NOx Abatement Research and Development

CRADA with International Truck and Engine Company

(Agreement 10035)

Josh A. Pihl and Todd J. Toops

Oak Ridge National Laboratory

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Ken Howden
Gurpreet Singh
Vehicle Technologies
U.S. Department of Energy

This presentation does not contain any proprietary or confidential information

Purpose of Work

- **Identify factors limiting NOx conversion during low temperature operation with CO and hydrocarbon (HC) reductants**
  - **Goal is to improve the effectiveness and efficiency of LNTs by understanding the participation of reductants in LNT regen**
  - **CO and HCs prevalent during HCCI and other LTC modes**
- **Evaluate series of engine-aged, fully-formulated Lean NOx Traps (LNTs) with bench-scale core reactor**
  - **Variants include temperature, space velocity, lean-rich cycle time and reductant**
  - **Understanding the behavior of fresh and aged catalysts is necessary to improve the efficiency over the vehicle lifetime**
- **Effort is a CRADA w/ International Truck & Engine Company (ITEC)**

Activity Addresses Multiple Barriers

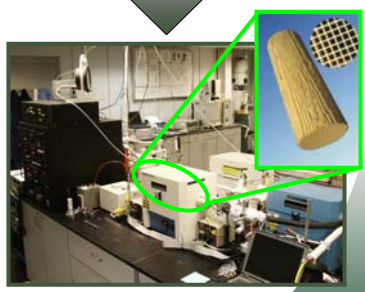
- **Some new diesel engines will require emissions control devices to meet emissions regulations**
  - **Either from a desire to have the lowest NOx emissions possible, or…**
  - **to achieve better fuel economy**
- **Developing a deep understanding of emission control chemistry over a wide range of engine conditions is essential for model development and ultimately fuel efficiency**
- **Cost-effective emissions control remain barrier to greater deployment of efficient diesel engines**

Guidance from FY 2007 Review

- **Project was well-received**
  - **Overall: 3.4 out of 4**
- **Only guidance was to better define research plan**
  - **Coordination has increased significantly**
  - **Research plan has been well-defined this FY**

Approach

- **ITEC aged catalysts under normal operating conditions**
  - **Long term engine dynamometer aging**
  - **Includes desulfation**
- **Catalysts delivered to ORNL for evaluation and analysis**
  - **Experimental protocol jointly developed between ITEC and ORNL**
    - **Low temperature operation not usually studied**
  - **Performed bench-core reactor evaluation at ORNL**
    - **Equipment not available at ITEC**
- **Results discussed with ITEC**



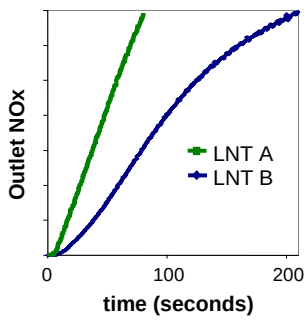
Technical Accomplishments

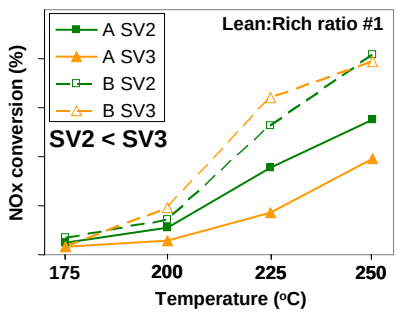
- **Evaluated 2 engine-aged catalysts at 175, 200, 225, and 250°C**
  - **Varied space velocity by a factor of 4**
  - **Evaluated reductants CO and C_3H_6**
  - **Varied rich:lean timing by a factor of 2**
- **Identified chemical processes limiting LNT performance**
  - **NOx activity is controlled by reductant and its ability to regenerate LNT**
  - **NO to NO_2 is <u>not</u> limiting process at low temperature**
- **Identified by-product variation as a function of temperature and space velocity**
  - **NH_3 increases at higher temperatures and space velocities**
  - **N_2O also increases with temperature, but decreases with space velocity**
- **Quantified relative reductant effectiveness**
  - **CO significantly more effective at NOx reduction than C_3H_6**

