Combining Low-Temperature Combustion With Lean-NOx Trap Yields Progress Toward Targets Of Efficient NOx Control For Diesels

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Sponsor: U.S. Department of Energy, OFCVT

Program Managers: Ken Howden, Gurpreet Singh, Kevin Stork

Diverse ORNL Team Working on This Project

- Engine system management, experiment design, data collection and analysis
  - Shean Huff
  - Brian West
  - Jim Parks
  - Matt Swartz

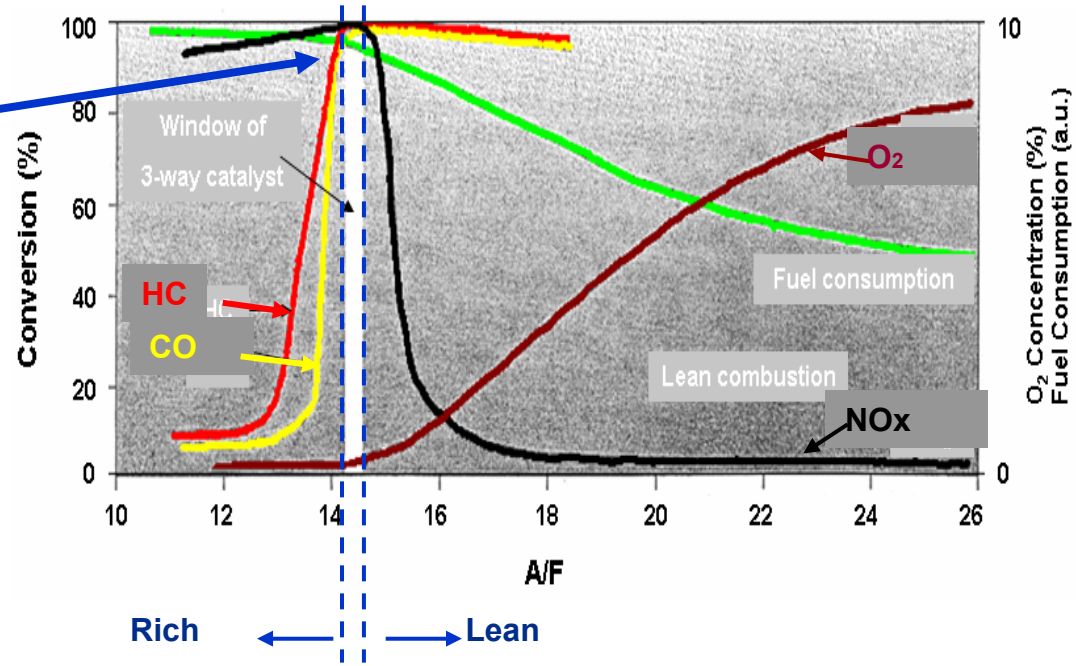
- Analytical chemistry
  - John Storey
  - Sam Lewis
  - Bill Partridge

- Bench reactors
  - Todd Toops
  - Jae-Soon Choi

- Modeling (CLEERS interaction)
  - Stuart Daw
  - Kalyan Chakravarthy

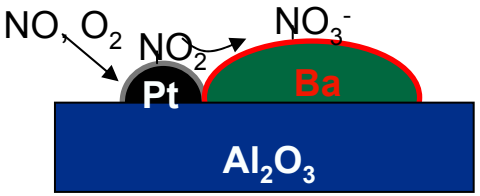
Lean NOx Trap Combines 3-way Catalyst Function with NOx Storage Material(s)

- **Conventional TWC oxidizes HC and CO, reduces NOx**
  - **Requires tight control of AFR**
- **LNT a.k.a. DNT, NOx Adsorber, NAC, NOx Storage and Reduction (NSR) Catalyst**
  - **Stores NOx during lean operation**
  - **Uses alkali and/or alkaline-earth metals for storage**
  - **Pt group metals for oxidation/reduction**
- **Periodic rich regeneration releases and reduces NOx**



Lean A/F

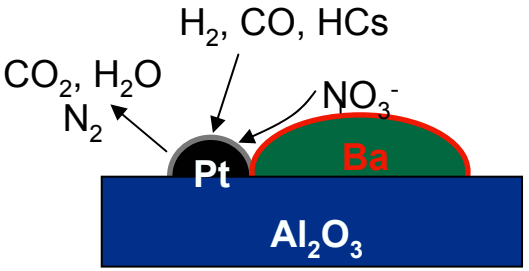
≳85% of time



NO_x stored as nitrate "storage"

Rich A/F

≲15% of time



NO_x released & reduced "regeneration"

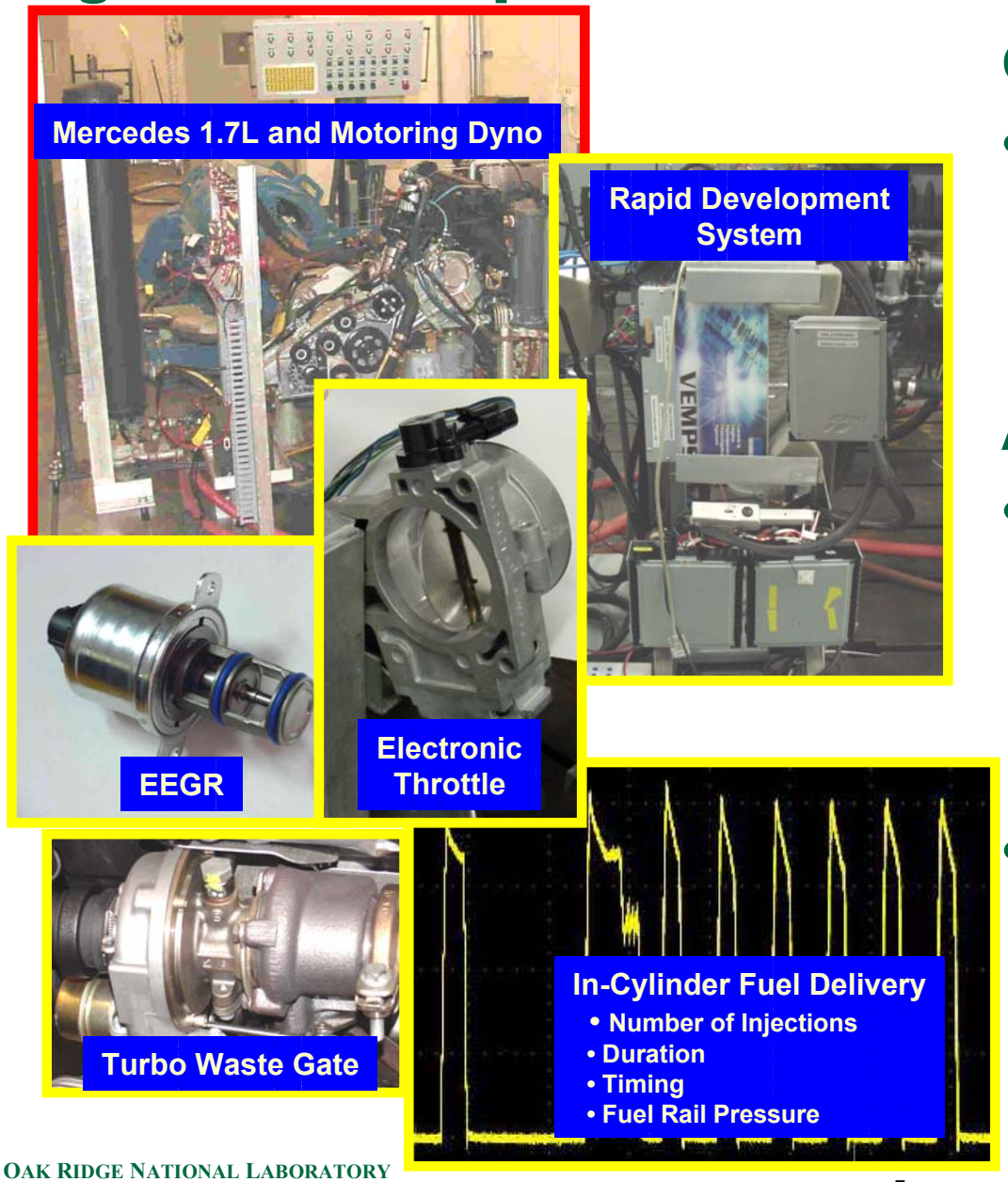
Several means of introducing reductant to LNT are being researched

