Lean-Rich Cycling for Passive SCR Lean Gasoline Emission Control

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CLEERS Workshop
April 28, 2015
Dearborn, MI

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Acknowledgements

- **Program Sponsors:**
  Gurpreet Singh, Ken Howden, and Leo Breton of the Advanced Combustion Engines Program in the Vehicle Technologies Office of the **U.S. Department of Energy**

- **Catalyst Supplier: Umicore**
  - Chris Owens, Tom Pauly, David Moser, Davion Clark, Ken Price, Corey Negohosian, Doug Ball

- **Technical Guidance: GM**
  - Wei Li, Kushal Narayanaswamy, Lucie Bednarova

U.S. DEPARTMENT OF ENERGY

umicore Automotive Catalysts

GM

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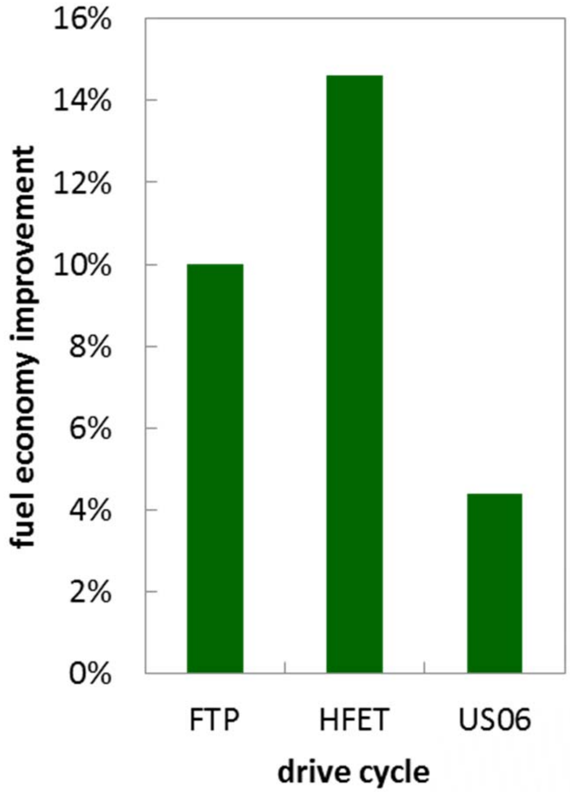
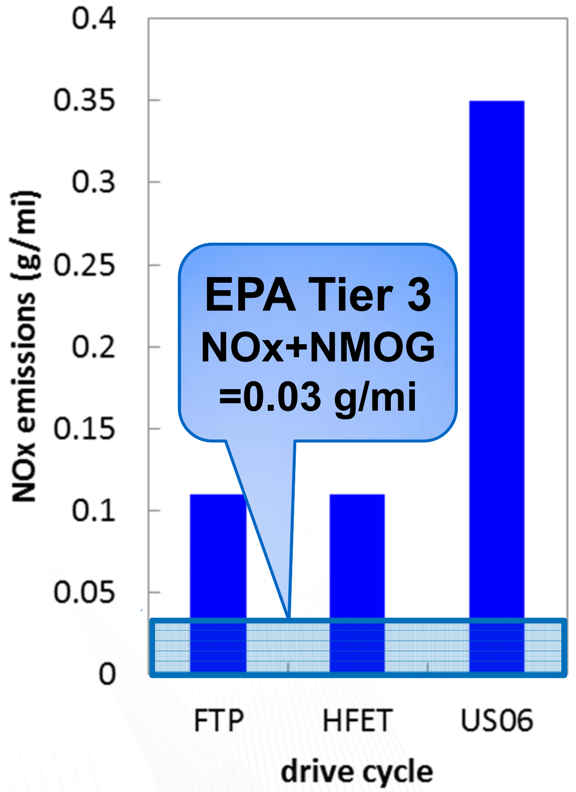
Lean operation of gasoline direct injection (GDI) engines improves efficiency, but creates emissions challenges

Case in Point:
The **European BMW 120i…**
a lean gasoline vehicle of marketable size that achieves
4-15% better fuel economy than common “stoich” gasoline vehicles, but…
does *not* meet U.S. Tier 2 Bin 5 emission regulations (designed to meet Euro regulations).

