Technology Solutions for Cleaning-Up Heavy-Duty Vehicles

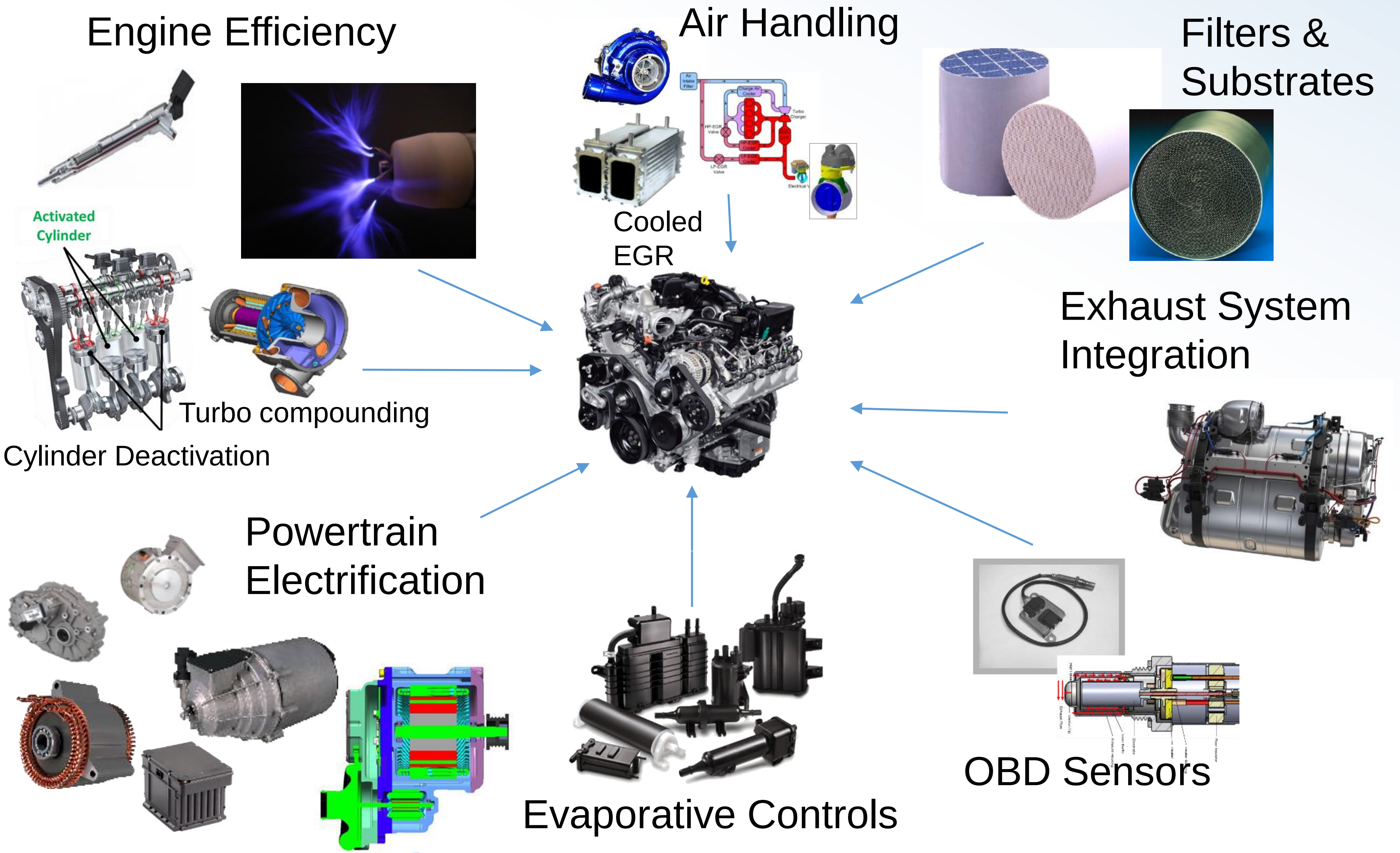
Manufacturers of Emission Controls Association
www.meca.org

February 25, 2020

NACAA

Mobile Sources and Fuels Committee Call

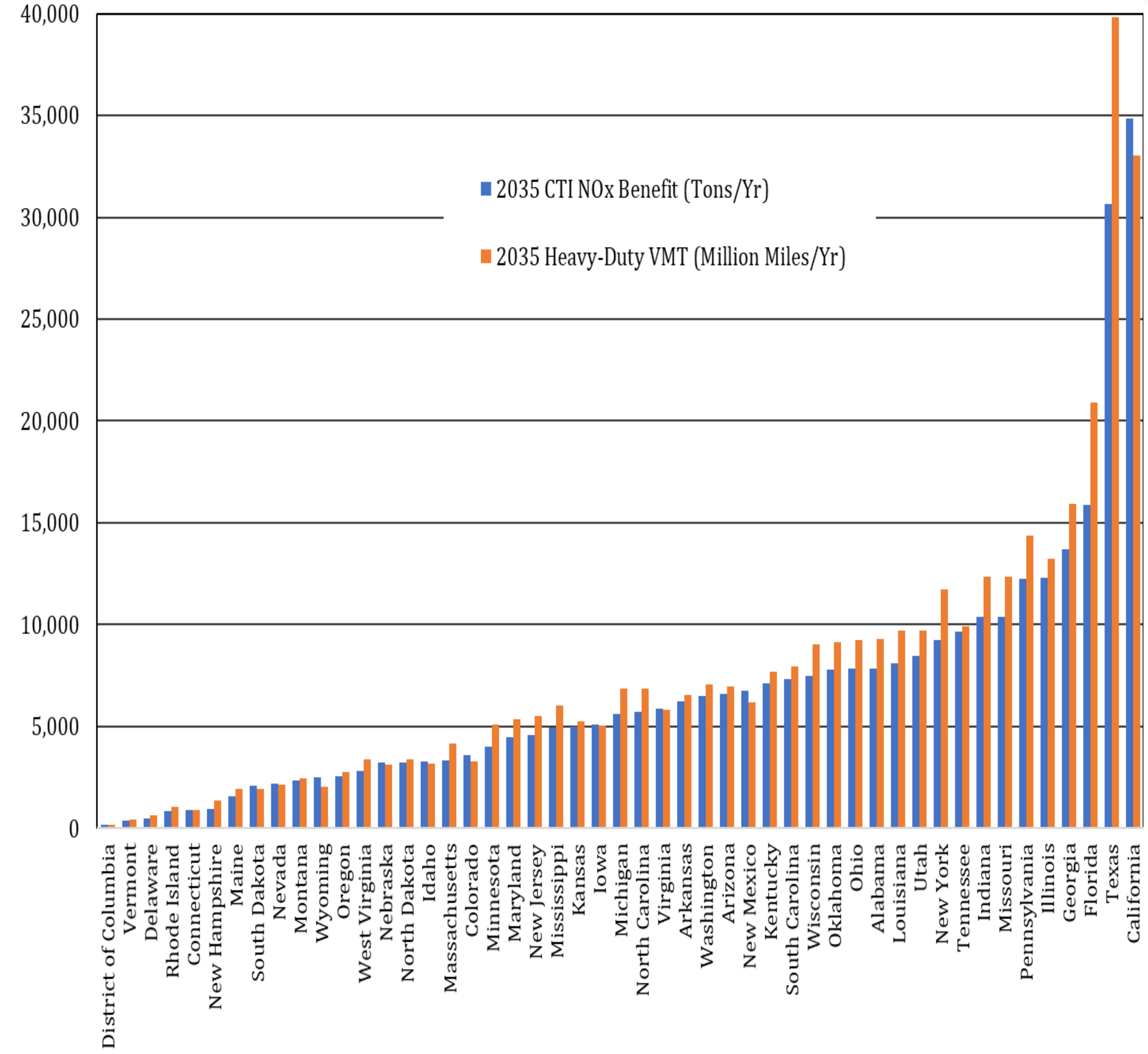
MECA Represents Suppliers of Technology Solutions for all Mobility Challenges

