USDRIVE and Advanced Engine Crosscut Teams: Roadmaps and Protocols

USDRIVE Low Temperature Aftertreatment Team

(sub-group of the Advanced Combustion and Emission Control Tech Team)

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Galen Fisher (UMich)
Ken Howden (DOE)

USDRIVE and 21st Century Truck are two major Government-Industry Partnerships in Transportation

USDRIVE

DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

Partners:

USCAR (United States Council for Automotive Research LLC)
FCA (Fiat Chrysler Automobiles)
Ford
GM
Tesla
bp
Chevron
Phillips 66
ExxonMobil
Shell
DTE Energy
Southern California Edison (An Edison International® Company)
EPRI (Electric Power Research Institute)

Associate Members at the Technical Level

www.vehicles.energy.gov/about/partnerships/usdrive.html

21st CENTURY TRUCK PARTNERSHIP

INDUSTRY PARTNERS

Allison Transmission
Meritor
BAE Systems
Caterpillar
Cummins
Daimler
Detroit Diesel
Eaton (Powering Business Worldwide)
Honeywell
Navistar
Oshkosh
Paccar Inc
Volvo
Mack
Novabus

GOVERNMENT PARTNERS

The Advanced Combustion and Emission Control Tech Team is relevant to emissions control

Advanced Combustion and Emission Control Tech Team

Low Temperature Aftertreatment Team

CLEERS is part of the Advanced Engine Crosscut Team (USDRIVE and 21st Century Truck)

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

21st CENTURY TRUCK PARTNERSHIP

Advanced Combustion and Emission Control Tech Team

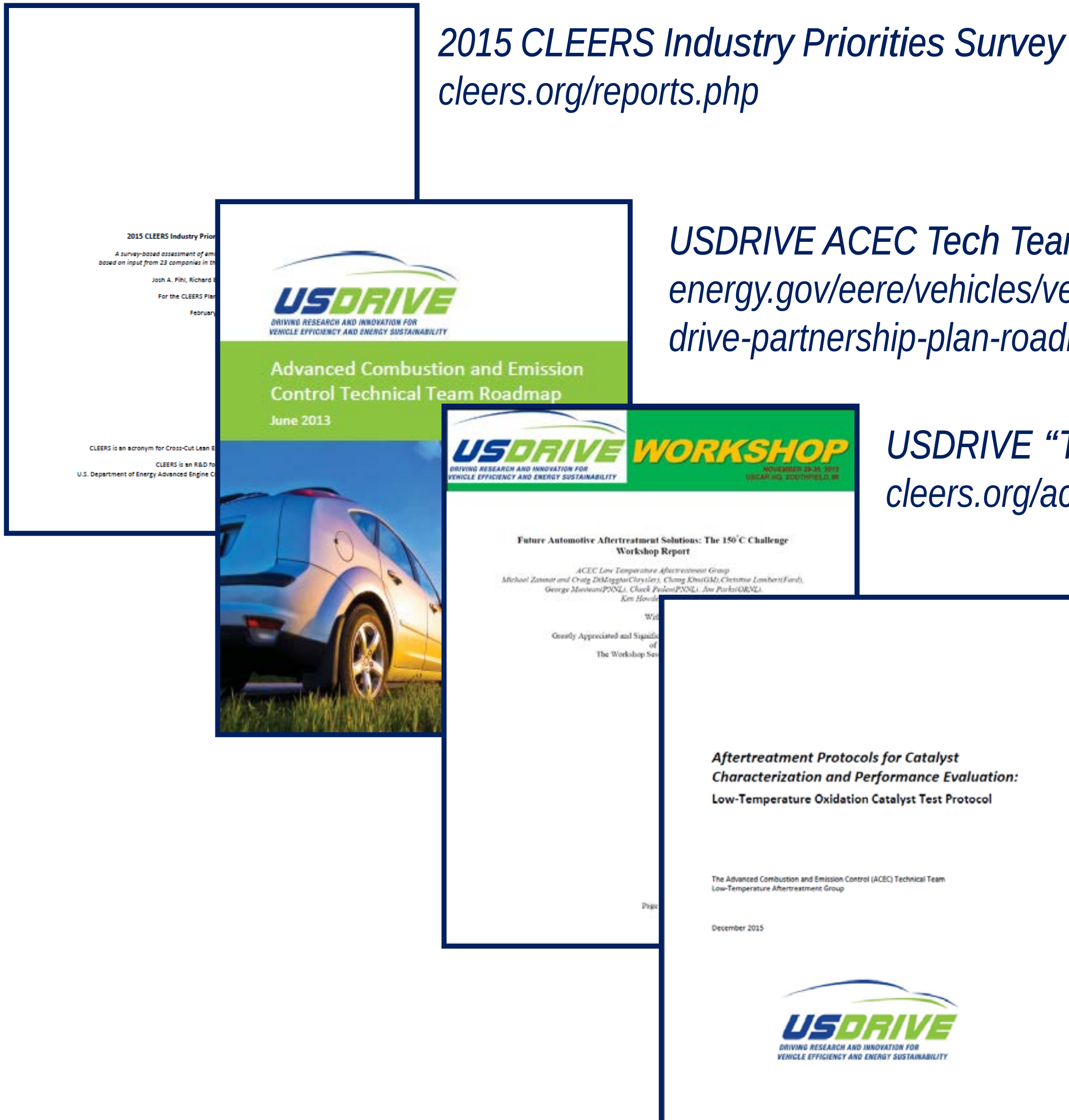
Engine R&D Team

Advanced Engine Crosscut Team

CLEERS

<u>CLEERS</u> = **<u>C</u>**rosscut **<u>L</u>**ean (/**<u>L</u>**ow-temperature) **<u>E</u>**xhaust **<u>E</u>**missions **<u>R</u>**eduction **<u>S</u>**imulations