Fuel economy improvement with lean operation (relative to stoichiometric)



NOx emissions problematic (from lean operation)



NOTE: fuel economy and emissions measurements included effects from operation of lean NO_X trap (stock on BMW 120i vehicle)

Reference: SAE 2011-01-1218

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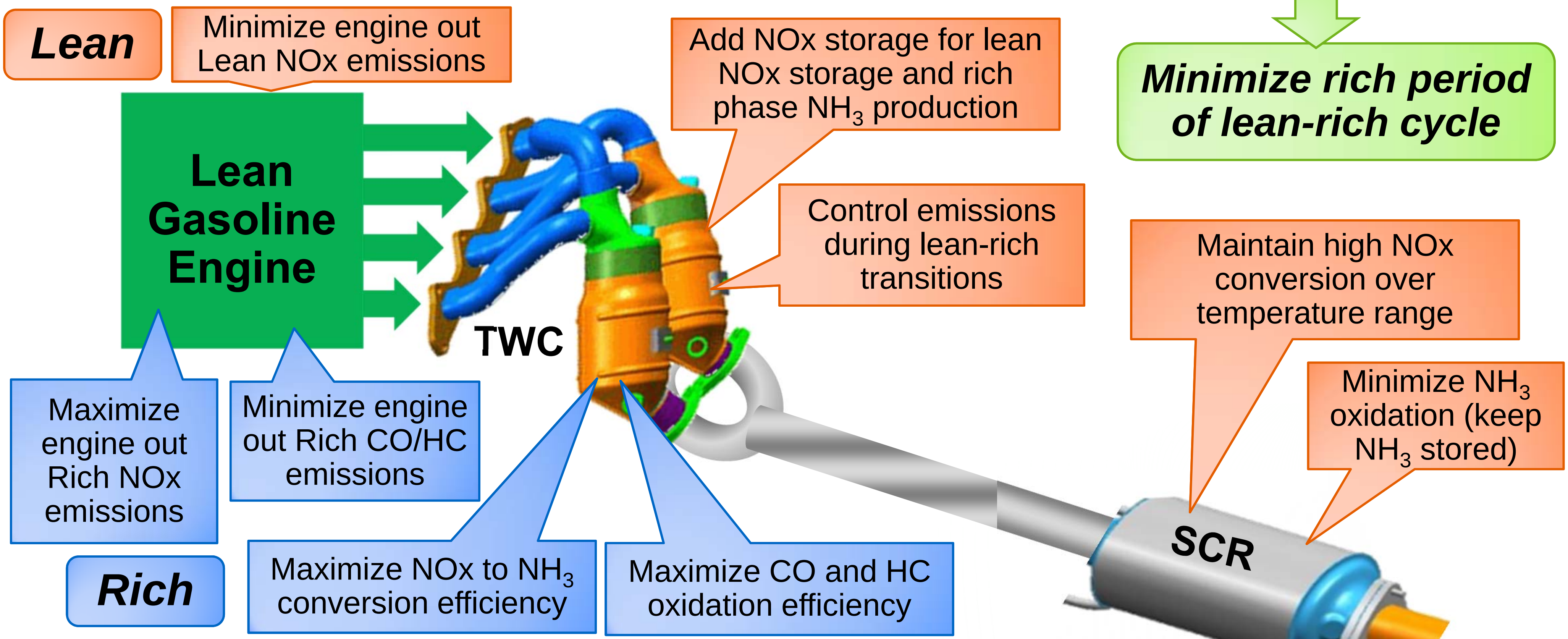
Passive SCR and LNT+SCR options for lean GDI emission control produce NH_3 onboard

Key Principle: system fuel efficiency gain depends on optimizing NH_3 production during rich operation and NOx reduction during lean operation



References to NH_3 production/utilization in Passive SCR, LNT+SCR, HC-SCR, etc.:

