Exhaust Speciation Studies

for Aftertreatment Technology Development

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Various exhaust aftertreatment devices require tailored exhaust species in order to be effective in reducing engine out emissions. Thus, the ability to determine exhaust species at various operating conditions is essential for the development of future aftertreatment technology. Knowledge of how design and operating parameters effect generation of particular species will lead towards optimization of integrated engine-aftertreatment systems.

This paper presents the results of a multi-year joint CRADA between DDC and ORNL on exhaust gas speciation. Results of various engine tests will be presented including in-cylinder and post engine reductant injection.

HC Speciation for Lean NOx Catalysis

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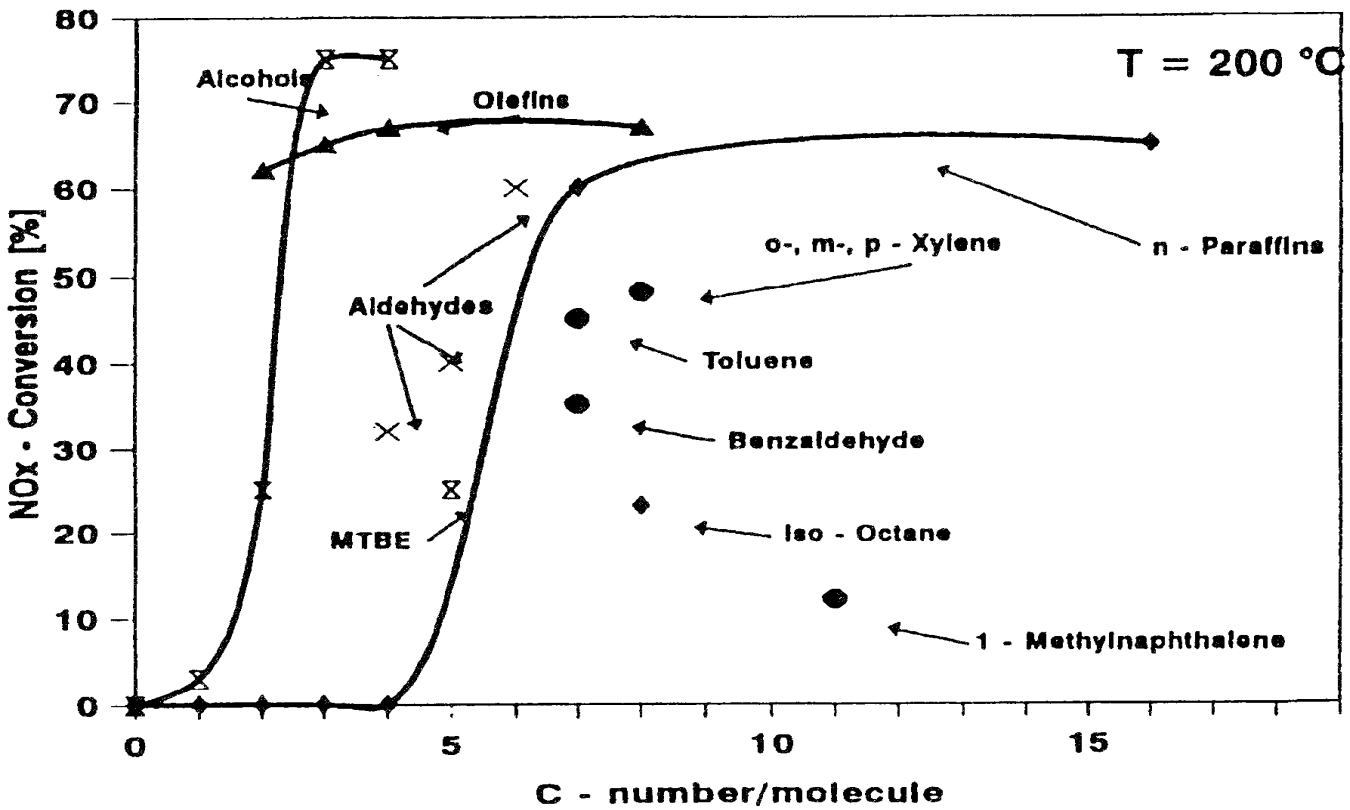
Motivation for study

- Lean NOx reduction shown to be strongly affected by HC reductant composition.
- Possibility exists to tailor exhaust HC composition by manipulating HC post-injection process.

Why is this relevant if lean NOx catalysis "isn't going to work" ?

- Lean NOx (esp. with post-injection of HC) offers unmatched "passiveness"
- NOx adsorber technology will require reductant - potentially introduced the same way

Data from ICT-Degussa (*SAE 952495*)
Pt Catalyst, bench flow data



Diesel engine exhaust hydrocarbon speciation and analysis for lean-burn NOx catalysts

