NATURAL GAS IN HEAVY-DUTY TRUCKS: A LOOK AT REGULATED EMISSIONS

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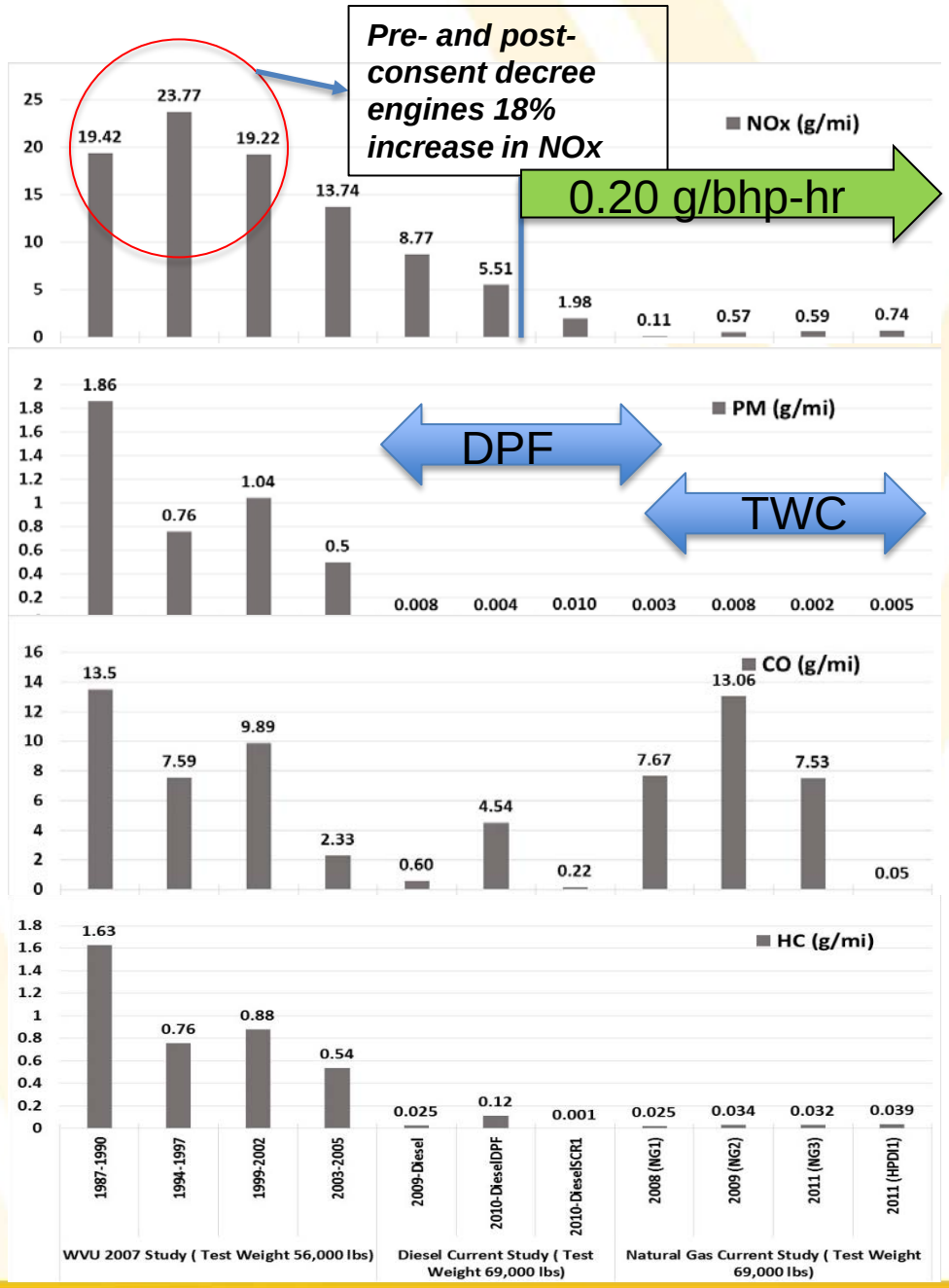
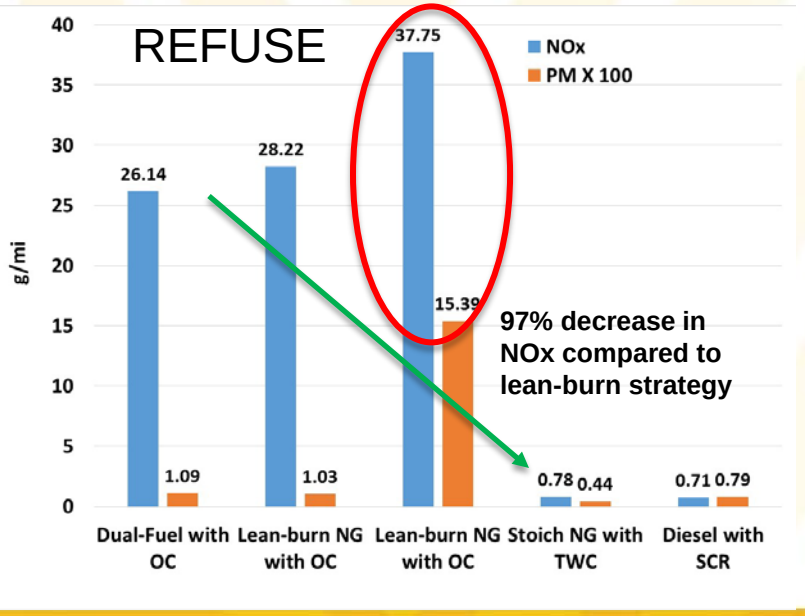
INTRODUCTION

