Evaluating The Impact Of Connected Vehicle Technology On Heavy-Duty Vehicle Emissions

SOUTHWEST RESEARCH INSTITUTE®

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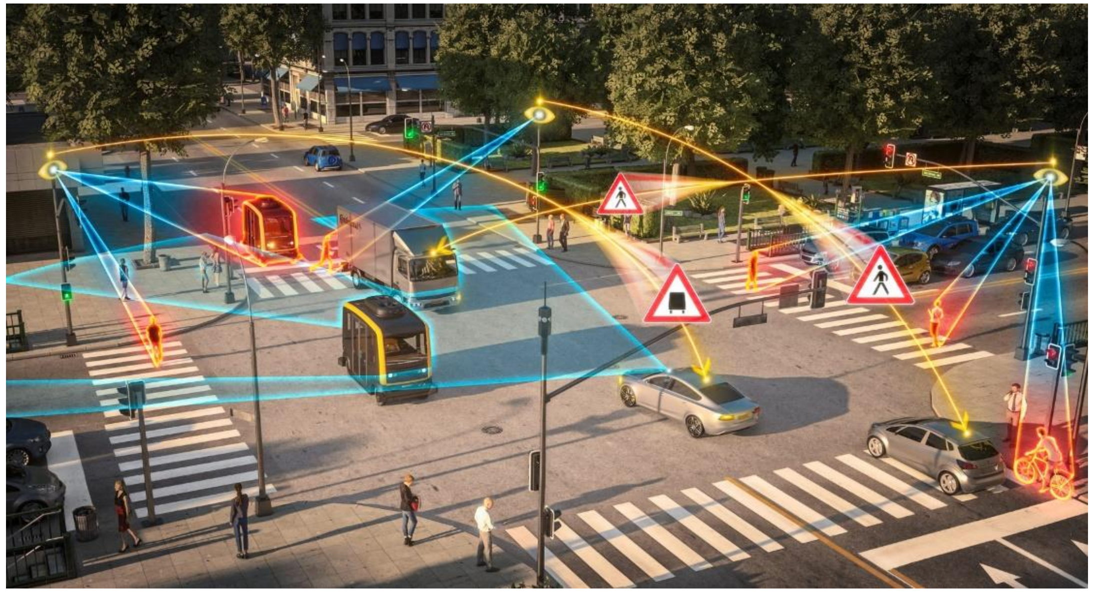
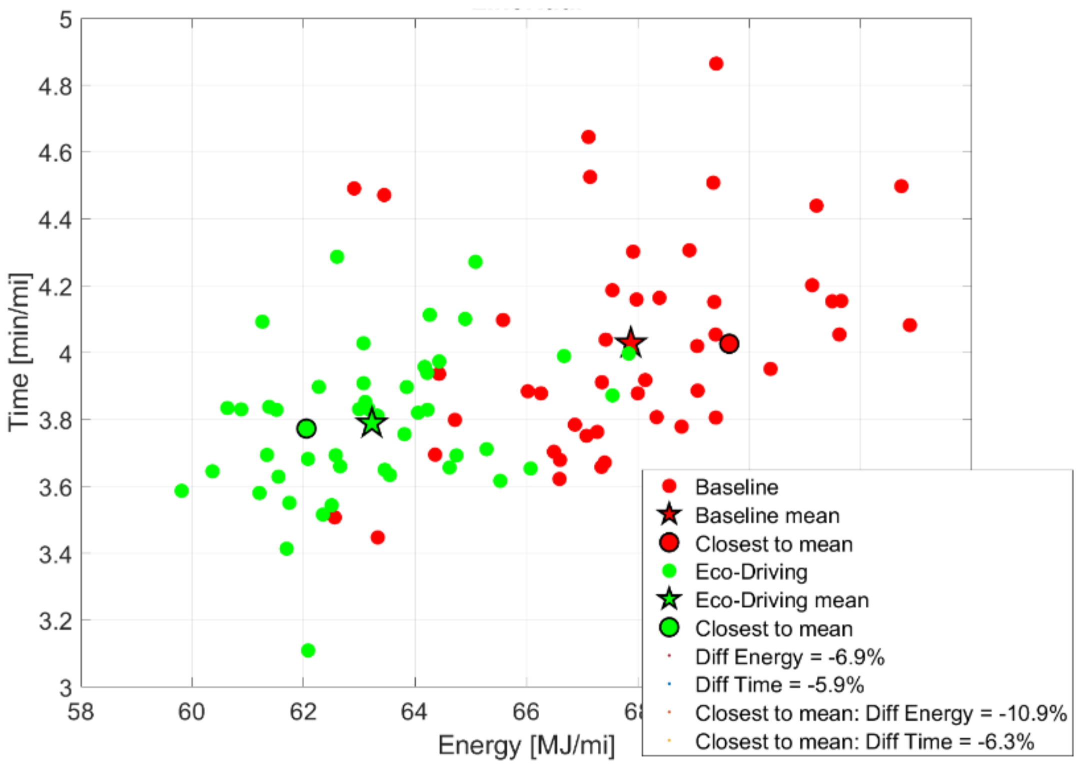
Introduction

