Clean Diesel Engine Component Improvement Program

By AEI &NOXTECH

With the Support & Cooperation of

DOE/NETL

DOE Contract: DE-FC26-00OR22811

AEI Business Segments

1) Instrumentation and Analytical Equipment

2) Testing and Development for Engines, Aftertreatment, and Components

3) Research & Development Cooperative Programs

AEI

NOXTECH

Instrumentation and Analytical Equipment
Engineering Design, Manufacture, Distribution, Support

Worldwide Locations: U.S. England, France, Germany, Austria, Brazil, Japan, Switzerland, India

2010 PM Measurements

Reduces Test Time from 250 hours to 15 minutes

AEI Proprietary Lubricant Analyzer

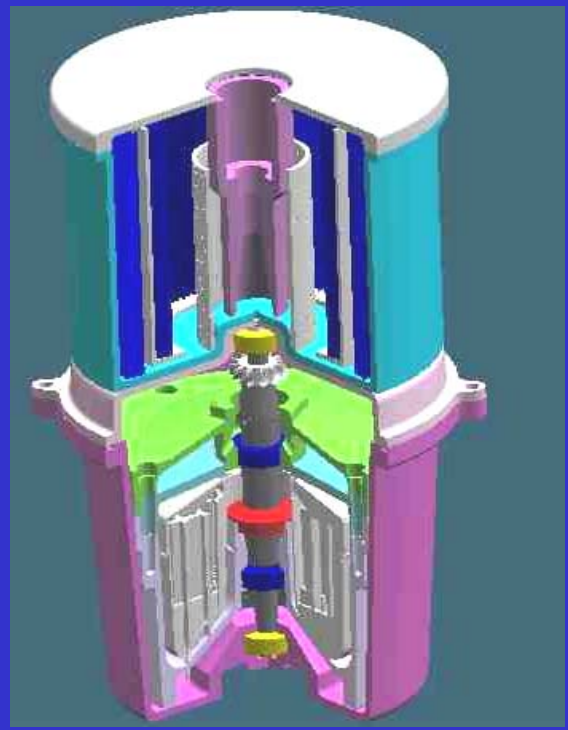
Engine and Aftertreatment Development

Results-Focused Confidential Environment for Innovative Engine and Emissions Research, From Test Cell to Vehicle

R&D Cooperative Development

OEMs contract with AEI for expediting product commercialization

Internal R&D Intellectual Property: AEI currently has 14 issued US patents, with several more pending.



Noxtech, Inc.

- MBO from Cummins Engine CO 1996: Total $28 million invested (Cummins & Noxtech) emissions control technology
- Over 30 years of experience and expertise in emissions controls for combustion exhaust with several issued patents
- Worked with SCAQMD, DOE, CEC & MSRC to develop unique aftertreatment systems.
- Transportation Market: Unique (patent issued & 4 patent applications) NOx reduction system (CCTR) being developed for demonstration
- Stationary Markets: Patent protected (four) Autocatalytic Process for boilers and IC engine powered generators commercially available and in-use products. Mitsui Babcock licensee has installed system in 3 coal fired boilers.

One MW Noxtech Reactor for Landfill Gas

TVA Installation

Customer Requirements

- Can reduce NOx (90%) below the 0.20 g/bhp-hr NOx levels requirement for the Federal transient cycle
- Durable system @120,000 - 435,000 miles to replacement
- Retail cost no greater than $1500-2000 @500 hp (minimize the use of precious metals)
- Parasitic loss 2.5-3.0% of engine consumption
- Effective temperature range 150-600 deg C.
- Size: 30,0000-50,000 hr-1
- Emissions system sulfur tolerant (500 ppm)
- Use single fluid (diesel fuel) for reductant and combustion

