Heavy Truck Clean Diesel (HTCD) Program & Light Truck Clean Diesel (LTCD) Program

Diesel Aftertreatment Systems Development

DOE Contract DE-FC05-00OR22806
and DE-FC05-97OR22605

DOE

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Caterpillar

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CATERPILLAR®

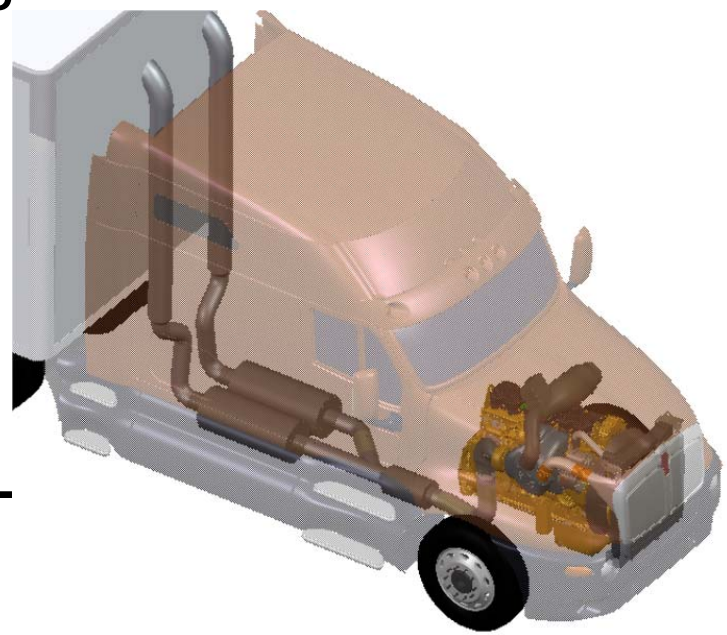
2004 DEER Conference
Coronado, CA

Aftertreatment Requirements for the Future

- 80 – 90 % NOx reduction
- Wide temperature range
- Same low PM, HC levels
- Limited impact on fuel consumption
- Packaging
- Competitive cost
- Durability of up to
  - 1 million miles (Truck)
  - 10,000 hrs (off-highway)

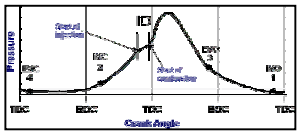
System Development Process

- Understanding of catalyst behavior
- Integration: Alignment of catalyst needs and engine system capabilities
- Control system/algorithm development
- Catalyst size and cost optimization
  - Various engine platforms and ratings
  - Various engine cycles
  - Real life application
  - Durability