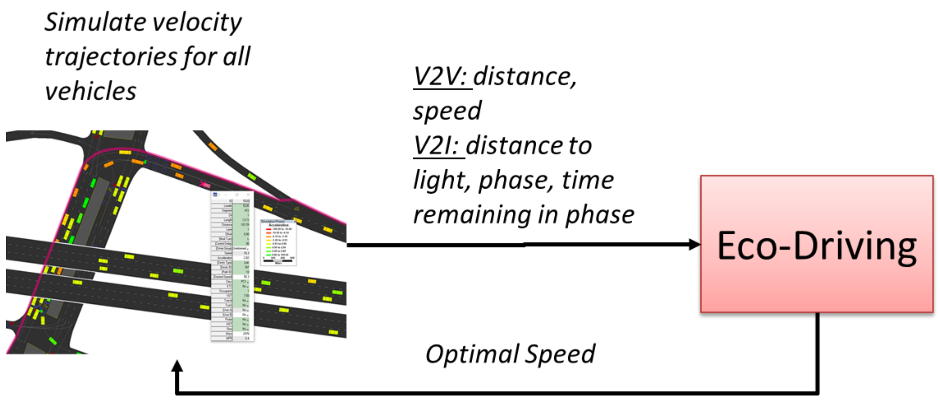
- Vehicles with advanced driver assistance systems (ADAS) like adaptive cruise control (ACC) could use connected (V2X) data to improve fuel economy
- Eco-driving generates an energy-efficient speed profile by minimizing acceleration events
- SwRI demonstrated a 7% reduction in energy consumption for fully loaded class 8 trucks by using nearby vehicle and traffic signal information
- How does eco-driving impact vehicle emissions and aftertreatment (AT) systems?

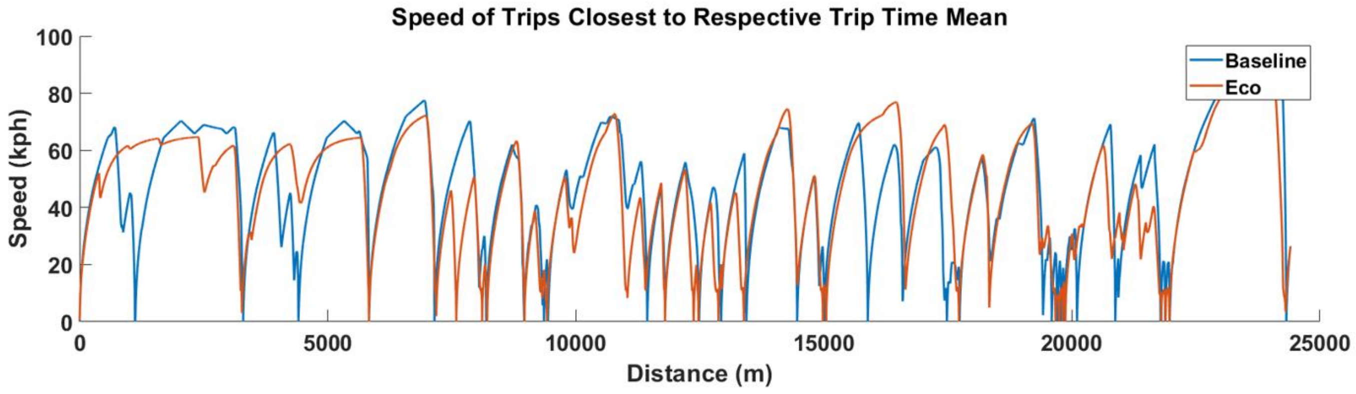




Demonstration

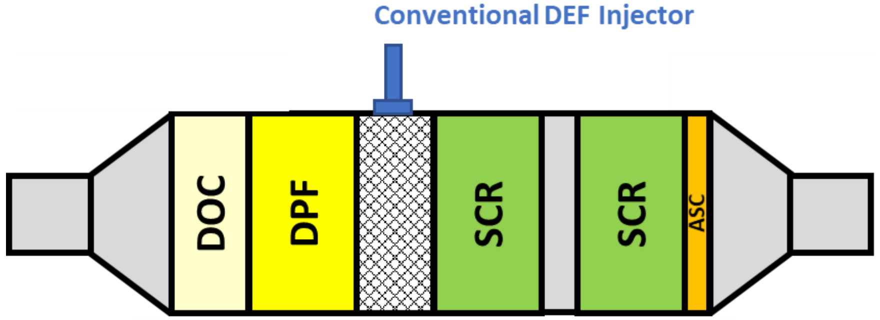
- Custom baseline and V2X-powered eco-driving cycles made by integrating algorithms with traffic simulator and tuning vehicle models
- "NREL" real-world cycle determined upper bound on energy savings with offline eco routine
- Fully-loaded trucks drove both sets per SAE J1321 testing methods with Mobile DEVCon (robot driver)
- Cycles then evaluated on production and low NO_X class 8 engines and AT configurations in a test cell