Important Partnership Documents for CLEERS Community



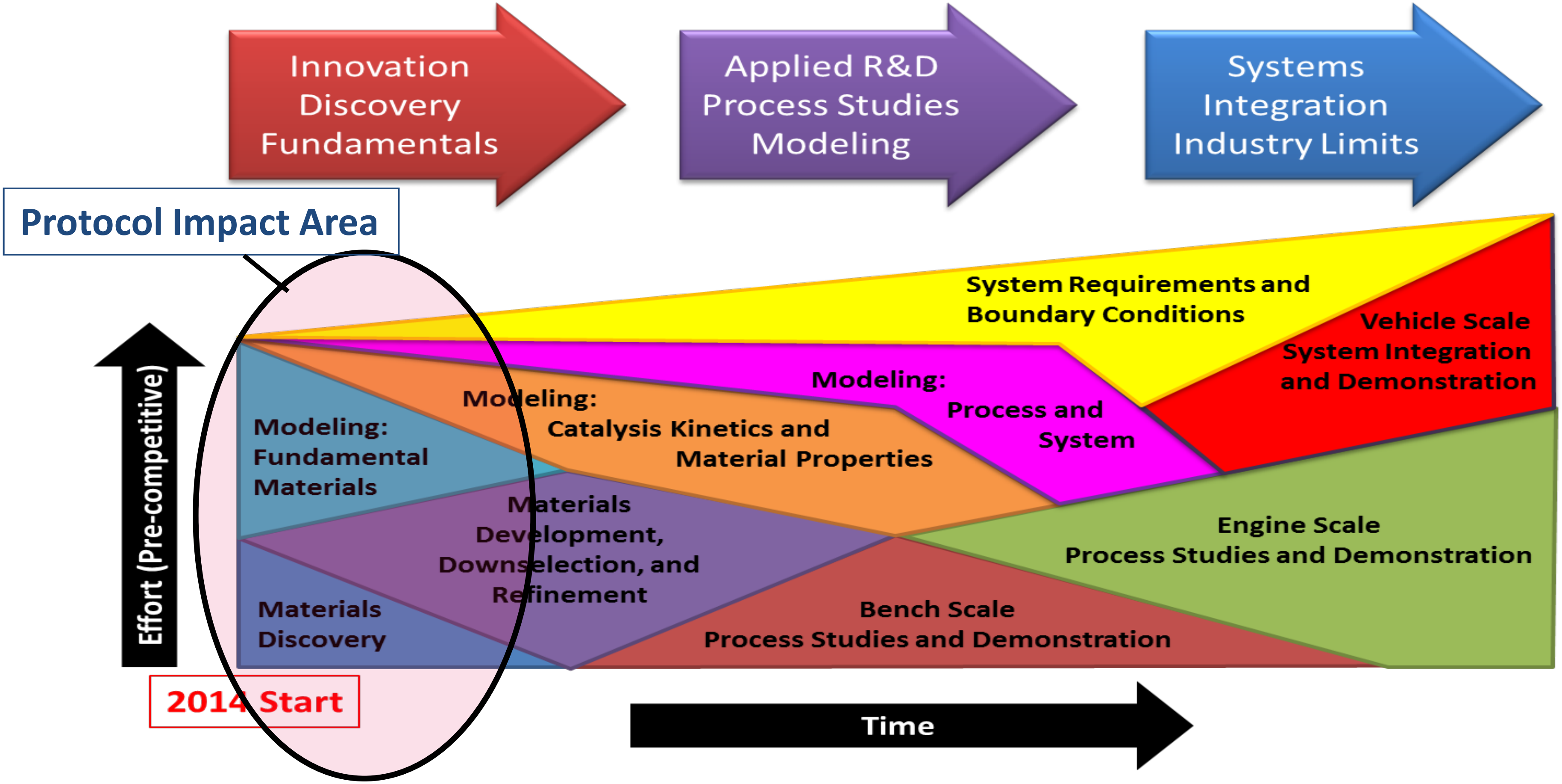
2015 CLEERS Industry Priorities Survey ***New!***
cleers.org/reports.php

USDRIVE ACEC Tech Team Roadmap
energy.gov/eere/vehicles/vehicle-technologies-office-us-drive-partnership-plan-roadmaps-and-accomplishments

USDRIVE "The 150ºC Challenge" Workshop Report
cleers.org/acec-lowt

USDRIVE Low Temperature Oxidation Catalyst Test Protocol
cleers.org/acec-lowt

Roadmap 2014 LTAT Technical Path Forward **(Protocol Intent)**



- Primary focus is inception stage material R&D
  - Accelerate the pace of development of appropriate catalyst technologies
  - Quickly "weed-out" inappropriate technologies early in development
- Verification and sharing of results across the technical community

2015 CLEERS poster

The **Advanced Combustion and Emission Control (ACEC)** Technical Team

Low Temperature Aftertreatment (LTAT) working group

Including representatives from:

- FCA, Ford, GM, ORNL, PNNL, & DOE

AFTERTREATMENT PROTOCOLS FOR CATALYST CHARACTERIZATION AND PERFORMANCE EVALUATION

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Why

- Harmonize aftertreatment direction with emerging combustion strategies
- Assist DOE and USDRIVE in evaluation & management of projects
- A pathway for ***comparative*** evaluation and benchmarking
- Accelerate pace of catalyst innovation by maximizing value and impact of reported data

Consistent and realistic standardized catalyst test procedures that sufficiently capture a catalyst technology's performance capability

- ❑ *Solely intended as guidelines for sharing results of research with the technical community*
- ❑ *Meant to be broadly shared in public forum to evaluate and benchmark performance*
- ❑ *NOT meant to replace or dictate individual research institute protocols*

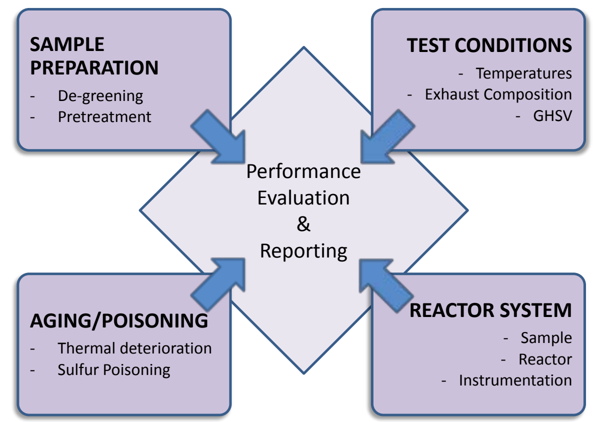
Aspirations

- General community consensus
- Consistent with anticipated technologies
- Reproducible, adaptable in various labs
- Be practical and have utility
- Literature citations

Protocol Considerations

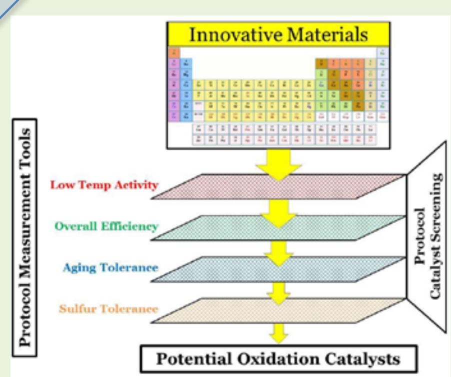
Performance ⇕ Modeling	**RESEARCH ACTIVITY THE PROTOCOL IS SUPPORTING** – Discovery stage: screening for overall performance, global in nature – Elementary step-based modeling: isolating each reaction/ads./des. step – Typically governed by relative maturity of technology – Will dictate complexity of the test methodologies employed
Conversion ⇕ Passive Adsorption	**TYPE OF FUNCTIONALITY BEING STUDIED** – Conversion: Rate (single reaction or class of reactions) versus temperature – Adsorption: Rate (ads/des) ***PLUS*** capacity ***PLUS*** desorption temperature – Adsorption characterization (procedures and equipment) more complex
Functionality ⇕ Device	**COMPLEXITY OF THE AFTERTREATMENT PROCESS** – Singular functionality: conversion- or adsorption-based – Device (e.g., system): often involves multiple functionalities (e.g., NSR) – Dictates complexity of steps required for adequate characterization
Combustion Platform	**ENGINE TYPE AND COMBUSTION STRATEGY** – Diesel versus Gasoline – Stoichiometric versus Lean combustion – Conventional versus "Advanced" low-temperature combustion (e.g., RCCI)

