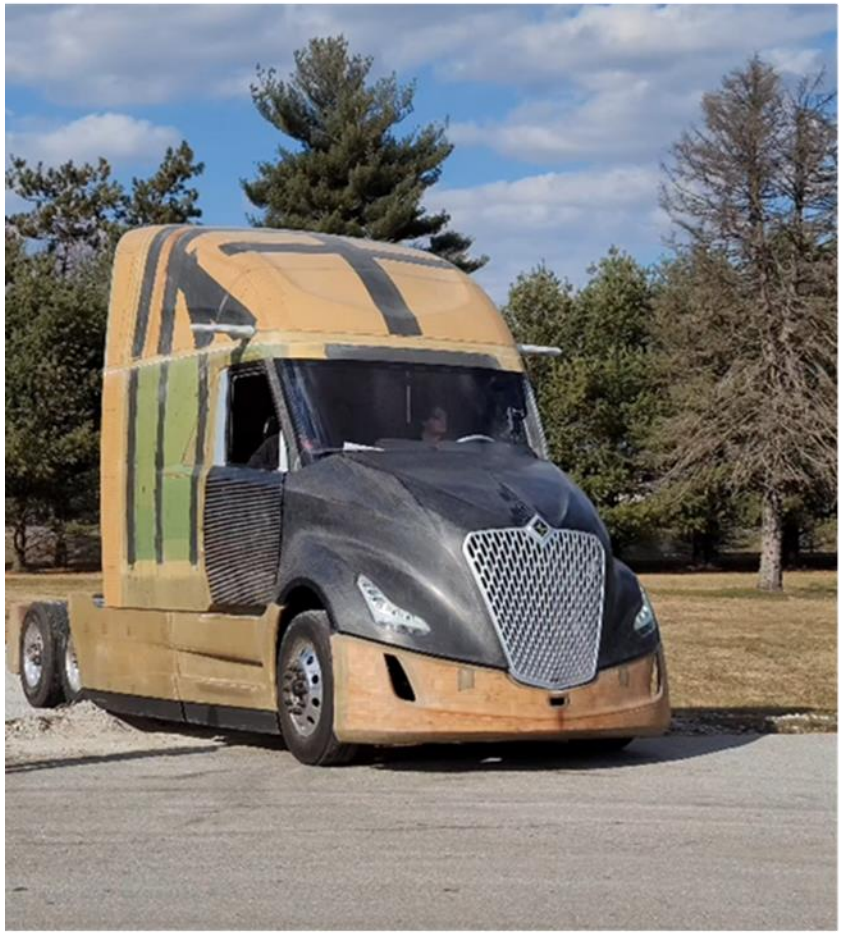
- Door and bumper assembly designed, fabricated and installed.
- Lights and harnessing installed

Exterior Trim:

- Installed primary underbelly
- Installed side skirts
- Installed rear diffuser
- Installed under axle pan
- Fabricated boat tail support hardware

# Vehicle: Build Progress-Tractor Commissioning

## Commissioning



**Tractor Testing:**

Subsystem Commissioning

- Power Steering
- Air Compressor
- HVAC
- Coolant Pumps/Fans
- Camera Mirrors

Powertrain Commissioning

- ICE engine operation
- Zero emission operation
- Stationary battery charging
- Transmission shift quality calibration

# Vehicle: Technical Accomplishments and Progress

## Tare Weight Analysis

### Weight Reductions:

Tractor:
- Composite Cab/Sleeper
- HSS frame rails
- Axle Weight Reduction (Drive & Tag)
- Transmission
- Engine (FEAD removal)
- Fuel/Tank

Trailer
- Composite Box

| | SuperTruck I | SuperTruck II |
|---|---|---|
| **Tractor** | 16,960 | 16,440 |
| **Trailer** | 13,370 | 12,800 |
| **Total** | 30,330 | 29,240 |

### Weight Adders:

Tractor:
- HV Battery and Cage
- HV Power Electronics
- Subsystem Electrification
- Additional Aero surfaces
  - Rear Bumper assembly
  - Belly pan