Production System

- 2017 Cummins X15 platform
  - Complies with current 0.2 g/hp-hr NO_X standards, certified with HD-FTP and RMC-SET cycles
  - Variable geometry turbo and an EGR system

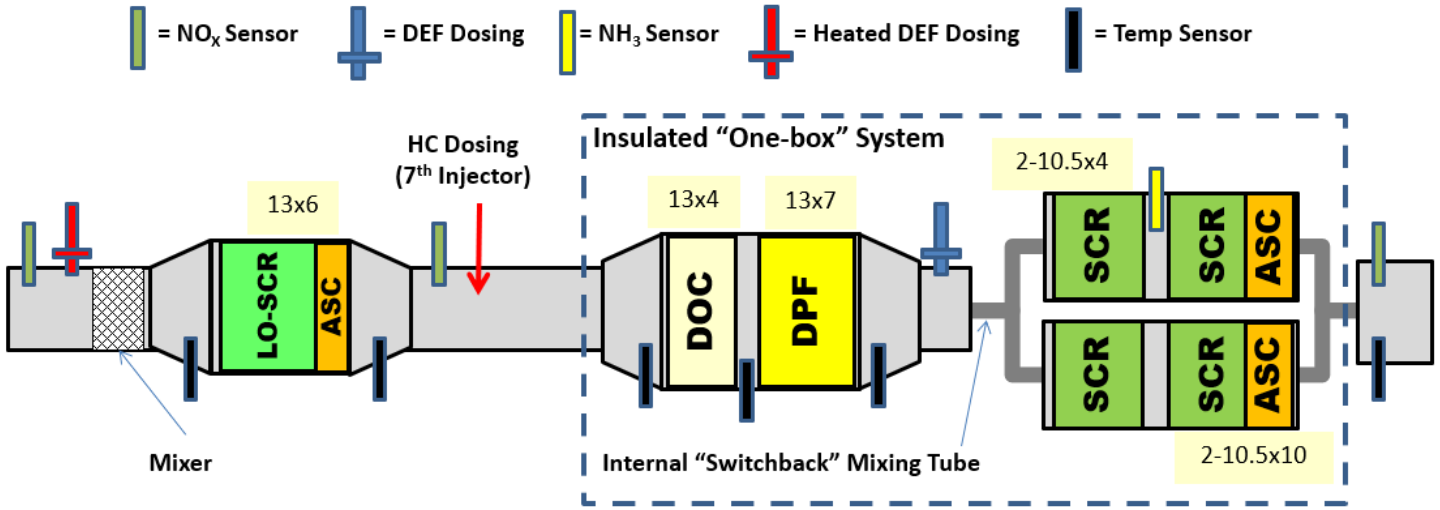


- Conventional AT configuration
  - Cummins UL2 dosing system and DEF dosing downstream of the DPF
  - Degreened and accumulated fewer than 1000 service hours

Engine Parameter	*Value*
Configuration	Inline 6
Bore x Stroke	137 x 169 mm
Displacement	15.0 L
Rated Power	373 kW (500 hp)
Rated Speed	1,800 rpm
Peak Torque	2,500 Nm
Peak Torque Speed	1,000 RPM
Service Hours	*>3000*