Protocol Structure



An update on "round robin" study provided

STEP 1 – Low-Temperature Oxidation

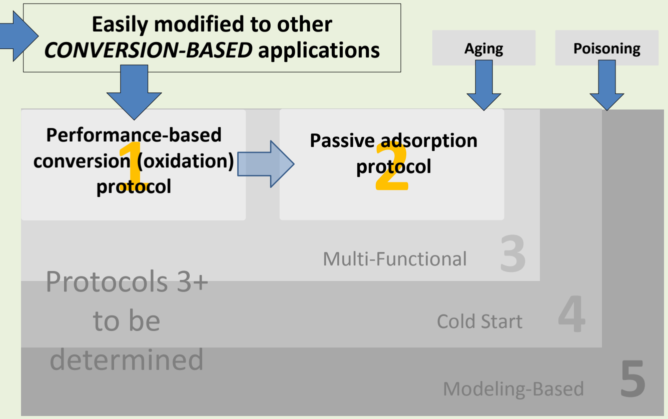


Performance

Conversion

Functionality ***AND*** Device

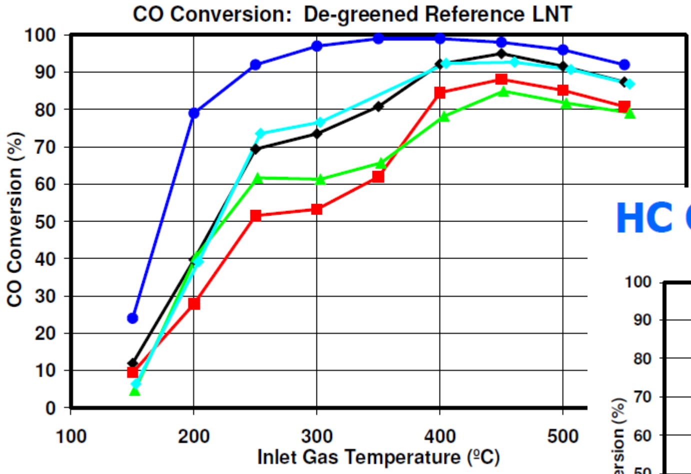
Easily modified to other *CONVERSION-BASED* applications



- **Additional protocols will be generated as needed based on technology area**

Round Robin Testing is Hard

CO Conversion

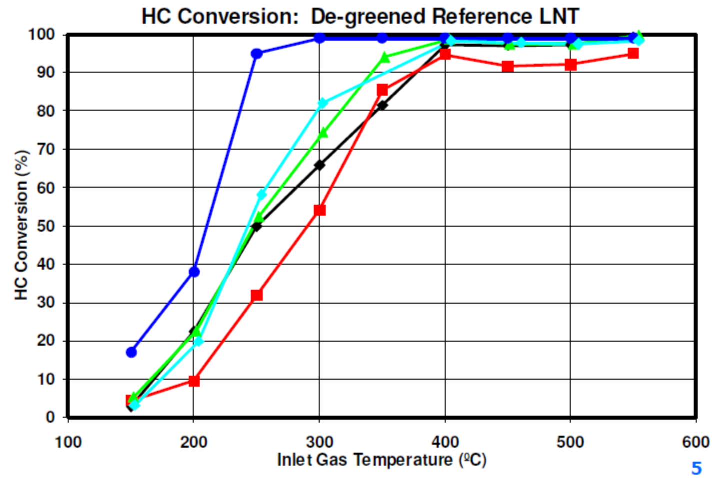


2004 DOE Crosscut Team Presentation

LNT Catalyst: Round Robin Testing at Six Labs

Data provided by **Ford**

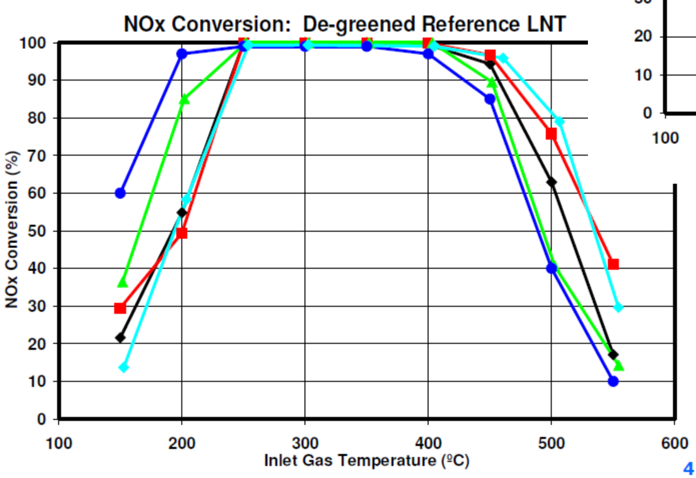
HC Conversion



Production LNT

Five catalyst supplier labs
OEM lab

NOx Conversion



Summary

- For now
  - Cannot compare results between labs reliably
  - Published data can't be compared!
- Future
  - Need repeatable tests with adequate precision
  - Avoid duplication of efforts
  - Enable analysis based on published data

Round Robin Testing
The Devil is in the Details

USDRIVE Low Temperature Oxidation Catalyst Test Protocol
cleers.org/acec-lowt

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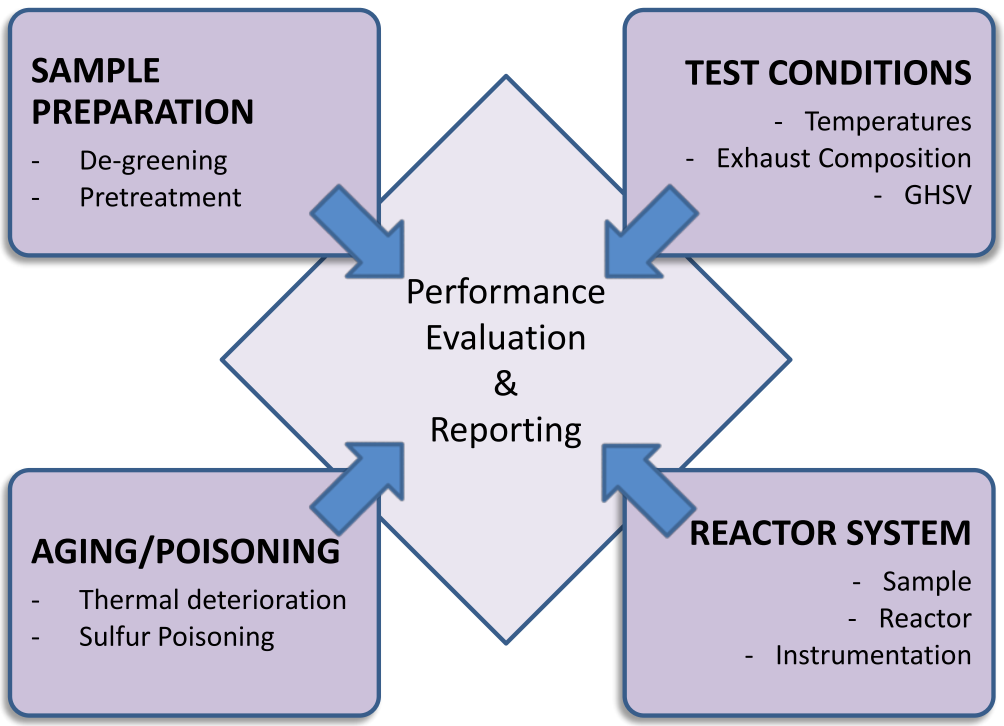
Consistent and Realistic Standardized Catalyst Test Procedures …