- USEPA 2010 emissions regulation: NOx at or below 0.2 g/bhp-hr and PM 0.01 g/bhp-hr
  - California has optional low NOx standard of 0.02 g/bhp-hr
- Engine technologies compliant to the current standards
  - Natural gas with Three-way catalyst (TWC)
    - Simple aftertreatment configuration
  - Dual-Fuel HPDI with DPF and SCR
  - Diesel with DPF and SCR
- Diesel engine depends on SCR technology for NOx reduction
- Natural gas engines equipped with TWC have shown the potential of low NOx emissions
- Natural gas fueling infrastructure has contributed to an increase in urban natural gas heavy-duty vehicle population
  - Fueling infrastructure not sufficient for long-haul application

BACKGROUND



- NG trucks with TWC show 96% lower NOx emissions compared to SCR equipped diesels.
- PM emissions from DPF equipped diesels and TWC equipped NG vehicles are in the same order of magnitude
  - PM emissions with engine age?
  - Lubrication oil emissions?
- CO emissions significantly higher due to the stoichiometric engine platform
- NMHC emissions is close to detection limits due to efficient catalytic action of TWC



CURRENT NATURAL GAS UTILIZATION PATHWAYS

OEM SOLUTIONS

- Stoichiometric engine
  - ISLG 8.9 L;
  - ISL12G,
  - 12 and15 L low NOx engine expected
- Dual-Fuel: High Pressure Direct Injection (HPDI)
  - GSX 450

NATURAL GAS DERIVED FUELS

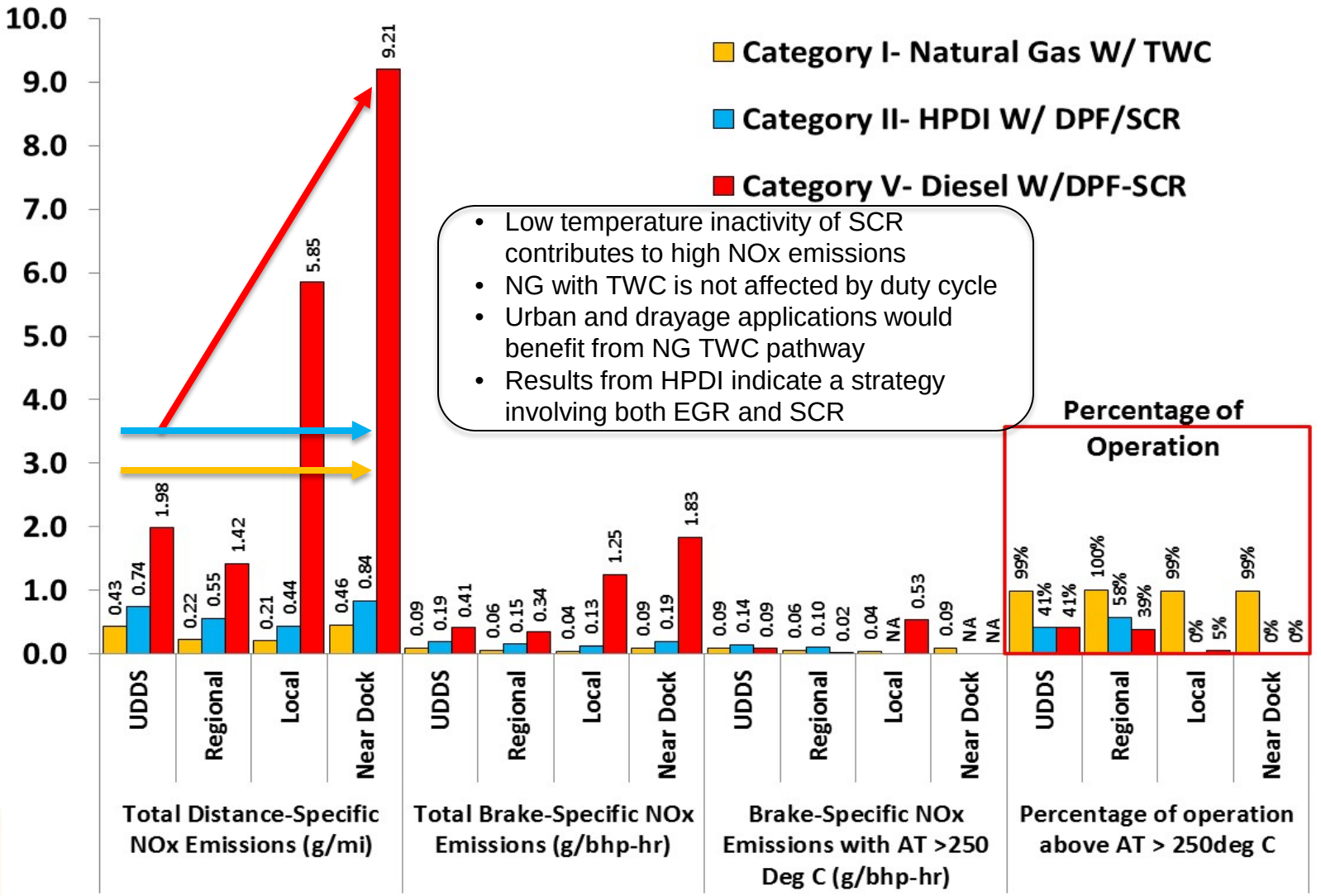
- Di-Methyl Ether- Volvo DME
- GTL fuels