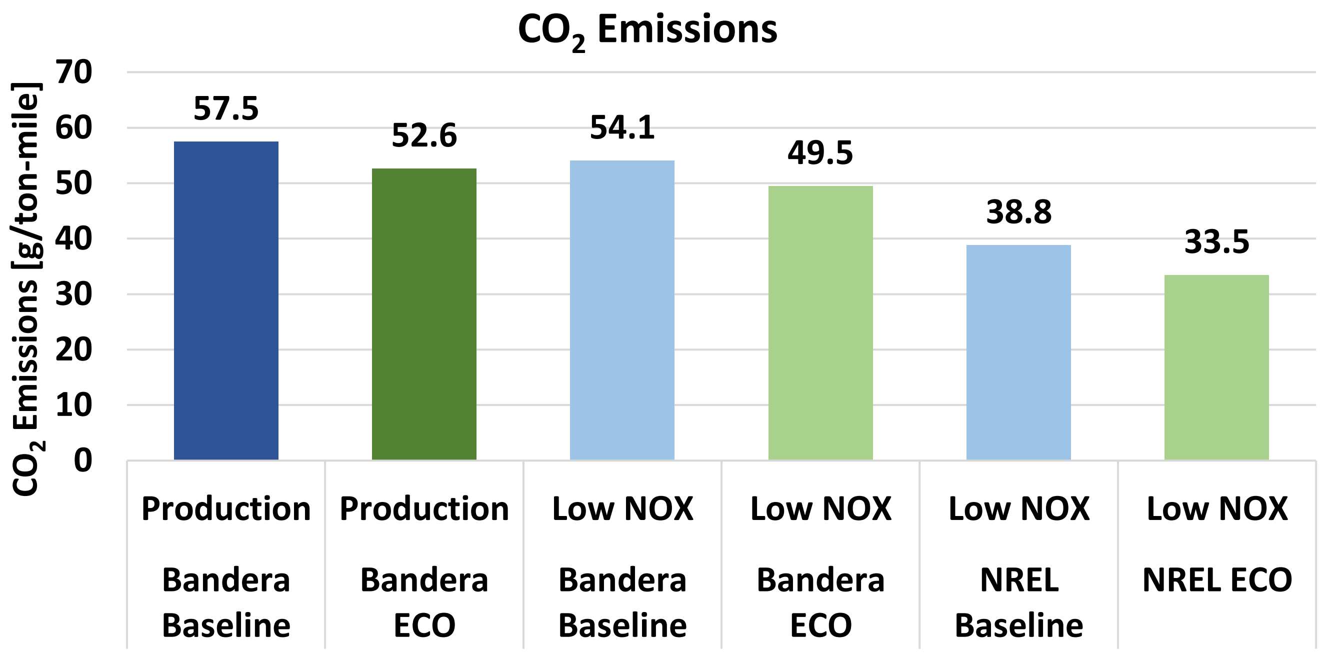
Low NO_X System

- Low NO_X program by CARB aimed at 90% NOx reduction resulted in stage 3 technology package that guided development of future NO_X regulations
  - Dual SCR AT system with advanced model-based control to maintain enough NH3 in the catalyst for NO_X conversion
  - Rule-based control used CDA and existing engine scheme to maintain AT temperatures without added fuel cost
- AT system aged to equivalent of 800,000 miles with DAAAC protocol and considered hydrothermal, sulfur, and lubricant derived poison deterioration



Experiments and Results

- Conducted six experiments, each with two prep runs, a test run, and two repeats
  - "Bandera" baseline and eco custom urban cycle tested on production and low-NO_X systems
  - "NREL" port drayage on production system only
- Lower CO_2 for eco cycles in line with expectations and correlates with observed on-track testing fuel
- Lower CO_2 with low NO_X system likely due to engine calibrations approaches, thermal management, and the advanced aftertreatment