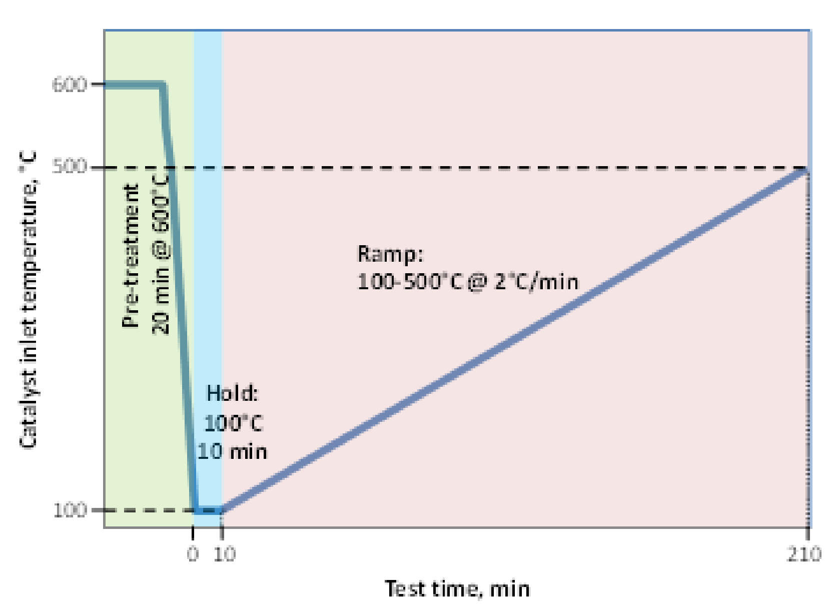
- General community consensus
- Consistent with anticipated technologies
- ***Reproducible, adaptable in various labs***
- Be practical and have utility
- To have utility, must be validated

Protocol Structure



Low Temperature Oxidation Catalyst Test Protocol
Round Robin Testing

Constant components	S-GDI	CDC		L-GDI	LTC-G	LTC-D
$[O_2]$	0.74%	**12%**		9%	12%	12%
$[H_2O]$	13%	**6%**		8%	6%	6%
$[CO_2]$	13%	**6%**		8%	6%	6%
$[H_2]$	1670 ppm	**100 ppm**		670 ppm	670 ppm	400 ppm
Variable components	all in [ppm]					
[CO]	5000	**500**		2000	2000	2000
[NO]	1000	**200**		500	100	100
	Hydrocarbon – [ppm] on C_1 basis**					
Total [HC]	3000	**1400**		3000	3000	3000
$[C_2H_4]$	700 (1050)	**500 (778)**		700 (1050)	700 (1050)	500 (1667)
$[C_3H_6]$	1000 (1500)	**300 (467)**		1000 (1500)	1000 (1500)	300 (1000)
$[C_3H_8]$	300 (450)	**100 (155)**		300 (450)	300 (450)	100 (333)
$[i\text{-}C_8H_{18}]$	1000 (0)	**-**		1000 (0)	1000 (0)	-
$[n\text{-}C_{12}H_{26}]$	-	**500 (0)**		-	-	2100 (0)



Production DOC

Tested by Ford, GM, ORNL, PNNL

Cores from same DOC brick, separate samples tested at each facility

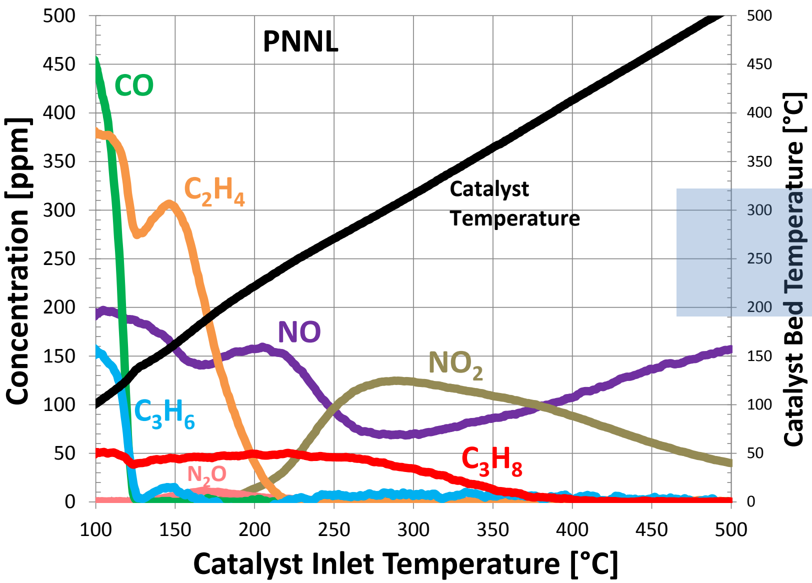
<u>Each Facility</u>

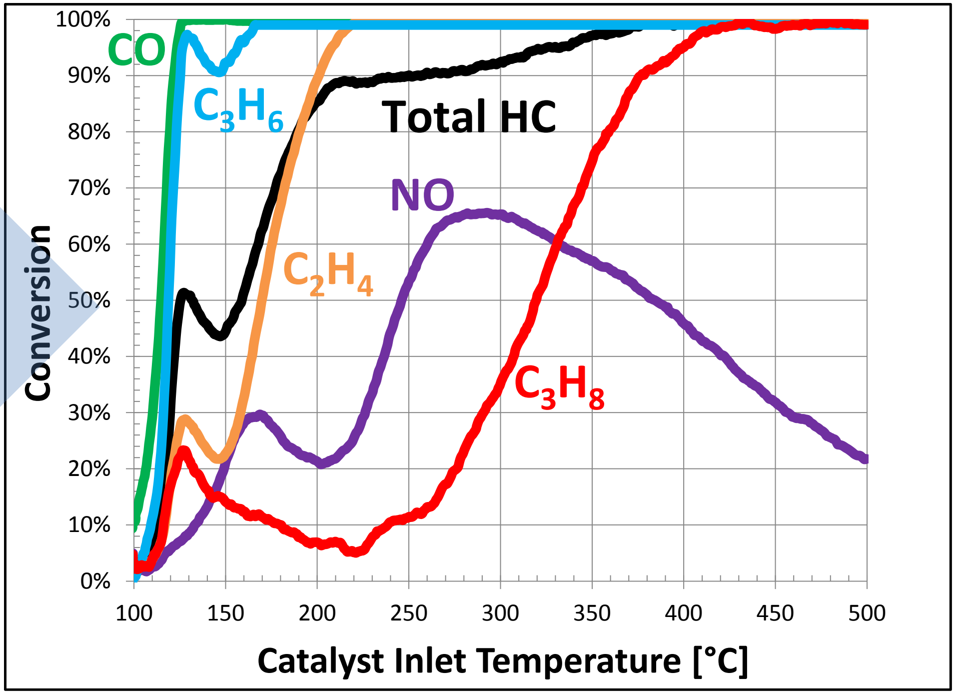
1. De-greened ⟶ Activity Testing
2. Aged ⟶ Activity Testing

TARGET ~90% agreement
of T50 and T90 results
(i.e., standard deviation <10%)

How Did We Do?