- **Engine or in-cylinder regeneration**
  - **Use engine controls (throttle, EGR, injection), to achieve rich combustion**

- **In-pipe injection**
  - **Introduce excess fuel downstream of engine**
  - **Can use two-pass exhaust system with exhaust valves**
  - **Fuel cracking accomplished in LNT or upstream catalysts**

- **Fuel reformers**
  - **Plasma or catalyst-based systems to feed reductant to LNT**

Common Rail Engine with full-pass control used for LNT regeneration experiments



Objective

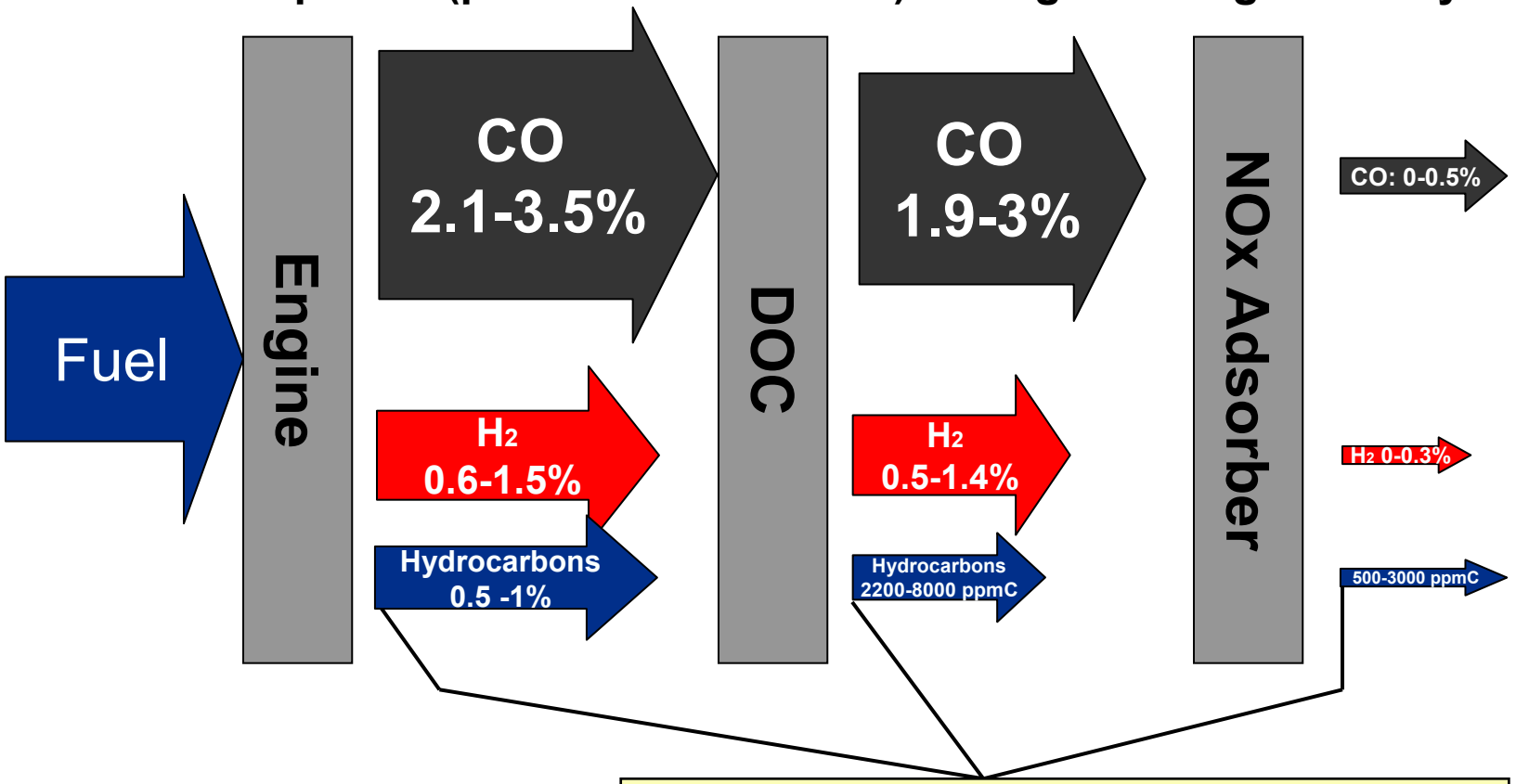
- Minimize fuel penalty while meeting emissions targets

Approach

- Characterize reductants generated by the engine
  - Select strategies with most distinct reductant pools
- Characterize candidate LNTs
  - Correlate various reductants with catalyst performance

Approach Summary: vary strategy or fuel to change reductant chemistry

Reductant Species (peak concentrations) through the engine/catalyst system



Other species measured:
Nitro-organics
Ammonia
N2O

methane	ethane	ethyne	propene
butene	formaldehyde	acetaldehyde	benzaldehyde
toluene	benzene	napthalene	
tridecane	indene	styrene	
benzofuran	phenol	methyl napthalene	
acenathalene	diphenylethene		…many others

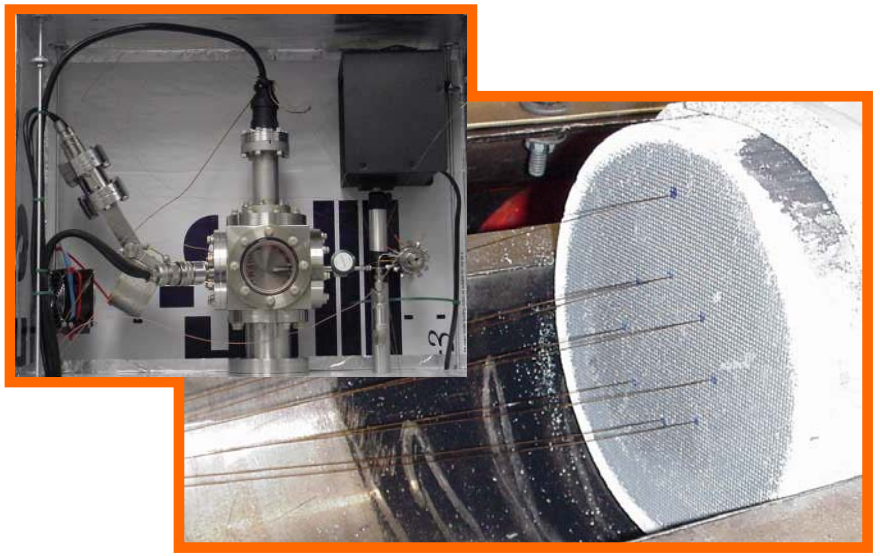
H2 and O2 transients measured using SpaciMS (SAE 2000-01-2952)