W. Li, K. L. Perry, K. Narayanaswamy, C. H. Kim and P. Najt, SAE 2010-01-0366 (GM)

Y. Liu, M.P. Harold, D. Luss, *Appl. Cat. B*, **121–122**, 239–251.

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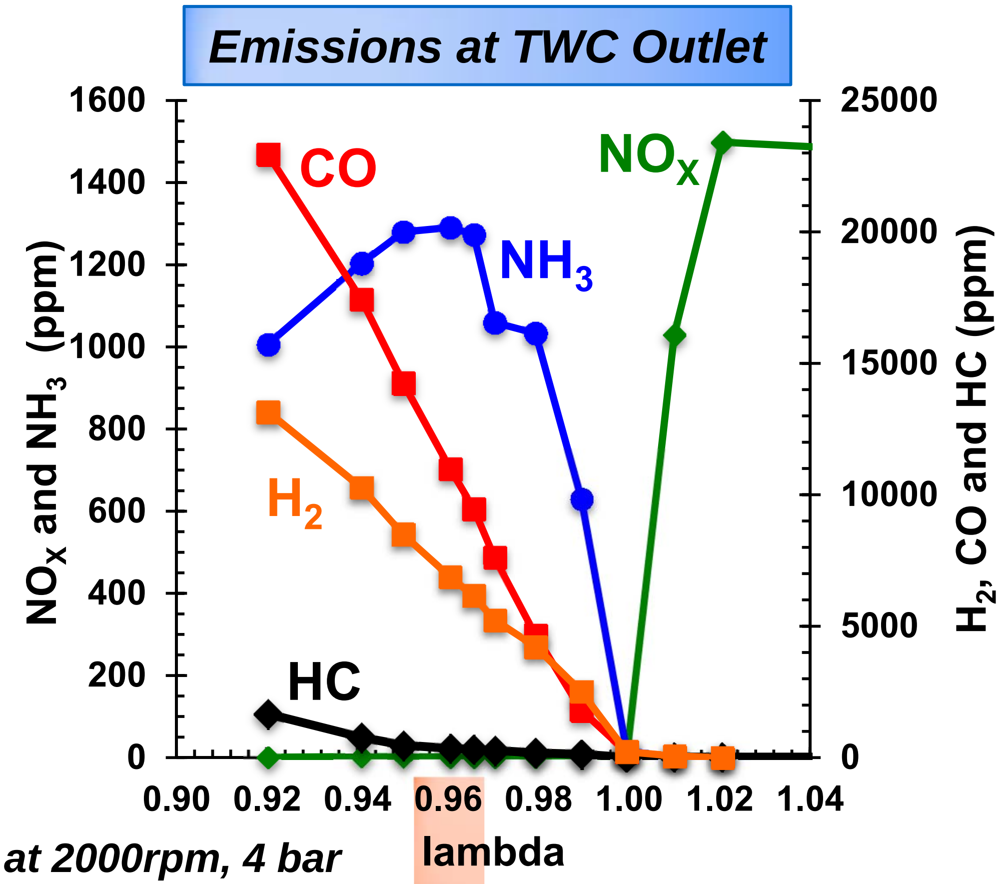
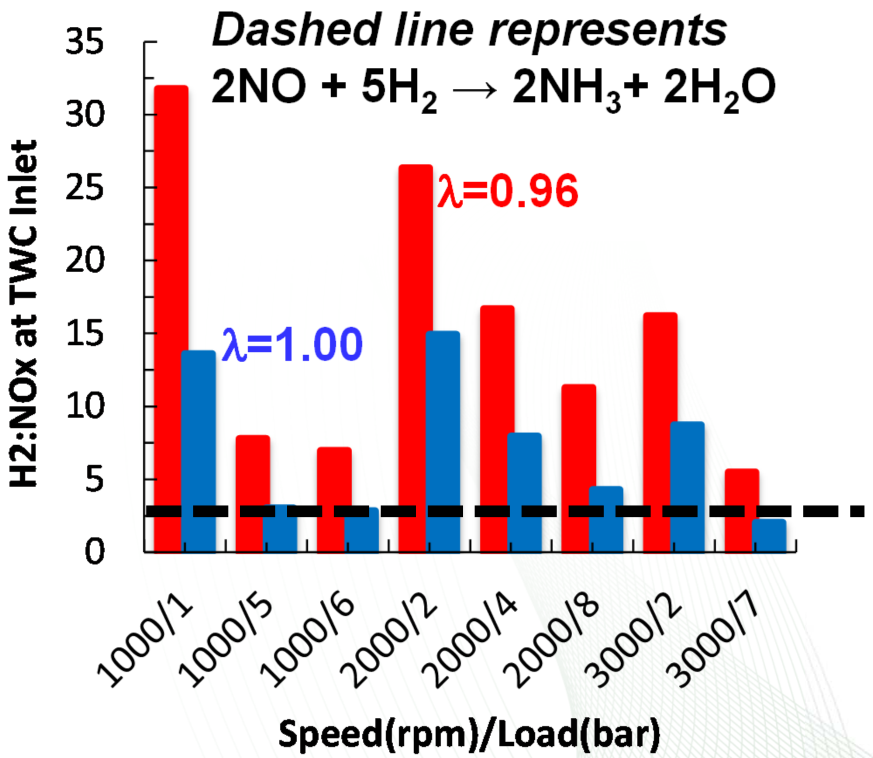
High efficiency of NH_3 production over TWC observed with low HC slip and reductant to spare