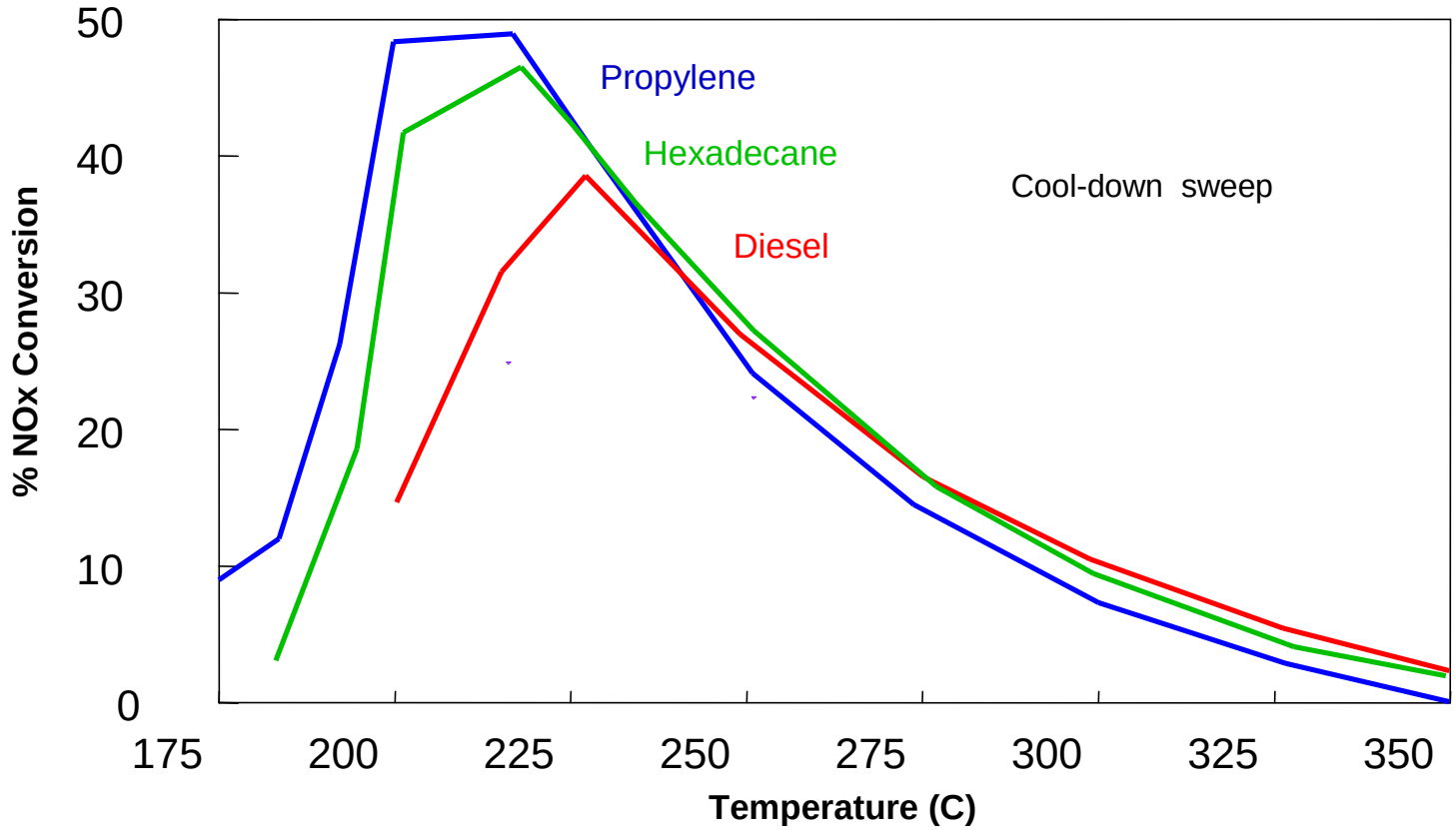
Objectives

- Determine chemical composition of hydrocarbons (HC) that exist or can be generated in diesel engine exhaust without and with in-cylinder HC injection
- Determine effectiveness of specific HC's on lean-burn catalyst NOx reduction

Work scope includes-

- Exhaust HC speciation from DDC Series 30 (Navistar 7.3l) and Series 50 diesel engines at ORNL facility
- Engine maps with and without in-cylinder post fuel injection
- Bench-mark testing of lean NOx catalysts

Work at ORNL Shows Effects of Different Reductants on Performance of Vendor Lean-NOx Catalyst



HC/NOx = 8; Space velocity = 50,000 1/hr

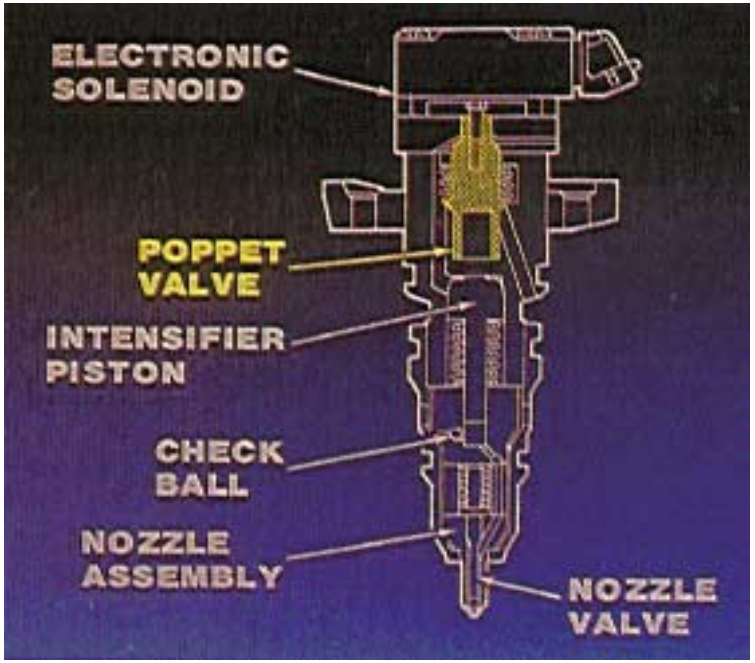
Secondary fuel injection system allowed variable timing and rate

Hydraulic Actuated

Electronic Controlled

Unit

Injector



- Both start and end of injection are electronically controlled
- Modified injection drive module provided by Navistar allowed secondary injection timing and rate control

Summary of completed tasks…over 50 data points and 50 compounds

Determined optimum injection timing for maximum engine out HC/NOx.

Determined secondary in-cylinder HC injection effects on NOx, CO, and HC species.