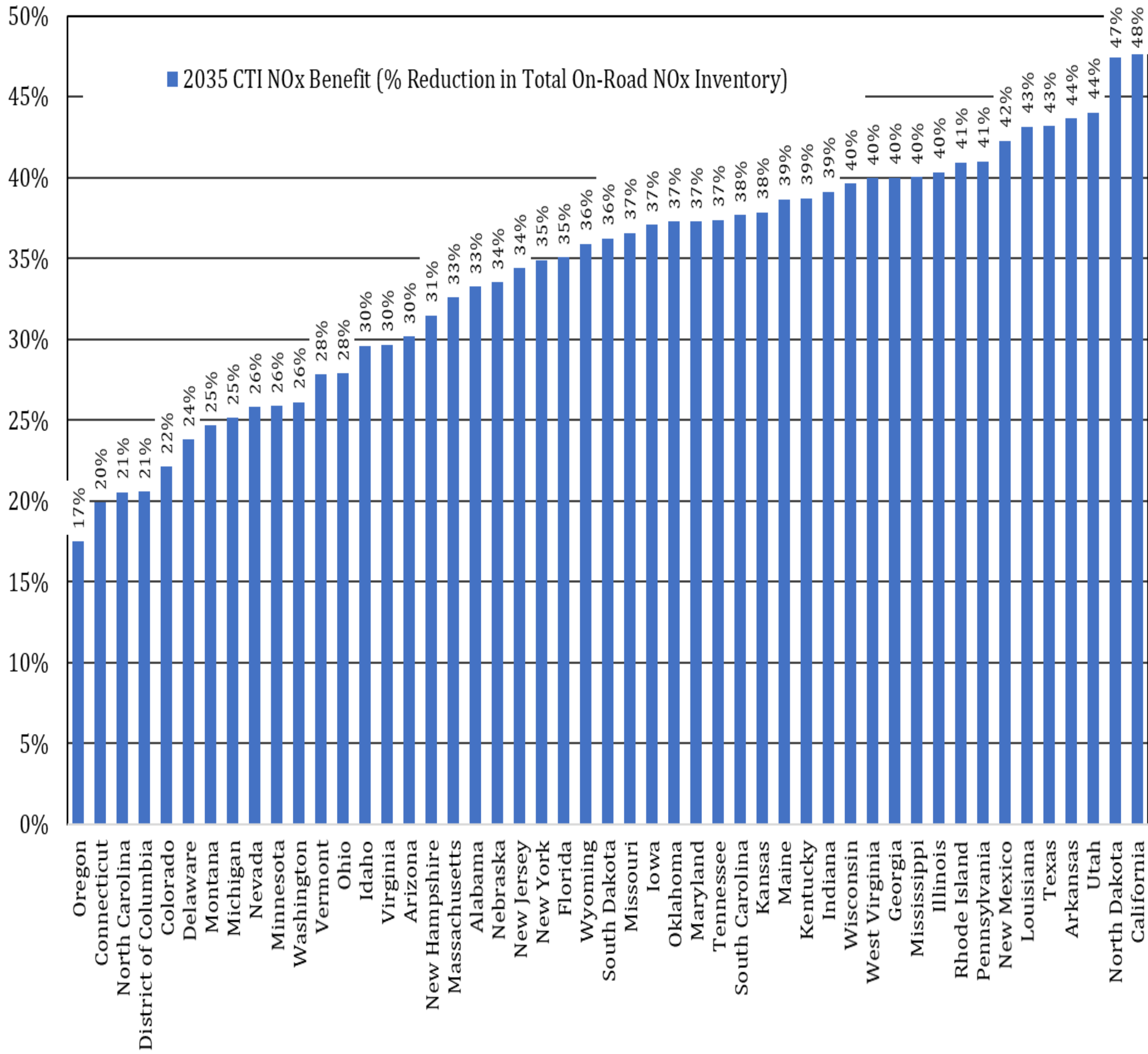


What NOx Emissions are Achievable

- MECA believes that by 2024 a 0.05 g/bhp-hr limit on the FTP is feasible without major changes to aftertreatment designs on trucks today.
- MECA supports the goal of achieving real world NOx reductions.
  - Addition of a low load certification cycle and new in-use compliance requirements will ensure low NOx emissions all the time.
  - The same technologies that reduce cold-start emissions deliver reductions during low load and low speed operation.
- By 2027, meeting 0.02 g/bhp-hr NOx over the FTP and low NOx emissions on the LLC are achievable with improved calibration, engine thermal management technologies, and advanced aftertreatment.
- MECA's June 2019 and February 2020 white papers highlight technology solutions that deliver both low CO_2 and low NOx in 2024 and 2027 timeframes, respectively.

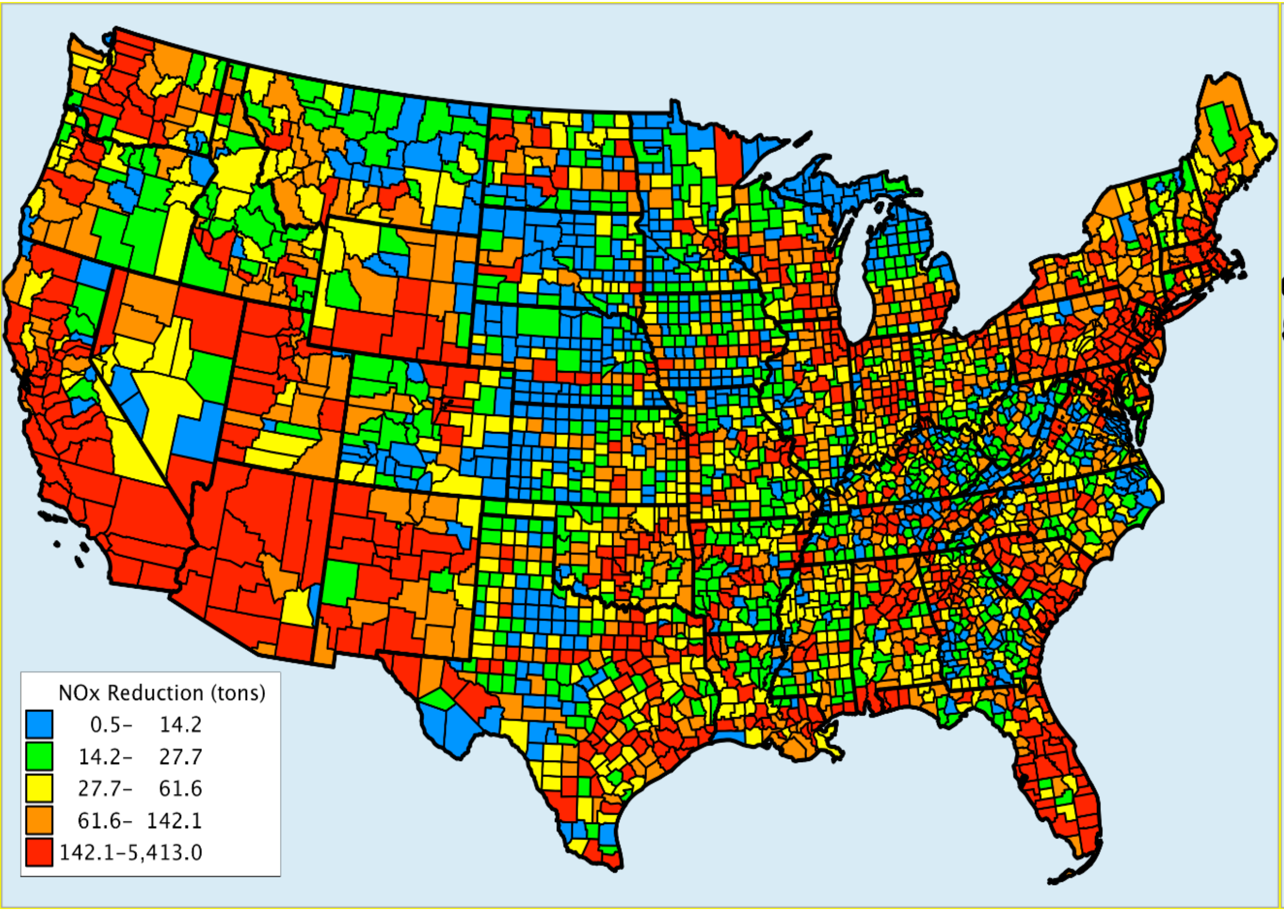
State-Level Annual NOx Benefit and VMT in 2035