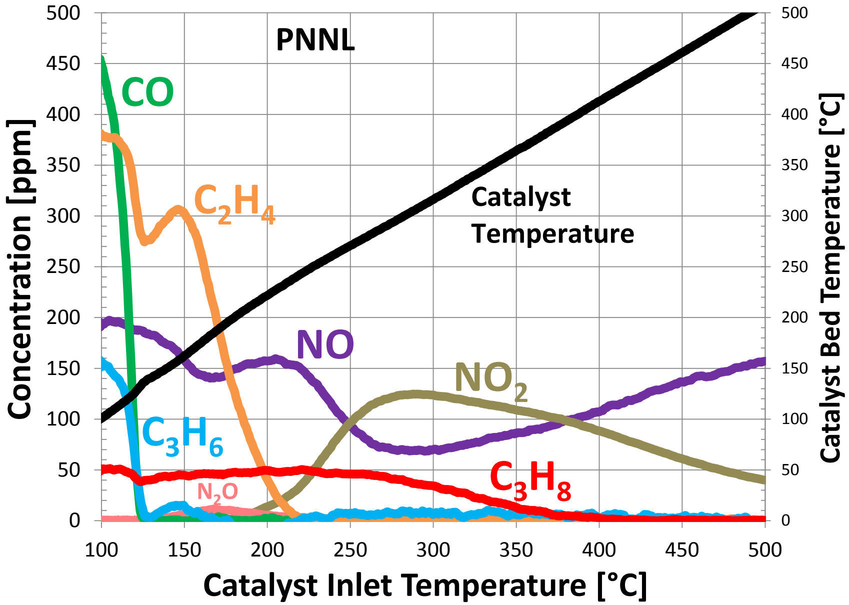
Round Robin Testing
Degreened DOC, CDC Protocol

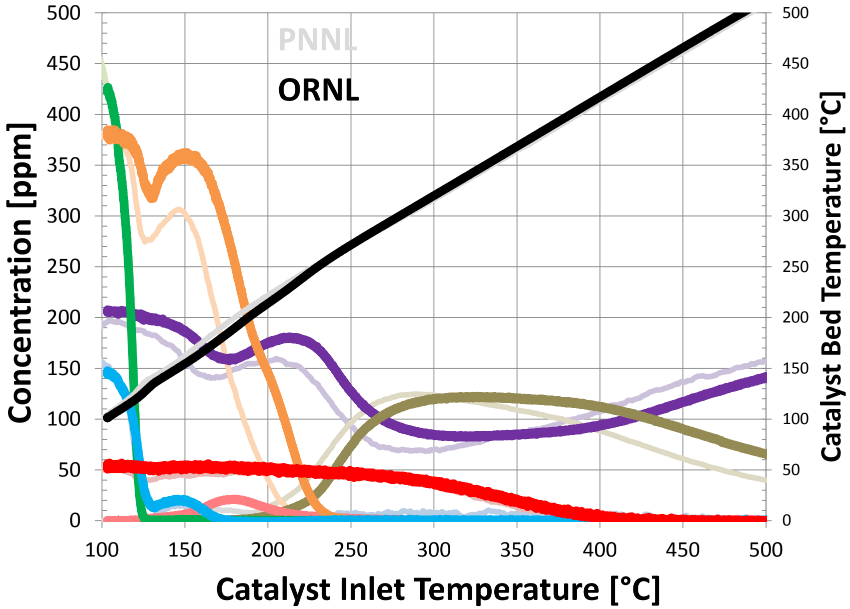


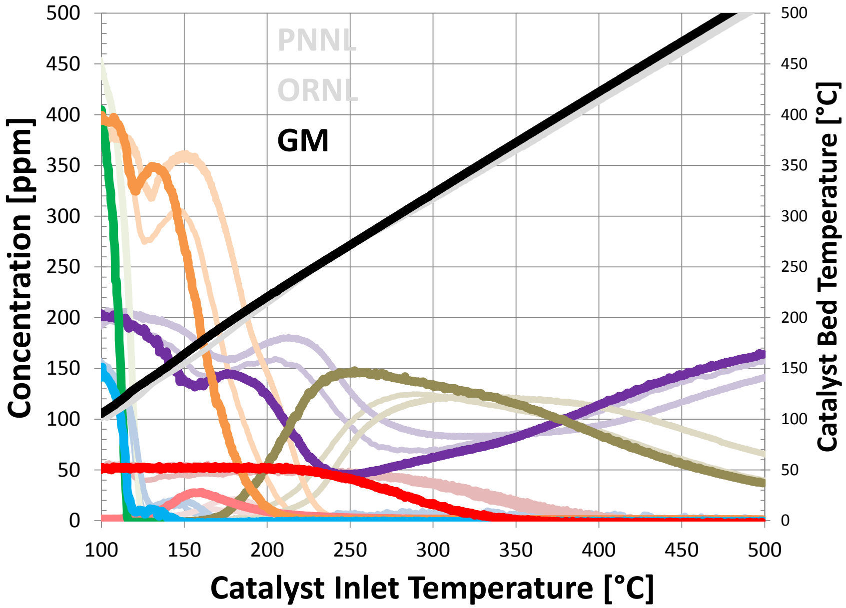


- Raw data generated as *<u>concentration vs. temperature</u>*
  - Converted to *<u>conversion vs. temperature</u>* for identification of T50s and T90s
- **Focus**: reproducibility of light-off chemistry, lab to lab results
- *<u>Detailed</u>* catalyst chemistry out of scope for purposes of RR
- HC blend shows good representation of low & high temperature activity

