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WEBINAR SERIES

Heavy Duty and Non-Road IC Engine Future

Charles Roberts
Southwest Research Institute

SwRI is committed to supporting research and development to meet Worldwide Clean Air and Clean Energy Objectives

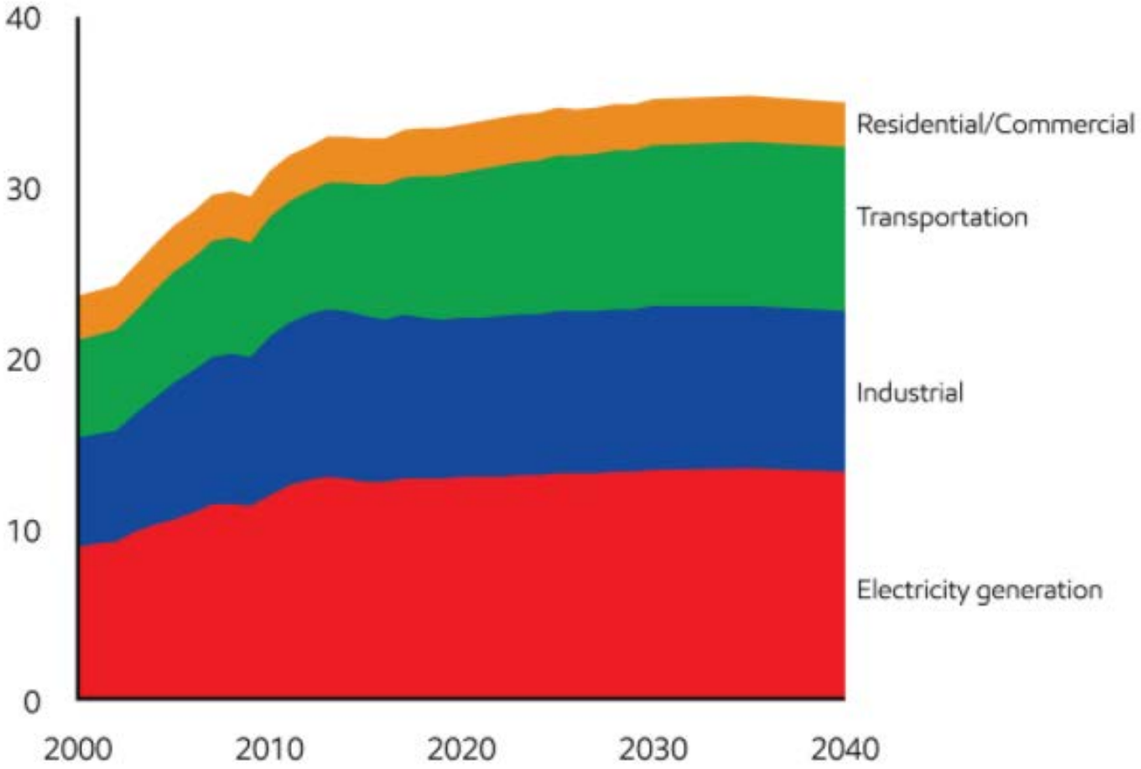
Our approach is to offer innovative, realizable solutions to assist commercial and government clients to achieve their goals

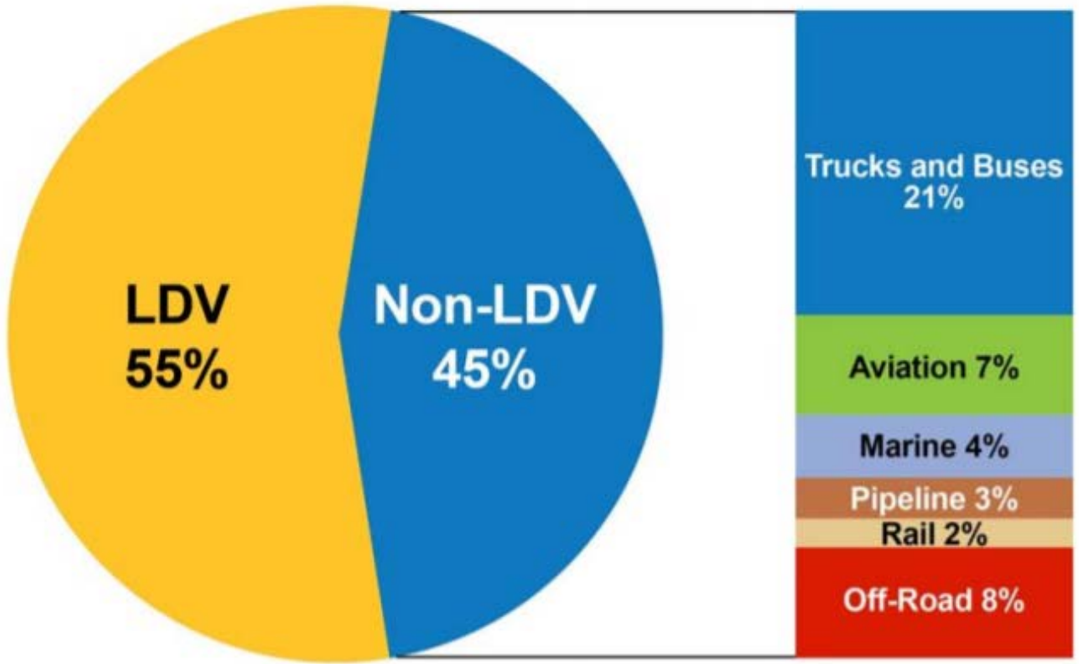
SwRI Commitment to Clean Air and Clean Energy Objectives

SwRI meeting with EPA Administrator, February, 2020

The Energy Picture

Energy consumption and potential GHG emissions are predicted to continue to climb





U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Heavy-Duty Trucks and Non-Road Vehicles are about 1/3rd of the Transport Energy Pie and less than 1/10th of the overall energy picture