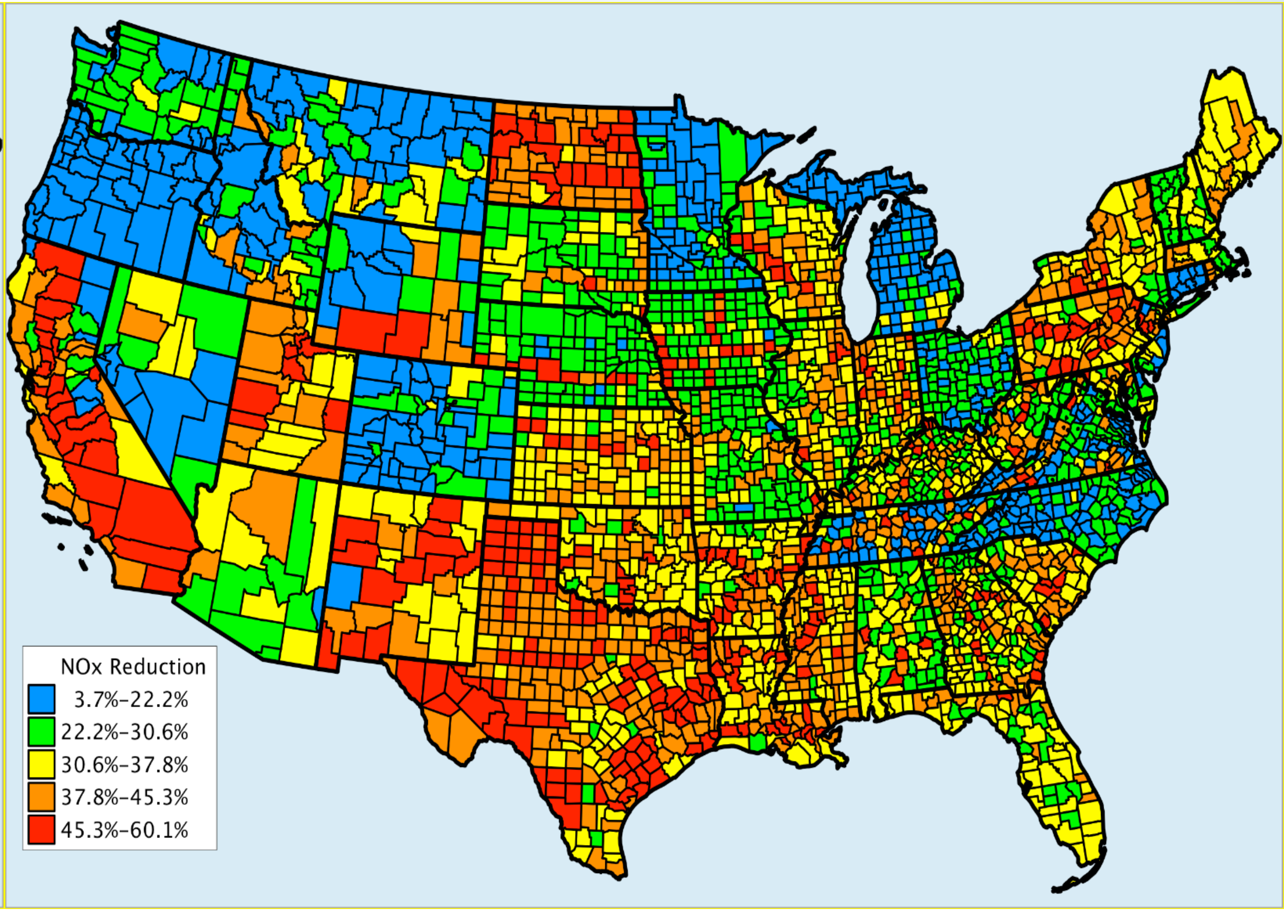




Preliminary data – Please do not cite or distribute

County-Level Annual NOx Benefit in 2035





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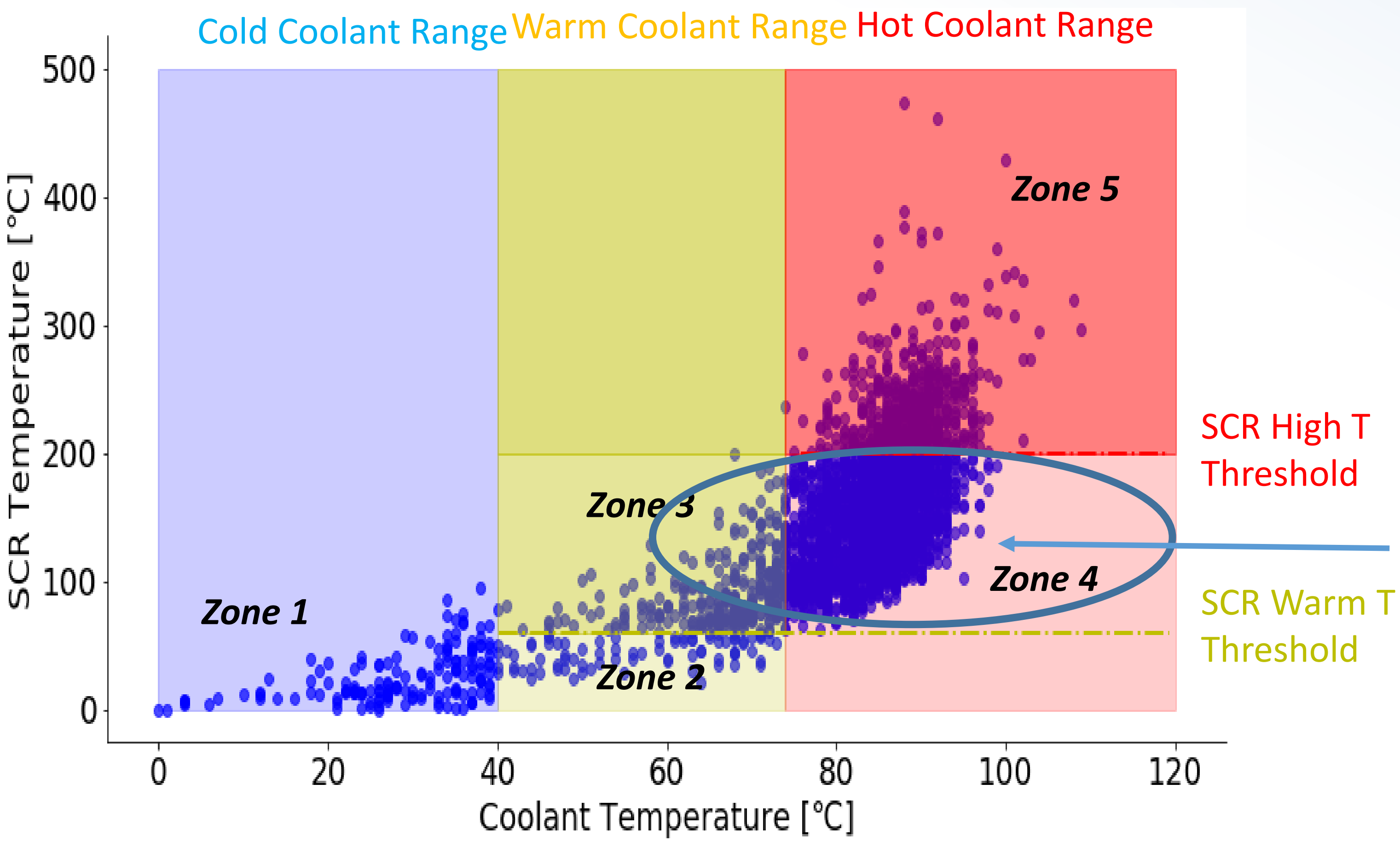
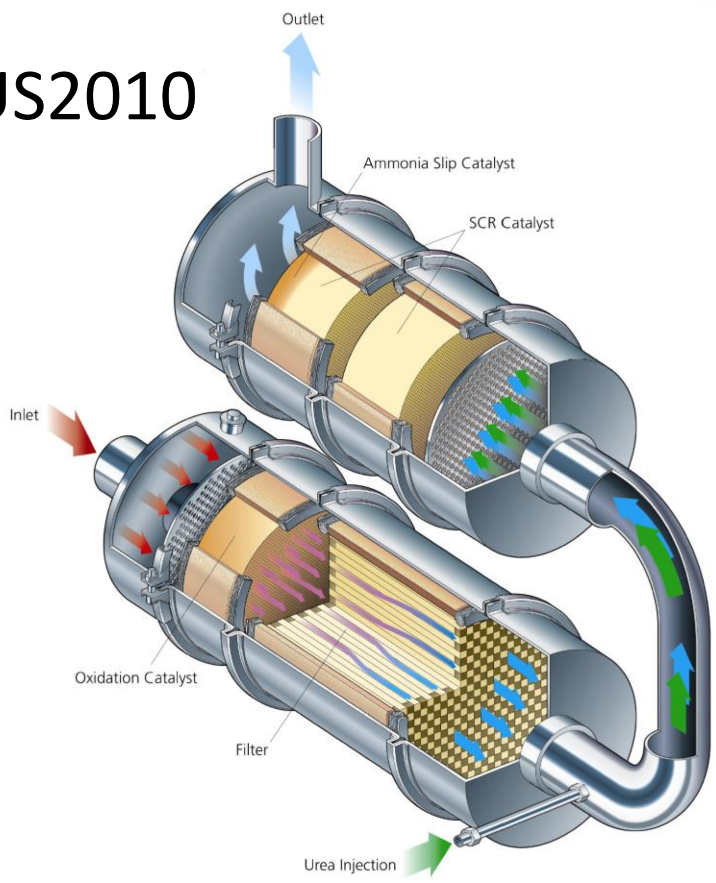
Summary of Cold and Hot Operation Analysis



- The ***cold-operational time*** of the ***FTP cycle (1.5%)*** is comparable to the ***in-use data (1.3%)***. However, its ***warm-operational time (21.8%)*** is much longer than ***the in-use data (7.2%).***
- The in-use data reflects that on average, ***12.0% of engine starts are cold.*** The current weight for cold-start emission in ***FTP cycle is 1/7 or 14.3%.***
- From the ***on-road vehicles***, almost ***20%*** of their operational time is within the ***hot-warm condition***, e.g. the coolant T is over 80 C but the SCR T is less than 200 C.
- In real-world driving, ***the engine-off time*** significantly extends the warm-up duration from both cold-start and warm-start.

Evolution of Heavy-Duty Exhaust Control Technology

US2010



Repackaged

A natural optimization has resulted in 2019 systems being 60% smaller, 40% lighter, and cheaper than 10 years ago.