RETROFIT SOLUTIONS

- Outside useful life
  - MY 2001 or older
  - Or greater than useful life (10 yrs or 435,000 mi)
- Intermediate age
  - MY 2002 to MY 2009
  - And less than useful life
- New engine
  - MY 2010 to 2012

http://www3.epa.gov/otaq/consumer/fuels/altfuels/altfuels.htm#4

CURRENT TECHNOLOGY- GOODS MOVEMENT APPLICATION



CHALLENGES TO TRUCK APPLICATION

- Vehicle mileage range constraints
  - LNG provides greater energy density than CNG, hence providing a longer range
  - Stoichiometric platform is constrained with range of operation
  - Immense fueling infrastructure is required to realize long-haul truck application
  - Stoichiometric engine pathway suited for urban goods delivery and drayage operation
  - Dual-fuel HPDI provides diesel like performance with mileage in the range of 300-400 miles depending on load
- Engine Durability
  - The impact of engine aging on emissions performance have not been accurately studied for natural gas engines
  - Studies have shown increased lubrication oil emissions with older engines
  - Crankcase emissions of methane and NOx have been observed from high mileage natural gas transit buses

Future Pathways

- Development of lean-burn engines coupled with SCR could address range challenges
- Advancements in low temperature catalyst technology can improve emission performance from HPDI platform
- Development of robust OBD strategies (2018 deadline) can identify engine component failure
- Over 95% of the hydrocarbon emissions are characterized by Methane, therefore development of methane oxi cat will be vital to meet 2017 GHG standard

RETROFIT PATHWAY

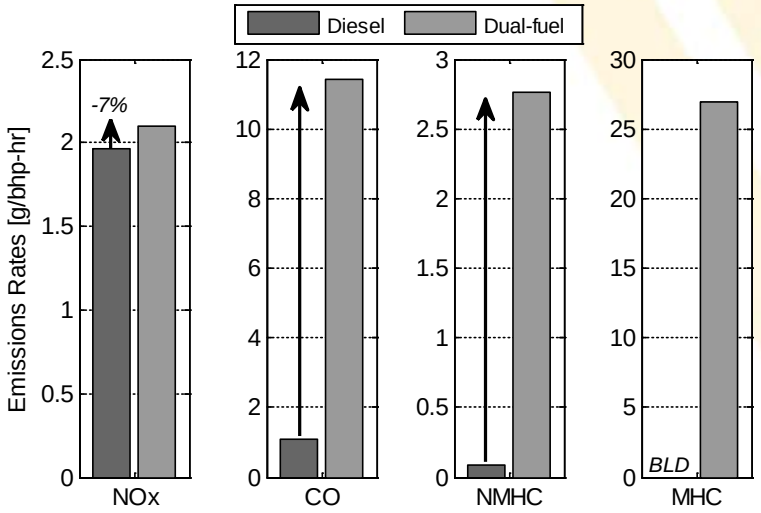
- Shale gas boom has contributed to a favorable market for alternative fuel retrofit kit manufacturer
- Retrofit technologies range from very basic, low key natural gas fueling algorithms to **relatively** advanced control strategies
  - Control algorithms often interrogate base engine injector pulses to determine natural gas fueling strategy
  - Altering injection strategy to gain fuel economy benefits is possible.
- Strategies are often aimed at meeting EPA inside useful life certification requirements.
  - Both engine dynamometer and in-use testing
  - Altitude testing