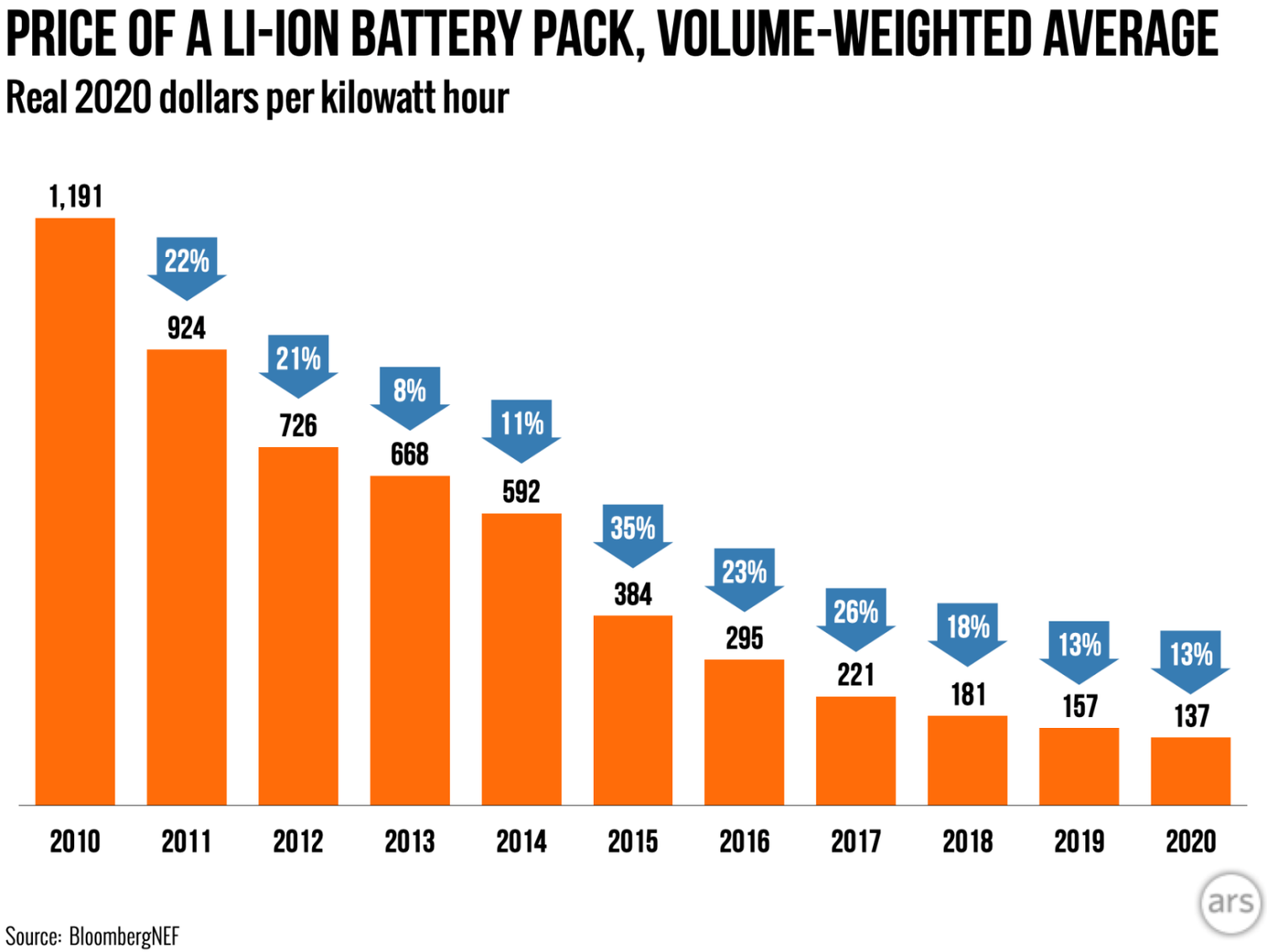
Solutions to the overall emissions issue are needed - The Electric Truck may be on the way…

But just how far is unclear…

Major OEMs Announcing EV Trucks

Generally, an option for heavily-regulated urban zones. Large scale mass adoption will depend much more on vehicle miles travelled and the economics of total payback time.

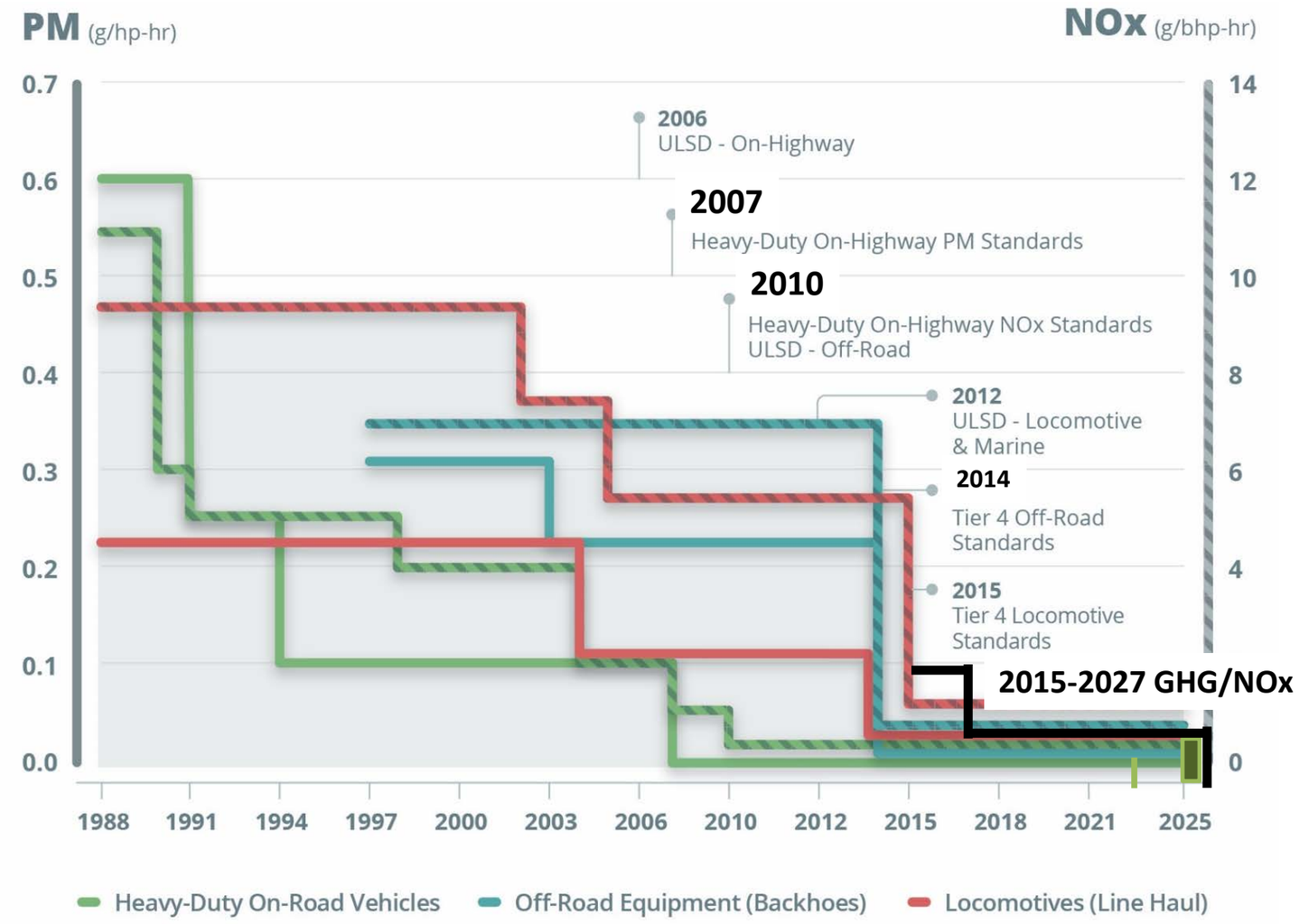
Battery Prices Dropping, making EV attractive for some markets, but not all.