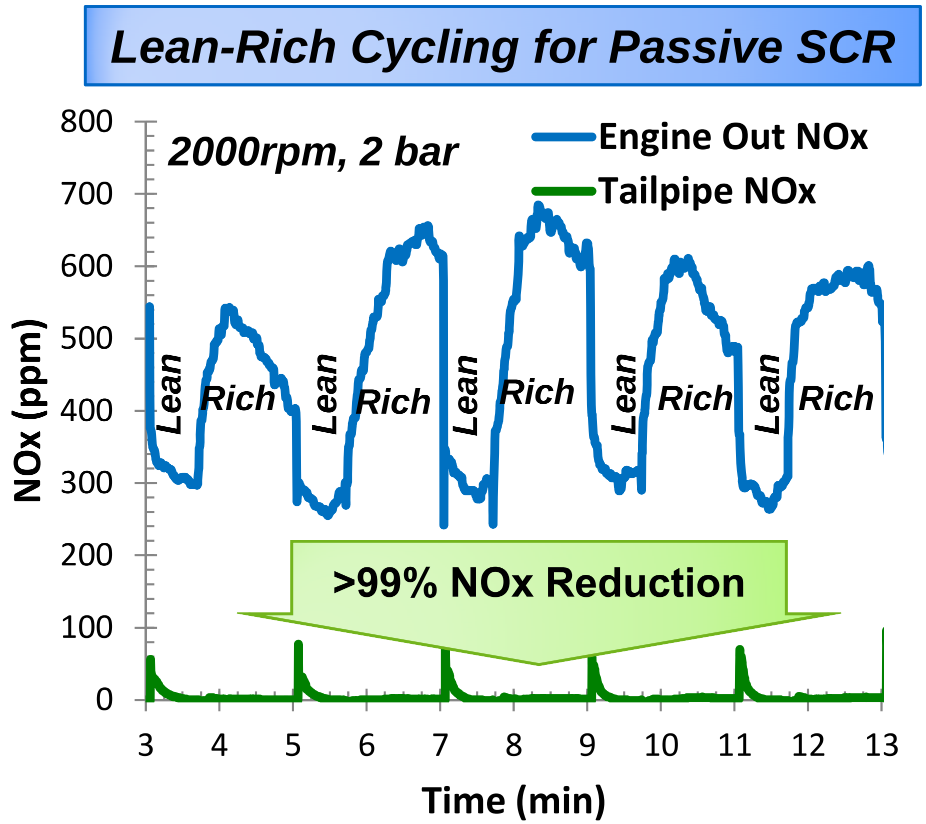


at 2000rpm, 4 bar



λ=0.96 nominally gives high NH_3 formation with low HC slip

Lean-rich cycling with NH_3 utilization-production gives high NOx reduction efficiency over SCR



Tailpipe	Avg (ppm)	Max (ppm)
NOx	5	126
NH_3	2	5
N_2O	1	10
CO	*1782*	*4658*
NMOG	*<1*	*16*

+5.5%
Fuel Economy (vs. Stoich)

With low tailpipe NOx emissions demonstrated, intent is to improve upon fuel efficiency gain reported at 2014 CLEERS Workshop (Prikhodko) by…