US2013

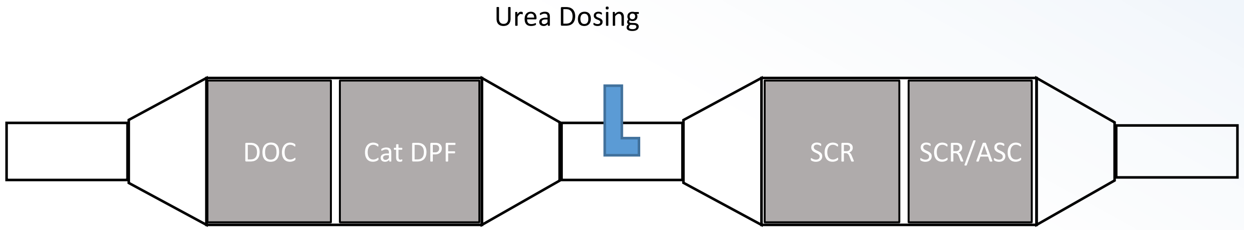
Downsized

US2019

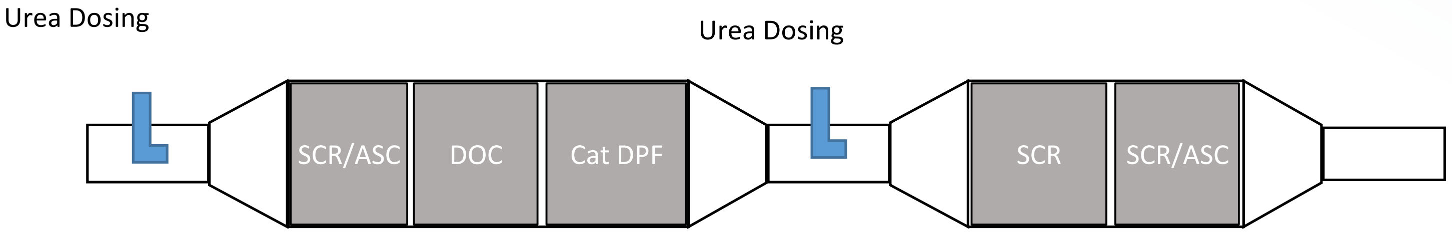
Future Exhaust Systems will be Similar to Today

- Technologies already on passenger cars will help trucks achieve low NOx emissions on cold-start and in low load operation.
- Low temperature active catalysts and engine technology like advanced turbos and cylinder deactivation will move from passenger cars to commercial vehicles by 2027.
- Front SCR and dual and/or heated urea dosing for start-up and low load operation.

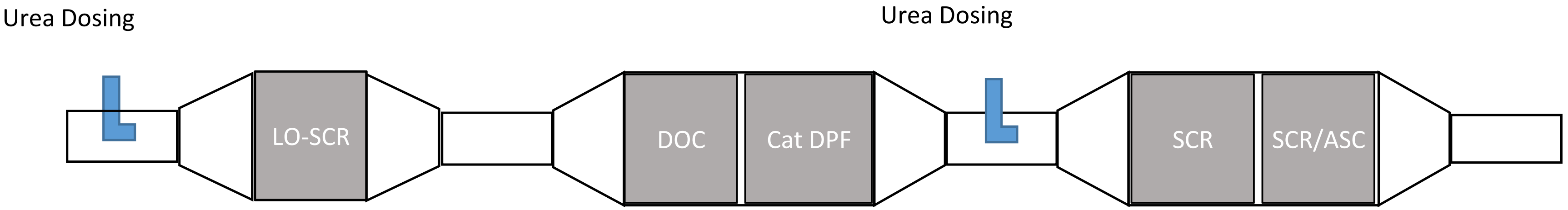
2019 System



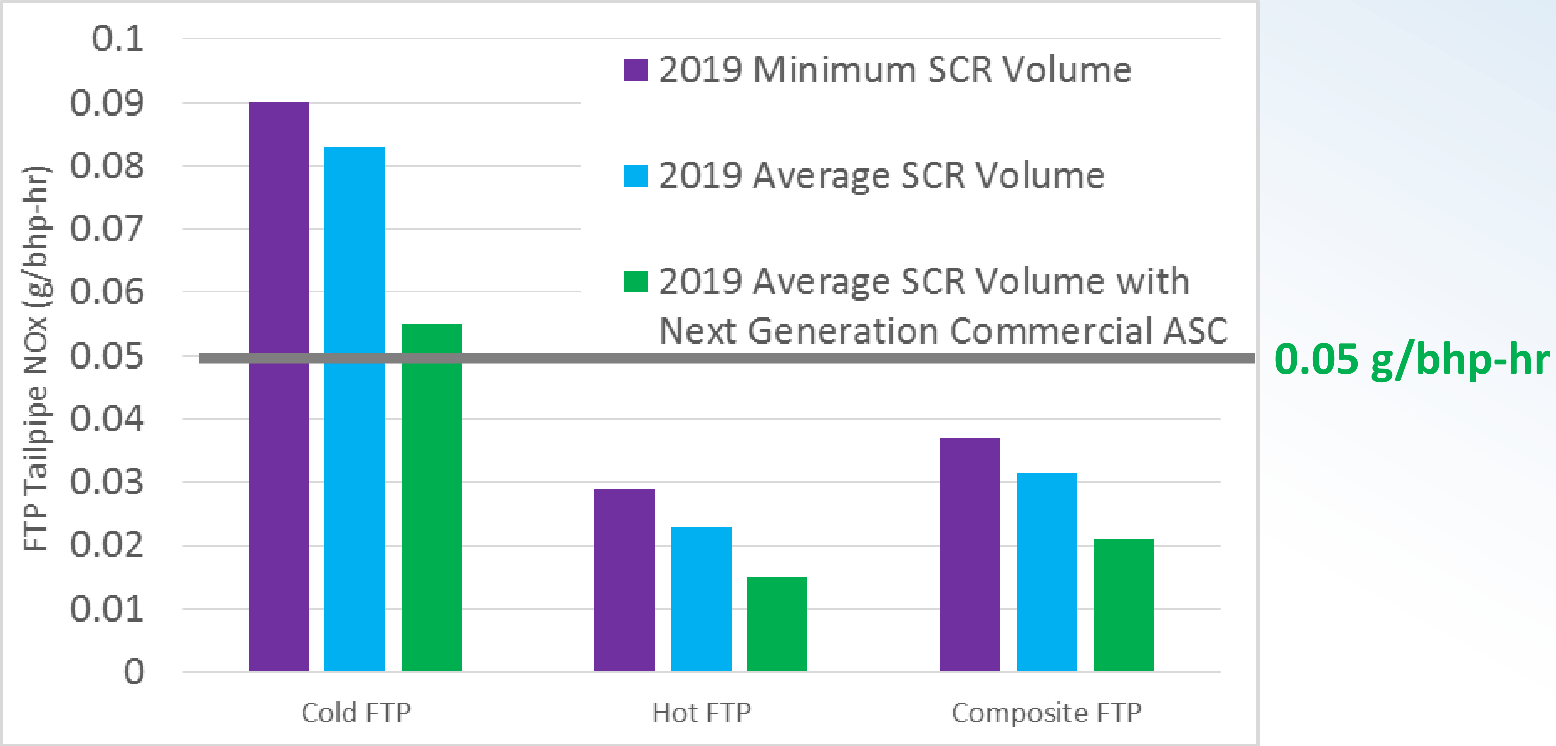
2024/2027 System



2027 System



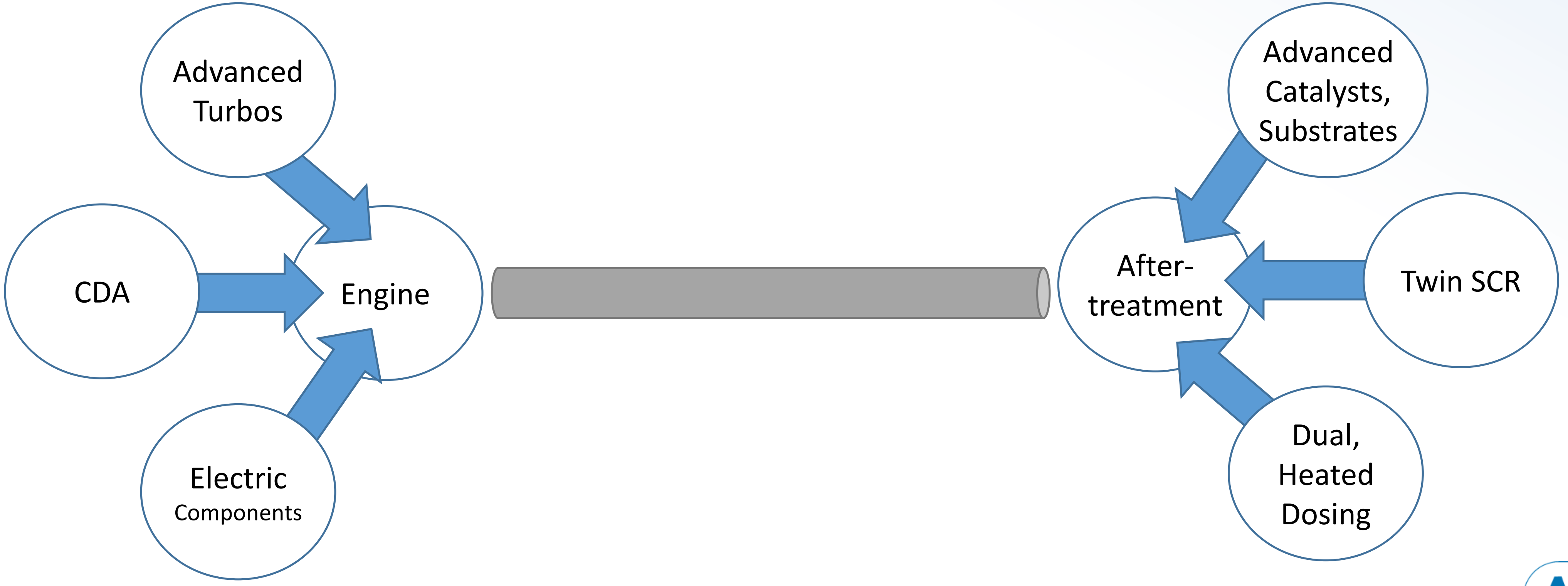
Emission Controls and Engine Thermal Management Can Achieve 0.05 g/bhp-hr by 2024



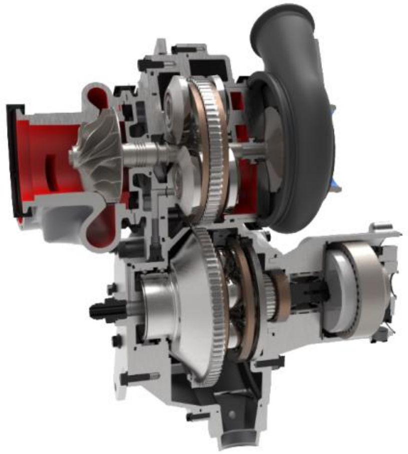
- Sophisticated reaction models based on engine out exhaust and temperature information combined with aged catalyst activity help suppliers design aftertreatment solutions.
- Tailpipe emissions were modeled with engine calibration from SwRI and fully aged commercial catalyst activity.
- An aged 2019 exhaust control system with better engine calibration can meet a 0.05 g/bhp-hr FTP limit.