Challenges

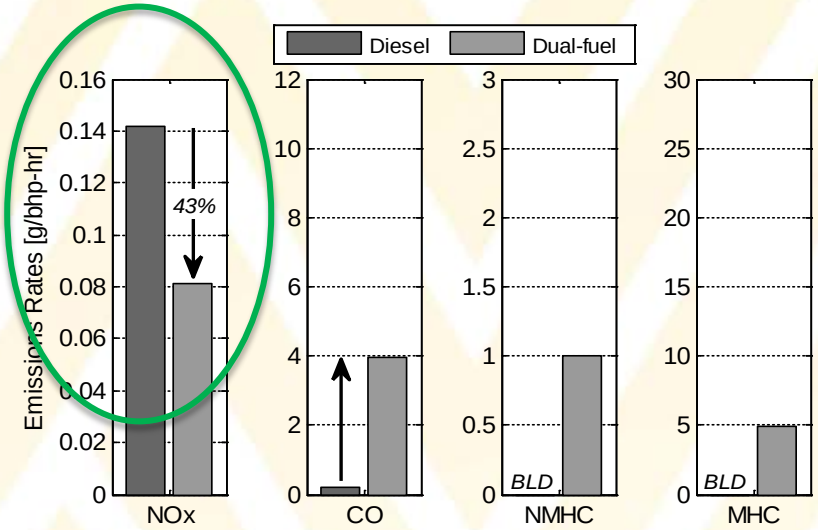
- Difficulty of dual-fuel operation during idle and low engine loads
- Limited NG substitution at full load due to engine knocking (knock limited gas replacement)
- Advanced after-treatment systems needed to comply with GHG emissions regulations
- Increased CH_4 emissions => diesel combustion chamber not optimized for port fuel injection, CH_4 slip due to flame quenching and crevices
- Limited CH_4 conversion efficiency of existing diesel oxidation catalysts (CH_4 light-off temperatures typically 400-450C)
- Possible accelerated aging or damaging of vanadium-based SCR after-treatment system

DUAL FUEL RETROFIT KIT

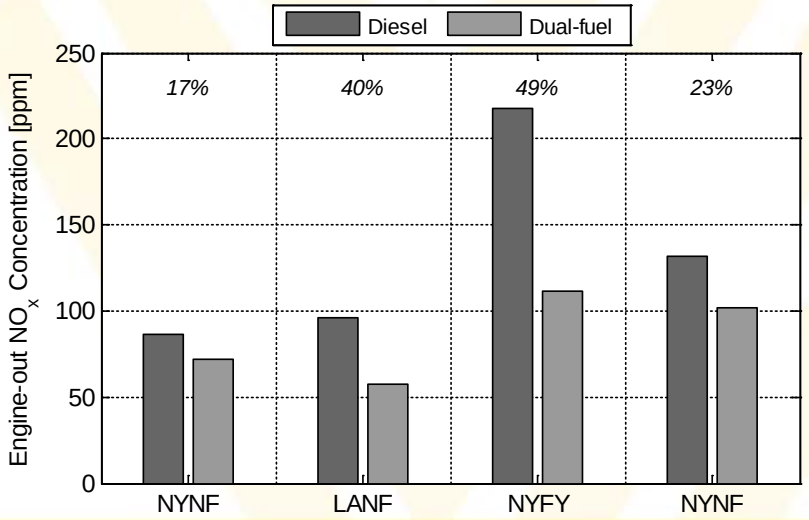
MY 2005 DIESEL ENGINE



USEPA 2010 DIESEL ENGINE



- Interestingly, dual-fuel system appears to lower engine-out NOx in modern engine platforms compared to older technology
- Could be due to interaction of NG fueling and higher EGR rates relative to MY 2005.



CONCLUSIONS

- Natural gas has shown promise as a clean burning fuel for heavy-duty application
- Combustion control to limit methane and CO emissions remains a challenge
- NG with TWC is the existing pathway to achieve low NOx standards
  - Research into lean-burn strategy with SCR can alleviate some of the long-haul range concerns
  - Development of low temperature catalyst or thermal management strategy would be necessary to combat THC emissions
- On-Board Diagnostic (OBD) for natural gas engines is of high importance
  - Oxygen sensor health monitoring to prevent overly lean or rich operation
  - TWC health monitoring
  - Develop OBD monitors that predict SCR aging for dual-fuel engines
- Fuels derived from natural gas such as DME could prove to be versatile in captive fleets such as delivery trucks, refuse, yard hostlers.