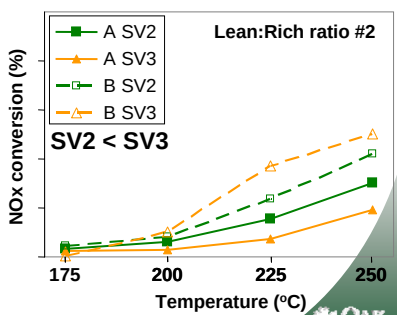
Technical Synopsis

Evaluated Key Kinetic Parameters for Aged LNTs

- **Reductant: CO-only**
- **Two catalysts with different aging conditions**
  - **Aged on-engine at ITEC**
- **Varied parameters**
  - **Two space velocities (SV)**
  - **Two lean:rich ratios**
- **Measured total storage capacity**

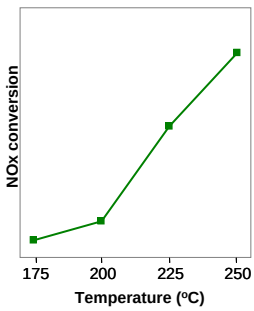


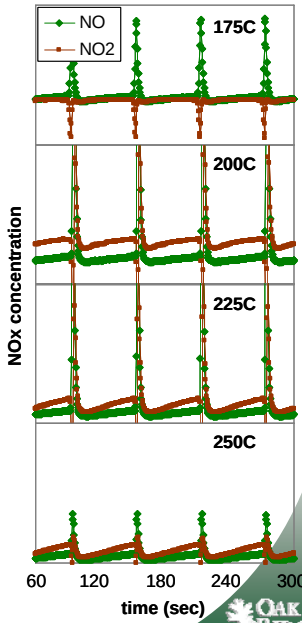




LNT Performance Limited by Reductant Activity

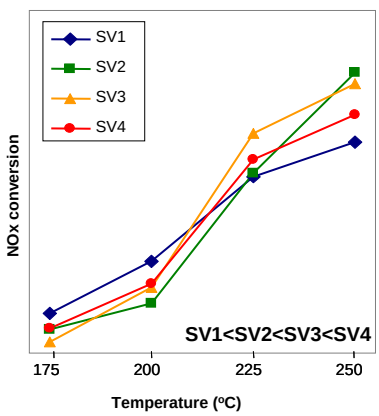
- **Reductant: CO-only**
- **Focused remaining efforts on catalyst B**
- **NO_2 breakthrough observed at all temperatures**
  - **Performance not limited by NO to NO_2 oxidation…even at 175°C**
- **NOx profile ~flat at 175°C**
  - **Storage sites saturated**
  - **Performance limited by LNT regen**
  - **Low reductant activity at low T**
- **NOx "puff" large at 200 and 225°C**
  - **Stored NOx released faster than it can be reduced**

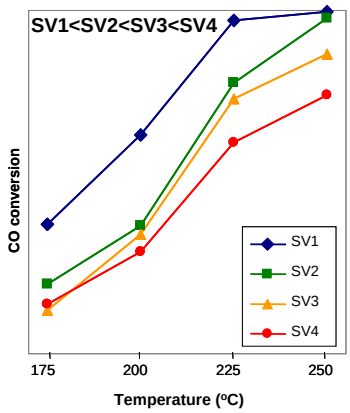




Conversions Strongly Decrease with Temperature

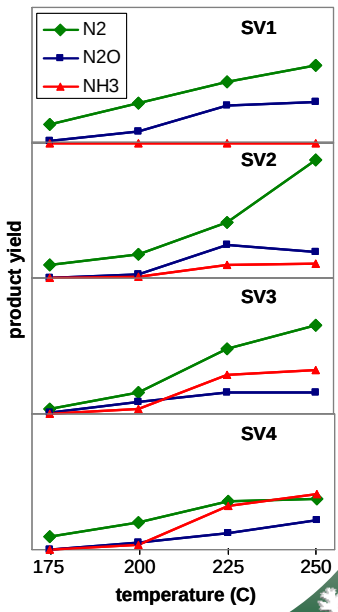
- **NOx conversion:**
  - **Decreases sharply with temperature**
  - **SV trends not apparent**
- **CO conversion:**
  - **Follows same temperature trends**
  - **Expected SV trends observed**
    - **Conversion increases at low SV**