Multiple analytical tools and techniques used to understand catalyst characteristics and performance

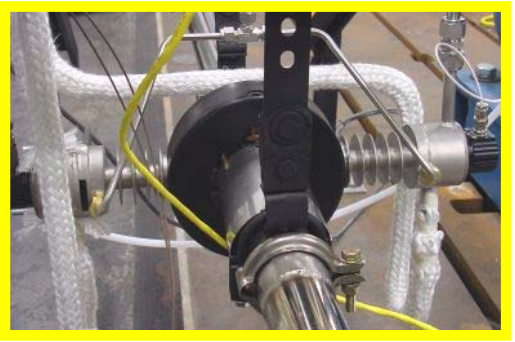
Conventional Five Gas Analyzers

GC/MS

FTIR

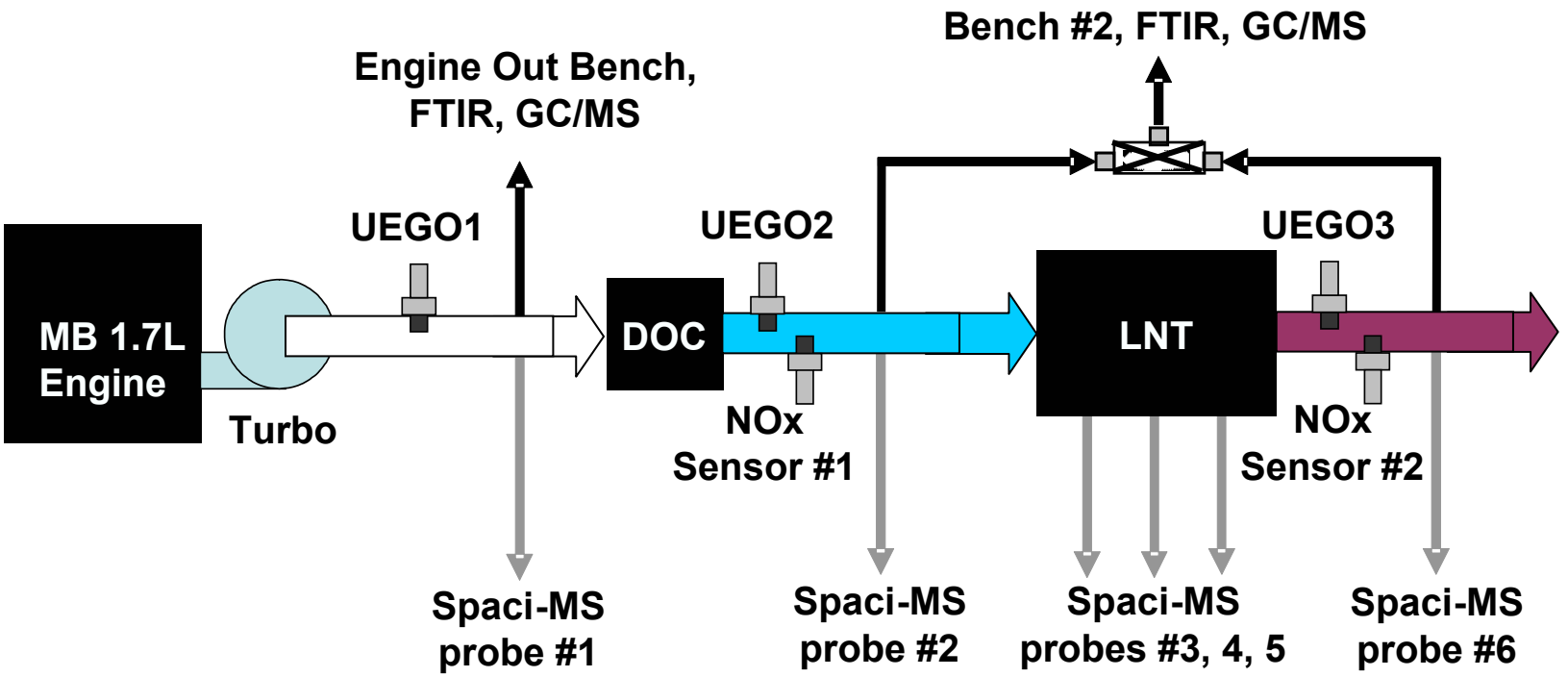


H2 Capillary Inlet MS (SpaciMS)



Celesco Opacity Meter

Experimental setup allows full exhaust species characterization throughout the catalyst system

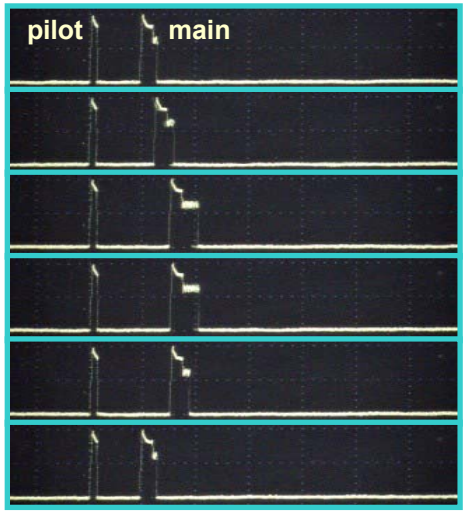


EGR used to induce rich LTC for LNT regeneration

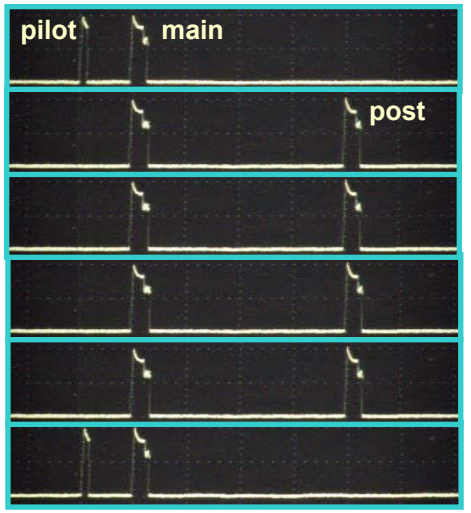
- Under moderate road load conditions (1500RPM/5bar BMEP), EGR drives the system rich
  - Combustion can be tuned to enter LTC (i.e., low NOx/low PM)
- Regeneration consists of . . .
  - transitioning to 50%-55% EGR rate
  - disabling pilot injection and advancing the main injection
  - a nominal increase in fuel delivered to induce a rapid lean/rich transition
- Regeneration concluded by simultaneously closing the EGR valve and returning to normal injection

Two throttled/non-EGR strategies for comparison

"Delayed and Extended Main" (DEM)