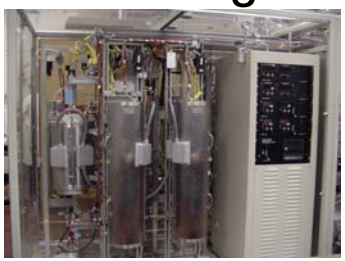


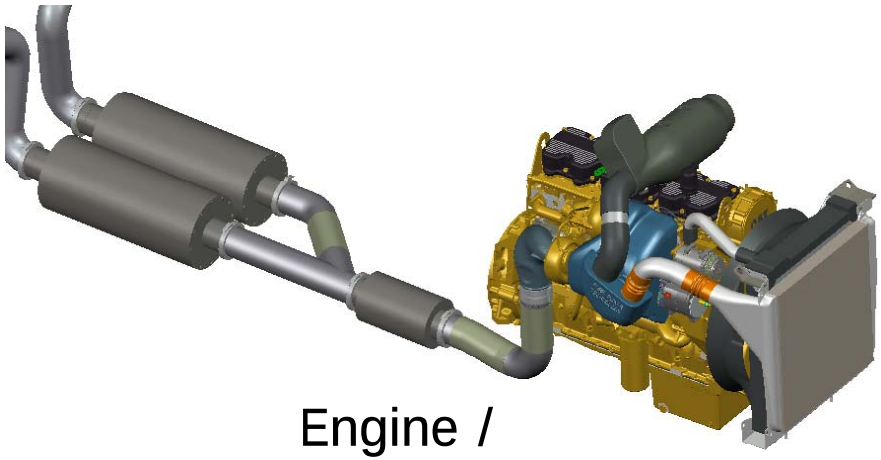
System Development Process

Combustion development



Bench Testing



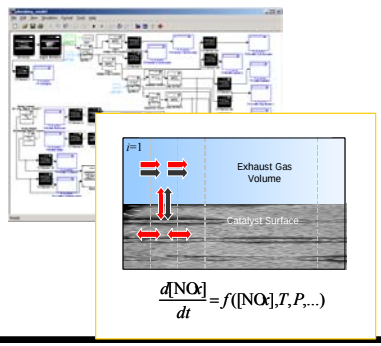


Engine / Aftertreatment System Integration

Design and Packaging

Supplier Relationships