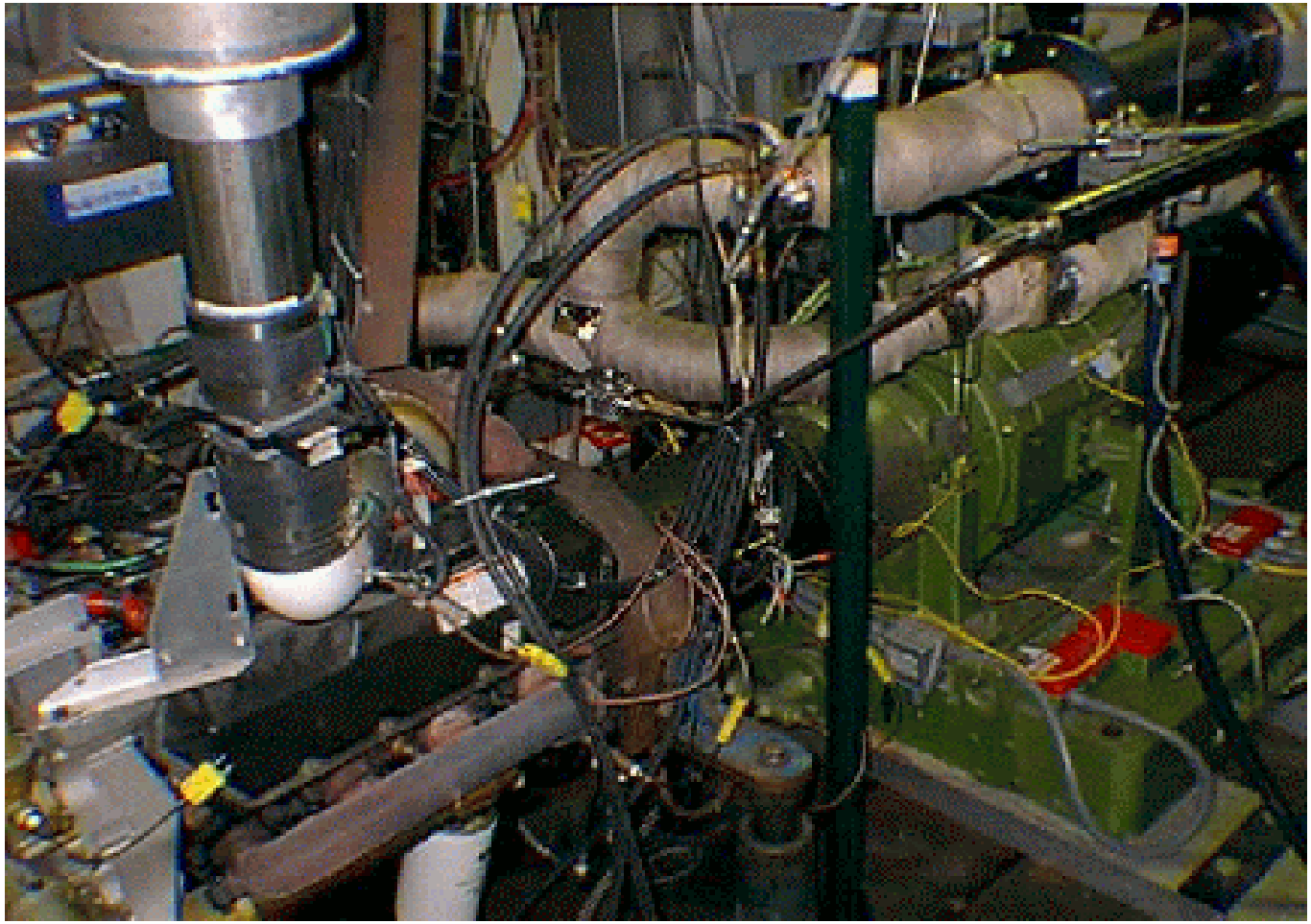
Mapped engine with secondary in-cylinder injection at peak torque and rated power RPM. Ran four point load sweep for each rpm and four HC/NOx ratios for each load point (42 point matrix).

Collected engine performance, regulated emissions and HC speciation data at each operating point. Measured over 50 compounds.

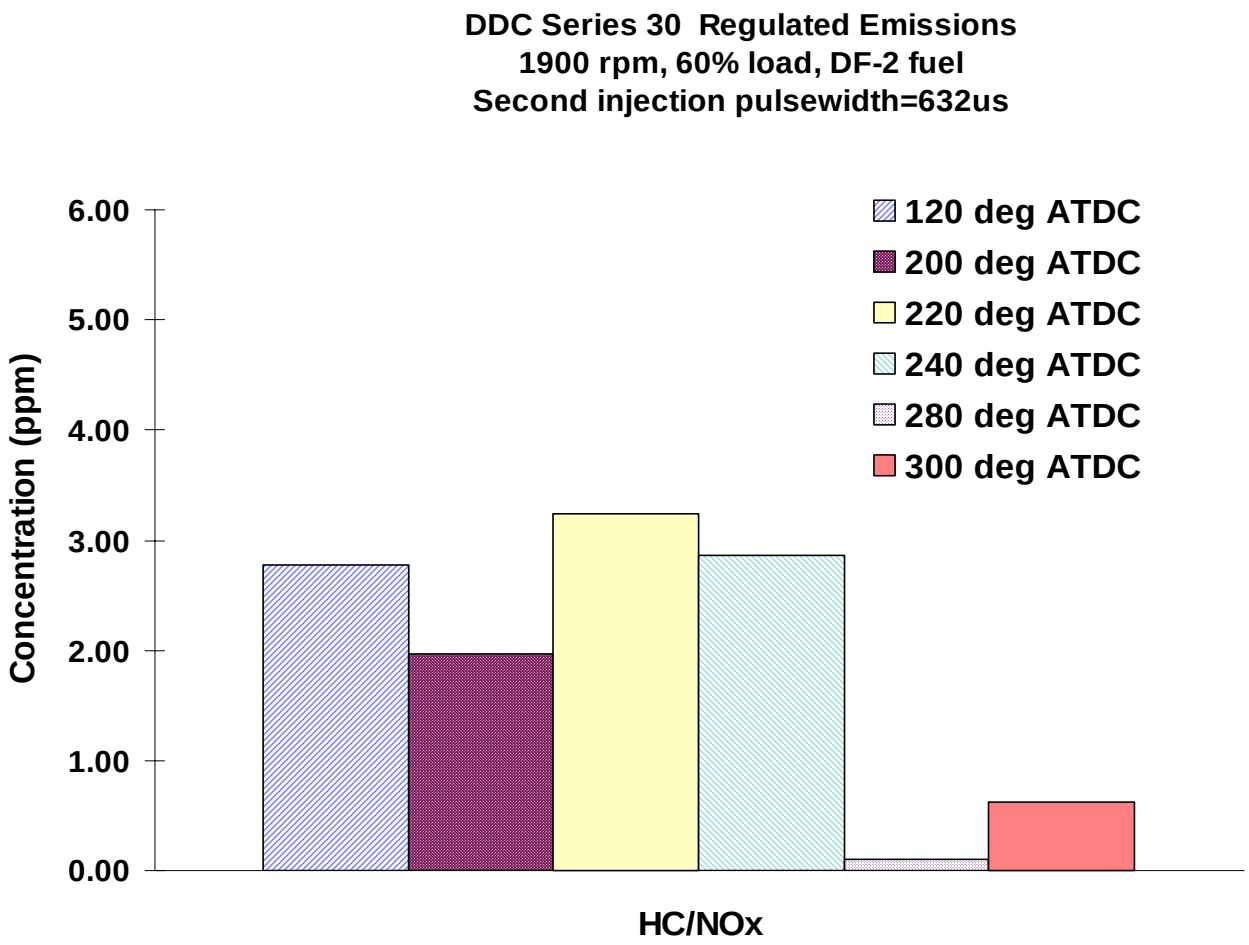
Compared emissions and HC species at turbo out and catalyst-in sampling ports.