Round Robin Testing
Degreened DOC, CDC Protocol







[ppm] shown instead of conversion for simplicity

Some spread in data expected and unavoidable

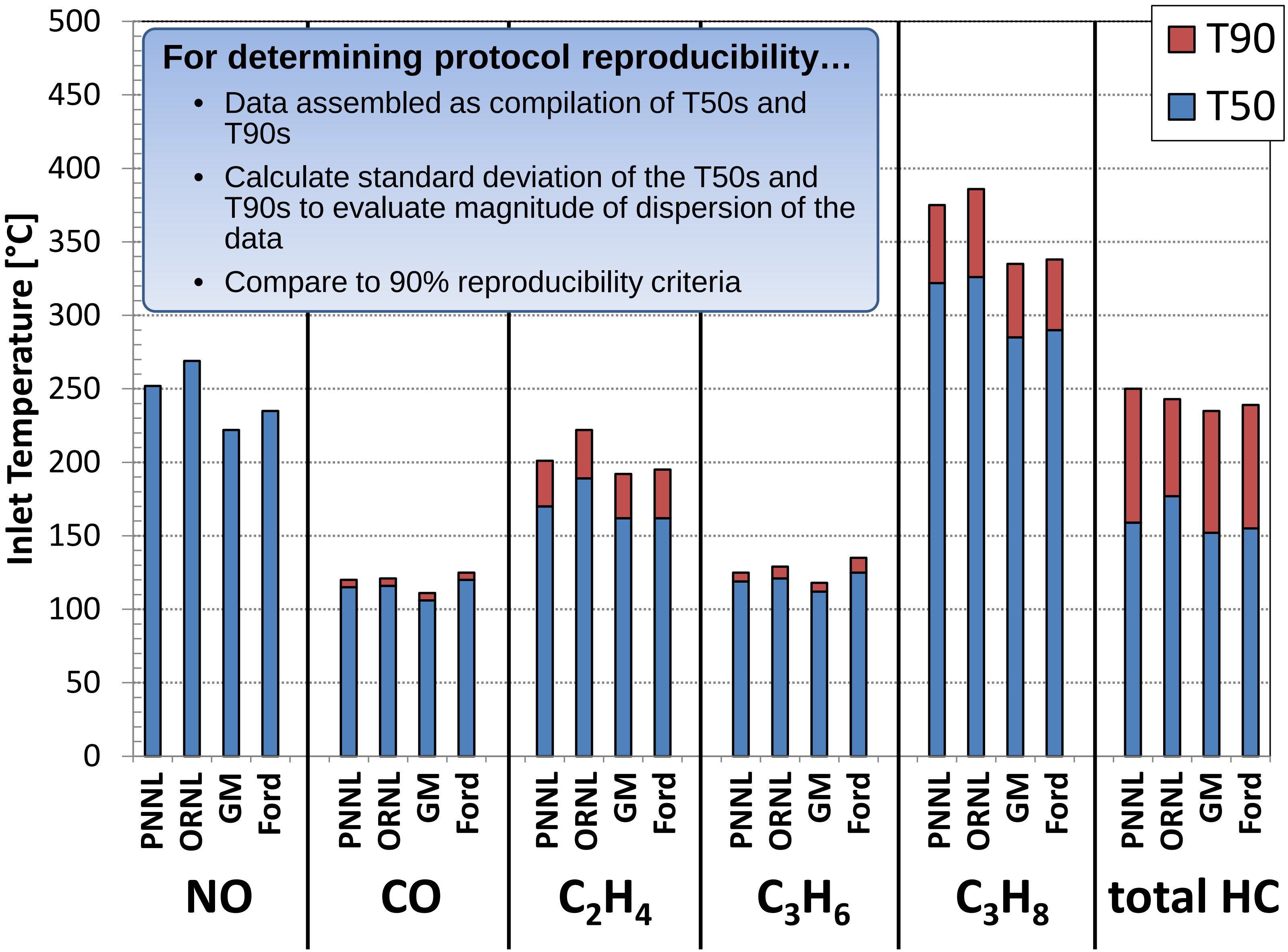
- Different labs with unique …
  - furnace(s) size/length
  - exact catalyst placement
  - thermocouple size/length
  - analytical method development

Although detailed chemistry out of scope, catalyst ***behavior*** reproduces well

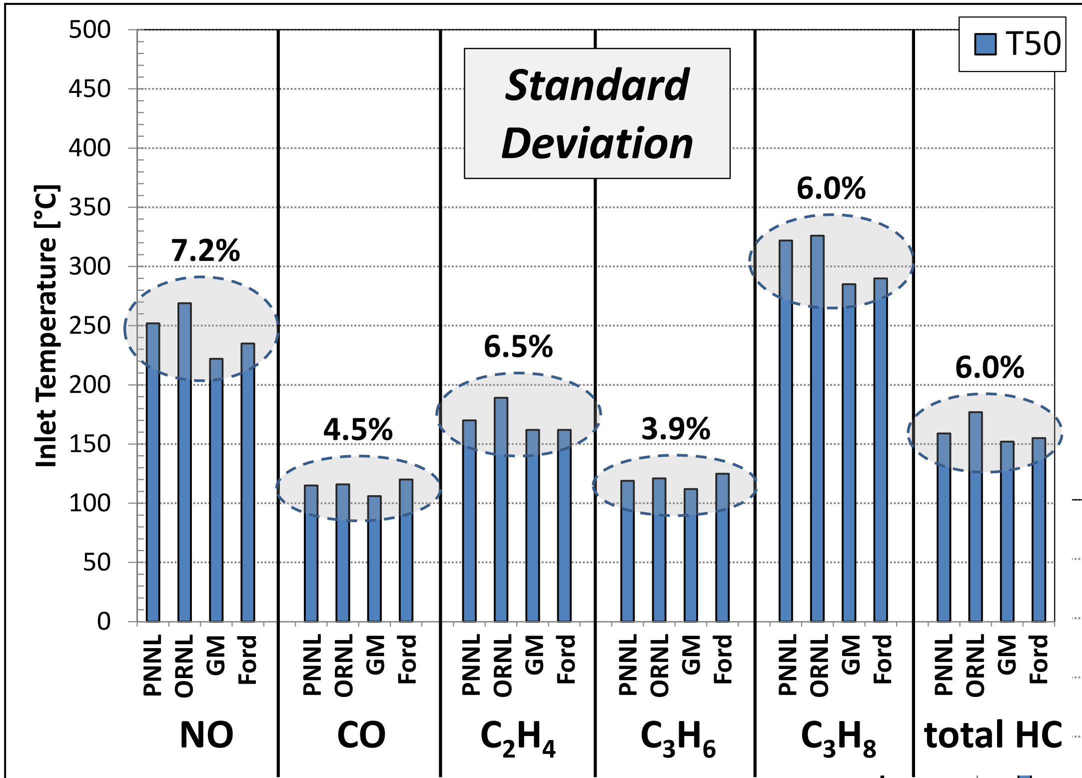
Round Robin Testing
Degreened DOC, CDC Protocol

For determining protocol reproducibility…

- Data assembled as compilation of T50s and T90s
- Calculate standard deviation of the T50s and T90s to evaluate magnitude of dispersion of the data
- Compare to 90% reproducibility criteria