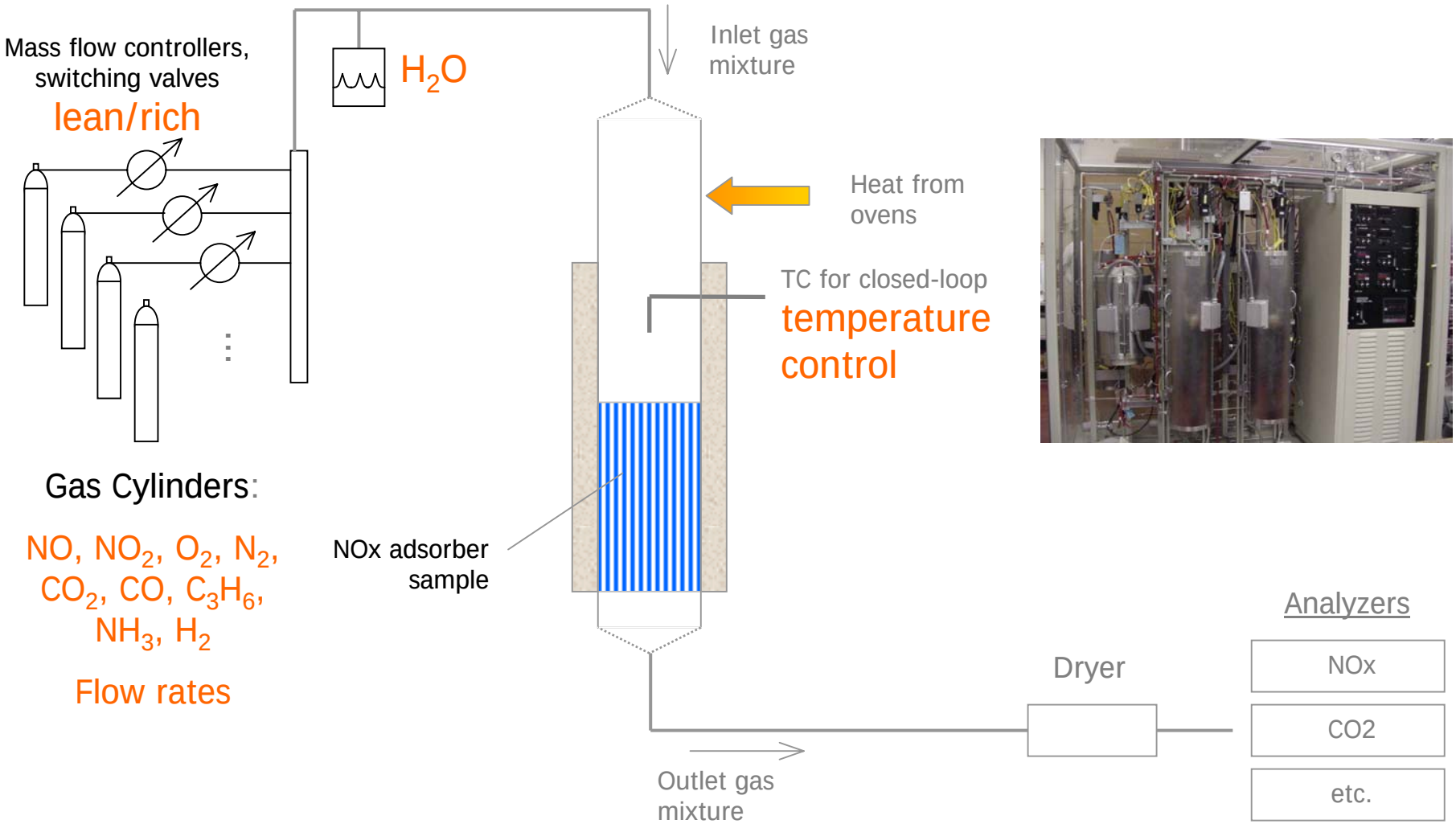
Modeling



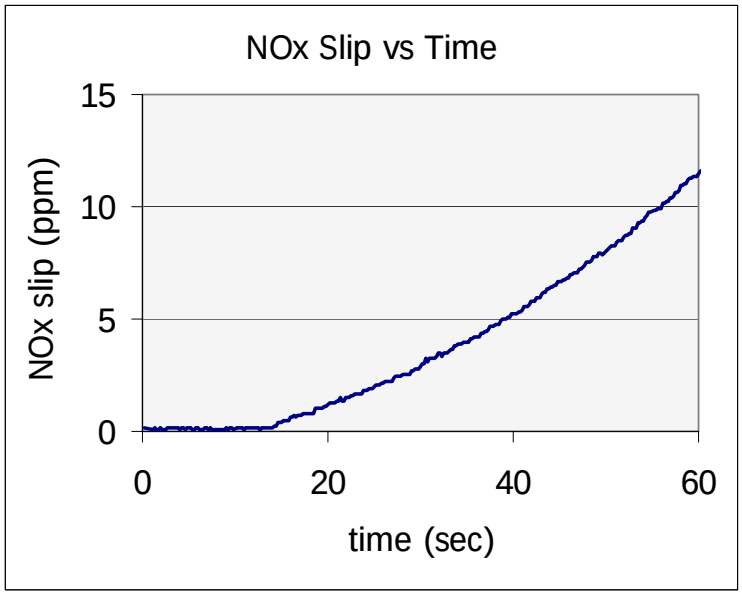
Research

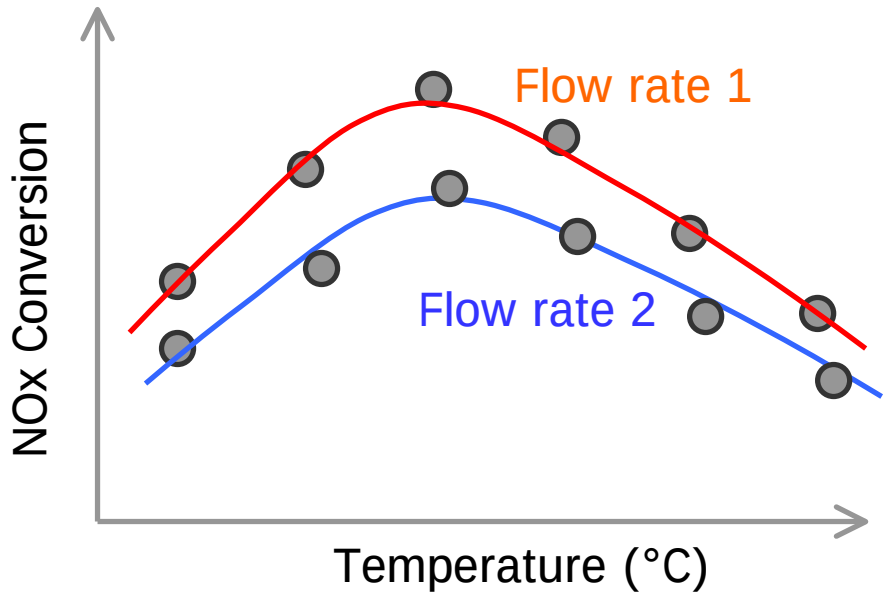
Catalyst Formulation Development

Caterpillar/Xytel MRCSS Catalyst Test Bench



Bench Tests: Quantitative Data





NOx Adsorber Catalyst behavior

Catalyst “mapping”