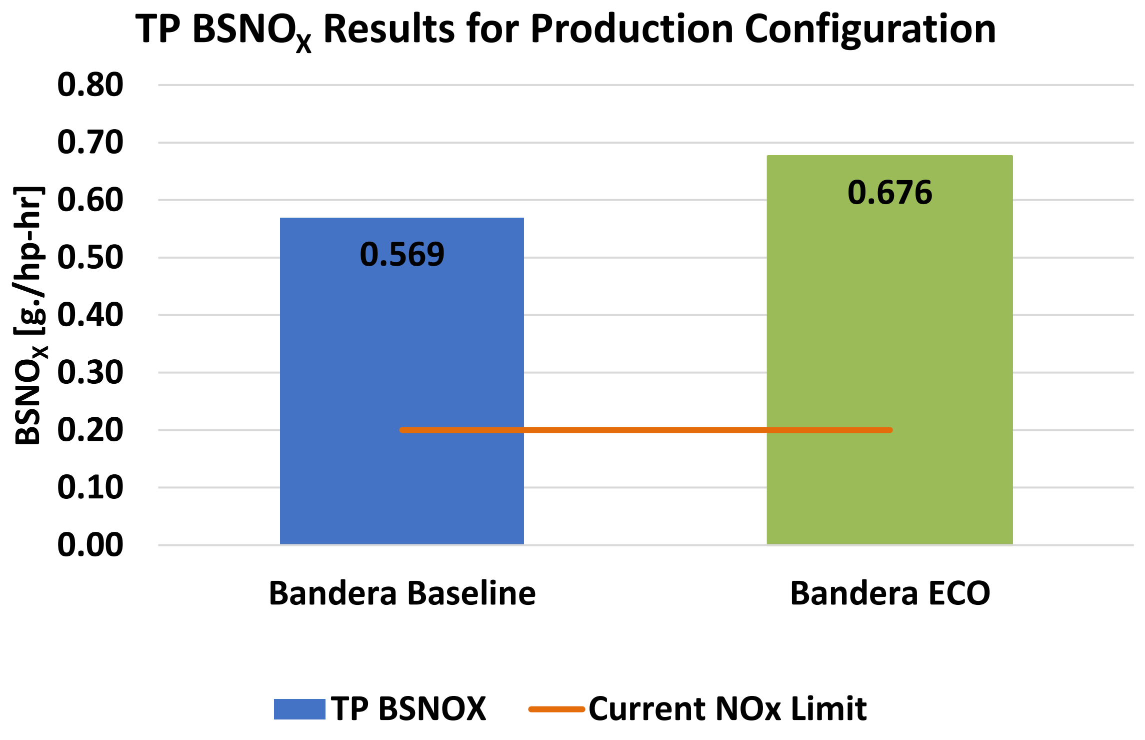


Eco Benefits Over Baseline

Test	*Production CO_2*	*Low NO_X CO_2*
Bandera Eco	-8.4%	-8.5%
NREL Eco	---	-13.6%

Production System NO_X

- HD-FTP compliance targets were applied to the custom cycles based on similar average load (22%-29% compared to 31% respectively)
- Eco cycle generated 8.4% less CO_2 but NO_X emissions increased by over 18%
- High emissions and poor NO_X control in both results indicate that the cycle likely operates in zones outside of the targeted system calibration

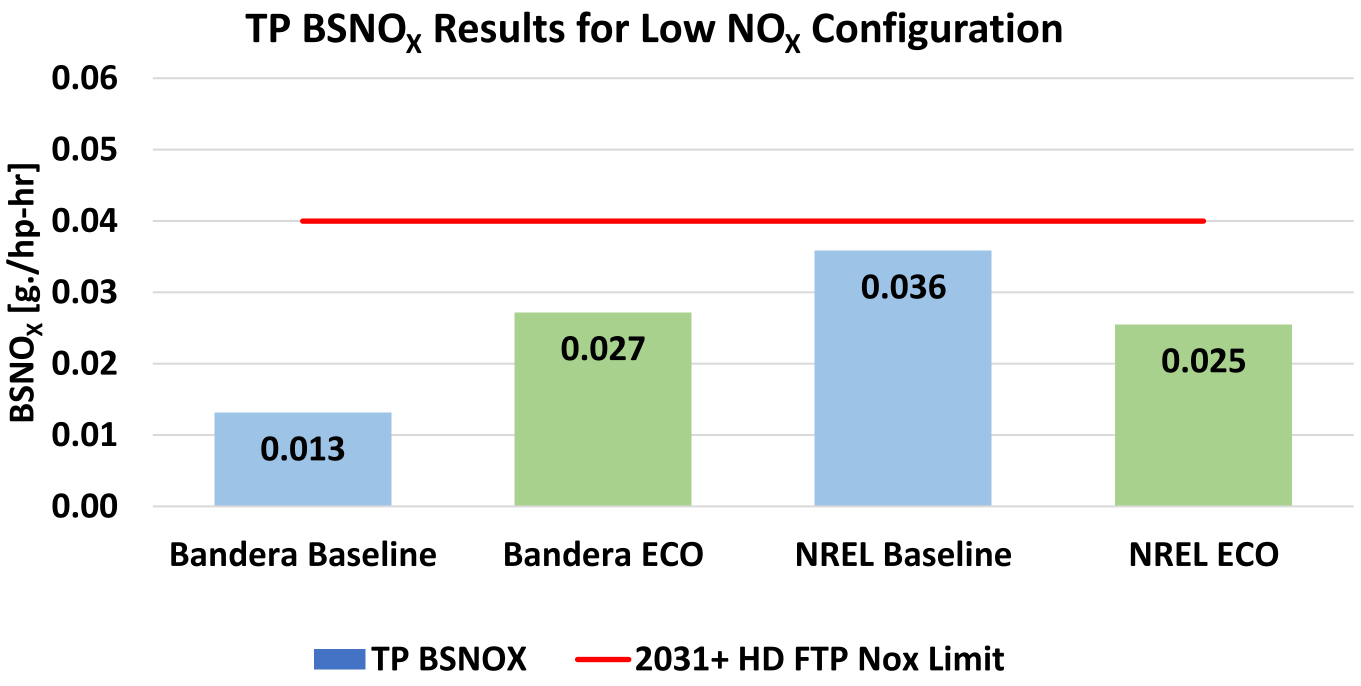


	NO_X Diff [%]	*CO_2 Diff [%]*
Bandera Eco	+18%	-8.4%

Low NO_X Results

- Bandera eco cycles resulted in decreased CO_2 but increased NO_X emissions
  - System still effective at meeting CARB emissions standards with upstream SCR catalyst