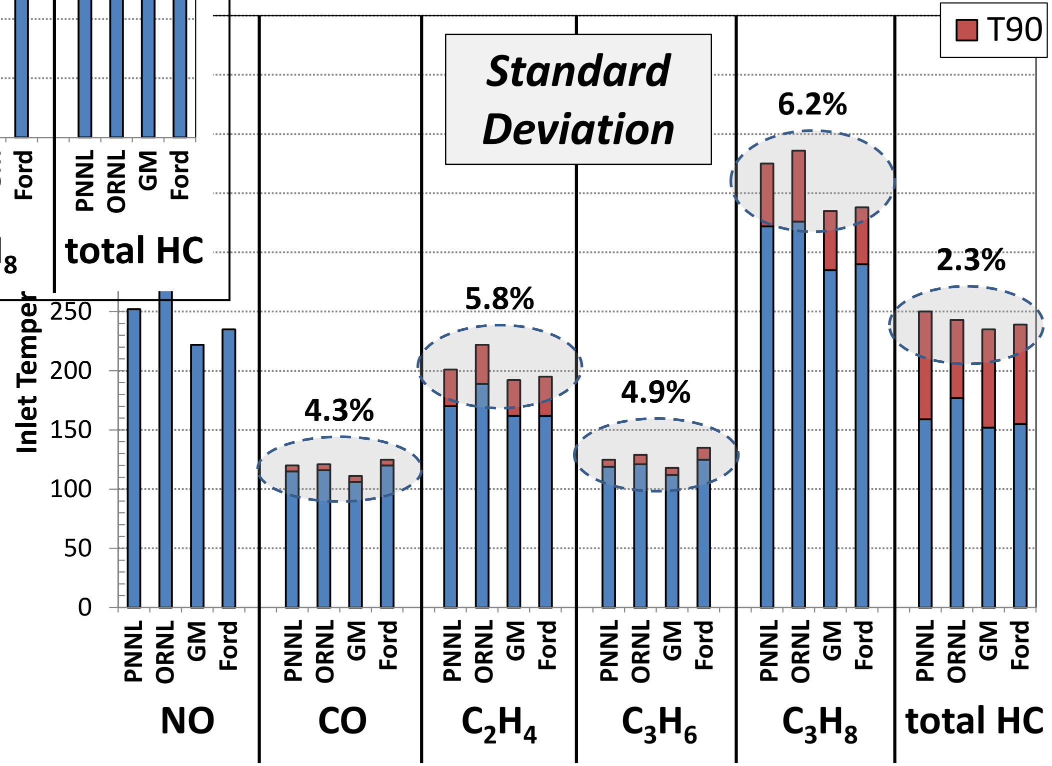


Round Robin Testing
Degreened DOC, CDC Protocol



Degreened catalyst, referencing activity to ***inlet temperature*** …

Reproducibility criteria met for both T50 and T90 data

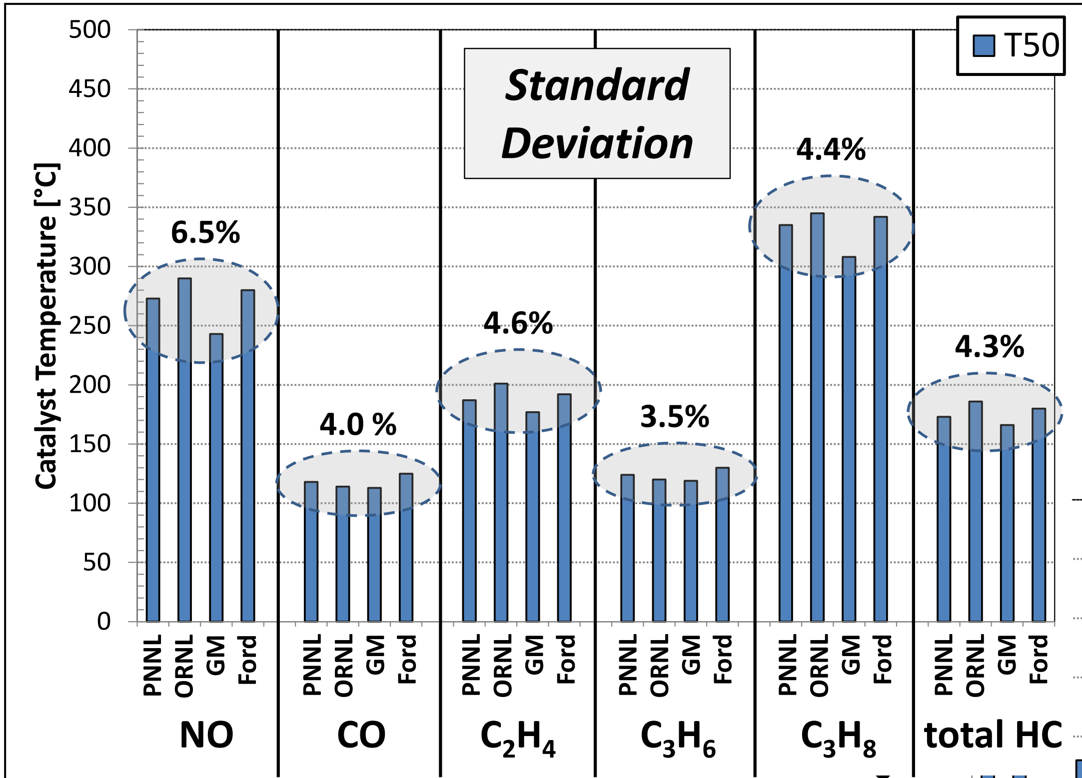


Consistent patterns and magnitudes in the comparative results between labs

- e.g., ORNL T50/T90 consistently highest, GM consistently lowest

Suggests potential for further improvement

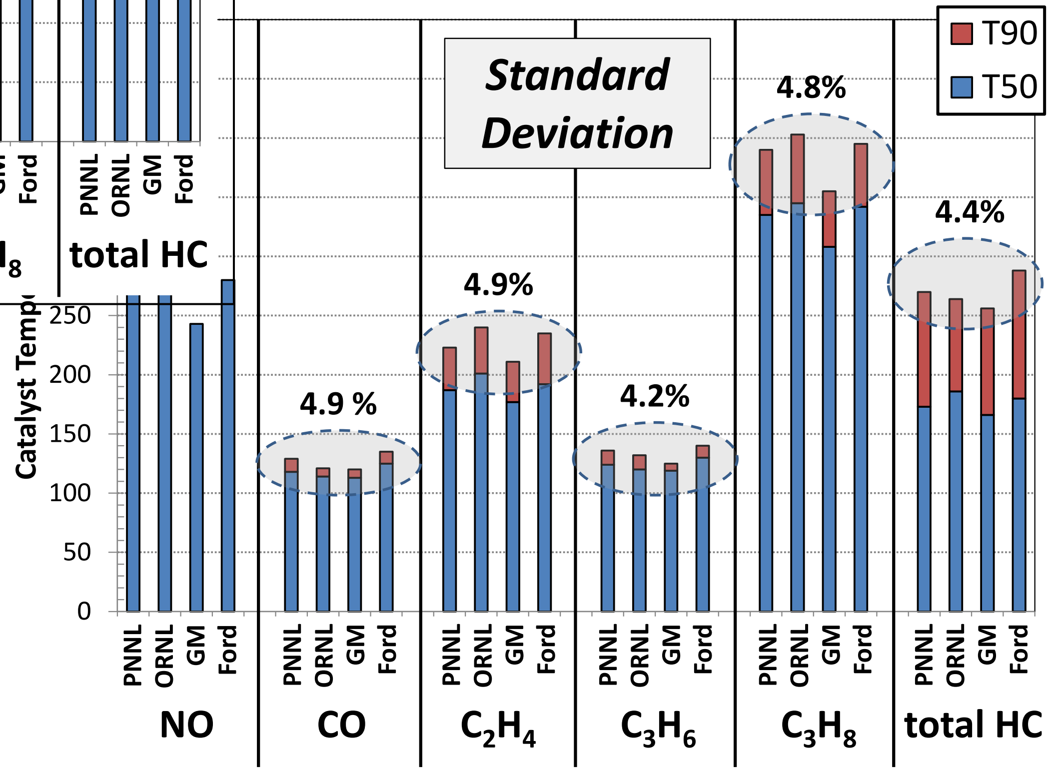
Round Robin Testing
Degreened DOC, CDC Protocol