Aftertreatment Performance Model

- Reduce bench data to generalize Catalyst behavior ("mapped" catalyst)
- Can be linked to full engine system model
- Couple with transient exhaust-gas emissions data
  - Temperatures
  - SV
  - Emission levels
- Predict system behavior
  - Transient emissions
  - Effect of active control measures
  - Thermal behavior
  - Aging/degradation prediction

NOx Adsorber Technology Requirements

- 80 – 90 % NOx reduction
- Limited impact on Fuel Consumption
- Packaging
- Competitive cost

- Main Issue: **Durability**
  - Sulfur deactivation
  - Thermal deactivation
  - Phosphorus deactivation

Case study: Modeling Phosphorus effect

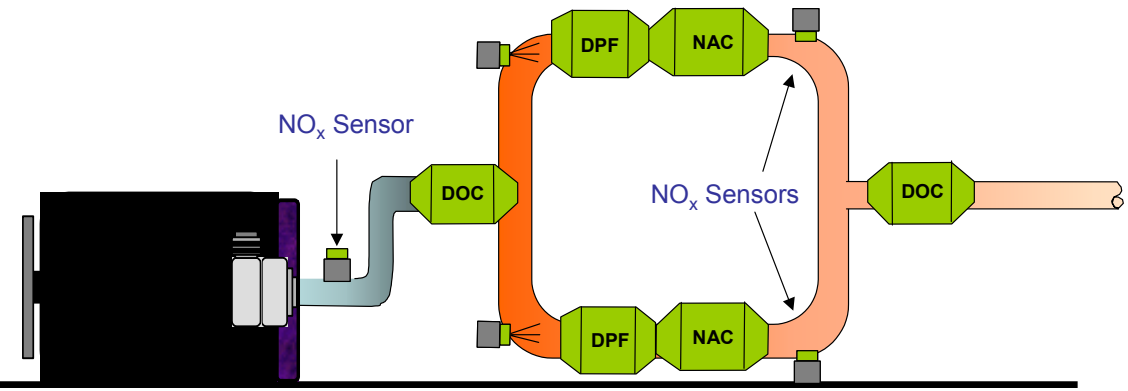
Long term deterioration from phosphorus deactivation

- Phosphorus (or other ash components) in lube oil can degrade catalyst performance
- Model can be used to predict effects of long-hours Phosphorus accumulation
- Compare transient simulation results with and without Phosphorus deactivation

- Results from APBF study will be used as baseline for simulation

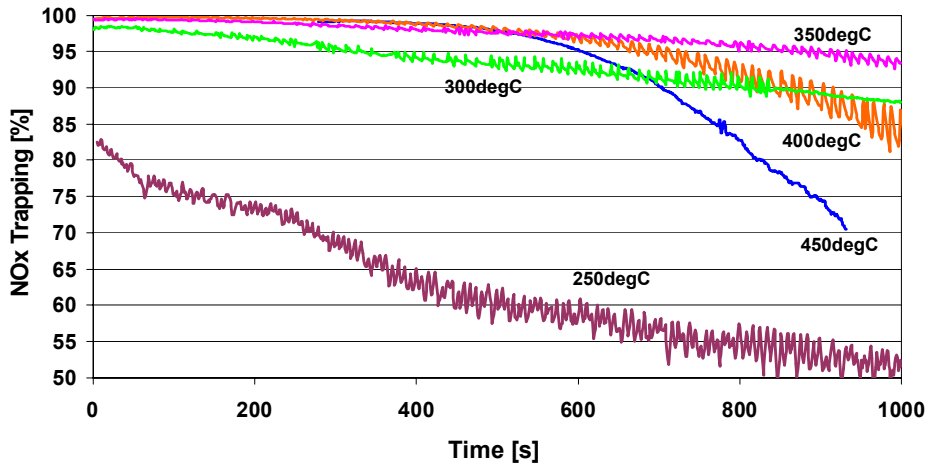
Baseline: APBF heavy duty NOx Adsorber

- APBF-DEC program investigated effect of fuels on aftertreatment durability (2000 hrs)
- Modified heavy duty Cummins 15 l engine (2004 emission level)
- “Single leg” NOx Adsorber system
- NOx adsorber volume: 44 liters
- Study performed by NREL and Ricardo Inc, Chicago Technical Center