Other System Issues

- NOx Adsorbers:
  - Durability issues: regeneration, sulfur sensitivity
  - Fuel penalty: 3-8%
  - High Cost: precious metals & large amounts of catalysts
  - Fuel quality sensitive (sulfur, other)
- SCR:
  - Urea: no infrastructure, carry extra fluid
  - Enforcement difficult
  - Fuel penalty : 5%
  - NOx: removal efficiency limited to 70-80% (higher at steady state)
  - Durability: questionable (early loss of activity)

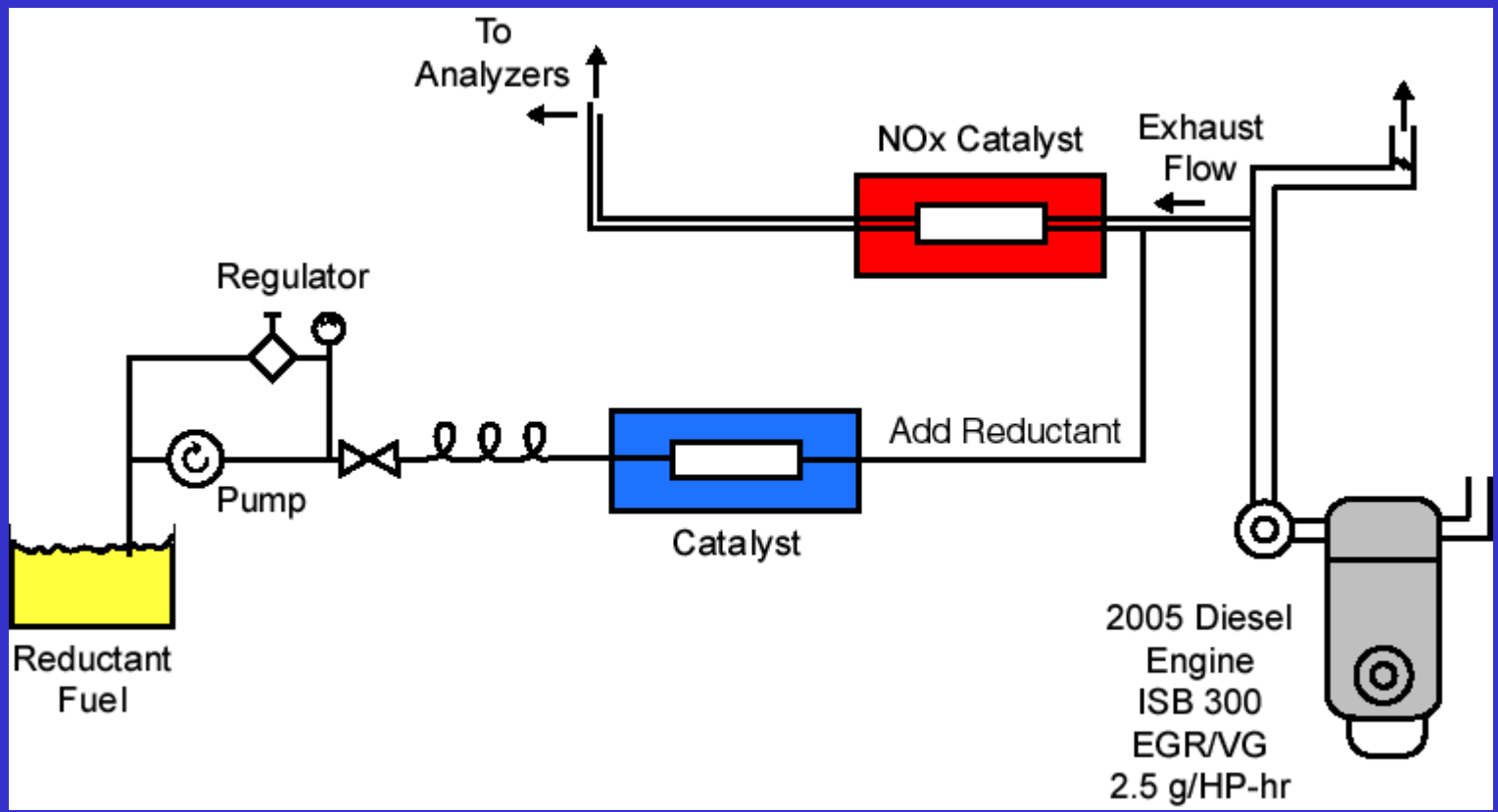
Solutions offered by NoxTech System

- 90%NOx Reduction
- Durable
- Cost Effective
- Reduced Parasitic Consumption
- Wide Temperature Range
- Improved and Smaller Package Size
- Sulfur Tolerant
- Diesel Fuel or other Hydrocarbon for Reductant and Combustion

Technology Development Strategy

- Generate tailored reductant(s) catalytically from diesel fuel or other organics
- Formulate ceramic NOx catalyst for tailored reductants
- Match/tailor reductant(s) with NOx catalysts to produce high NOx reduction over very thermally stable sulfur tolerant ceramic catalyst(s)
- Produce easily scaleable system