… when referencing activity to ***catalyst bed temperature*** …

Reproducibility criteria met for both T50 and T90 data

>95% reproducibility

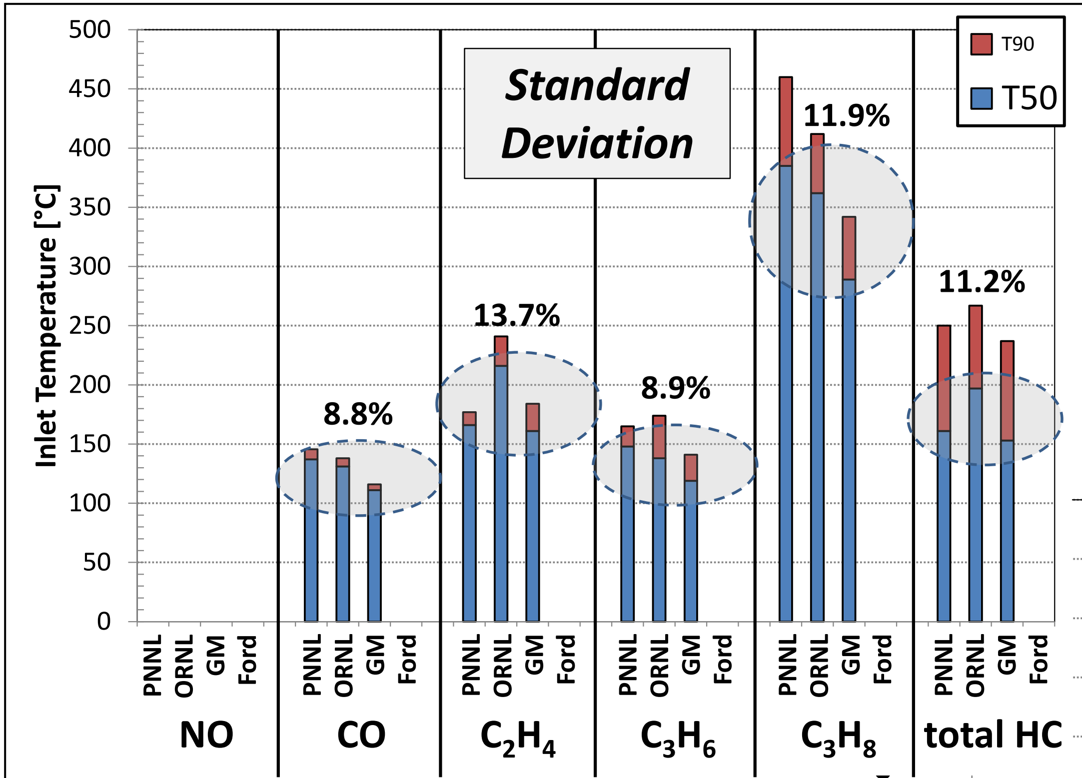


No pre-determined standard placement of catalyst bed thermocouple

Only inlet thermocouple placement explicitly stipulated

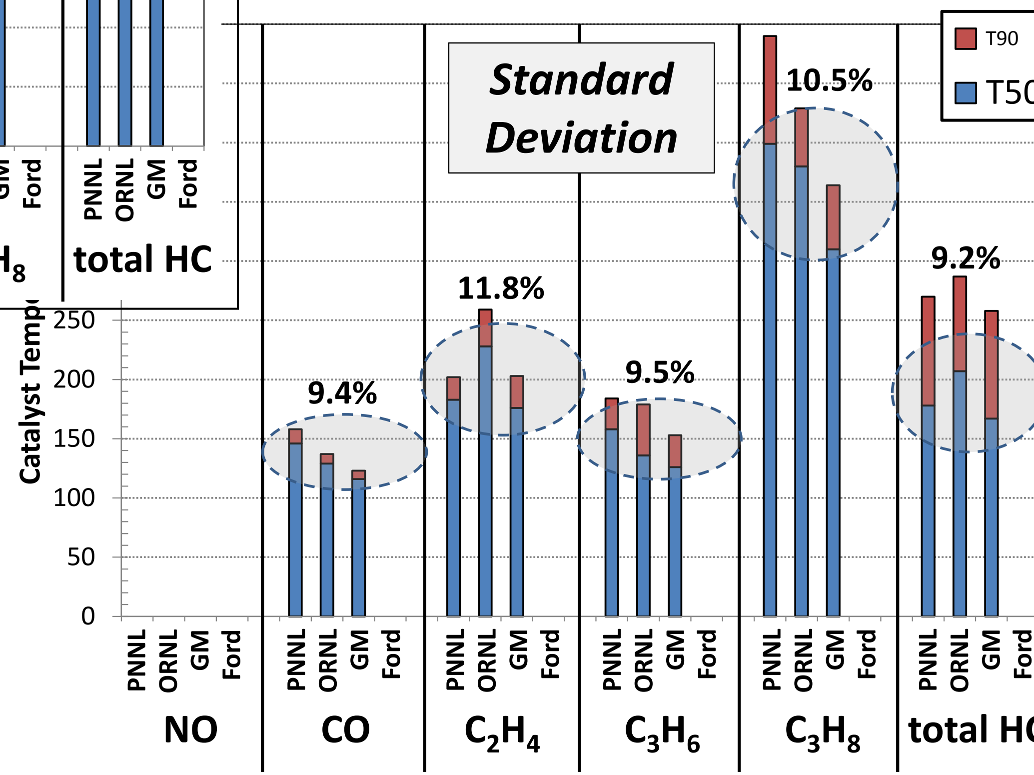
Suggests measuring catalyst bed temperature <u>may</u> be more robust

Round Robin Testing
Aged DOC, CDC Protocol



Aged catalyst …

Reproducibility criteria** *<u>almost met</u>* **for T50 data
referencing *catalyst temperature*

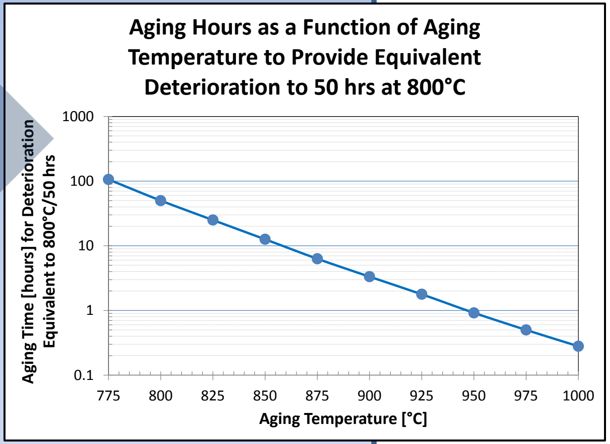


Could use <u>*your*</u> feedback on aging differences that we need to understand better

Again, consistent patterns in the comparative results suggests ***potential for further improvement***

Summary and Take-Aways
CDC Protocol Round Robin Testing

- Oxidation catalyst protocol works !!
  - Round robin testing complete
  - >90% agreement between four (4) OEM and NL labs
  - Some consistent differences we can understand better
- Need to improve catalyst aging consistency
  - Could use your help in how to standardize thermal environment during aging



- Protocols can be found on the CLEERS website
  - *cleers.org/acec-lowt*
  - *Feedback is greatly appreciated*
- **Storage & Release protocol** complete, currently under review
  - Will soon be posted on CLEERS website for user feedback
- Currently beginning development of TWC test protocol