Compared emissions and HC species generated via in-cylinder and exhaust pipe HC injection.

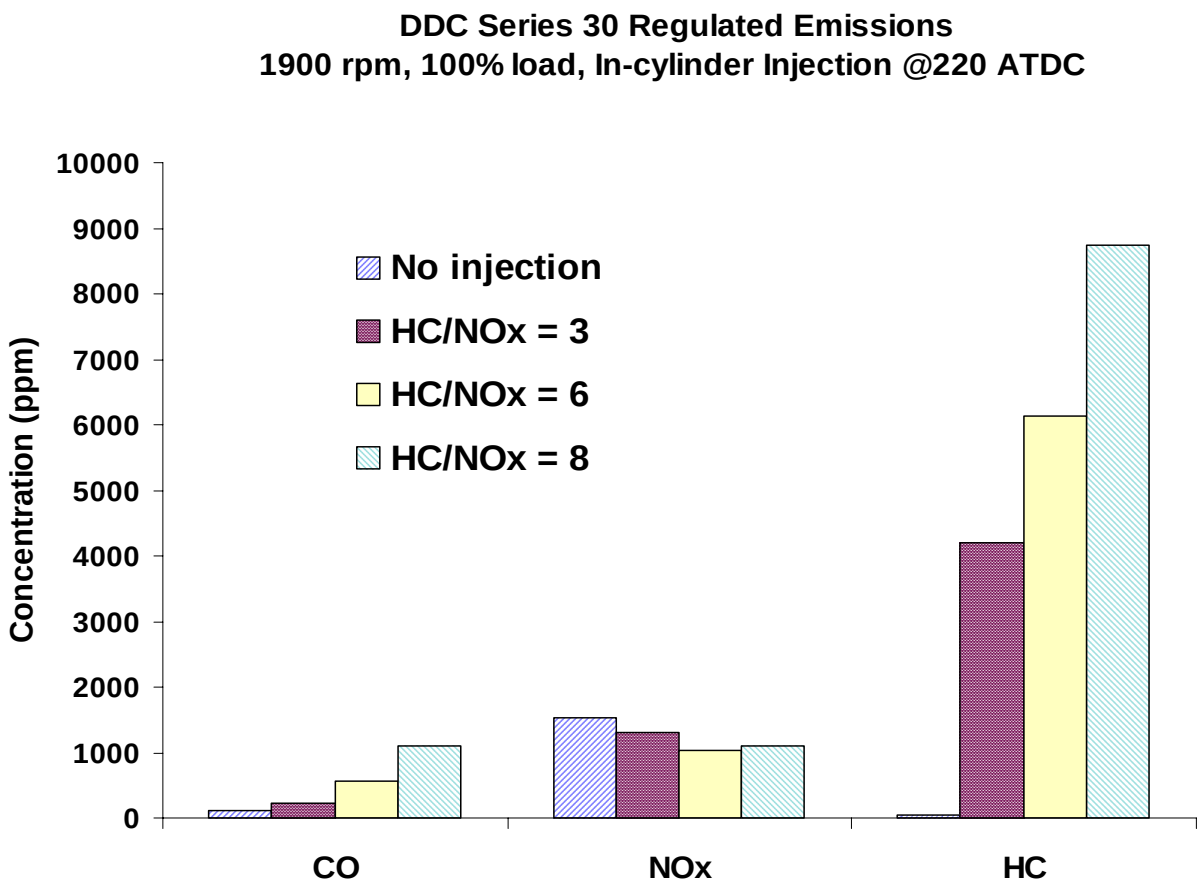
DDC series 30/Navistar 7.3 liter diesel engine installed in ORNL research cell



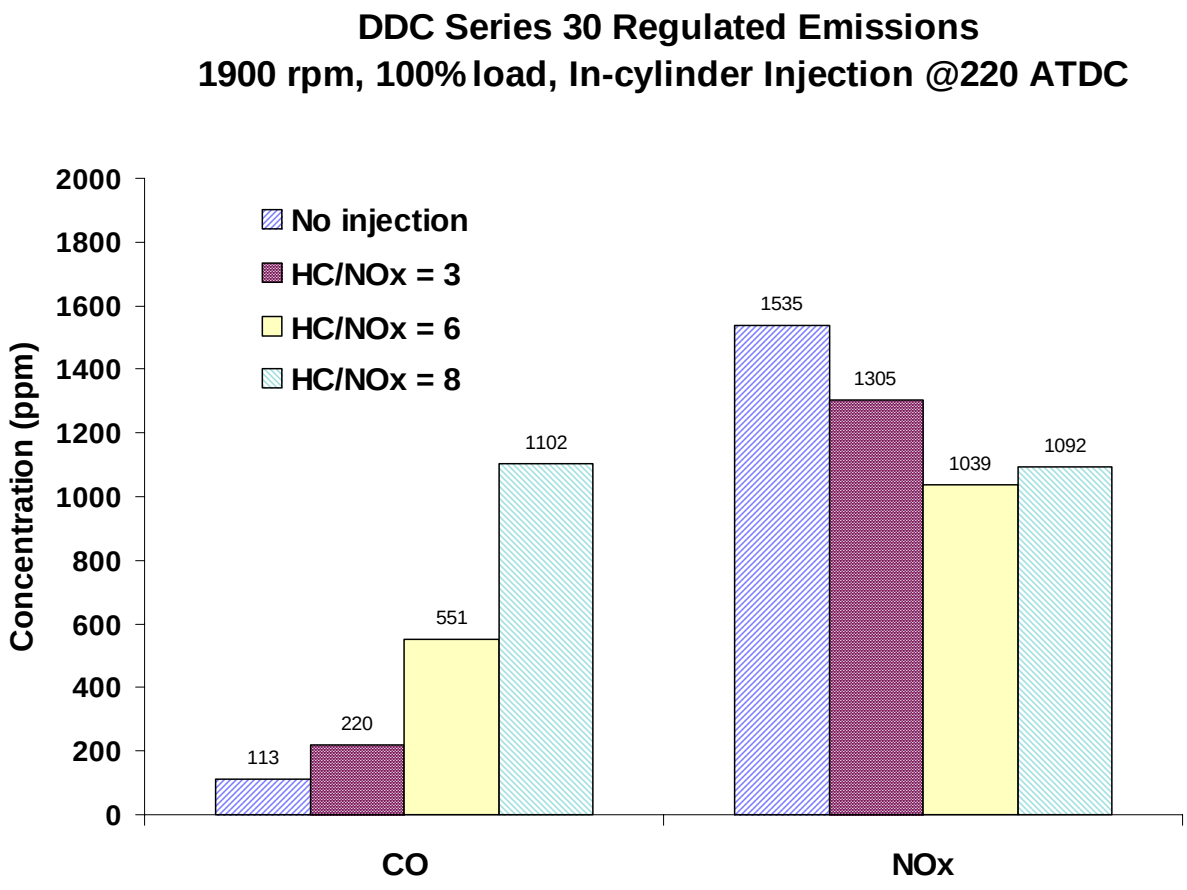
Sweep of secondary injection timing found 220 deg. ATDC gave highest HC/NOx ratio. Used for remaining tests