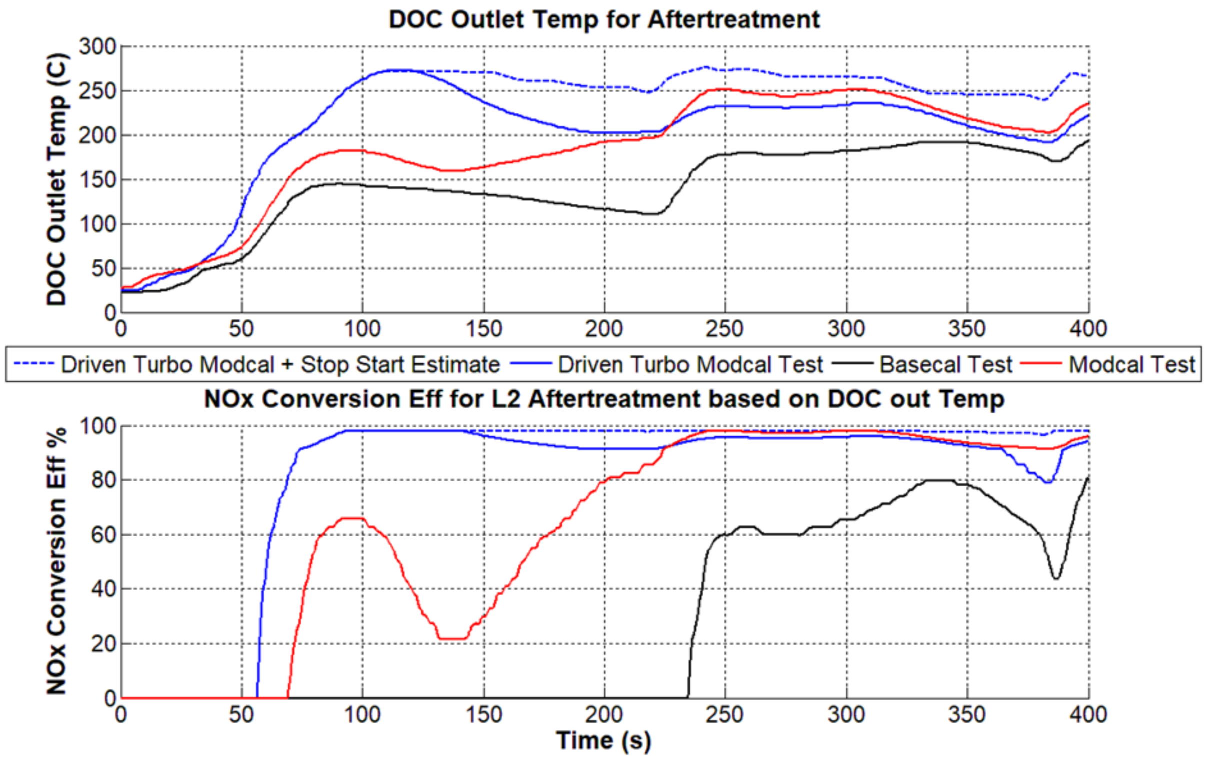
Meeting 90% Lower NOx Standards During Real World Operation for MY 2027

- By 2027, meeting 0.02 g/bhp-hr NOx over the FTP and low NOx emissions on the LLC (and real-world) are achievable with advanced aftertreatment, engine thermal management technologies and improved calibration.



Engine & Powertrain Technologies Deliver Simultaneous NOx and CO_2 Reductions: Driven Turbochargers



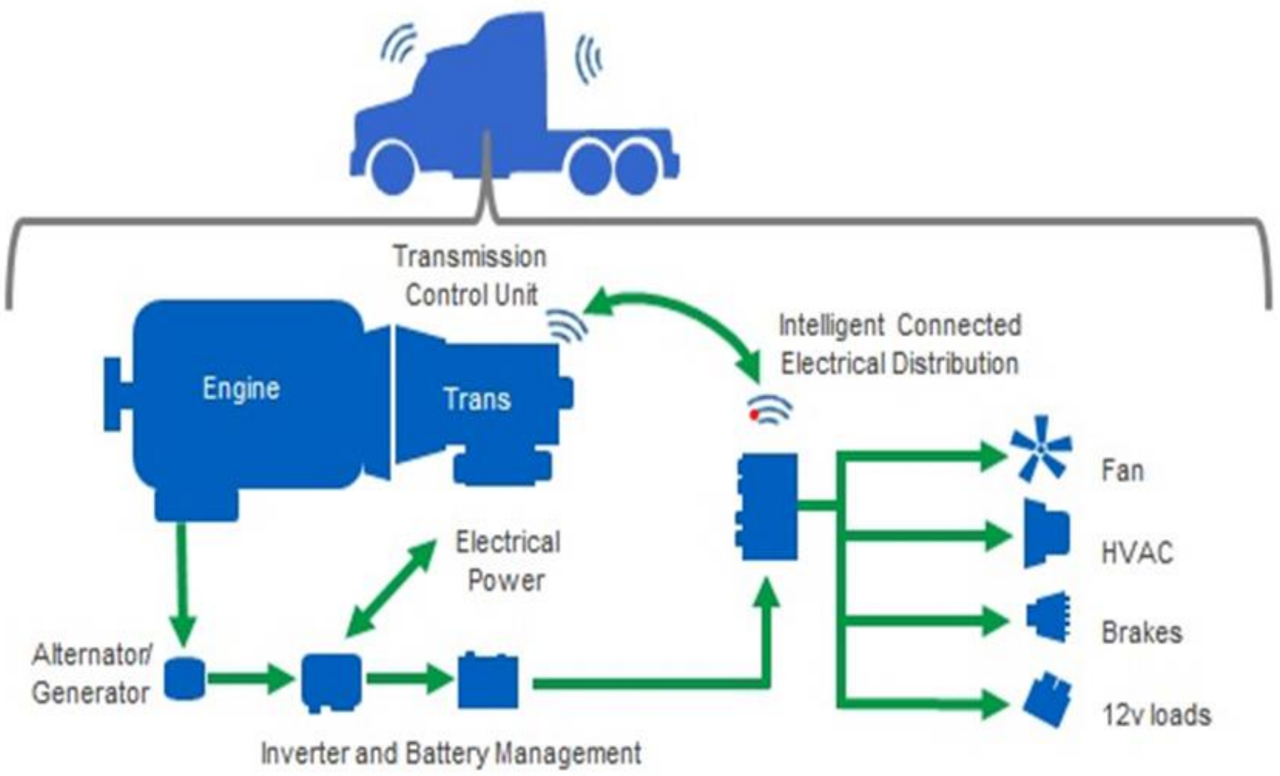


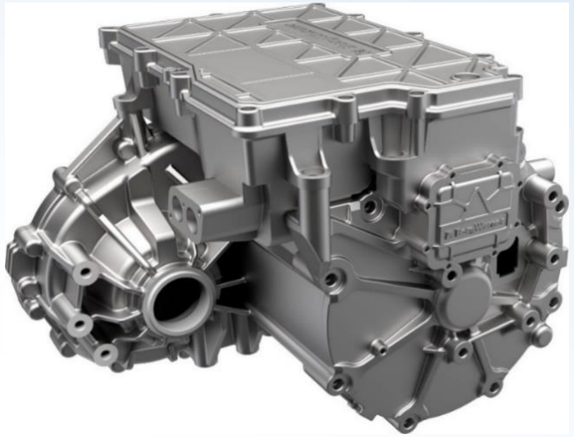
- High efficiency and driven turbos enable faster catalyst heat-up and exhaust energy recovery
- Driven turbos can act as superchargers, turbochargers and turbo-compounds
- Combining stop-start technology with driven turbos provides additive benefits

Start-up	Idle	High load/Acceleration	Steady-state/Deceleration	Total Cycle
Supercharging for faster heat-up	Start-stop for heat retention	Turbocharging to reduce turbo-lag (downsized engine)	Turbo-compounding for energy recovery	
NOx ↓	NOx ↓	PM ↓	NOx ↓	NOx ↓
CO_2 ↑	CO_2 ↓	CO_2 ↓	CO_2 ↓	CO_2 ↓

Engine & Powertrain Technologies Deliver Simultaneous NOx and CO_2 Reductions: Mild and Full Hybrids

- Electrified vehicles enable capture and use of braking energy and efficiency gains from electrified components





Integrated Electric Drive

The types of components that may be electrified include:

- electric turbos
- electronic EGR pumps
- AC compressors
- electrically heated catalysts
- electric cooling fans
- oil pumps
- coolant pumps