Source: BloombergNEF

- At current battery prices, the premium for a long-haul heavy-duty EV truck more than doubles the purchase price
- This solution is not yet viable for many HD and NR vehicles

Key Regulatory Drivers



- Criteria pollutants and fuel consumption have been drastically reduced in the last decade
- Ongoing R&D is showing that we can still do more, creating near zero criteria emissions and large reductions in GHGs

SwRI's Clean Hybrid Electric Diesel Pathway

CHEDE
CLEAN HYBRID ELECTRIC DIESEL ENGINES

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Adopt the best of the new technologies, using a systems approach, reducing all areas of energy loss to increase vehicle efficiency

BTE (%FE)

45.5%
Starting Point

1.8%

Combustion
Compression ratio >22:1
Increased injector flow
Reduced injector losses
Thermal coatings
250-300 bar PCP

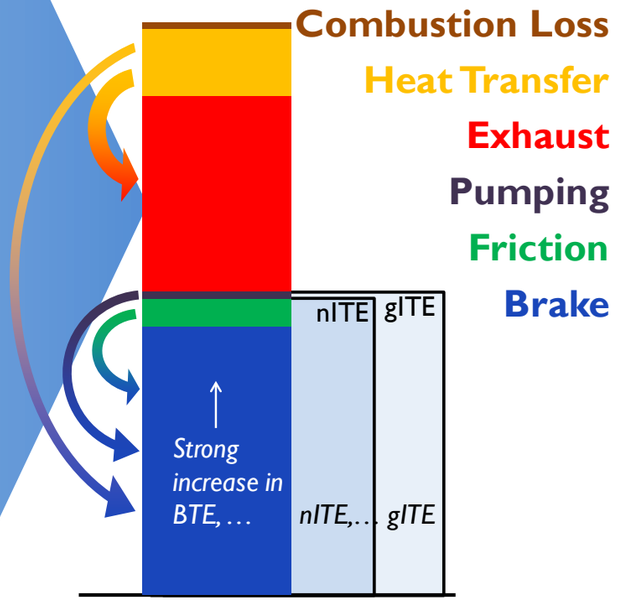
0.9%

Parasitics Reduction
Reduced oil flow crankshaft
Reduced oil flow pistons
Removal of front belt drive
Variable accessories
Advanced lubricants
Bearing optimization

2.4%

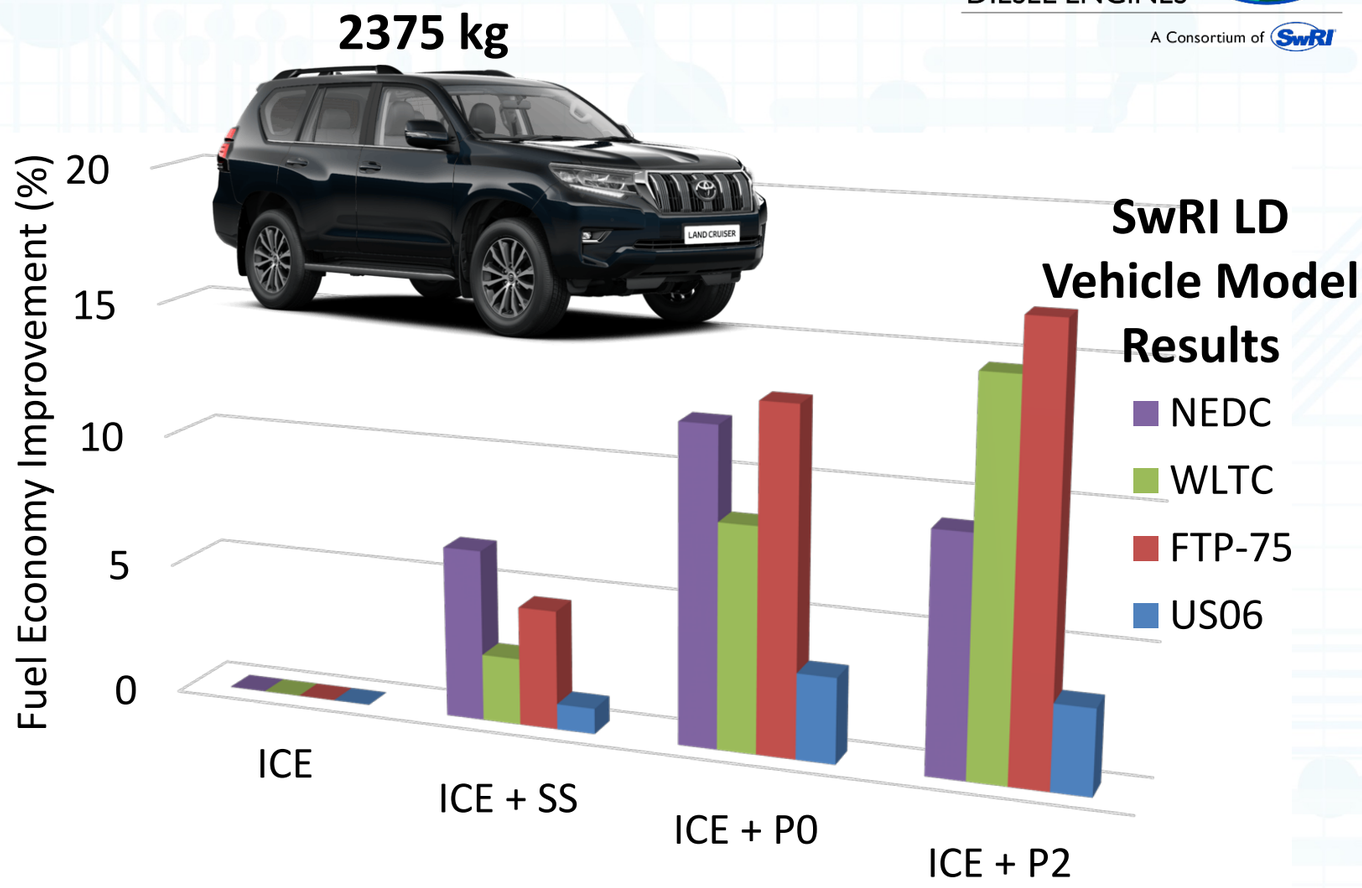
Air Handling System
Optimized exhaust volume
Pulse turbocharging
Aggressive Miller cycle
Thermal coatings