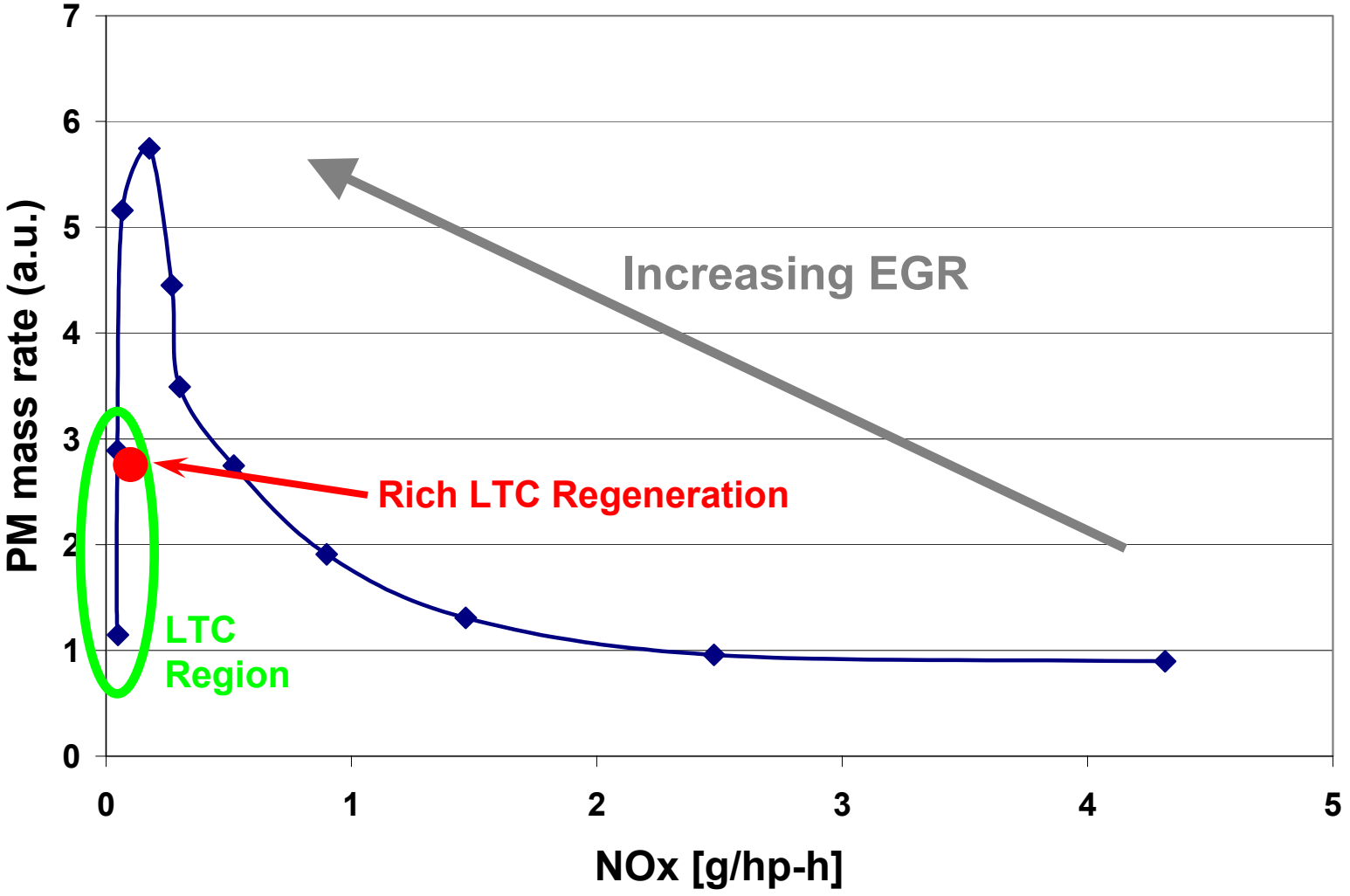


Time

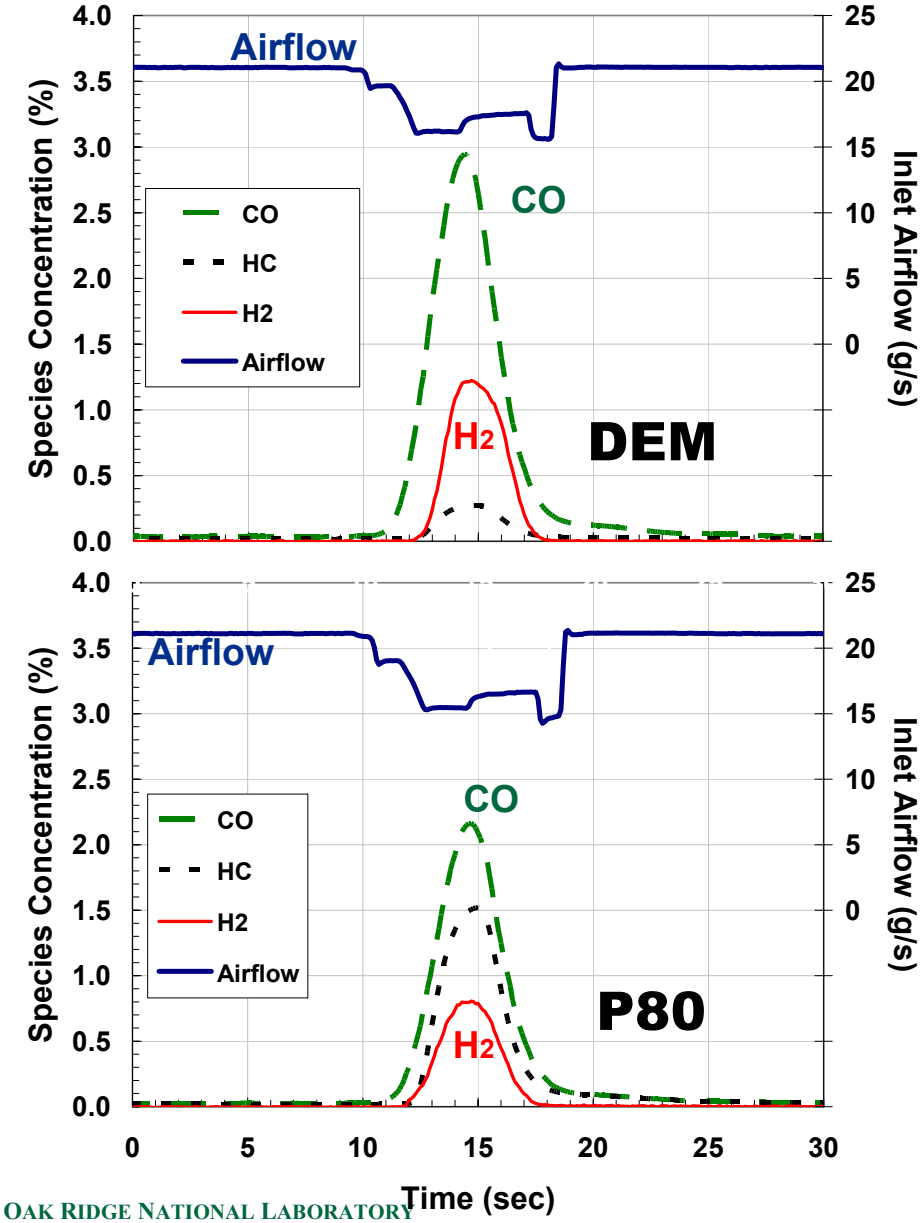


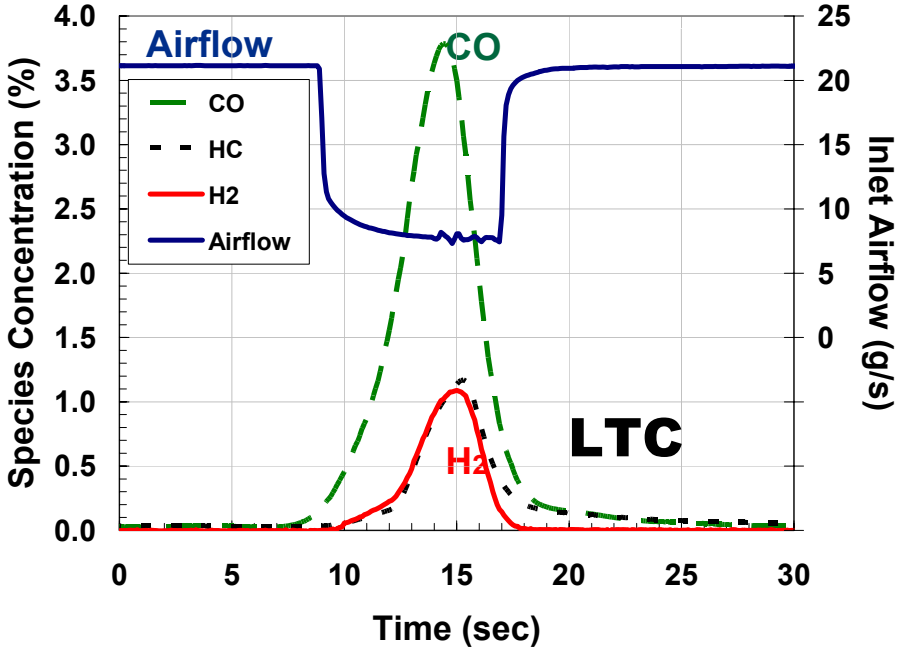
"Post 80 Injection" (P80)

Rich LTC regeneration maintains low NOx/low PM



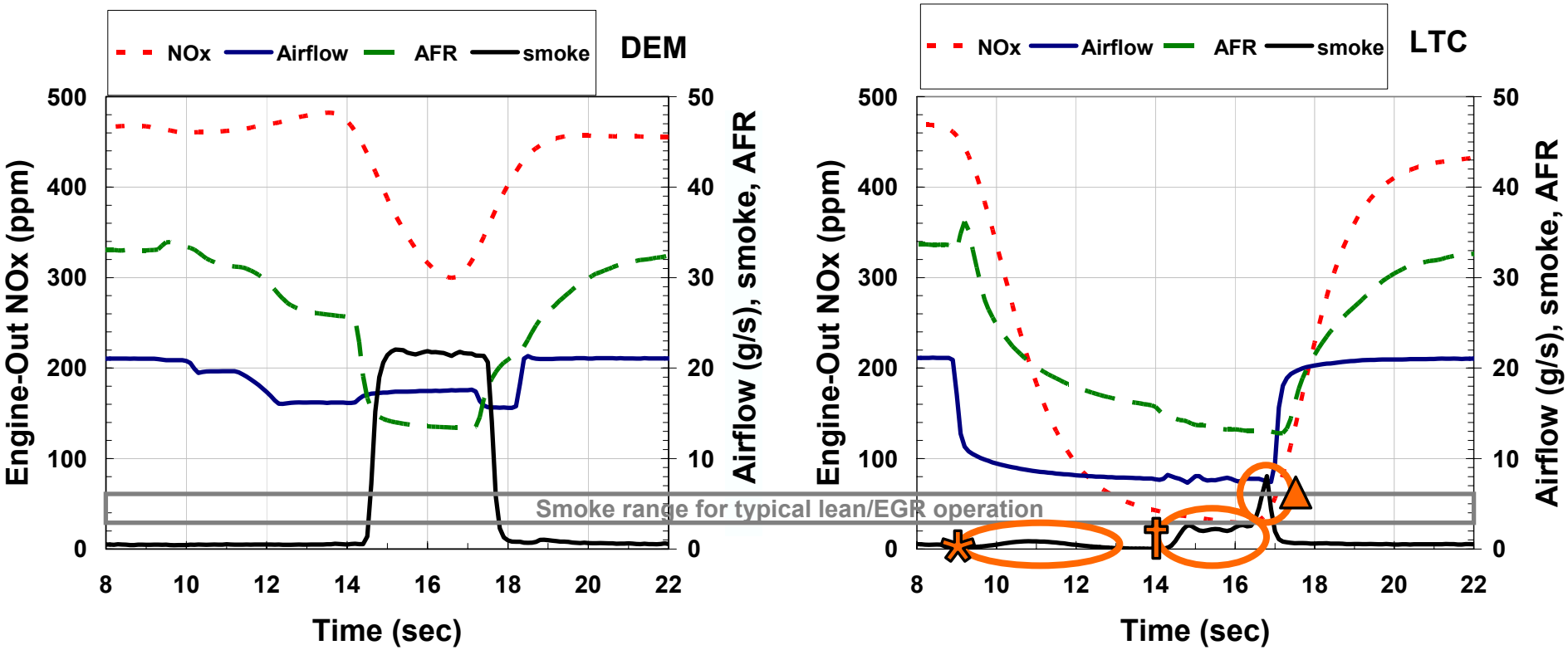
Real-time data highlights approach of strategies