(1) optimizing TWC formulation for more NH_3 production

(2) utilizing more realistic engine load-step conditions

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Catalysts studied on bench flow reactor

- Thanks to Umicore for supplying prototype catalysts (labelled ORNL-x)
- The Malibu catalyst is from an SULEV Chevrolet Malibu commercially available vehicle (represents existing state of the art)

sample ID	Description	Pt (g/l)	Pd (g/l)	Rh (g/l)	OSC	NSC
Malibu-1	Front half of TWC	0	7.3	0	N	N
Malibu-2	Rear half of TWC	0	1.1	0.3	Y	N
Malibu-combo	Full TWC	0	4.0	0.16	Y	N
ORNL-1	Pt + Pd + Rh	2.47	4.17	0.05	Y	Y
ORNL-2	Pd + Rh	0	6.36	0.14	N	N
ORNL-6	Pd	0	6.50	0	N	N
ORNL-5	Pd + OSC high	0	6.50	0	H	N
ORNL-4	Pd + OSC med	0	4.06	0	M	N
ORNL-3	Pd + OSC low	0	1.41	0	L	N

OSC=oxygen storage capacity
NSC=NOx storage capacity

Conducted transient flow reactor experiments to estimate TWC effects on fuel consumption

- Used feedback-controlled cycles on flow reactor to evaluate dynamic TWC response in context of passive SCR
- Evaluated two different simulated engine cycles (fixed load, load step)

	fixed load		load step	
	rich	lean	rich	lean
load (BMEP)	2 bar	2 bar	8 bar	2 bar
SV (h^{-1})	**27000**	45000	**60000**	45000
NOx (ppm)	**600**	360	**1200**	360
max lean time	**50%**		**80%**	
simulates	cruise		"hill" transient	

	Rich						Lean
λ	0.95	0.96	0.97	0.98	0.99	1.00	2
O_2 (%)	0.96	1.02	1.07	1.13	1.17	1.22	10
CO (%)	2.0	1.8	1.6	1.4	1.2	1.0	0.2
H_2 (%)	1.0	0.9	0.8	0.7	0.6	0.5	0
NO (ppm)	600 (or 1200)						360
C_3H_8 (ppm C_1)	3000						1900
H_2O (%)	11						6.6
CO_2 (%)	11						6.6
TWC SV (hr^{-1})	27000 (or 60000)						45000

- Compositions & flows selected to mimic BMW GDI engine exhaust
- Space velocity changed with λ and load
- C_3H_8 chosen as challenging HC