50.6%
High BTE Engijne Pathway



Class 2 Hybrid Passenger / Light Commercial Vehicle

- Start-stop provides about 2.5% benefit over WLTC and less than 1% over US06
- 48v P2 hybrid with small battery and 25 kW motor can improve WLTC CO_2 nearly 15%+
- Stronger hybrid adds more improvement, following trend for small LD vehicles



Heavy Hybrid Class 6-7, Off-road, Vocational Class 8

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Strong industry interest in hybrid powertrain strategies

- Downsized diesel engine
- Strong hybrid (high voltage)
- targets vocational and off-road applications

Optimization program ongoing

- Engine + Motor + Battery sizing
- Novel powertrain energy management strategies
- HIL and SIL test cell demonstrations

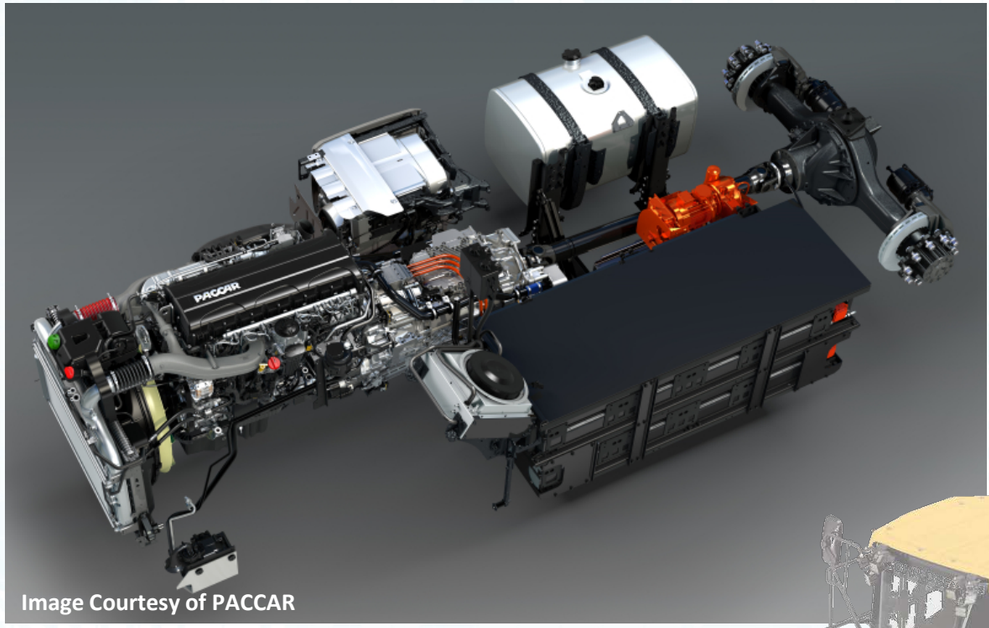


Image Courtesy of PACCAR

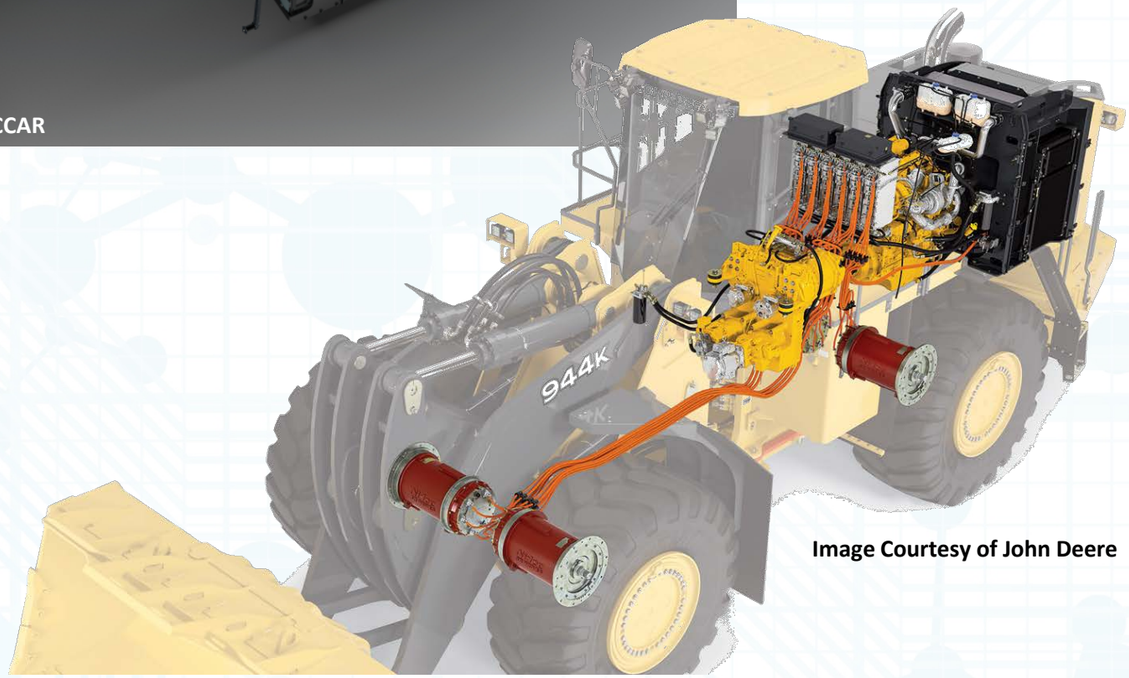
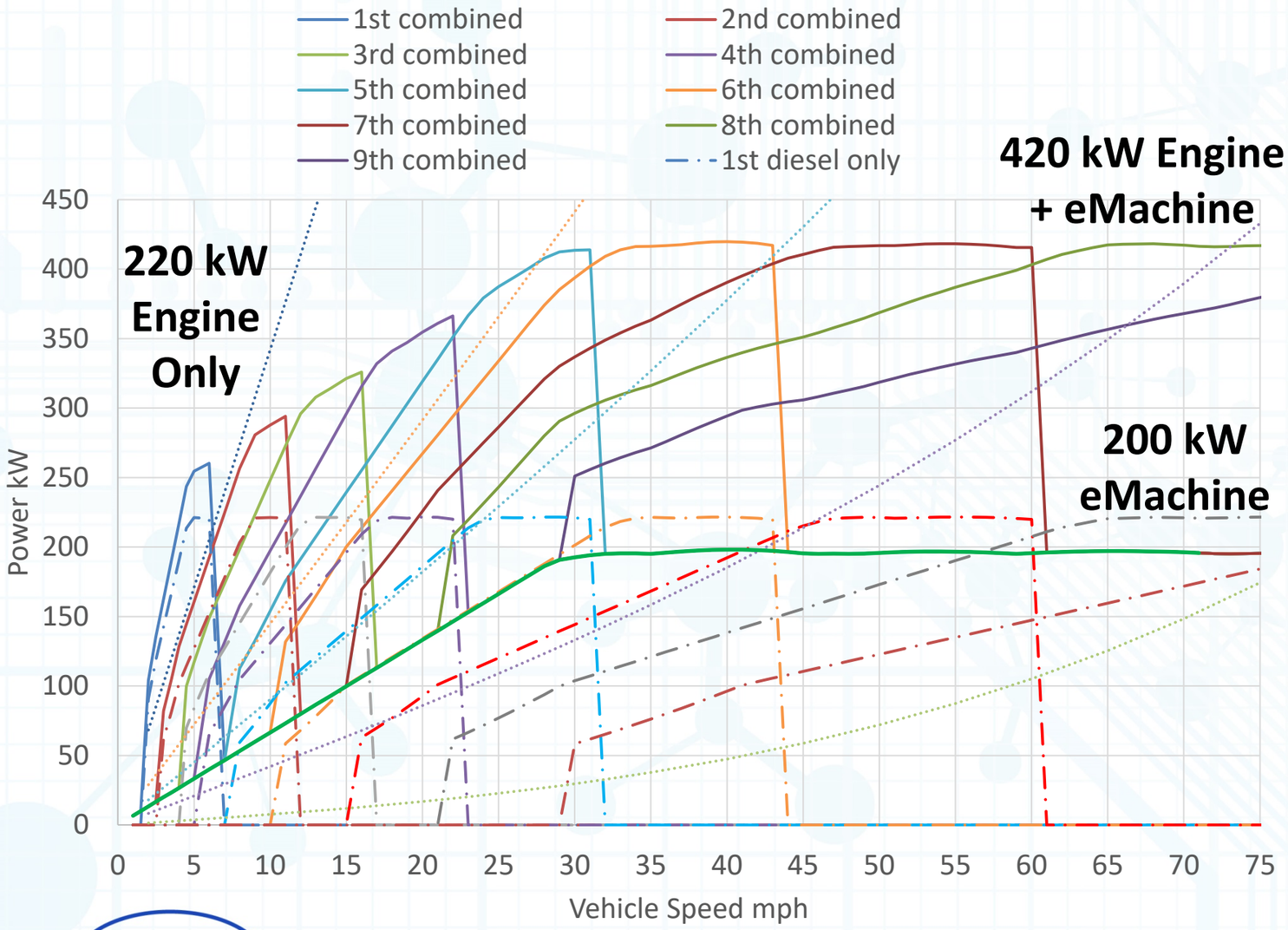