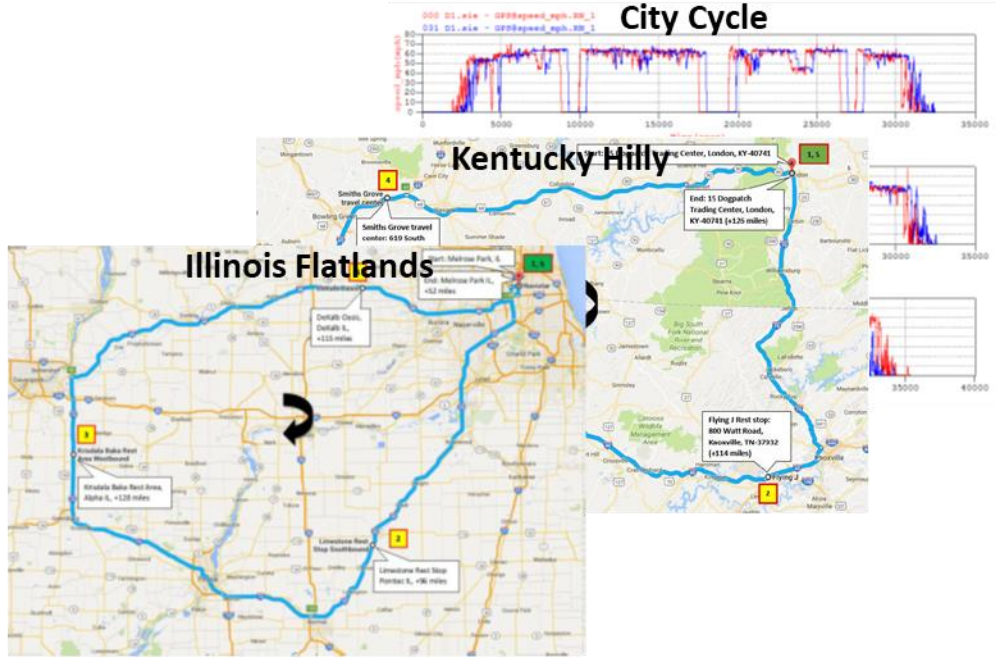
Trailer
- Additional Aero Surfaces
  - Full Belly Pan
  - Diffuser
  - Larger Boat Tail assembly

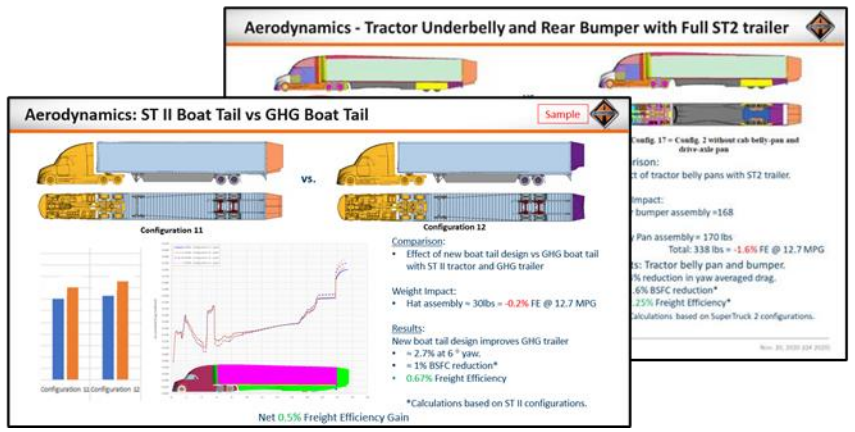
+14% Freight Efficiency at SuperTruck 1 Fuel Economy.