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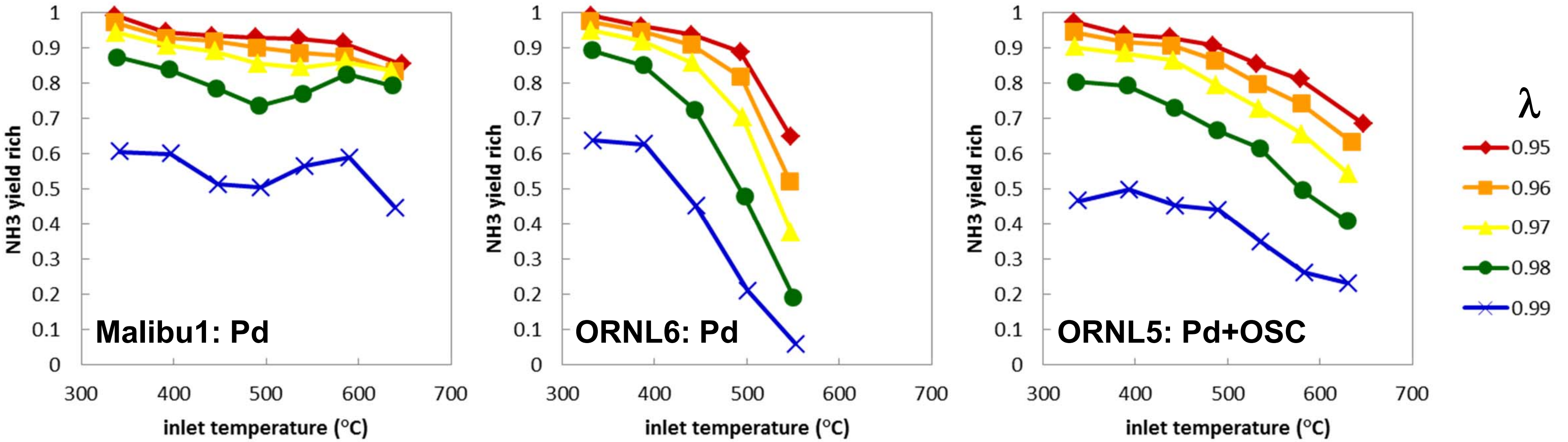
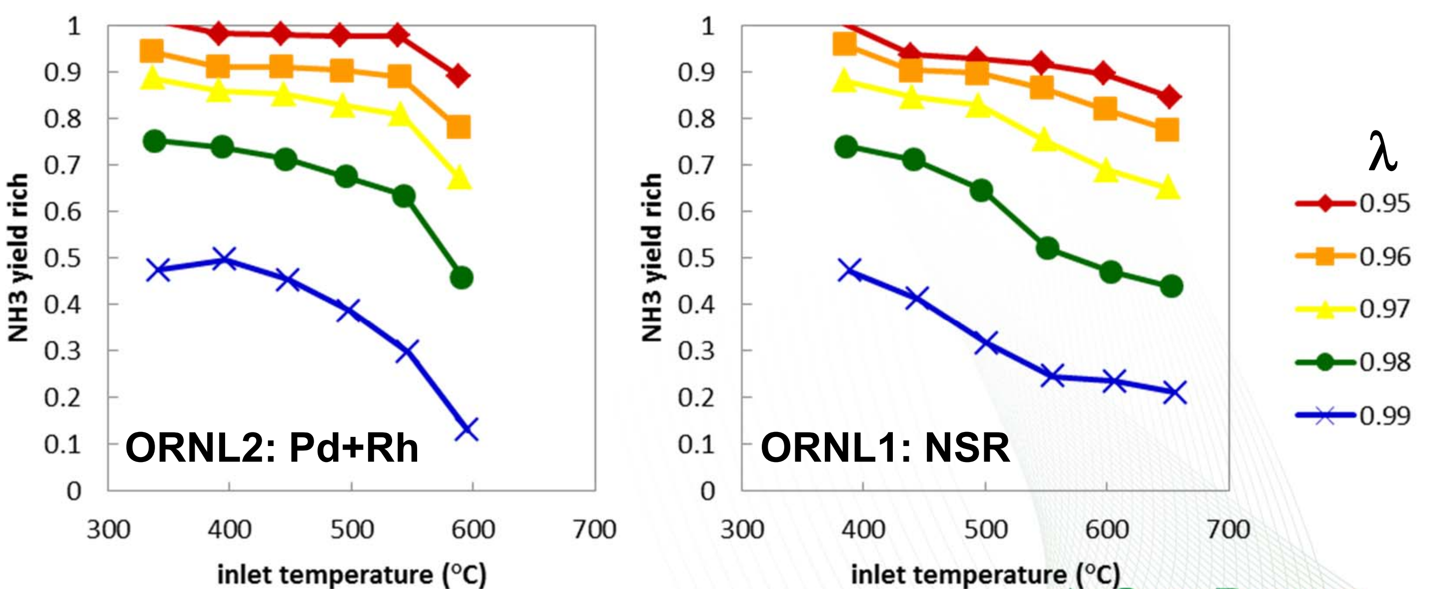
TWC formulation affects NH_3 yield during rich operation, particularly at high temperatures