Image Courtesy of John Deere

Heavy Hybrid Class 6-7, Off-Road, Vocational Class 8



- Highly downsized engine with P3 machine
- Lower peak power at low vehicle speeds
- Highway cruise capable with engine off
- Minimize weight increase due to hybrid system with half size engine

Mild Hybrid Class 8 Long Haul Truck

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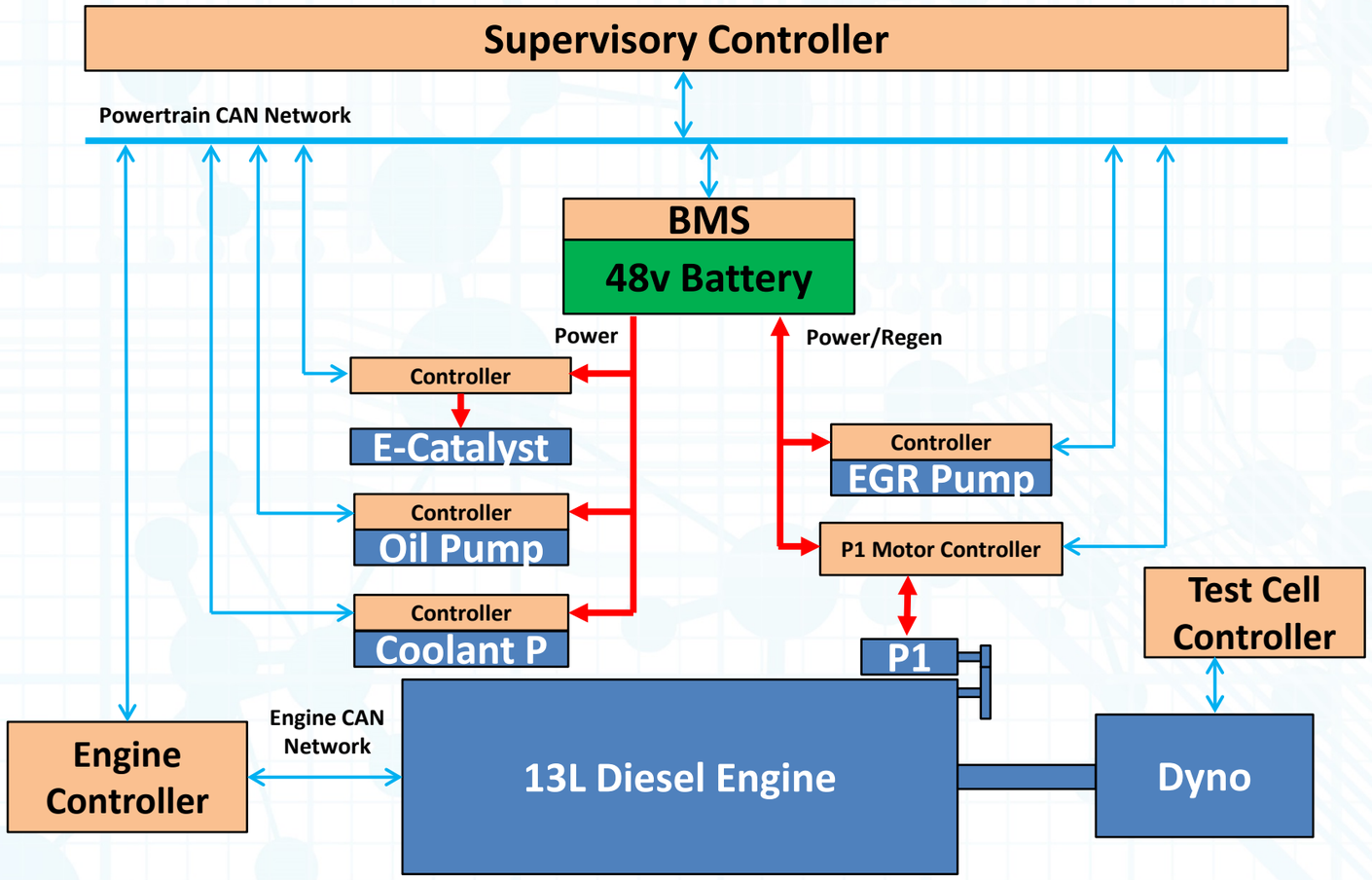
Test cell setup shown