Slip-Stream NOx Reduction System Schematic



Research Progression

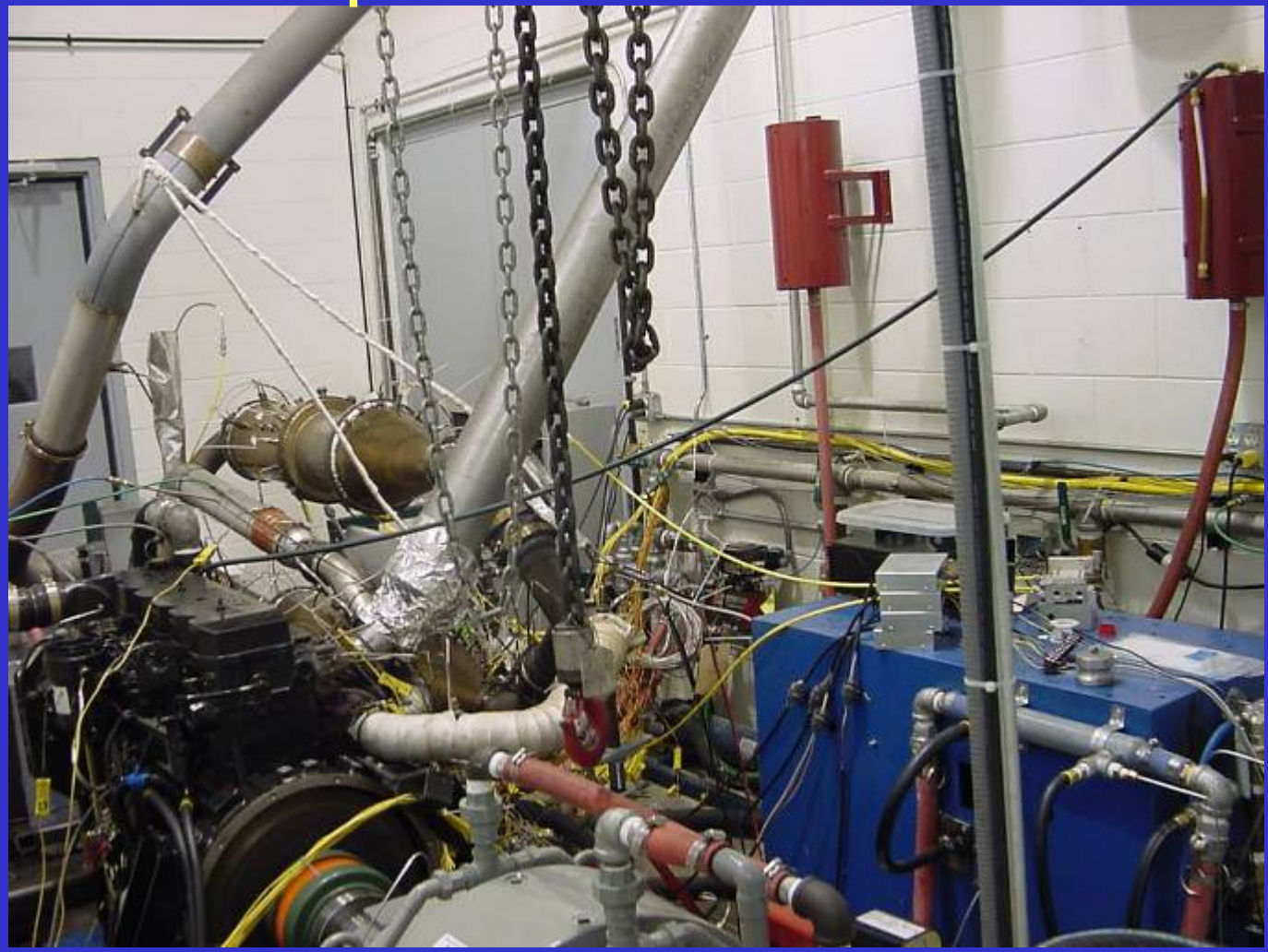
1) Laboratory research and screening

2) Test cell slip-stream

3) Test cell full flow development

Laboratory Testing

Test Cell Slip-Stream Demonstration



Reductant Work

- Optimize reductant composition and formation from diesel fuel:
  - Catalyst Design (coking and selectivity)