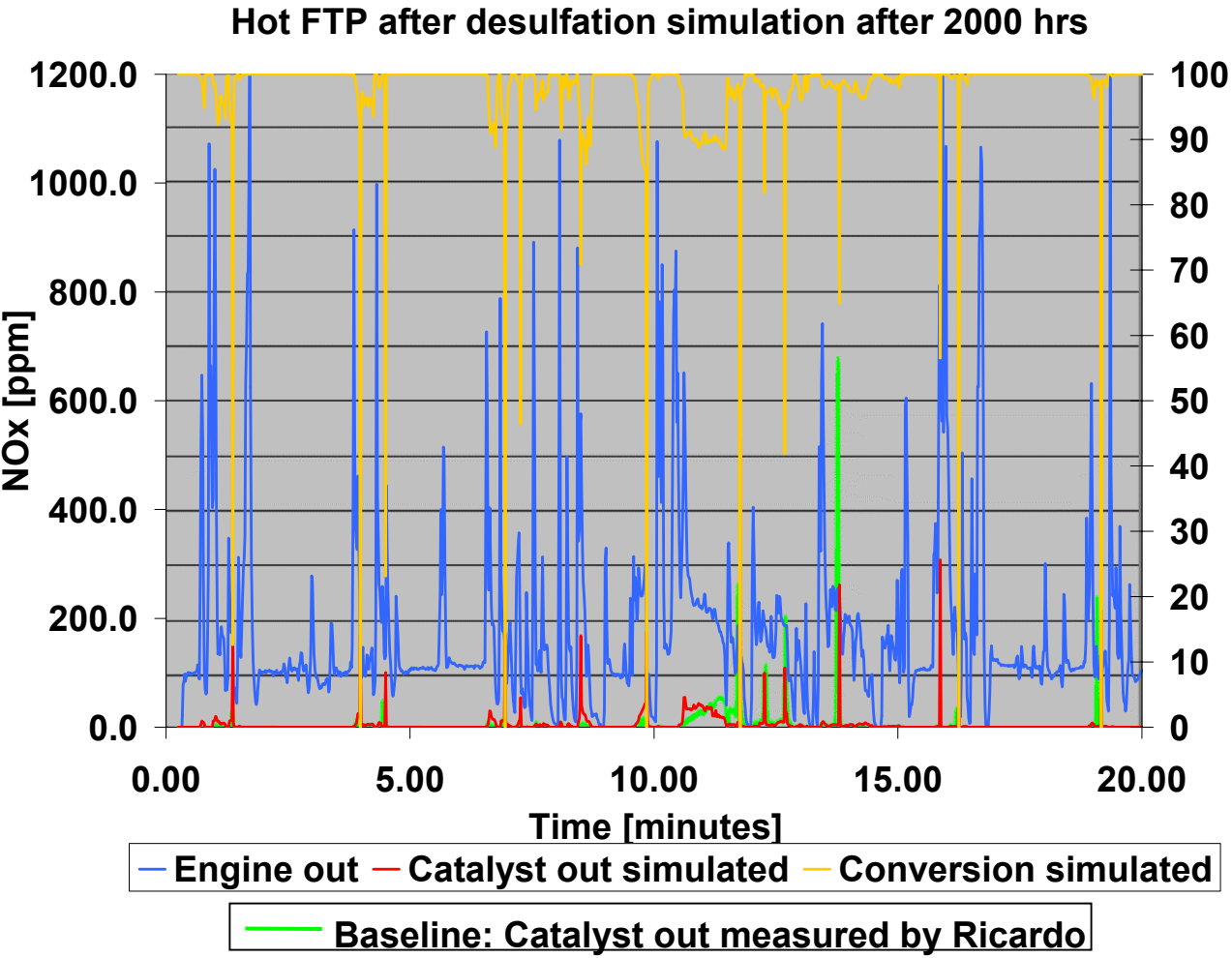
Baseline modeling

- APBF was not involved in modeling activities by Caterpillar
- Phosphorus deactivation was out of scope of APBF program



- Caterpillar used FTP results reported by NREL and Ricardo as input for model
- NOx adsorber model was estimated from reported results of catalyst used by APBF