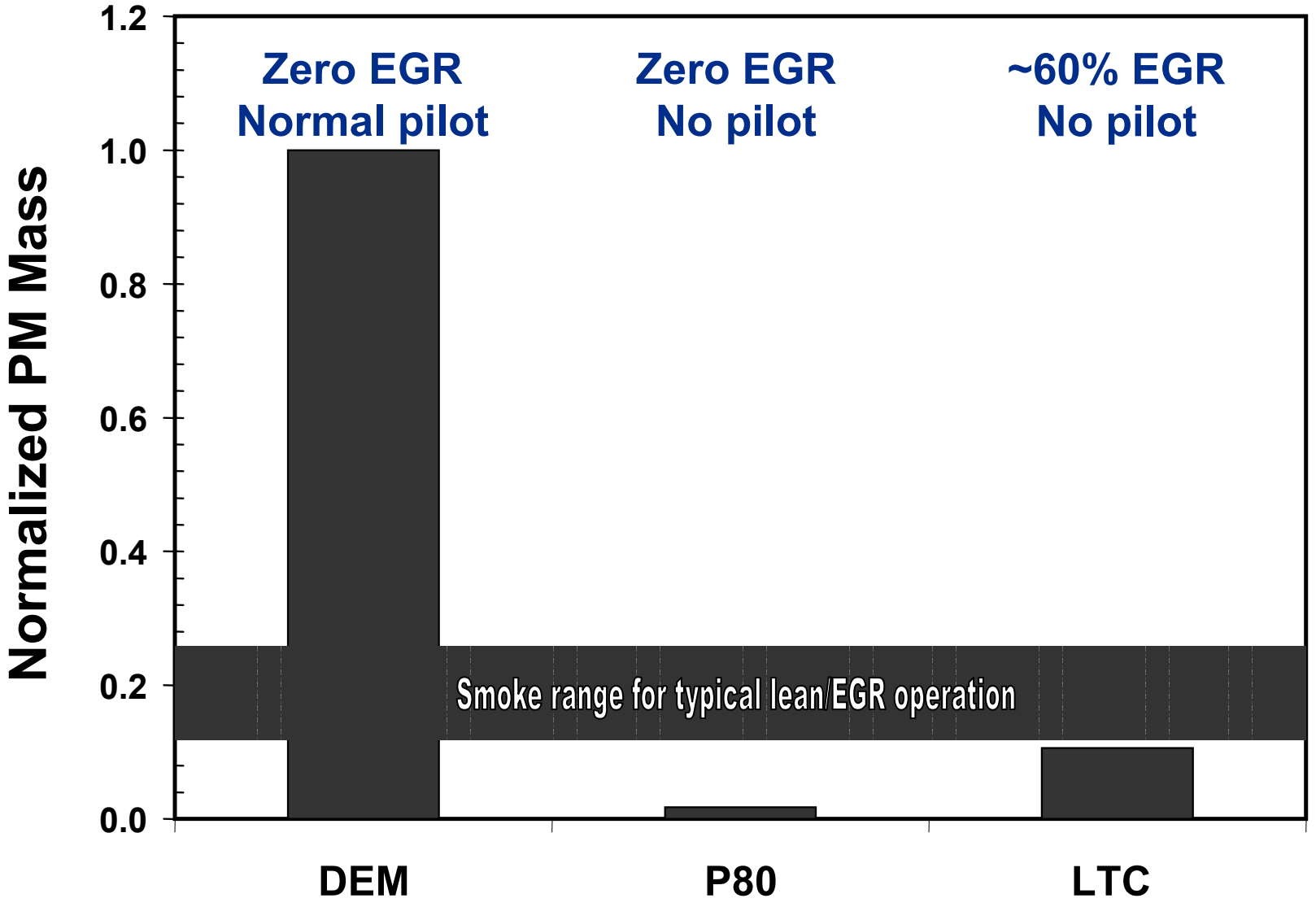
- DEM and P80 strategies employ identical throttling schedule, similar reduction in intake air mass (reduction of AFR)
  - Approach to excess fuel addition affects reductant species formed, concentrations
- "LTC" strategy uses EGR and nominal injection control for rich transition