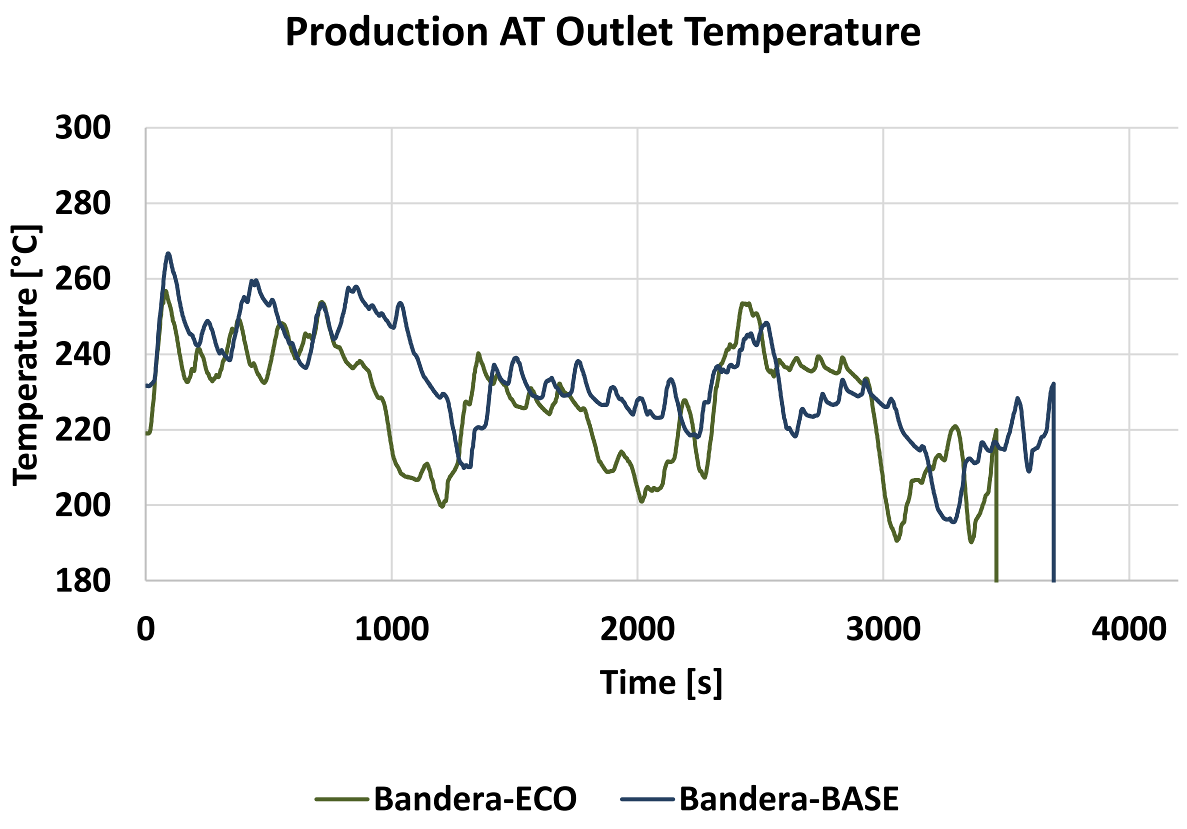
- Conversely, NREL eco cycle improved both CO_2 and NO_X