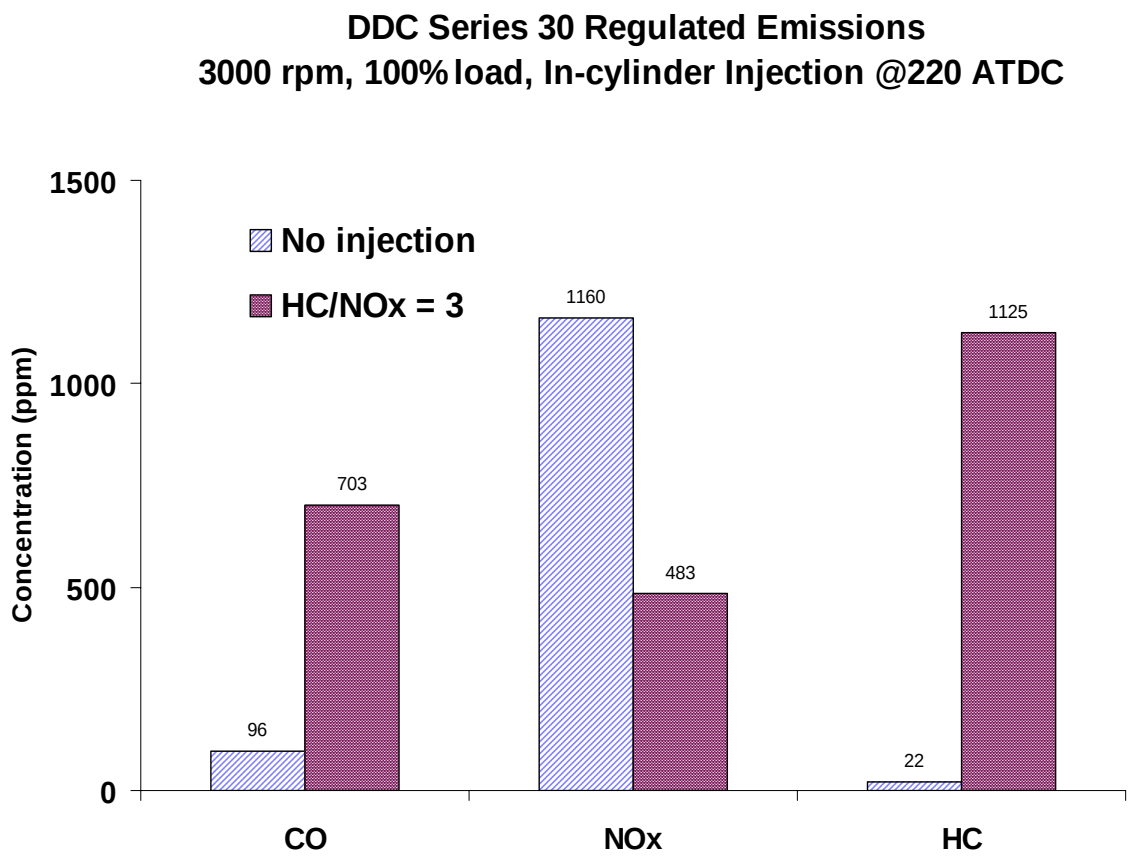
Engine out emissions at peak torque (1900 rpm) with and without in-cylinder secondary injection



In-cylinder secondary injection makes CO and reduces NOx



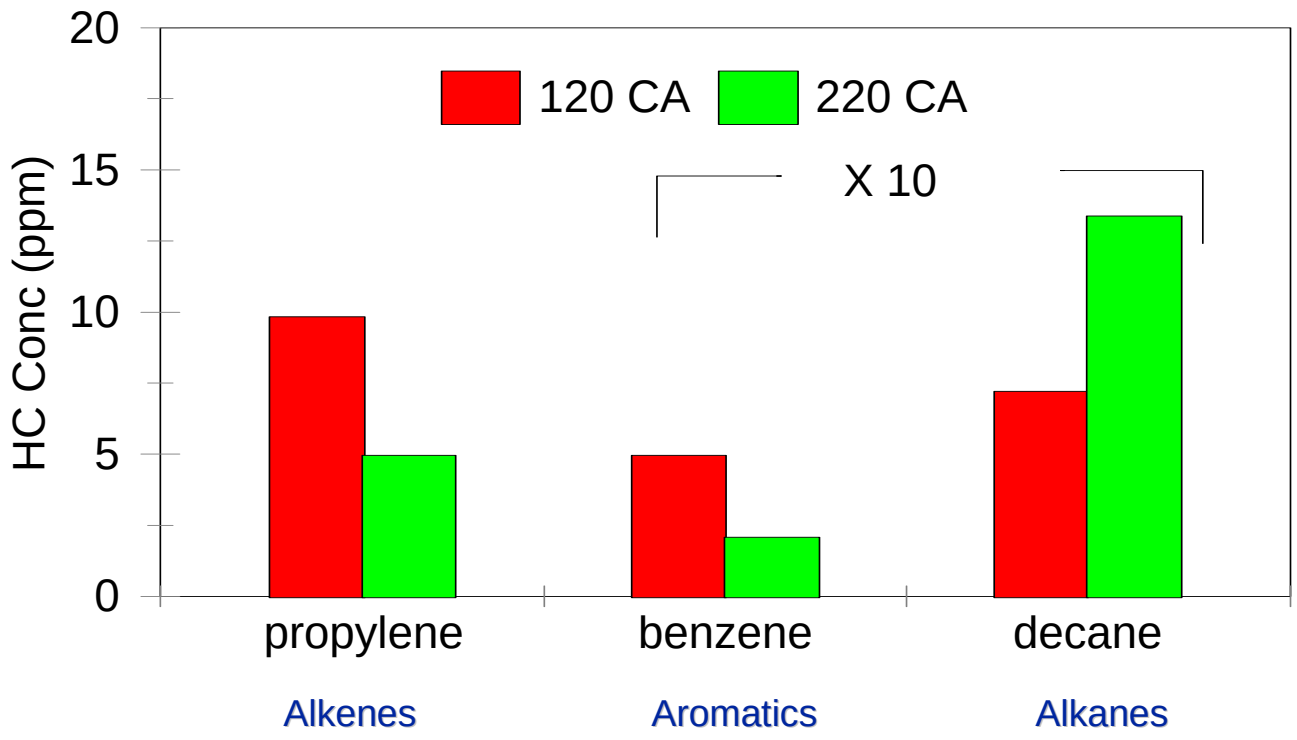
At rated power, CO levels increase sharply and NOx drops abruptly with in-cylinder secondary injection