- Engine optimized for cruise power of future long-haul truck
- Electrified accessories to further optimize part load operation
- P1 system used for energy recovery to drive accessories

Mild Hybrid Class 8 Long Haul Truck

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System optimization to meet 0.02 g/hp-hr NO_X and maximize fuel efficiency

- Start – stop for CO_2 reduction and idle elimination (NO_X impact)
- Advanced aftertreatment integration

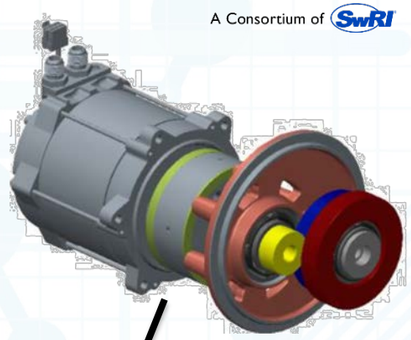
Engine system improvements

- Minimize heat loss, improve exhaust energy
- High efficiency air path designs

Electrification of accessories and components

- Potential for E-Turbo or E-boost to improve cold start / cycle emissions
- Need 48V systems for coolant, oil, motor-generator, etc.
- Heated AT components

Image Courtesy of PACCAR


48V ISG

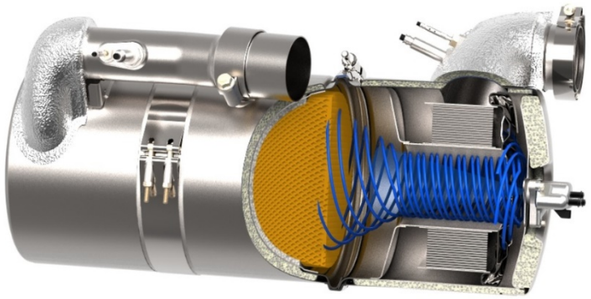


Image Courtesy of Donaldson

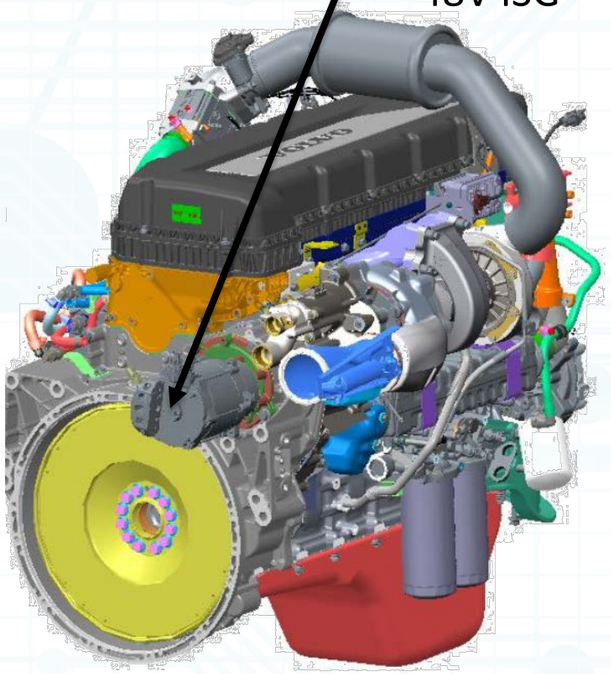


Image Courtesy of Volvo Trucks

Advanced Hybrid IC HD-Vehicle

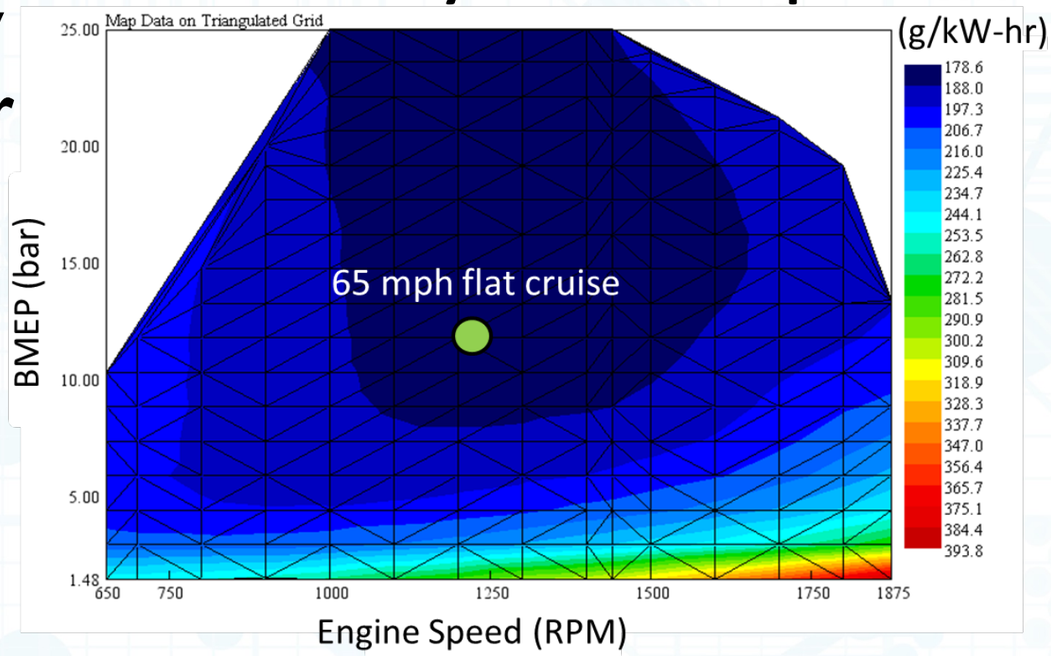
- Cruise BSFC within 3% of peak BSFC

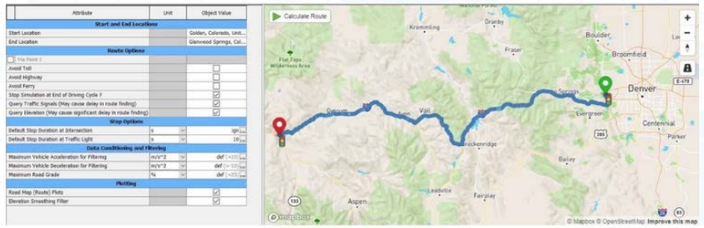
Novel **electrified air system** developed for wide peak efficiency