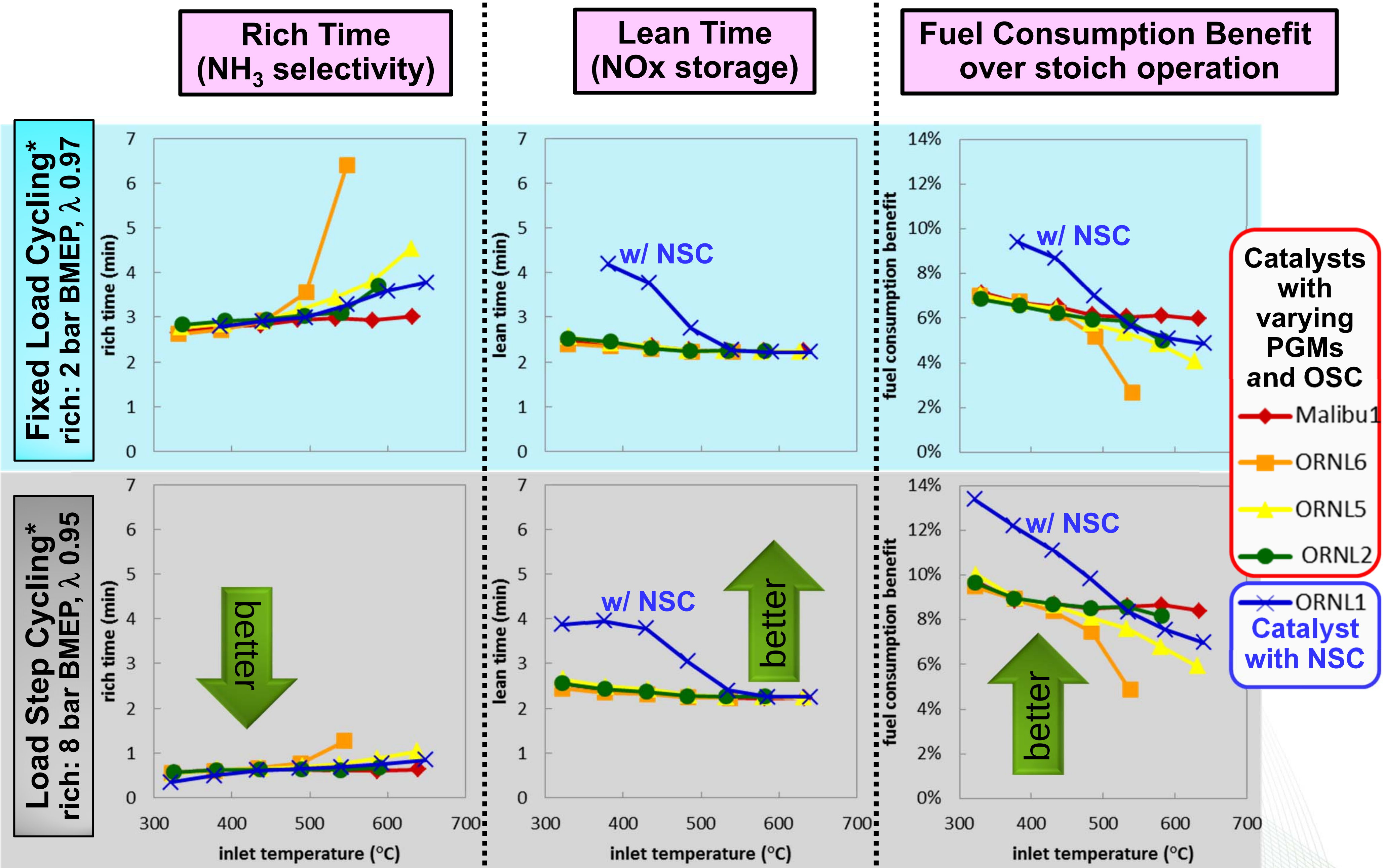
Results from fixed-load lean-rich cycles with feedback control based on NH_3:NOx



- Extensive data set: 5 formulations, 7 Ts, 5 λs, 2 conditions, 5 cycles
- Temperature, λ, TWC formulation all impact NH_3 selectivity
- Working to understand correlations between formulation & selectivity



TWC formulation impacts fuel consumption through NH_3 selectivity (rich time) and NOx storage (lean time)