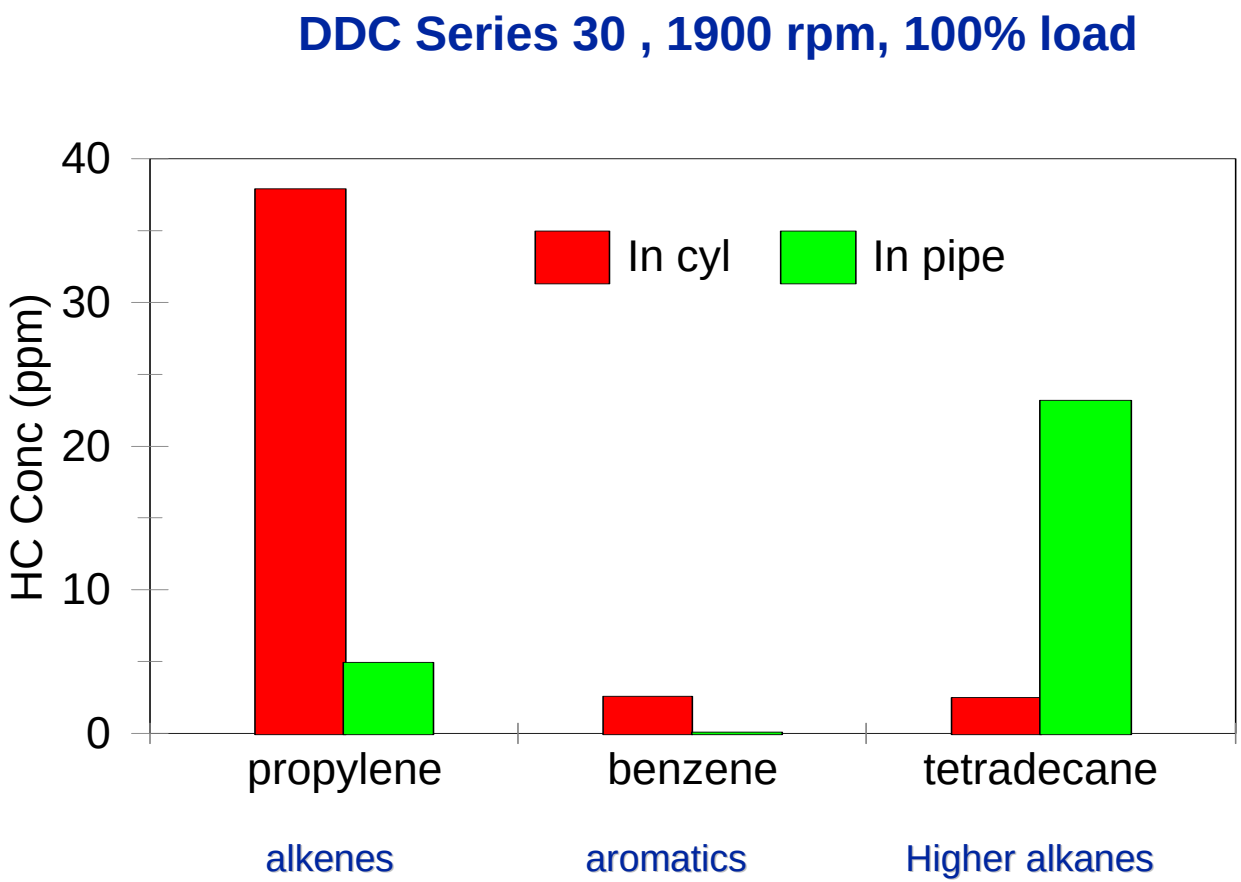
Secondary injection timing affects HC species