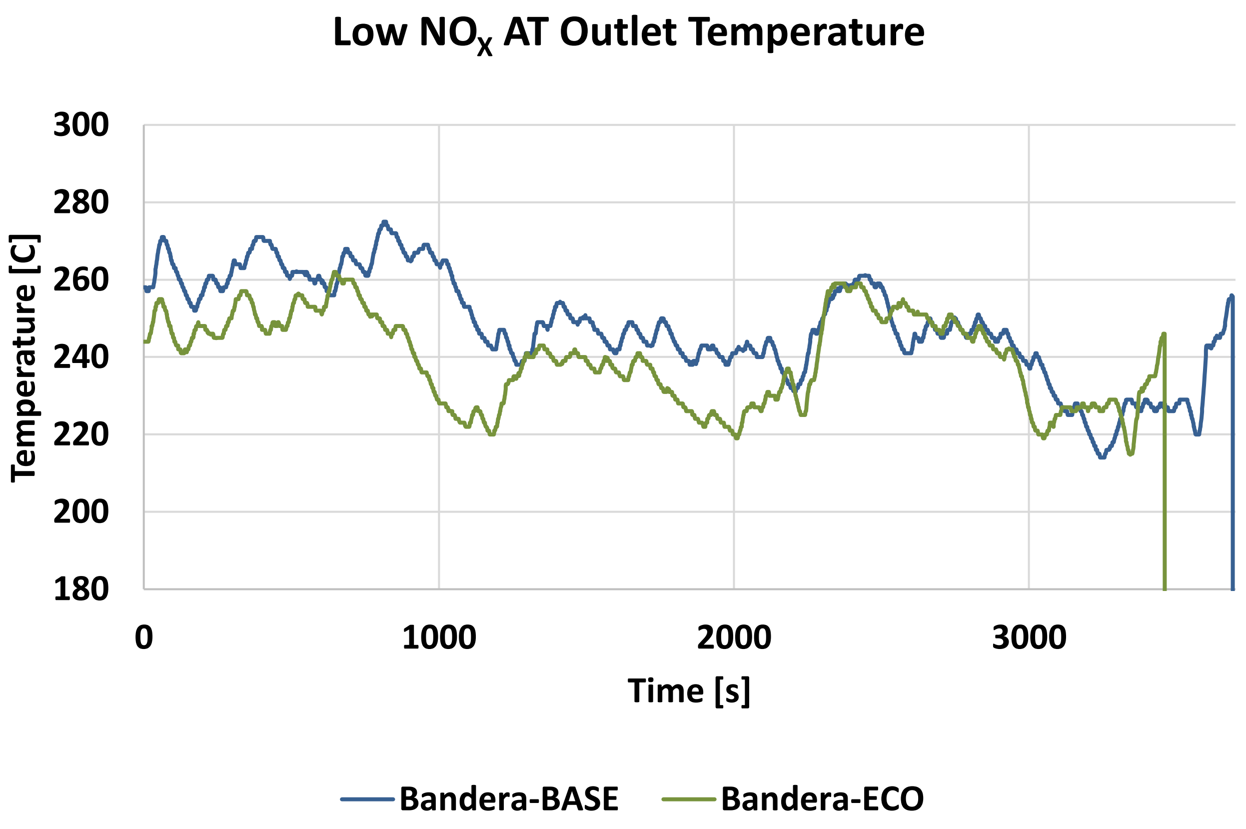


Test	*NO_X Diff [%]*	*CO_2 Diff [%]*
Bandera Eco	+108%	-8.5%
NREL Eco	-31%	-13.6%

AT Temperature

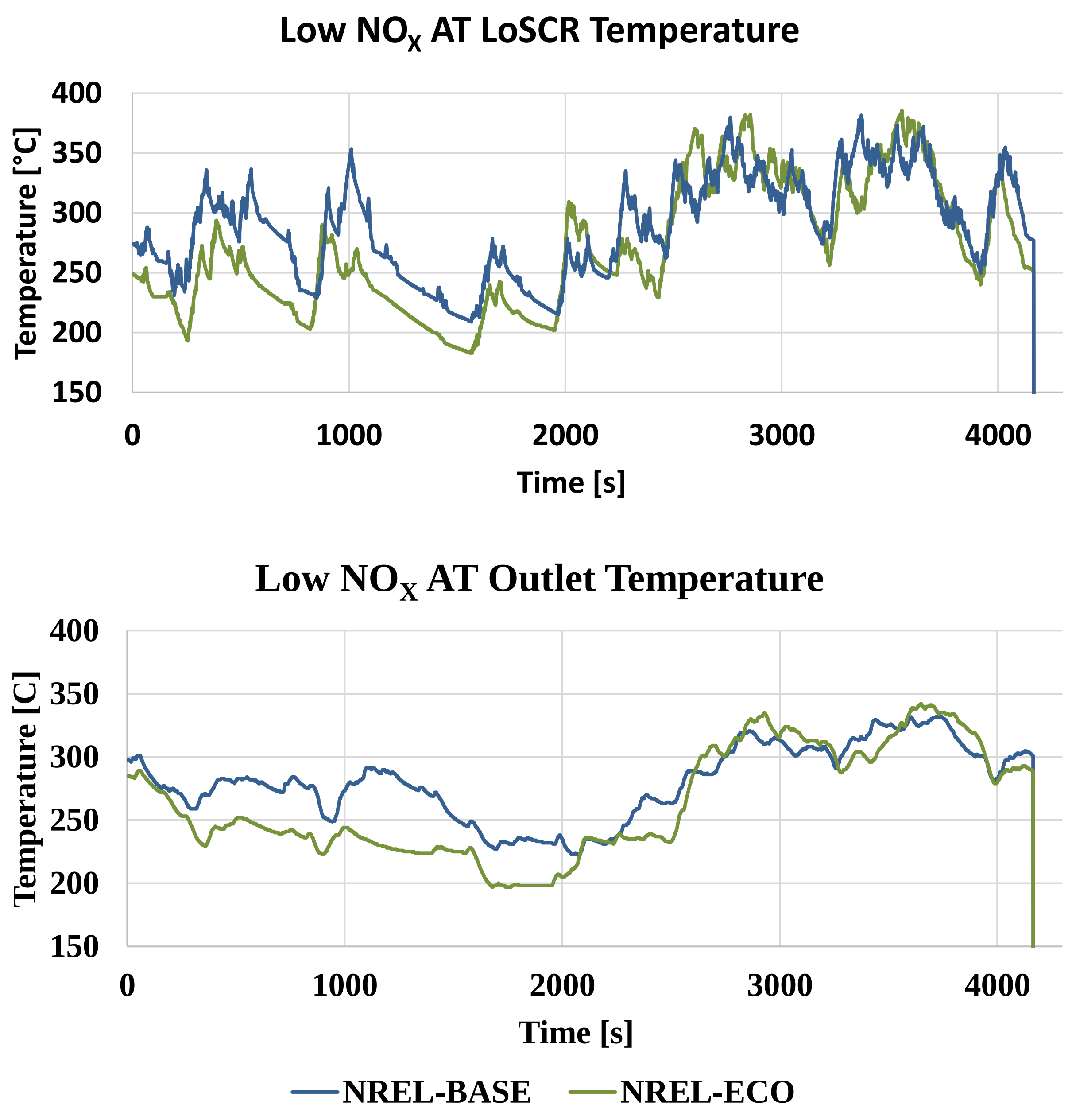
- System temperatures dropped below 225°C more frequently in the eco cycle, negatively impacting NO_X conversion efficiency