# Budget Period 5 – Vehicle Calibration, Testing and Reporting

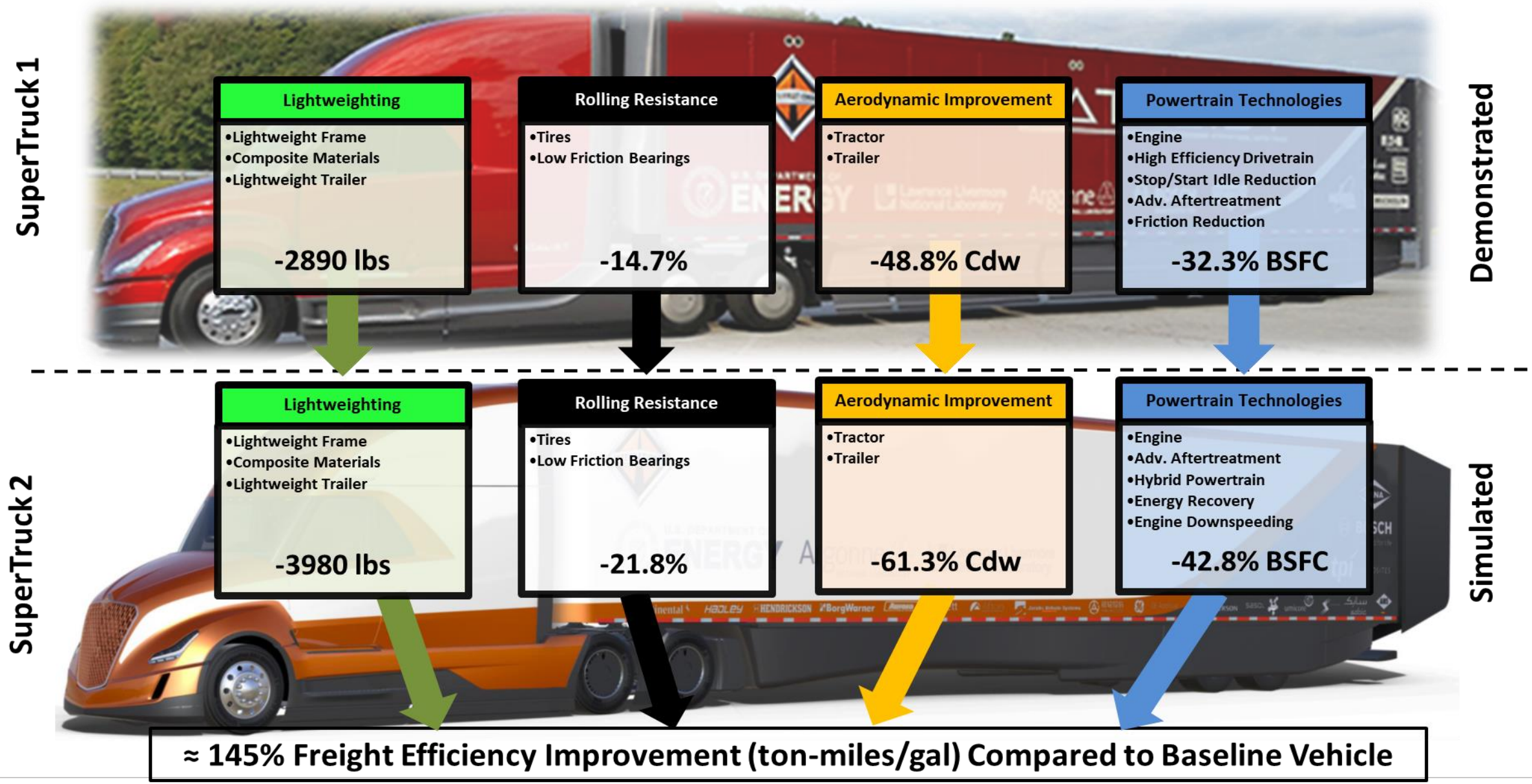
## Continue Efforts: Vehicle

- ✓ Tractor and trailer FAI inspection
- ✓ PCC/ACC speed control & optimization for fuel economy
- ✓ Fuel Economy Testing:
  - ✓ Illinois Flatlands
  - ✓ Kentucky Hilly
  - ✓ City Cycle (Closed track, simulated cycle)
- ✓ Report:
  - ✓ Freight efficiency calculations
  - ✓ Technology business case evaluation
    - ✓ Hybrid drivetrain
    - ✓ Composite aerodynamic components
    - ✓ Light weight components
    - ✓ Electrified subsystems
    - ✓ Engine technologies



# SuperTruck Vehicles Technical Approach



# Responses to 2021 Comments

| Categories | Reviewer Comments | Navistar Response |
|---|---|---|
| Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule | …It seems to point out that the engine may have trouble meeting the 55% BTE goal.. | The complexity of achieving 55% BTE program goals required a multi-level approach of system-level hardware development and component integration to meet goals.<br>The final hardware configuration was able to demonstrate 55.2%. |
| Collaboration and Coordination Across Project Team | The reviewer noted that the team, including suppliers and various contributors, is actually larger than the list shown on the summary slide. | Although many suppliers supported the program, the list would be too long to include. We recognize the major contributors that absorbed part of the cost burden to meet the program goals. |
| Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion? | The reviewer said this discrepancy may indicate some level of risk with maturity of designs or hardware availability with respect to the stated schedule completion. Extending the schedule has budget ramifications on labor and/or facility use. | Due to COVID 19, there were substantial unknowns and concerns over availability of hardware and support to meet program timing requirements.<br>Extending the program schedule aided in addressing this concern. |

# Thank you