1900 rpm, 60% load

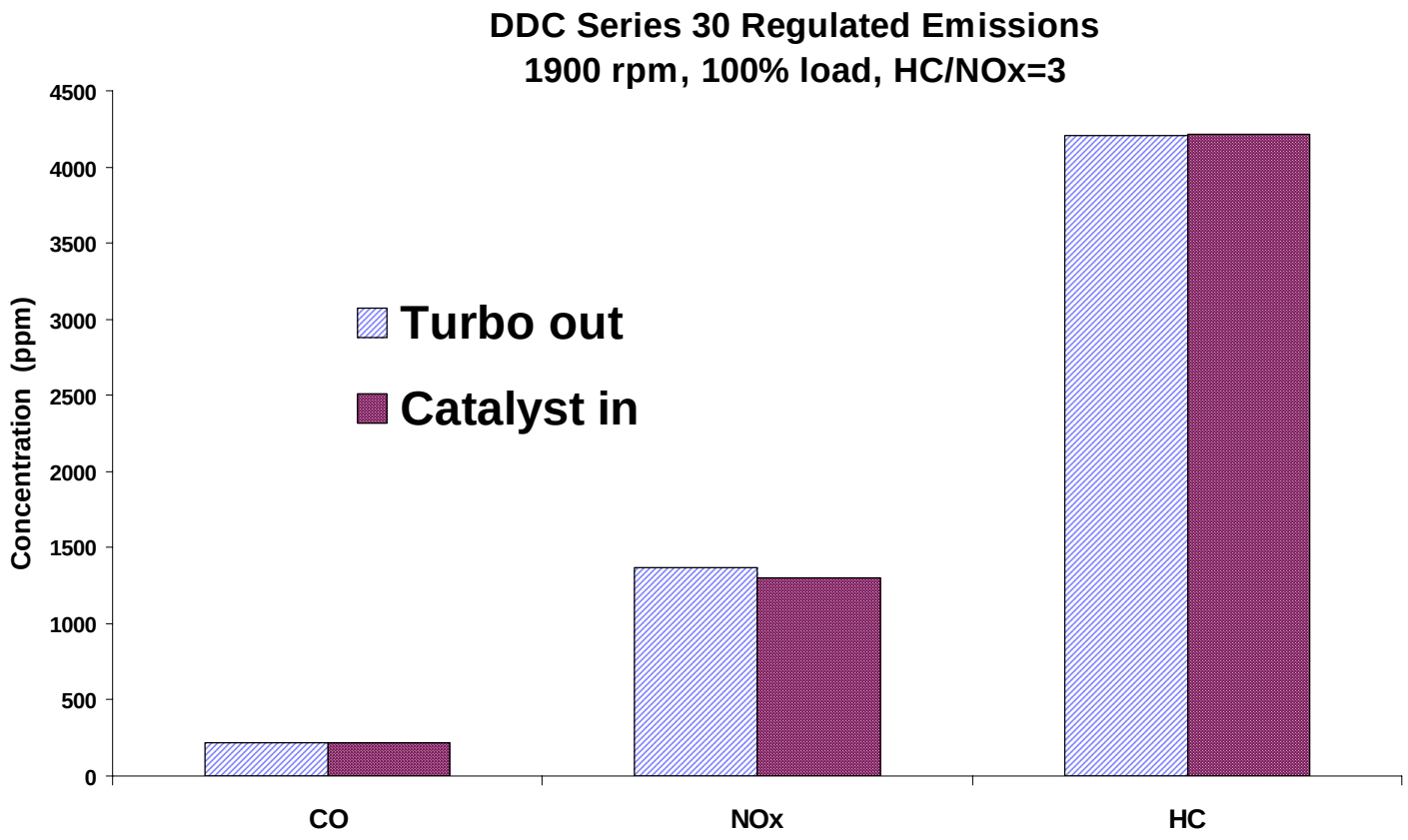
120 CA = secondary injection at 120 degrees ATDC



Late-cycle and in-pipe injection give different HCs

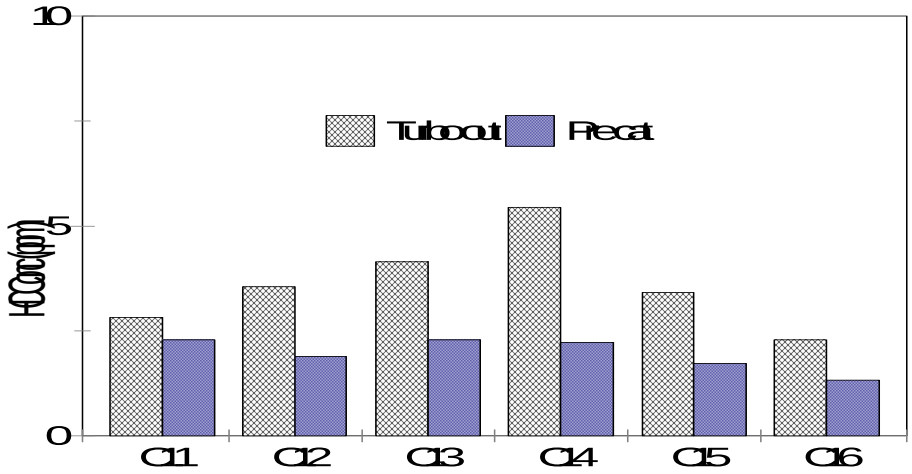


Emissions data for two sample locations indicate no substantial change in regulated emissions past turbo

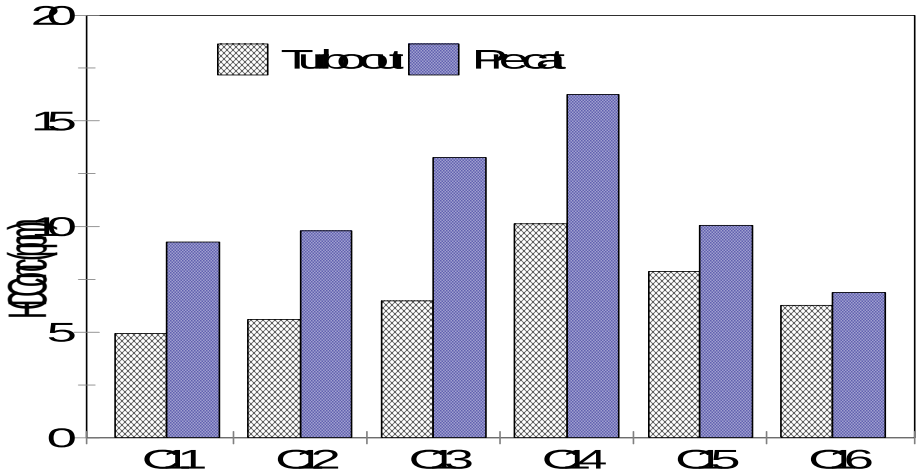


Closer inspection of HC's for two sample stations show dependence on load….exhaust temperature