Low NO_X AT Temperatures

- Despite similar speed profiles, effectiveness of eco versions tends to produce less work, resulting in lower exhaust temperatures
  - This causes engine to enter different thermal management modes
- For NREL cycle, the low NO_X system was able to decrease NO_X without higher CO_2 emissions

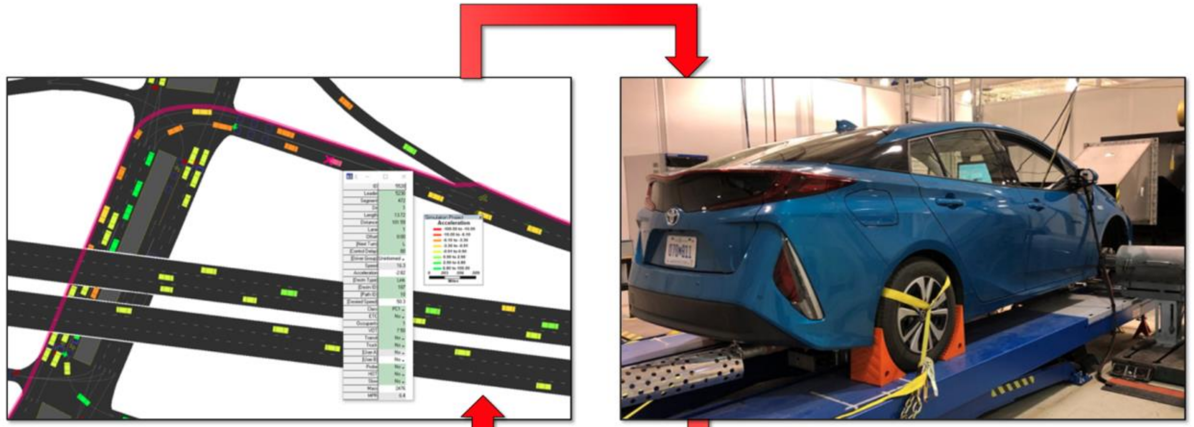


Summary

- Eco cycles showed *8%-14% CO_2 reduction*
- Emissions remained *below* the 2031+ HD-FTP compliance limit with the Low NO_X system
- In certain cases, tailpipe NO_X *increased* for eco-driving vehicles
- Results demonstrate need for new emissions control strategies which could employ connected technology
- SwRI to evaluate conventional and autonomous vehicles using digital twins and dyno integration

Eco-Driving Test Differences Over Baseline

	NREL	Bandera
Cycle Time	0%	-5.8%
Distance	0%	0%
Fuel (Sim)	-16.9%	-10.9%
Fuel (Track)	-16.61% ± 2.11	-7.34% ± 4.95
CO_2 (Production AT)	-	-8.4%
CO_2 (Low NO_X AT)	-13.8%	-8.5%
NO_X (Production AT)	-	+17.7%
NO_X (Low NO_X AT)	-29.3%	+105.6%



The Ego Vehicle (Red) Interacting With Traffic in the Simulator

The Development Vehicle Mounted on The Hub Dynamometer

Thank You

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  - Stas.Gankov@swri.org

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