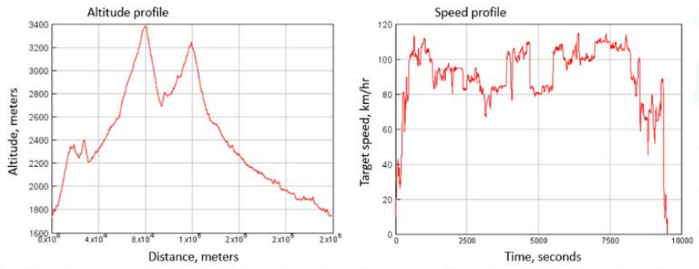
- **EGR Pump for HP EGR only**
- **High efficiency turbocharger**
- **Additional eCompressor**

Engine concept targets
178 g/kW-hr BSFC

HD 8.5L 4-cylinder concept

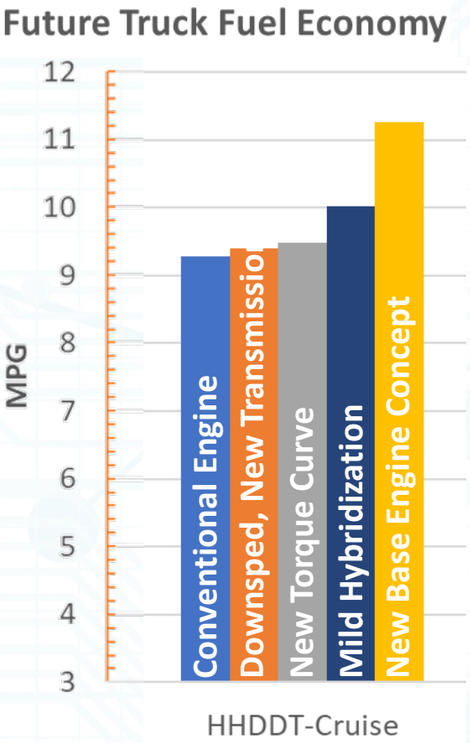






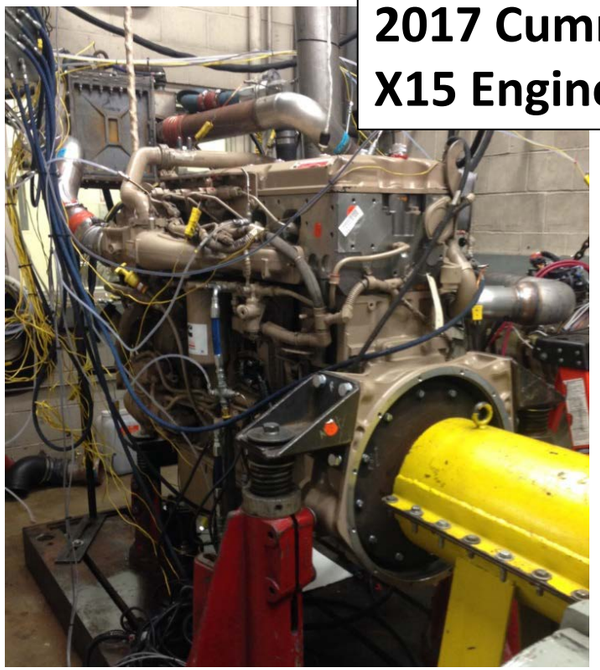
20 kW ISG
40 kWh battery
Smart GPS

Passes Eisenhower pass, most challenging in the USA

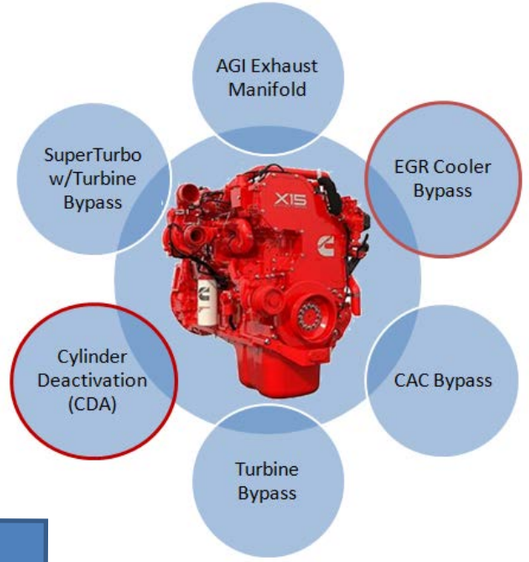


Seeing the Bigger Picture…

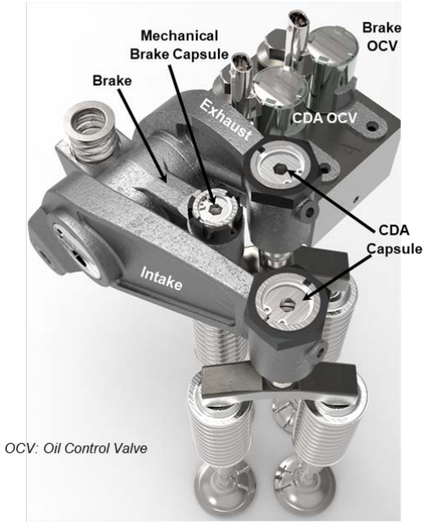
Combining Low NOx Aftertreatment and New Engine Technologies