Close look at LTC-based regeneration shows traits of LTC (low-NOx, low PM)

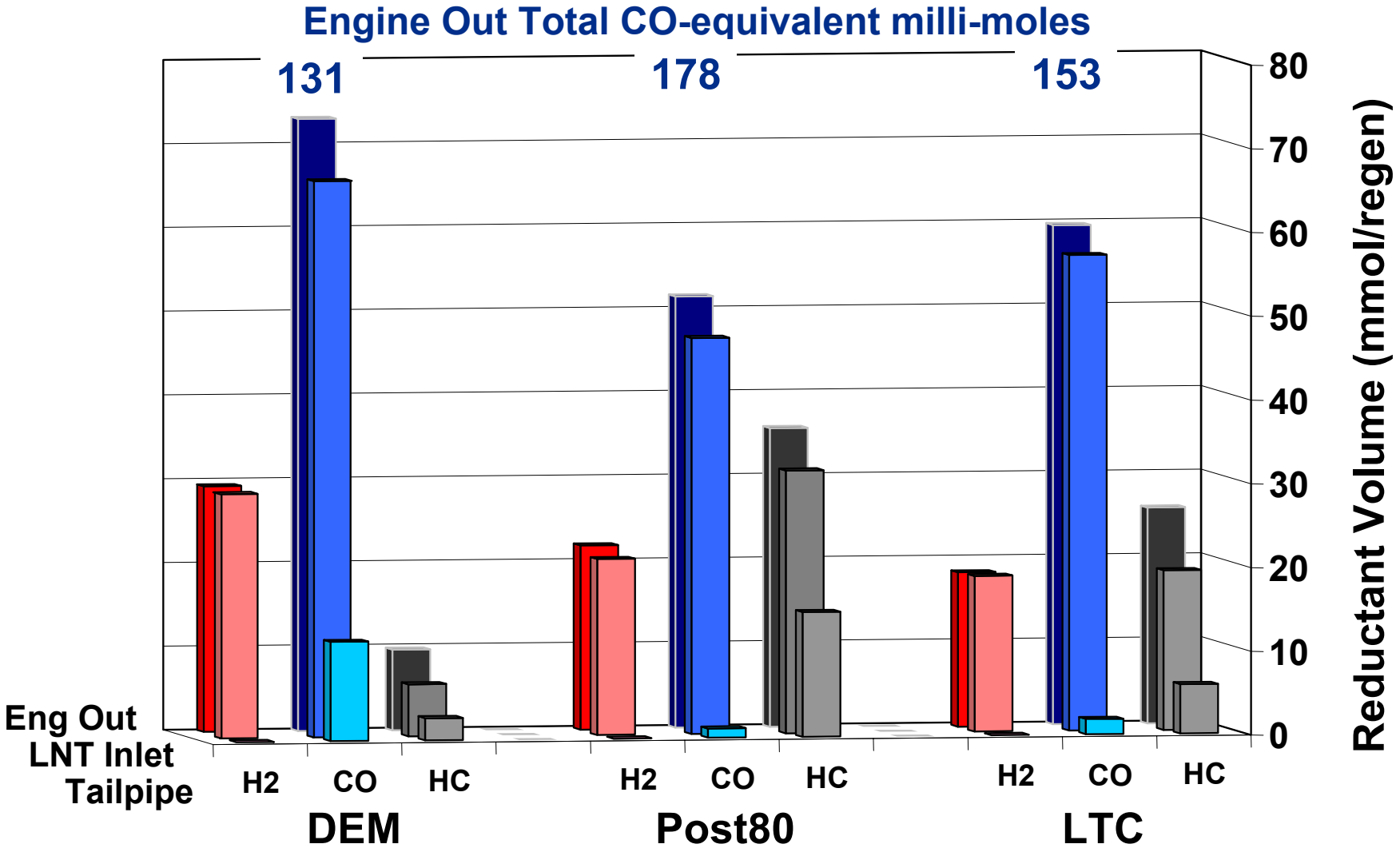


- Intake airflow decreased via EGR in lieu of throttle
- PM "hump" discernible as EGR increases (*)
- Small PM increase with 15% increase in main fuel pulse (†)
- PM spike at end due to rapid transition back to zero EGR (▲)

