

NO_x Abatement Research and Development CRADA with International Truck and Engine Company (Agreement 10035)



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Purpose of Work

- **Identify factors limiting NO_x 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 NO_x 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)**



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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**

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Guidance from FY 2007 Review



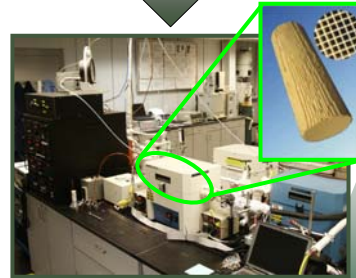
- **Project was well-received**
 - Overall: 3.4 out of 4
- **Only guidance was to better define research plan**
 - Coordination has increased significantly
 - Research plan has been well-defined this FY

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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**



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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 C₃H₆
 - Varied rich:lean timing by a factor of 2
- **Identified chemical processes limiting LNT performance**
 - NO_x activity is controlled by reductant and its ability to regenerate LNT
 - NO to NO₂ is not limiting process at low temperature
- **Identified by-product variation as a function of temperature and space velocity**
 - NH₃ increases at higher temperatures and space velocities
 - N₂O also increases with temperature, but decreases with space velocity
- **Quantified relative reductant effectiveness**
 - CO significantly more effective at NO_x reduction than C₃H₆

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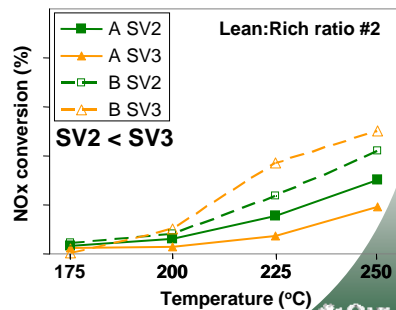
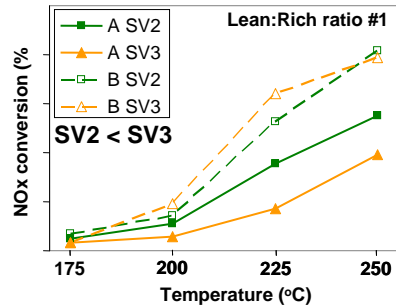
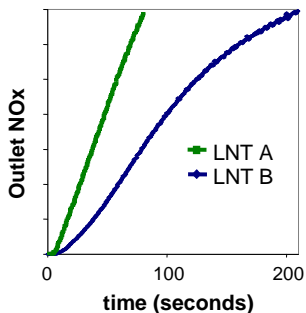
Technical Synopsis

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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**

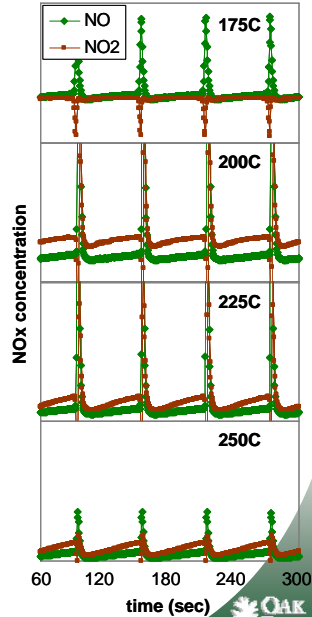
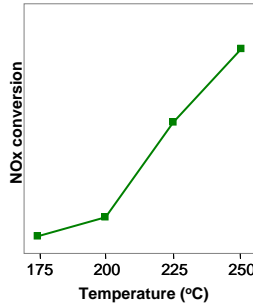


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LNT Performance Limited by Reductant Activity

- **Reductant: CO-only**
- **Focused remaining efforts on catalyst B**
- **NO₂ breakthrough observed at all temperatures**
 - Performance not limited by NO to NO₂ 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

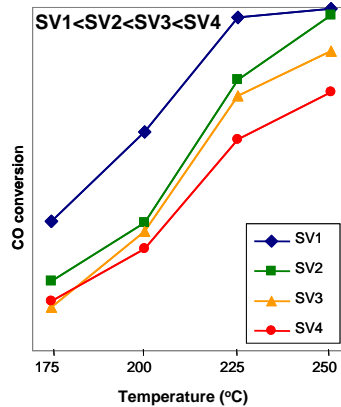
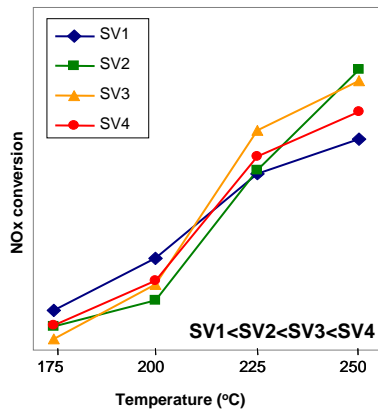


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Conversions Strongly Decrease with Temperature

- **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

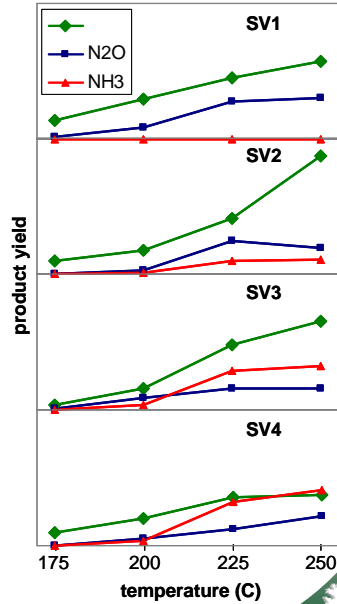


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NH₃ Yield Increases with SV & Temperature

- SV1 < SV2 < SV3 < SV4
- Substantial N₂O formed
 - N₂O selectivity decreases as space velocity increases
- NH₃ 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 NH₃ is regen intermediate

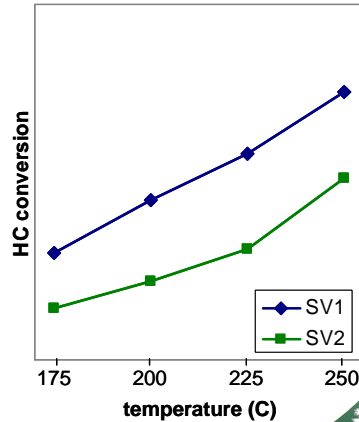
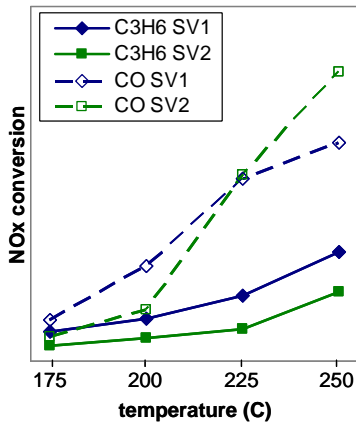


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C₃H₆ Significantly Less Effective than CO

- NOx conversion
 - Significantly lower for C₃H₆ at same SV and Temperature
- C₃H₆ conversion
 - lower than CO conversion
 - Expected SV trend observed
 - small amount of CO at outlet
 - Indicative if HC cracking in LNT



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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**

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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
 - NH₃ storage and reactivity
 - Aging samples:
 - Simulated thermal aging
 - Employ a subset of baseline kinetics and NH₃ 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**

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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