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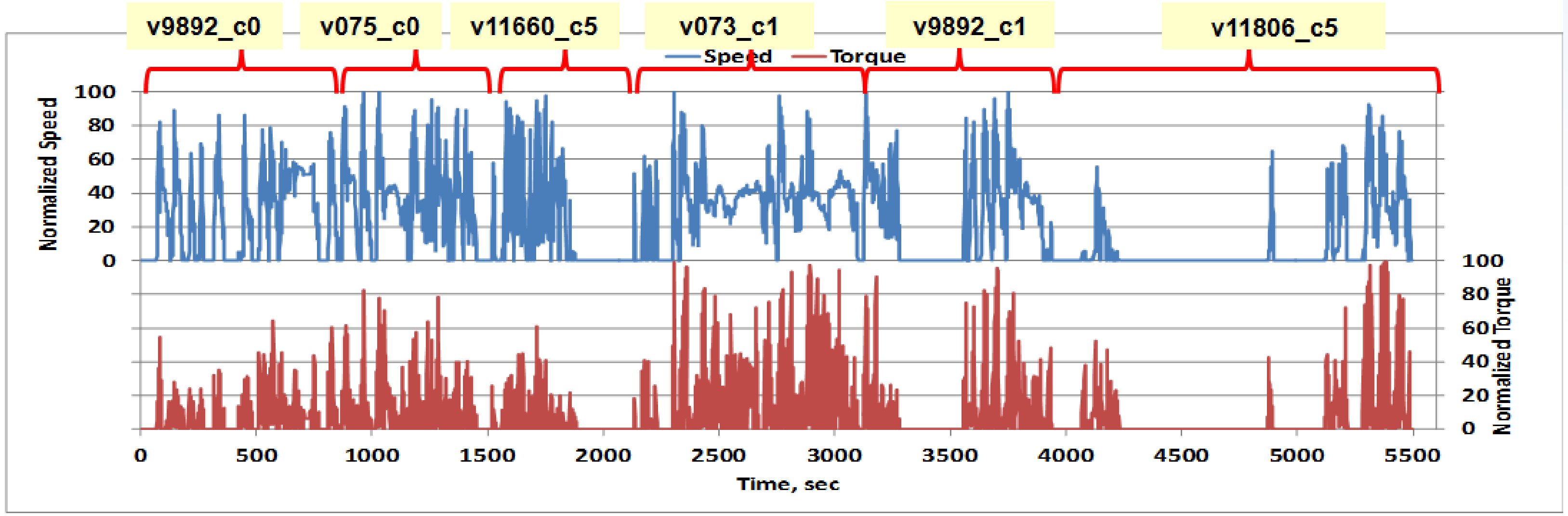
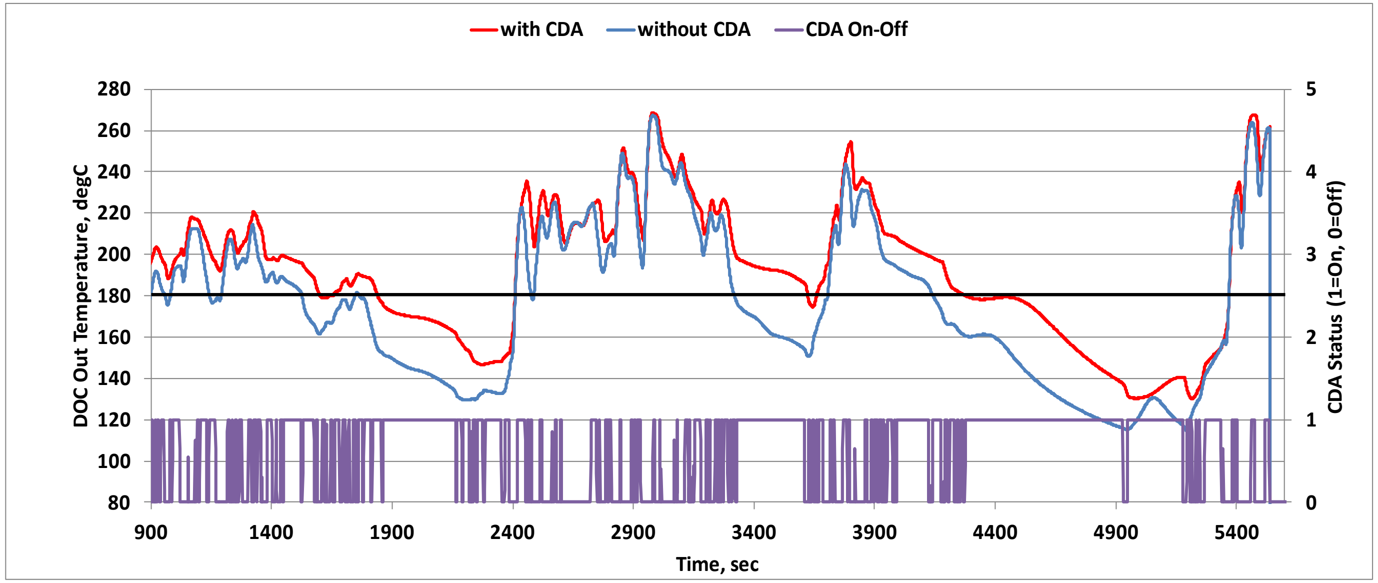
CDA Delivers Heat and Retains Heat in Low Load Operation

SwRI Proposed Low Load Cycle (LLC-7)



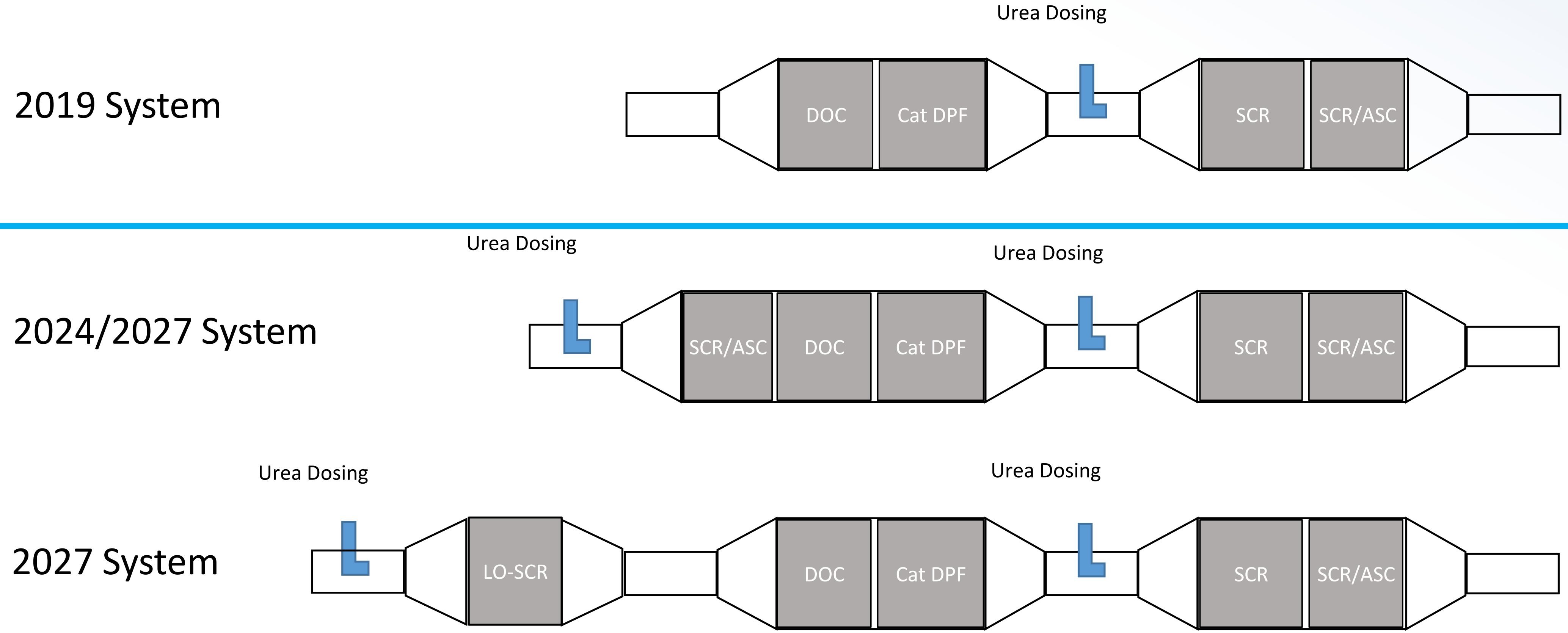


Non-optimized CDA results (LLC)	No CDA	With CDA	Improvement over baseline
CO_2 (g/hp-hr)	614	597	2.7%
NOx (g/hp-hr)	1.8	1.0	45%
AT conversion efficiency (%)	58%	76%	31%