LTC-based regeneration produces very low PM



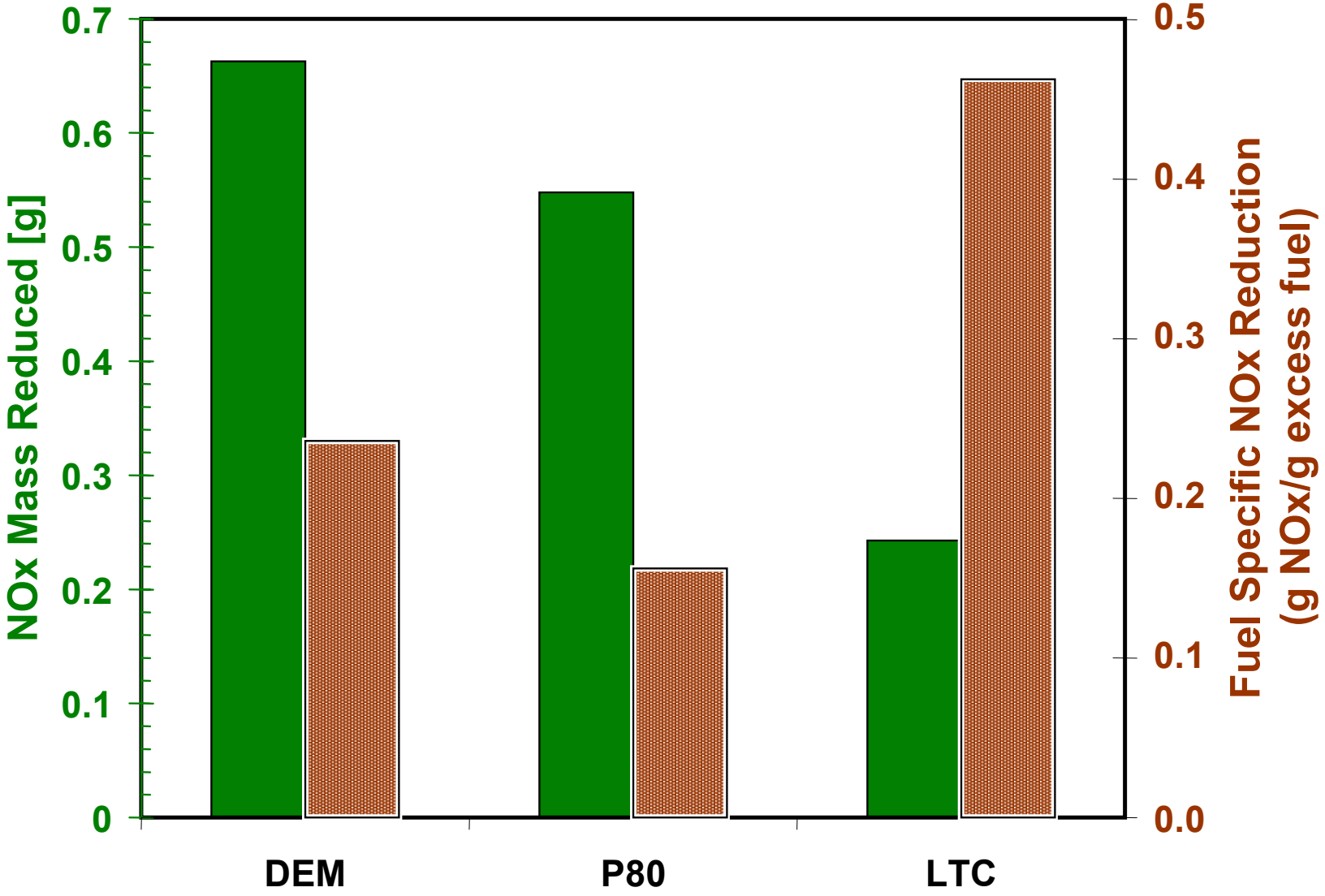
Integration of reductant produced shows similar total mole count for LTC case



- Previous data indicates that H_2 production dictates efficiency (SAE 2004-01-3023)

LTC strategy has potential for lower overall fuel penalty, despite lower average NOx conversion

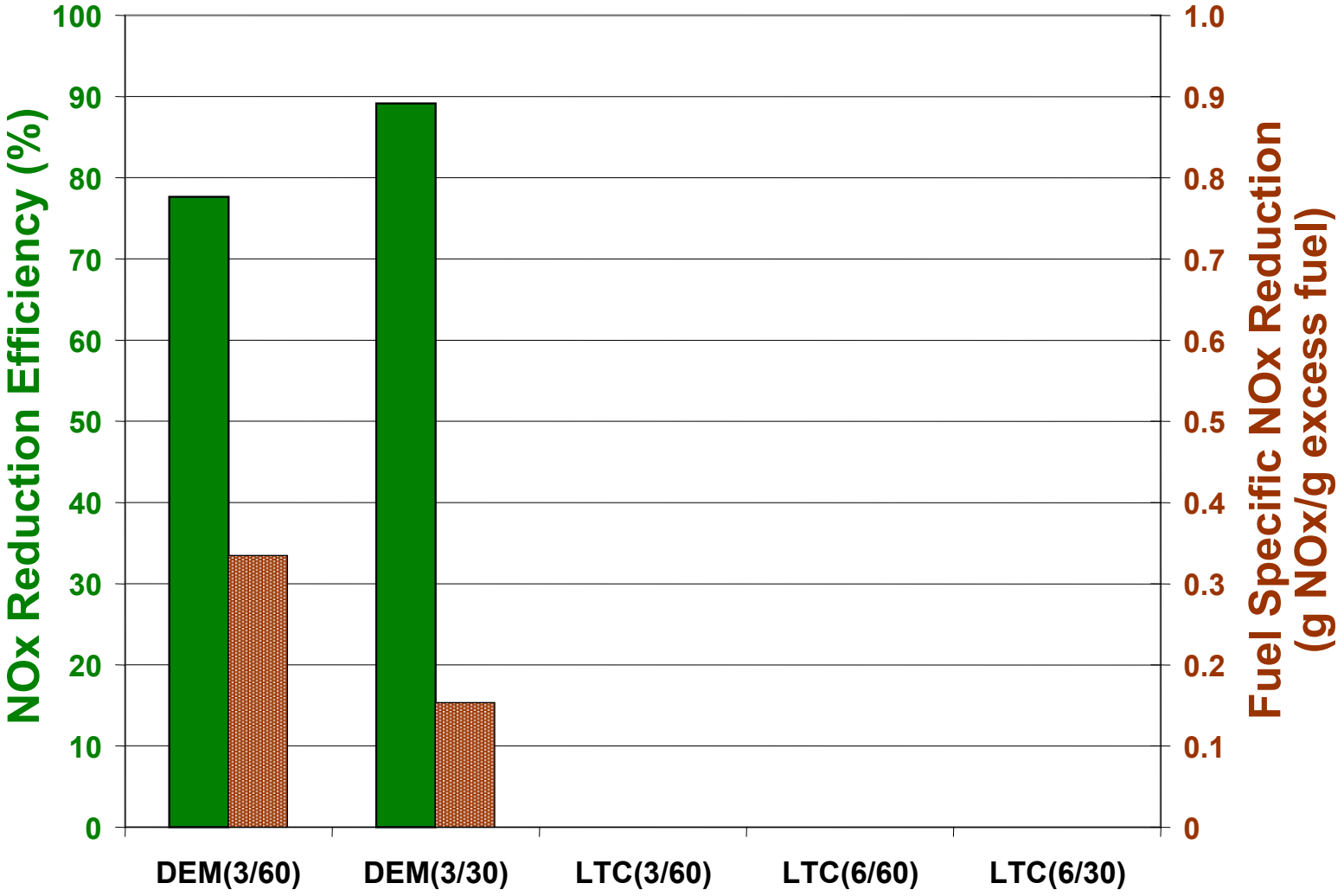
Strategies not optimized for FEP, NOx, torque, etc.



Further study attempting to leverage the LTC regeneration's superior fuel specific NOx reduction

- Comparing the benefits of improving LTC regeneration (lowest fuel penalty) vs. improving DEM regeneration (best NRE)
- Revised experiment to improve assessment of regeneration fuel penalty

Preliminary results from attempts to increase NOx Reduction Efficiency while maintaining low fuel penalty