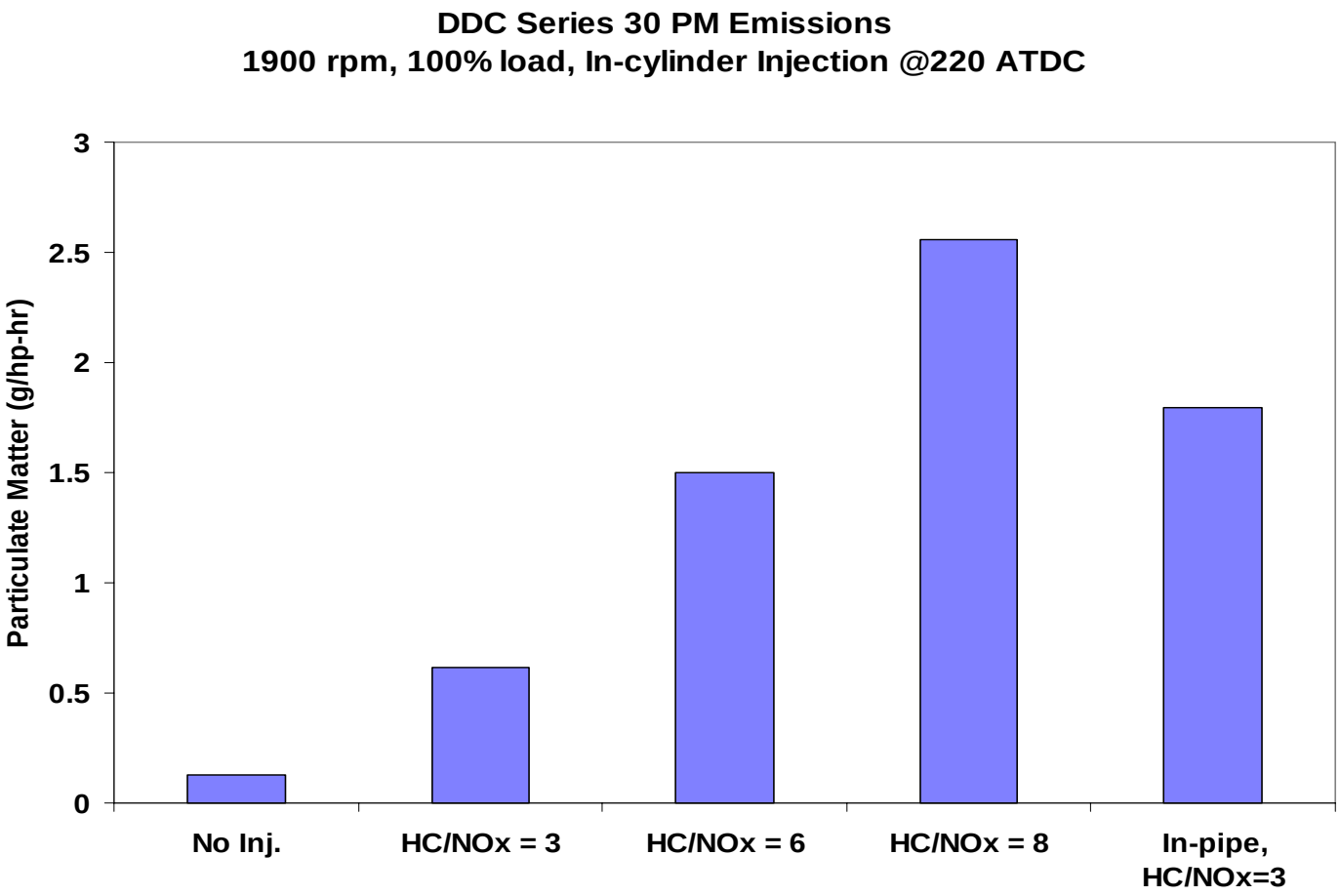
1900 rpm, 100% load



1900 rpm, 60% load



Secondary injection generates substantial PM, though mostly SOF



In-cylinder secondary injection provides different mix of HC's for catalyst

	Rating		Fraction of Total HCs	
	Precious Metal	Base Metal	HC in-cyl (changes with load)	HC in pipe (changes with load)
alkenes (e.g. ethylene)	10	6	20-50%	1-5%
Higher alkanes (>heptane)	10	10	10-20%	30-50%
Branched Alkanes	3	5	5-15%	10-30%
Mono-aromatics(e.g. benzene)	7	6	5-50%	5-25%
Oxygenated Aromatics (e.g. phenol)	0	0	0-5%	0-5%
Aldehydes (>propanal)	9	9	0-5%	0-5%
Napthalenes, PAHs	2	0	5-10%	1-10%

[1]Rating is based on relative effectiveness for lean NOx reduction

Summary observations/conclusions

•Engine out CO levels increased substantially with secondary fuel injection. Engine out NOx levels were lower. Enables NOx adsorber catalyst?

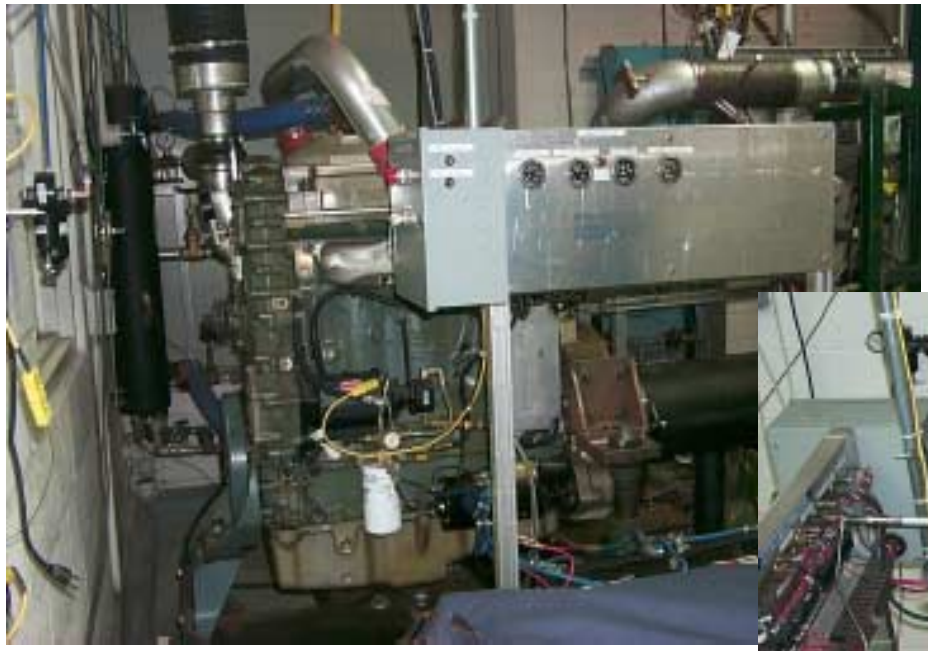
•In-cylinder injection species were affected by injection timing and HC/NOx ratios. PM emissions (mostly SOF) increased as secondary injection rates increased.

•In-cylinder HC injection makes alkenes (e.g ethylene), higher alkanes (>heptane), and mono-aromatics (benzene) which are good reductants for NOx aftertreatment systems

•.In-pipe HC injection provided very low fractions of alkenes but large fractions of higher alkanes and branched alkanes which are fair reductants for lean-burn catalysts

•No substantial change in regulated emissions past the turbo was noted for two sample locations. However, measured HC components were dependent on engine load

DDC Series 50 installation in ORNL research cell



To be used for future work.