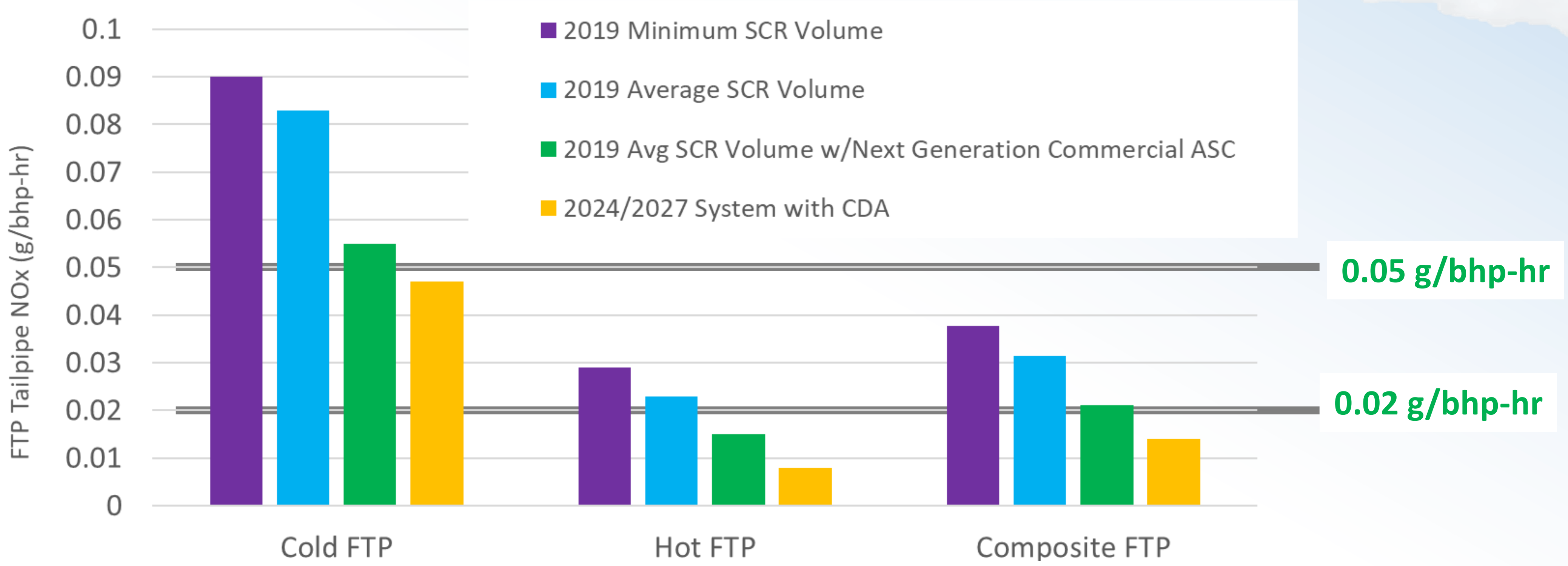
Source: SAE WCX 2019

Future Exhaust Systems will be Similar to Today

- Technologies already on passenger cars will help trucks achieve low NOx emissions on cold-start and in low load operation.
- Low temperature active catalysts and engine technology like advanced turbos and cylinder deactivation will move from passenger cars to commercial vehicles by 2027.
- Front SCR and dual and/or heated urea dosing for start-up and low load operation.

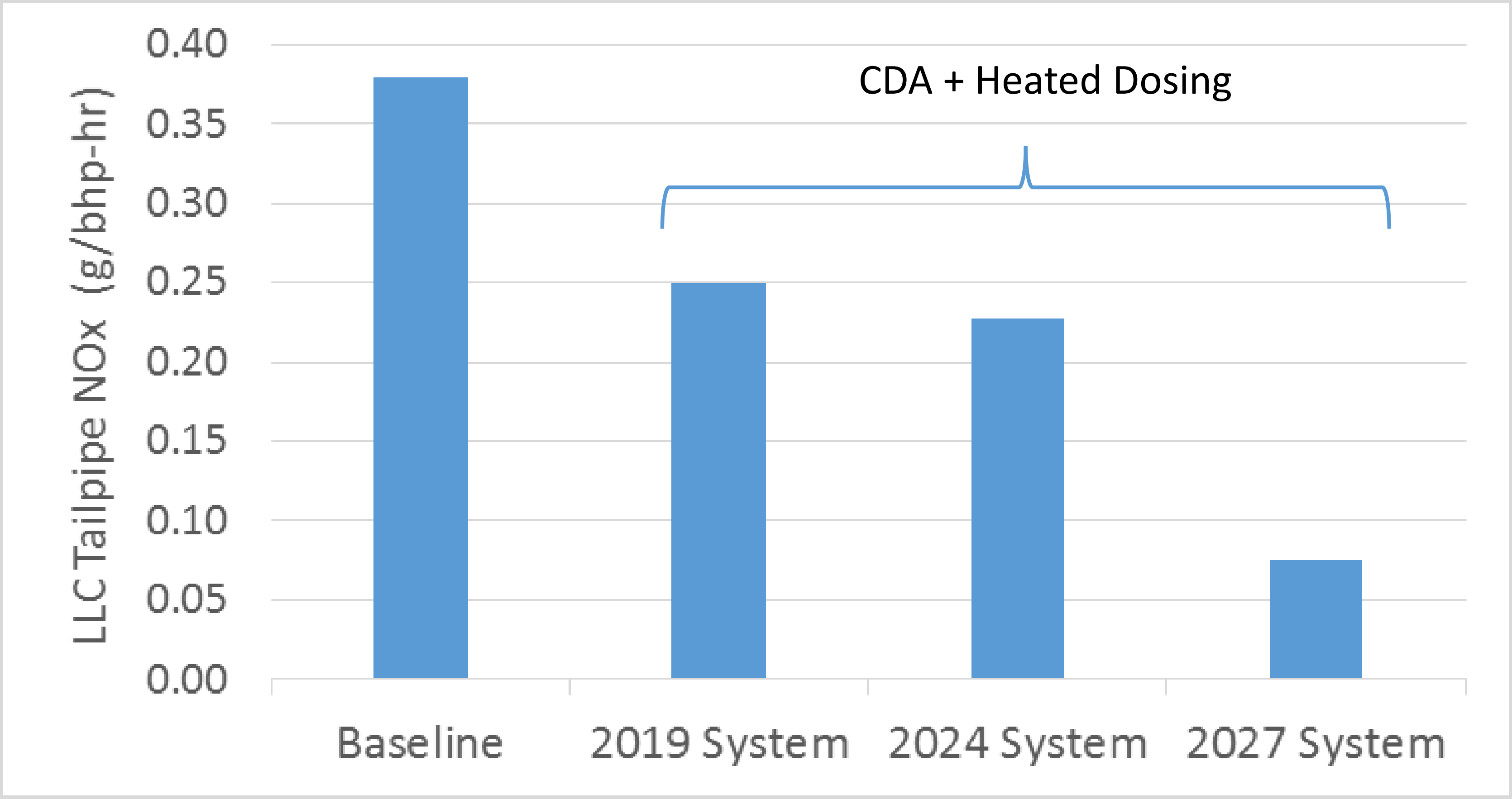


Emission Controls and Engine Technologies and Thermal Management Can Achieve FTP limit of 0.02 g/bhp-hr by 2027



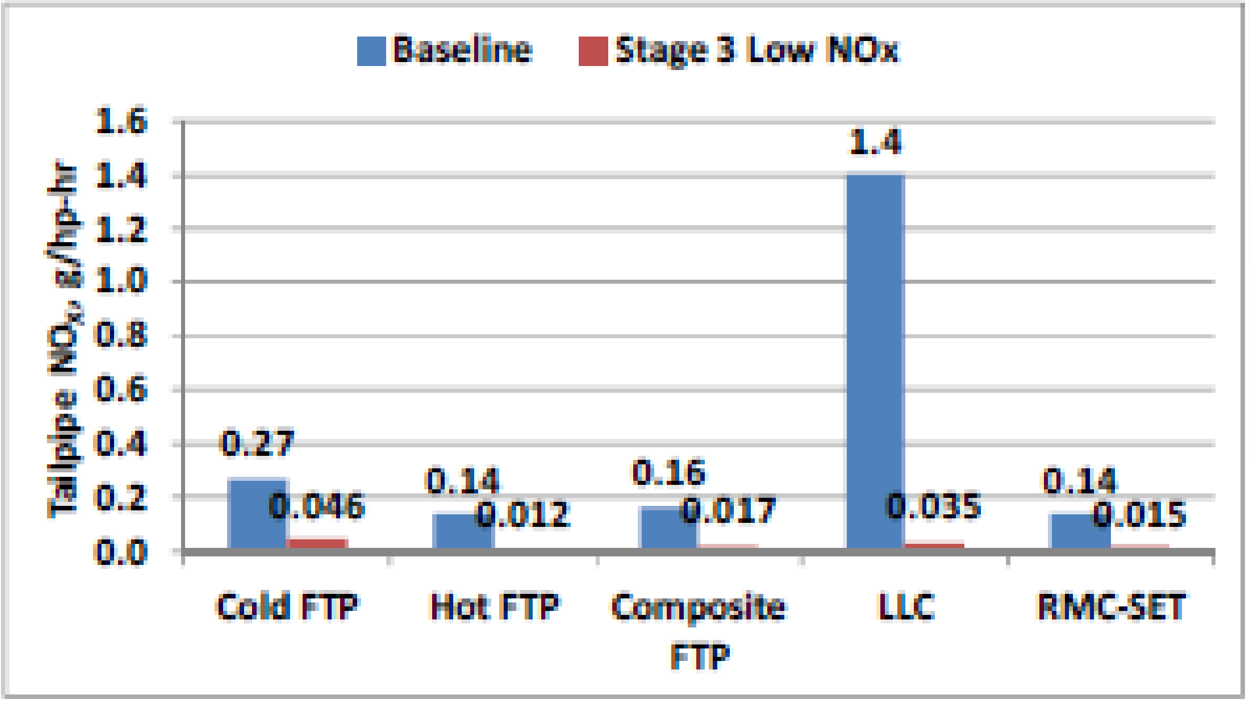
- Sophisticated reaction models based on engine out exhaust and temperature information combined with aged catalyst activity help suppliers design aftertreatment solutions.
- Tailpipe emissions were modeled with engine calibration from SwRI and fully aged commercial catalyst activity.
- Engines with cylinder deactivation and advanced catalysts with a front SCR and dual dosing can achieve a 0.02 g/bhp-hr FTP limit.