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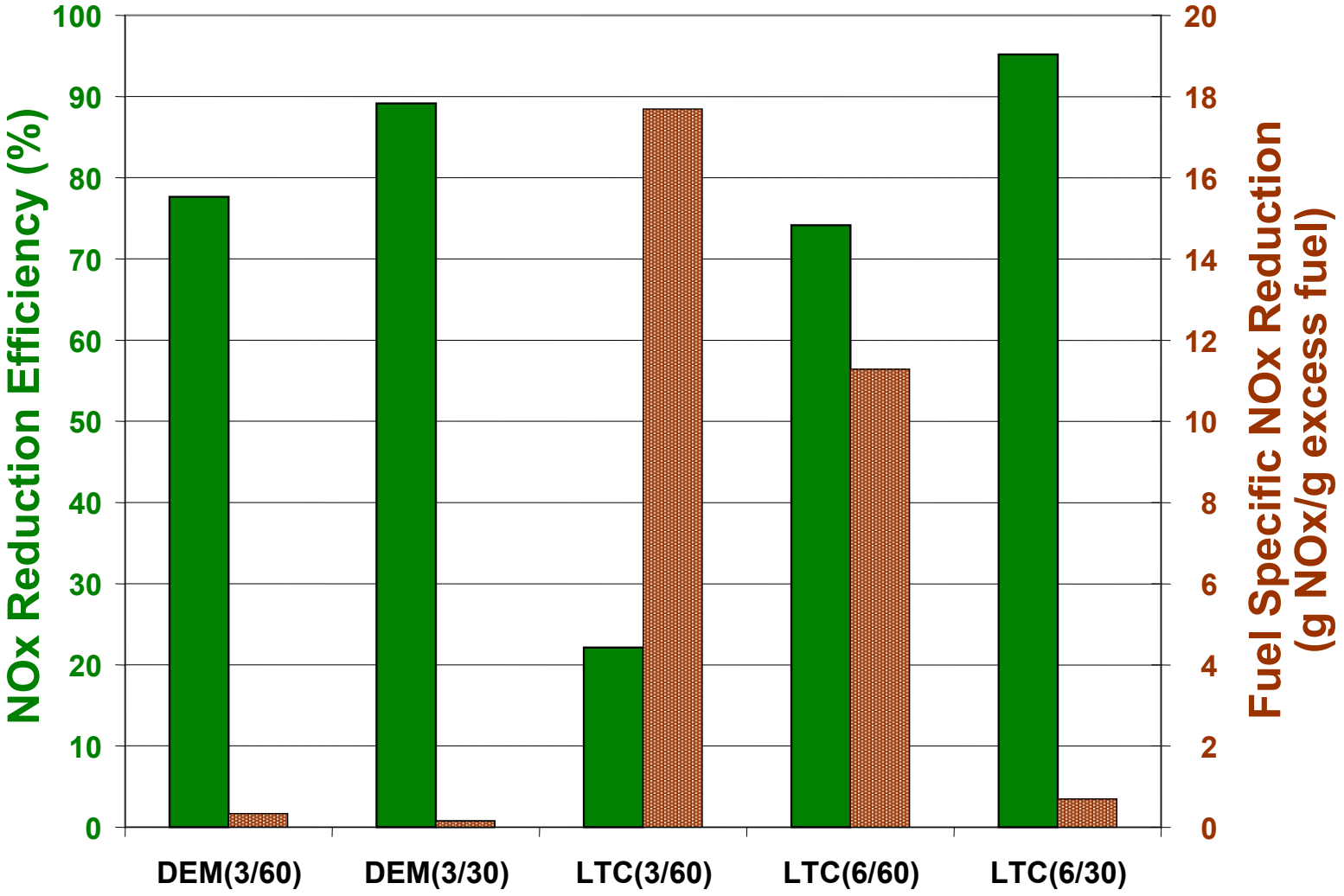

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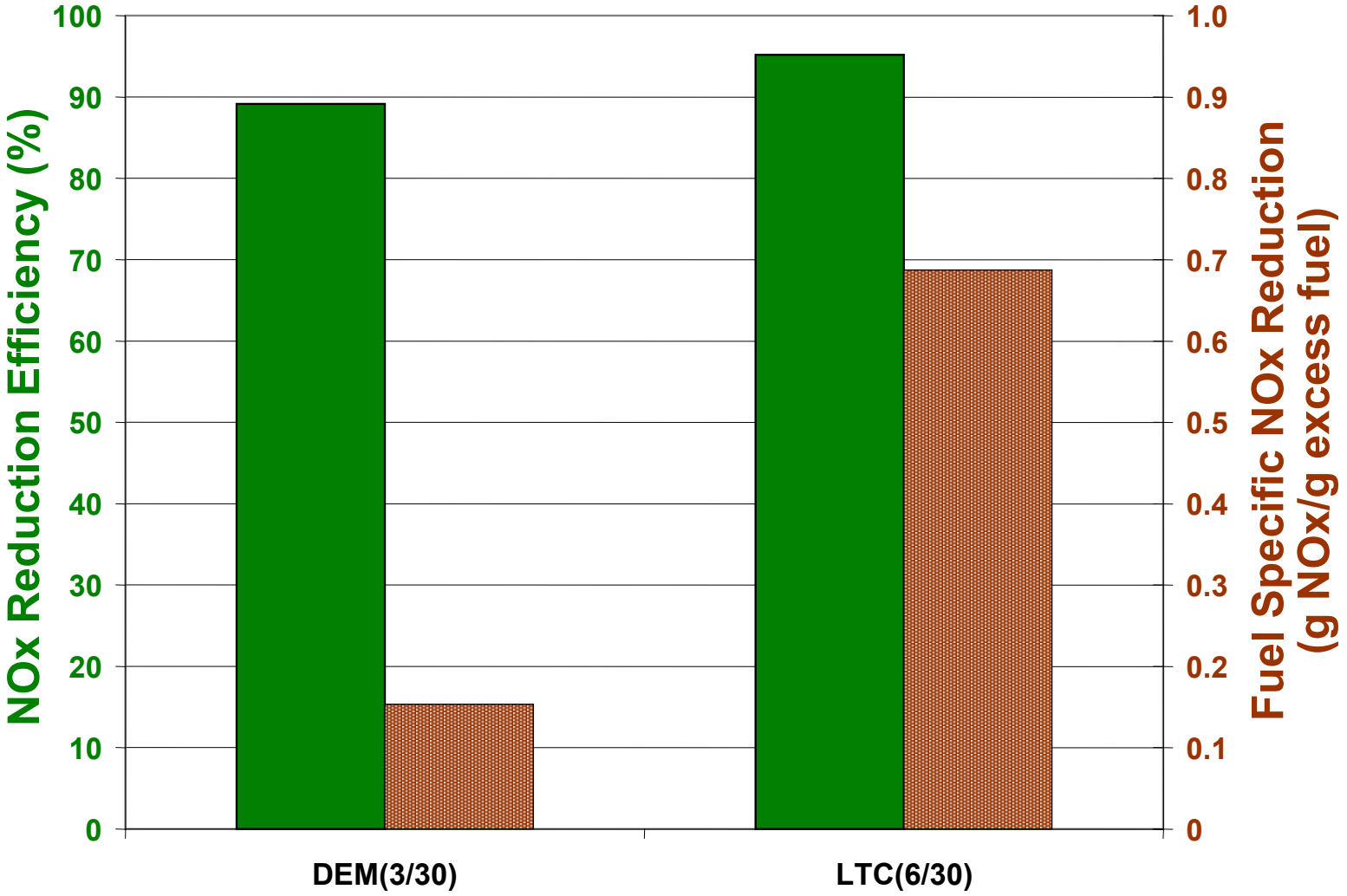

Summary - Preliminary LTC Regeneration Strategy Has Many Benefits

- LTC regeneration produces PM levels less than typical lean/EGR operation, and considerably less than DEM
- Low fuel consumption for LTC regeneration yields superior Fuel Specific NOx Reduction
  - Increasing frequency and duration of regeneration improves NOx reduction for LTC at minimal cost
- Preliminary data indicates potential for catalyst performance equivalent to DEM and P80, but with 5x-10x more efficient fuel utilization
  - potential for improving NOx conversion, fuel efficiency, PM generation, and torque smoothing with further effort

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