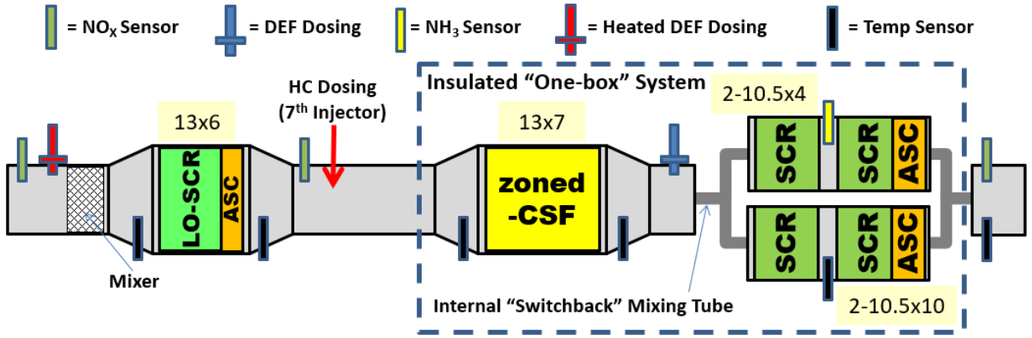
2017 Cummins X15 Engine



Eaton CDA Hardware



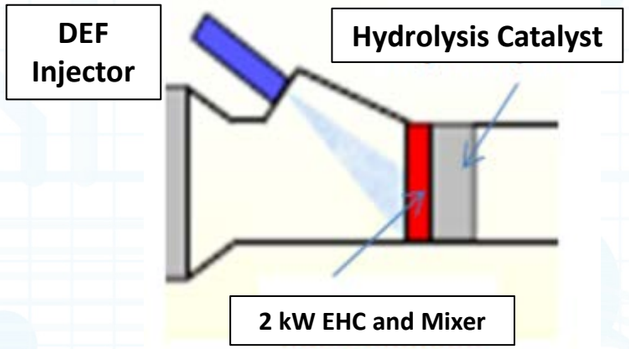
Advanced Low NOx Aftertreatment (Dual SCR-Dual Dosing)

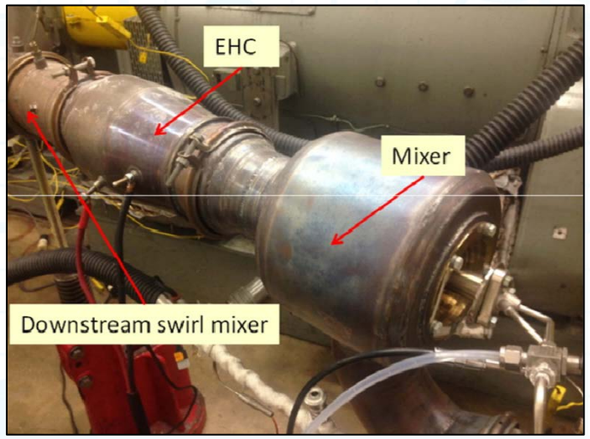


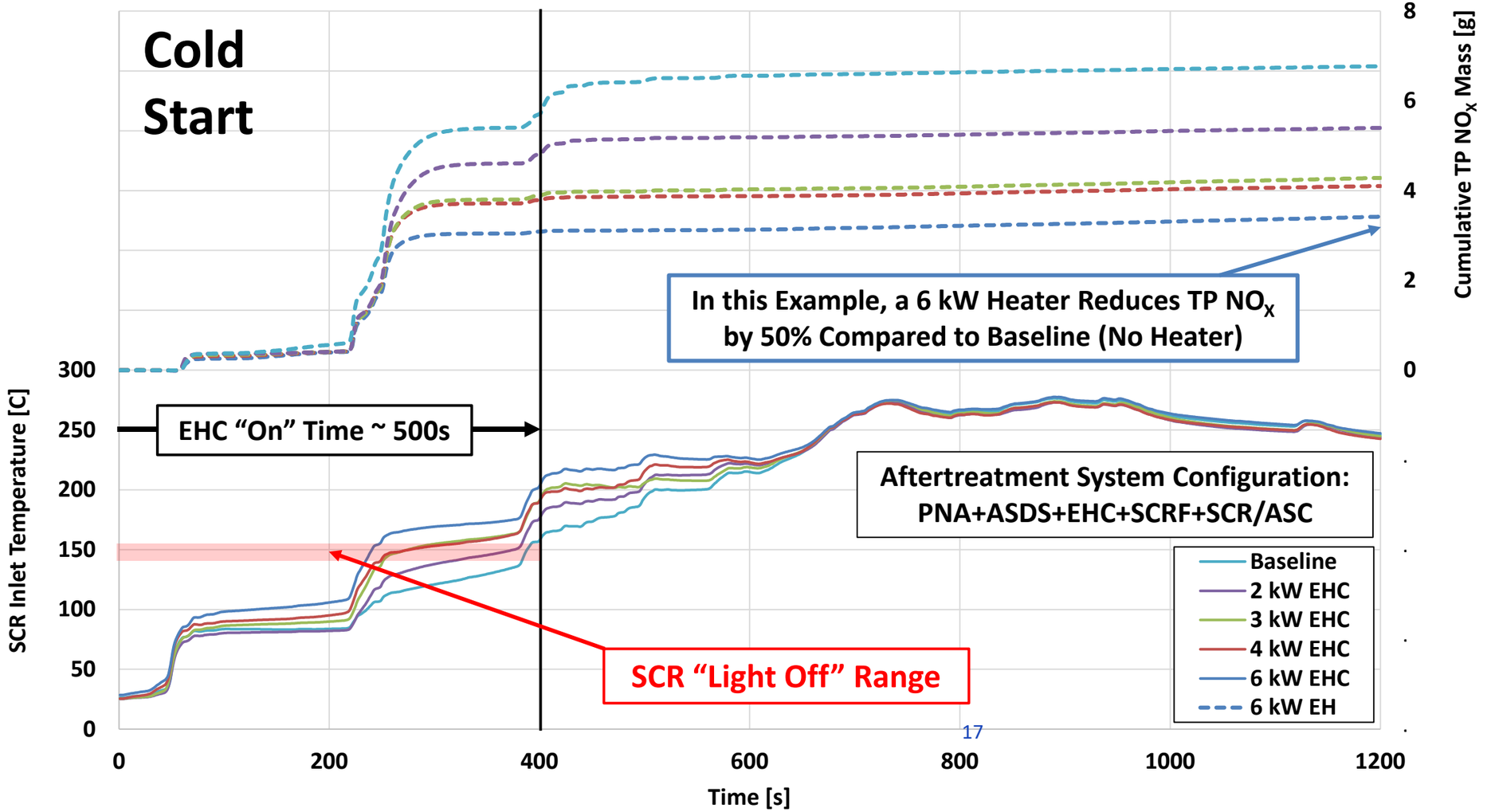
Goals:

- **FTP/RMC NO_X 0.02 g/hp-hr**
- **No adverse GHG impact**

Electrifying the Aftertreatment System- Heated DEF Dosing and Electrically Heated Catalyst







Advanced Hybrid Diesels are the Best Next-Step

- SwRI programs are applying a full systems approach to the analysis, design, and demonstration of next-step technology for HD and NR
- Hybrid systems are key to the approach
- Potential for wide near-term adoption and scalable solution to a variety of markets for immediate carbon reduction
- Protects for future success of higher risk technologies
  - Compatible with sustainable Efuels, CI-Hydrogen, etc;