Modeling of Fully Aged Catalysts Shows Pathways to Meet CARB's LLC Targets



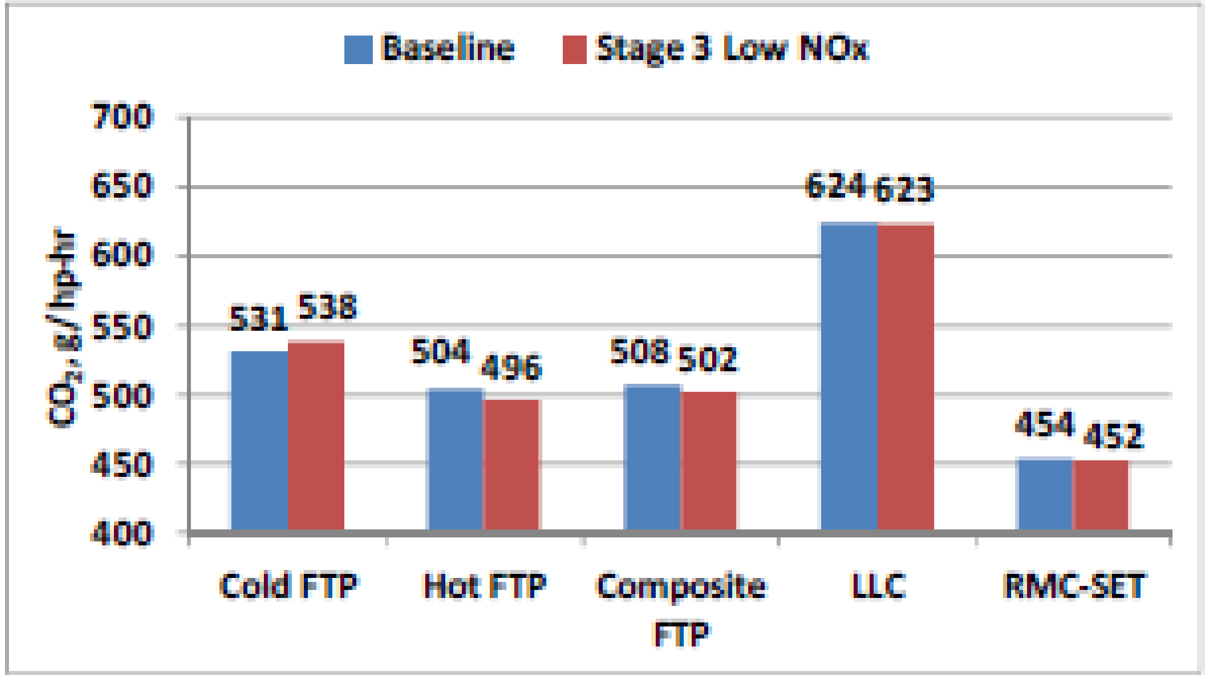
- Using calibrated engine out information from SwRI and NOx conversion tests on full useful life aged catalysts, is an important tool for system design.

Stage 3 Low NO_x – Current Development Status



NOx Emissions

CO_2 Emissions



Source: SwRI, Chris Sharp unpublished data.

Costs

Current HDV aftertreatment emission controls meeting 0.2 g/bhp-hr, 435,000 miles FUL:

6-7 liter engine - $2,600 to $3,500 per truck
12-13 liter engine - $3,500 to $4,600 per truck

Roughly 15%-38% less than that estimated by the ICCT ($4,152) in a 2016 cost study.

Future HDV emission control incremental costs to meet 0.02 g/bhp-hr, new LLC requirement, today's FUL and warranty requirements:

6-7 liter engine - $1,300 to $1,800 per truck (additional)
12-13 liter engine - $1,500 to $2,050 per truck (additional)

FUL out to 1M miles (Class 8) and 550k miles (Class 4-7) and warranty out to 800k (Class 8) and 440k (Class 4-7):

6-7 liter engine - $1,800 to $2,450 (additional)
12-13 liter engine - $2,000 to $2,750 (additional)

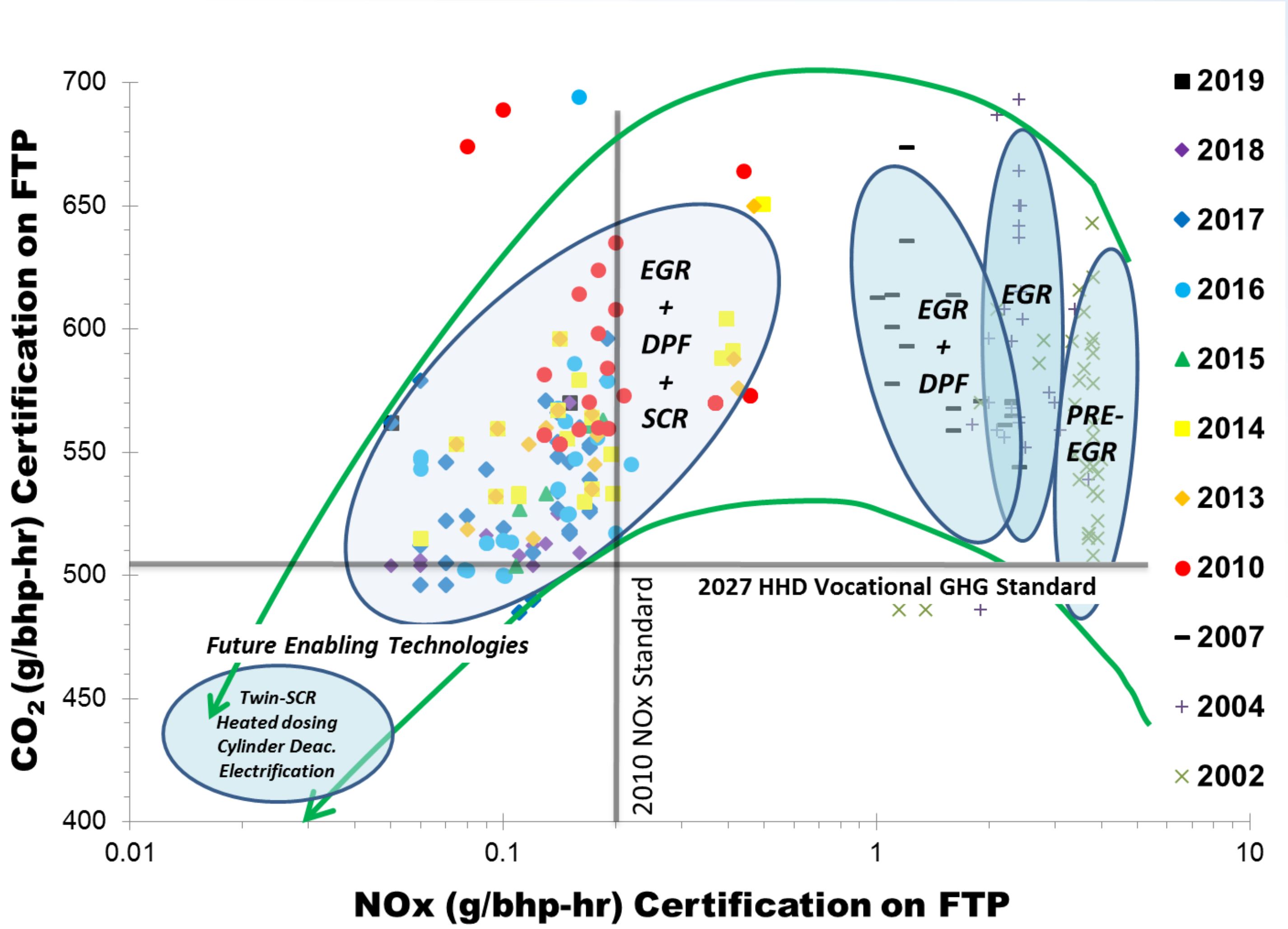
MECA

Conclusions

- Millions of truck engines will be sold in the next 20 years, and they can last for decades.
- CTI will result in significant NOx reductions that will help states to meet NAAQS attainment goals.
- MECA supports CARB's conclusion that FTP limits of 0.05 g/bhp-hr NOx in 2024 and 0.02 g/bhp-hr in 2027 are achievable.
- The natural migration of engine and exhaust system technologies from passenger cars to commercial vehicles is providing proven solutions for meeting 2027 GHG and future low NOx standards.
- Catalyst modeling and testing at SwRI are demonstrating that engine and aftertreatment technologies deliver a 90% NOx reduction below todays standards without dramatically changing system architectures.
- Engine technologies combined with advanced aftertreatment designs will deliver both 90% lower NOx as well as lower in-use emissions at low loads while meeting GHG goals.

Supplemental

How are today's engines performing in certification testing?



Simultaneously optimizing engines to meet NOx and CO_2 standards is the most cost effective path to reducing pollution and GHGs