    - Design, obtain & define reforming catalysts
    - Identification & characterization of reductant formed
  - Minimize slip from NOx catalyst

Results Reductant Formation Work

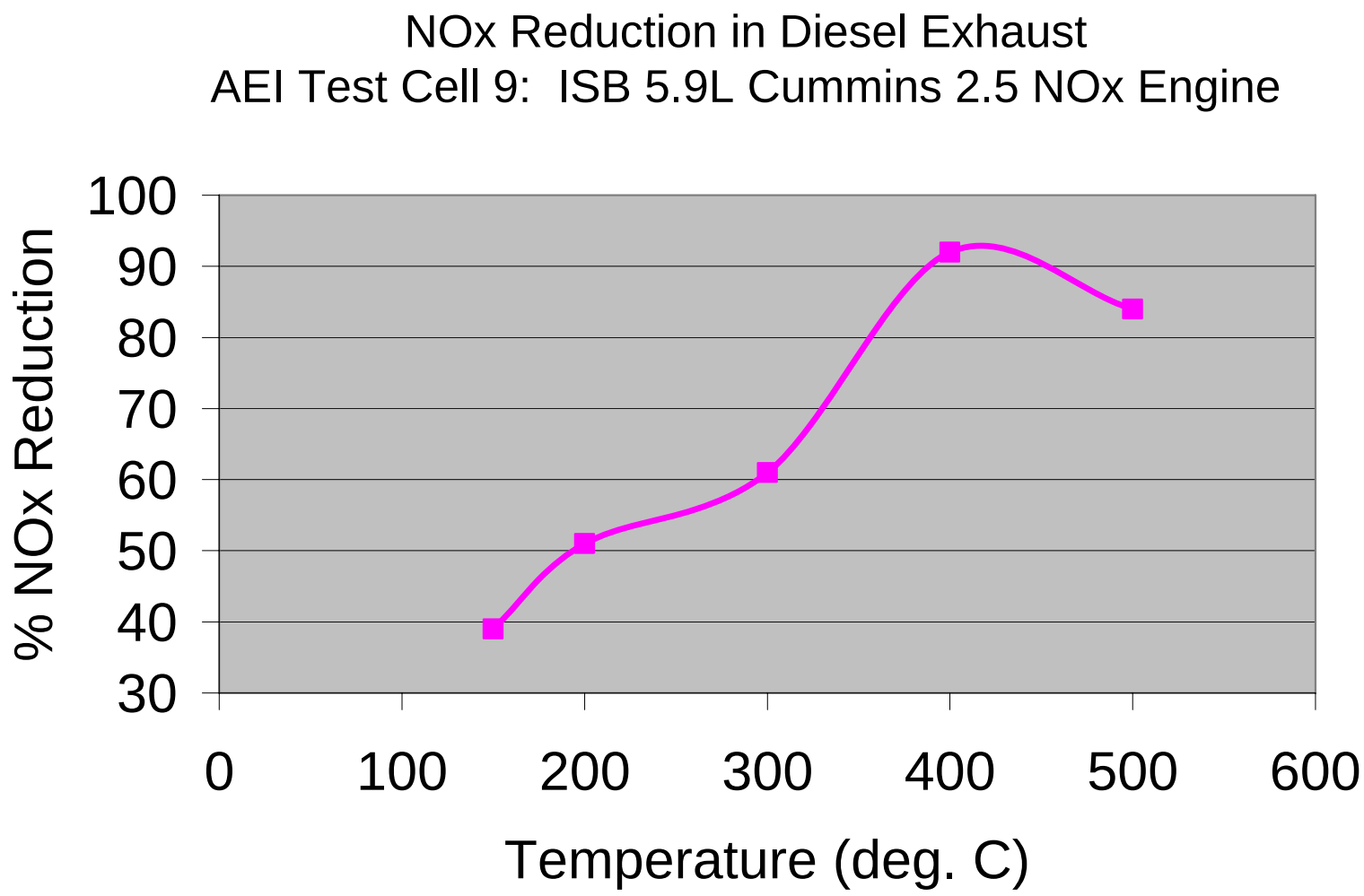
- Obtained and characterized in excess of 20 custom formulated reforming catalysts
- Demonstrated ability to control reductant composition from diesel fuel:

General NOx Catalyst Improvement Work

- Improvements:
  - Increase hr-1 (to 50,000hr-1)
  - Low temperature activity to 150 deg C
  - Selectivity for NO2 and/or NO
  - Match reductant with stable and inexpensive ceramic catalysts
- Approaches:
  - Optimize surface area (surface available for reaction)
  - Optimize pore distribution (including cage structure)
  - Optimize dopent levels and basic composition
  - Optimize surface chemistry: acidity, electronics

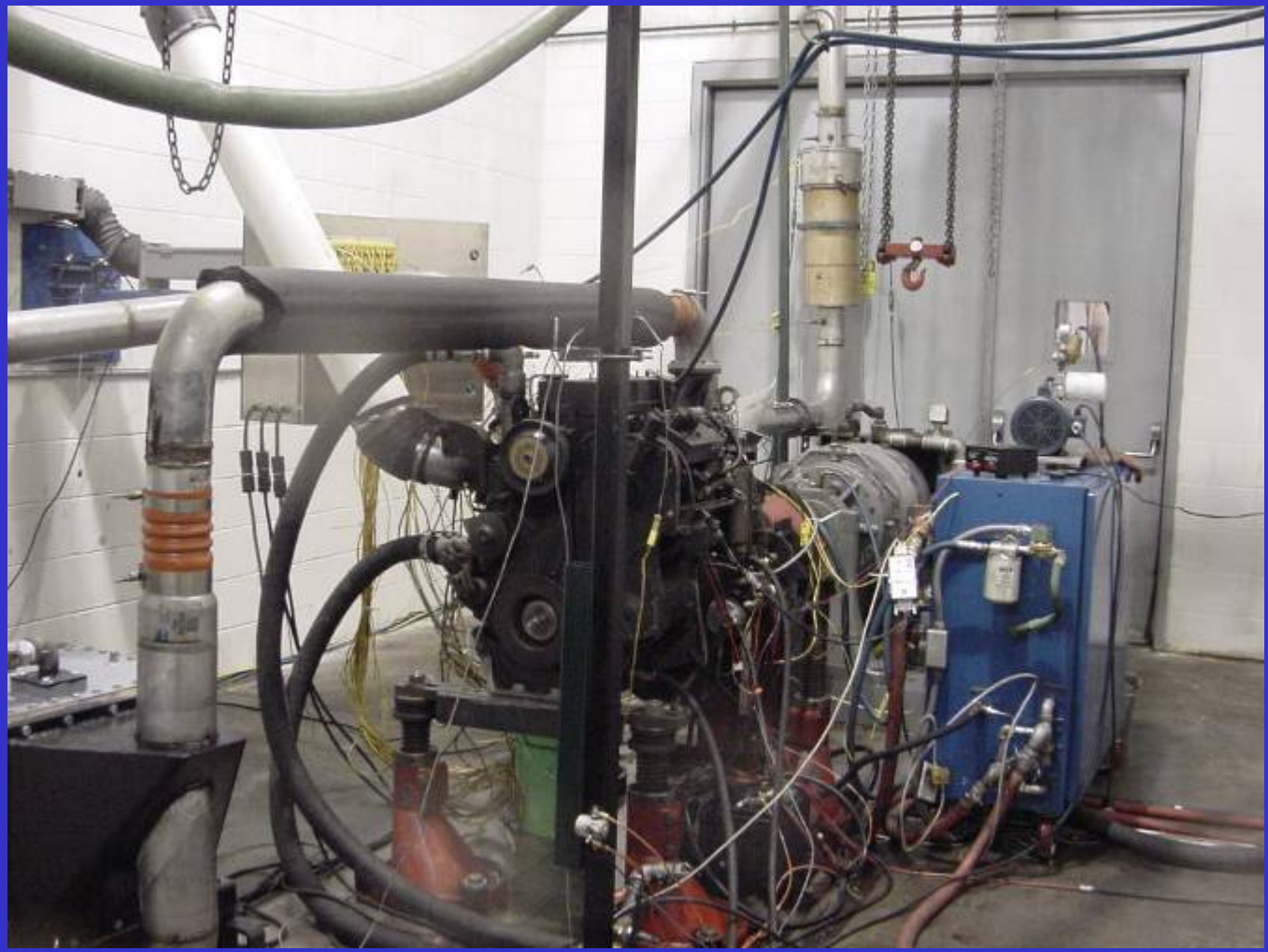
NOx Reduction System Results

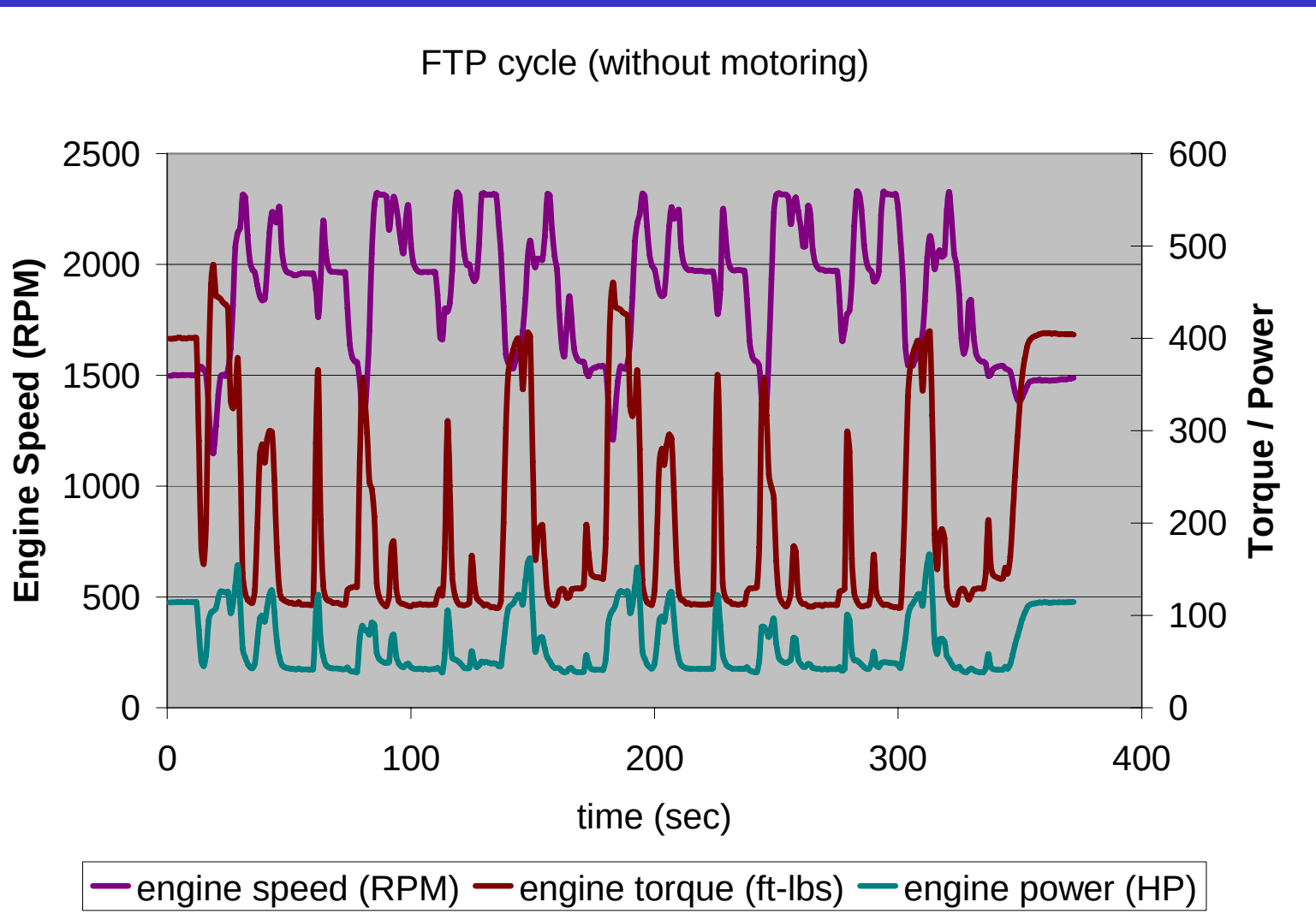
- Formulated and obtained over 20 NOx catalysts with broad range of properties: surface areas, pore distributions, acidity and crystal structures.
- Characterization of the reforming catalysts:
  - 92% NOx reduction @400 deg C
  - No apparent formation of deposits
  - Minimum HC slip from NOx catalyst
- Patents Pending