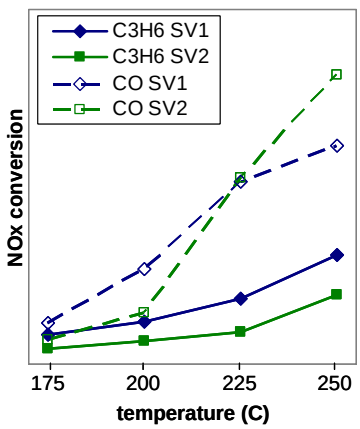
NH_3 Yield Increases with SV & Temperature

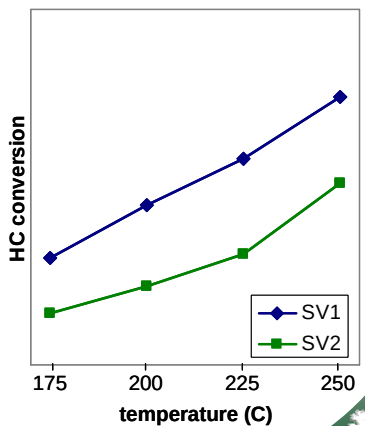
- **SV1<SV2<SV3<SV4**
- **Substantial N_2O formed**
  - **N_2O selectivity decreases as space velocity increases**
- **NH_3 formation increases with temperature & space velocity**
  - **selectivity driven by stored NOx/reductant ratio**
    - **for saturated LNT, higher SV = higher CO dose for same NOx stored**
  - **In general, increasing SV leads to higher reaction intermediate yield**
    - **suggests NH_3 is regen intermediate**



C_3H_6 Significantly Less Effective than CO

- **NOx conversion**
  - **Significantly lower for C_3H_6 at same SV and Temperature**
- **C_3H_6 conversion**
  - **lower than CO conversion**
  - **Expected SV trend observed**
  - **small amount of CO at outlet**
    - **Indicative if HC cracking in LNT**





Technology Transfer

- **ITEC: "We are still actively developing NOx aftertreatment and are relying on our CRADA to support these efforts."**
- **Results have been actively shared with ITEC**
- **Results from this effort guided ITEC LNT research and modeling efforts**
- **2007 Annual Report has been submitted to DOE**

Activities for FY 2008 and Beyond

- **ITEC: "[Catalysis] group is tasked with preparing SCR for all platforms by the 2010-2012 timeframe."**
- **Refocus efforts on SCR performance and aging**
  - **NOx performance and kinetic evaluation**
  - **NH_3 storage and reactivity**
  - **Aging samples:**
    - **Simulated thermal aging**
    - **Employ a subset of baseline kinetics and NH_3 storage/reactivity experiments for evaluation of aged samples**
    - **Materials characterization**
  - **Evaluate both Fe-based and Cu-based SCRs**
- **Establish three-way NDA with ITEC-catalyst supplier**

NOx Abatement R&D (CRADA with ITEC)

- **Relevance**
  - Understanding emission control chemistry over a wide range of engine conditions essential for model development and fuel efficiency
- **Approach**
  - Evaluate engine-aged LNTs provided by ITEC
  - Perform detailed kinetic study to provide data for models and identify limiting factors
- **Technical Accomplishments**
  - Demonstrated reductant activity is key limitation at low temperature
  - Identified NH_3 and N_2O trends with temperature and space velocity
  - Demonstrated CO and C_3H_6 kinetics and relative NOx reduction effectiveness
- **Technology Transfer**
  - Work closely with ITEC to define experiments and share results
  - 2007 DOE Annual Report
- **Future Research**
  - Transition efforts to SCR kinetics, characterization and aging effects