***Feedback controlled cycles (cycle average NH_3:NOx=1)**

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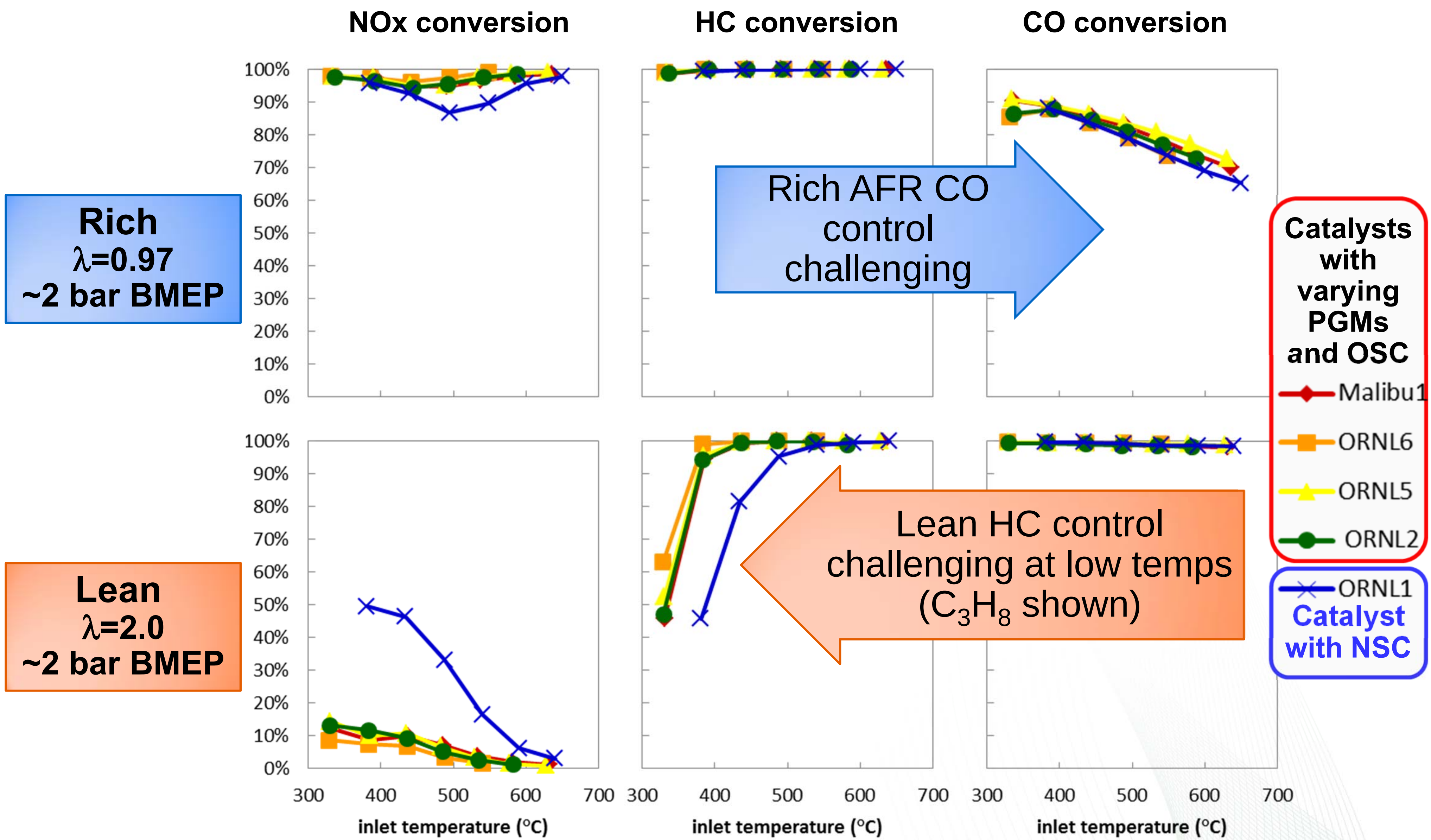
TWC conversions highlight other emissions challenges for HCs (lean) and CO (rich)



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Summary

- Lean gasoline engines offer significant fuel economy benefits (vs. stoichiometric gasoline), but NOx emissions during lean operation problematic
- Passive SCR approach offer >99% NOx reduction efficiency with little HC slip (important for EPA Tier 3 compliance)
- Maximizing NH_3 formation during rich phase can enable greater fuel efficiency benefit for lean gasoline:
  - Bench reactor studies show adding NOx storage component to TWC can improve fuel efficiency gain to 7-14% during load step cycling experiments mainly through NOx storage during lean phase

Thanks for your attention!

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