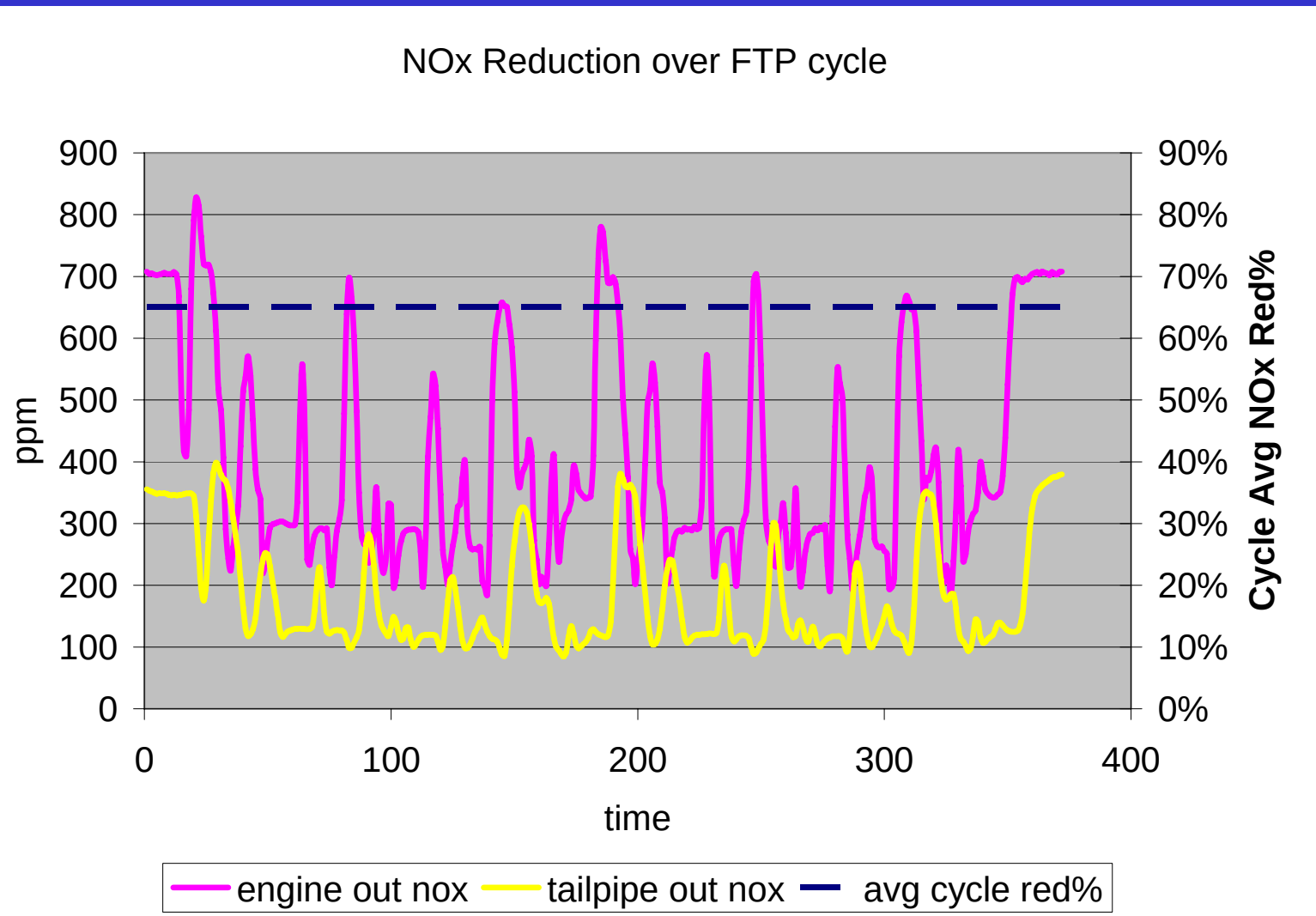

NOx Reduction in Diesel Exhaust
AEI Test Cell 9: ISB 5.9L Cummins 2.5 NOx Engine
% NOx Reduction
100
90
80
70
60
50
40
30
0
100
200
300
400
500
600
Temperature (deg. C)

NOx Reduction During the Transient Heavy Duty FTP

Test Cell Full-Flow Demonstration




FTP cycle (without motoring)
Engine Speed (RPM)
2500
2000
1500
1000
500
0
Torque / Power
600
500
400
300
200
100
0
0
100
200
300
400
time (sec)
engine speed (RPM)
engine torque (ft-lbs)
engine power (HP)


NOx Reduction over FTP cycle
900
800
700
600
500
400
300
200
100
0
ppm
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cycle Avg NOx Red%
0
100
200
300
400
time
engine out nox
tailpipe out nox
avg cycle red%

Work In Progress

- Perform 300 hp diesel exhaust demonstration tests on 3 catalysts:
  - Modify catalyst composition to improve performance
  - Can catalysts & perform steady state/transient NOx reduction tests
- Status: All catalysts have been received and testing initiated

Preliminary Test Results for 300 Horsepower

- Greater than 70% NOx reduction at 100 horsepower
- - Remainder of test in progress

Objective for Mobile