Model validation: Hot FTP after 2000 hrs



NOx Conversion

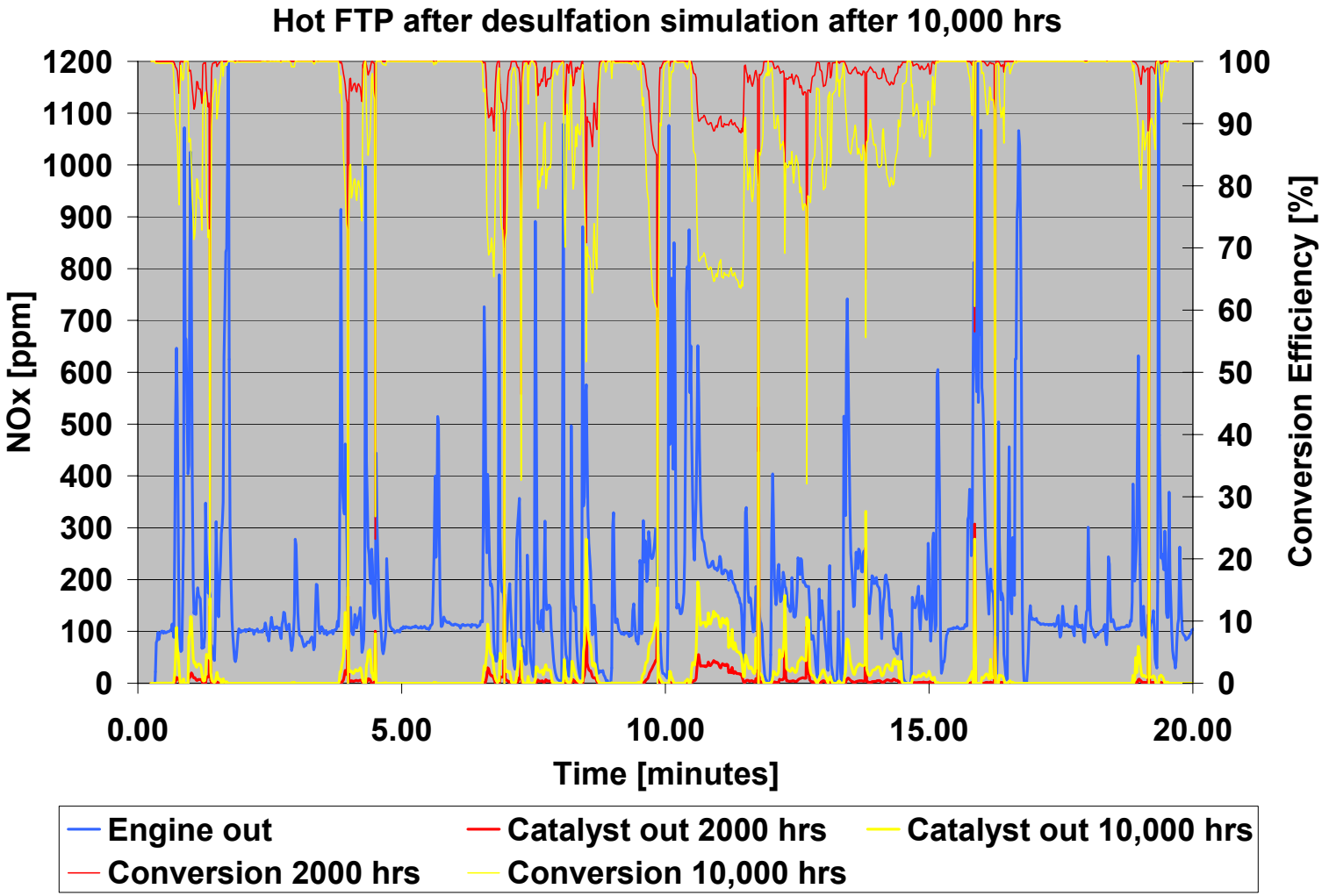
Measured: 95 %

Simulated: 94 %

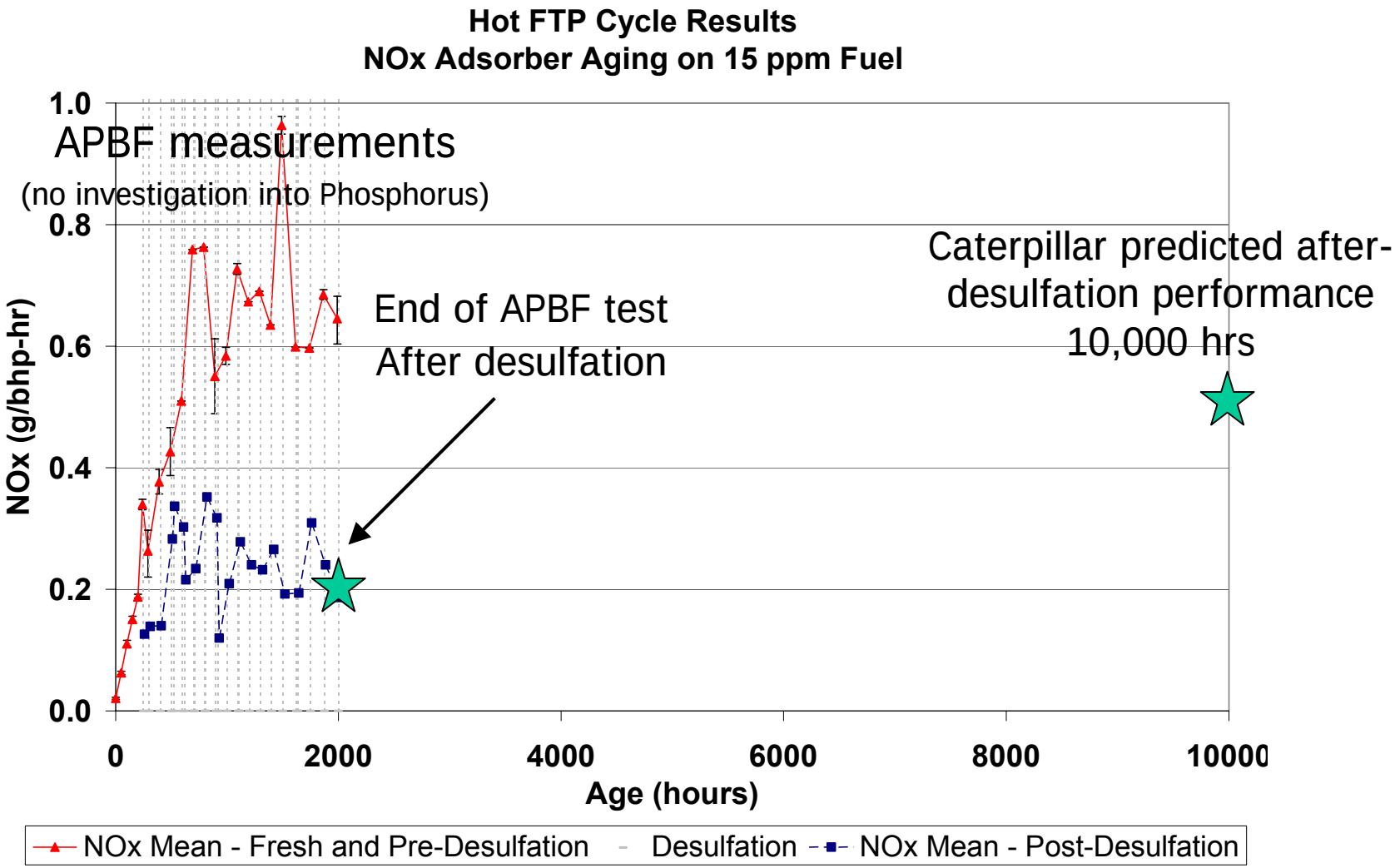
NOx tailpipe: ~ 0.2 g/hph

Caterpillar FTP prediction after 10,000 hrs

- Catalyst model was modified for Phosphorus effect
- Simulated Conversion @ 10,000 hrs: 84%



Predicted deterioration due to Phosphorus deactivation



Conclusion

- NOx Adsorber Technology is a promising candidate for future NOx reduction, BUT.....

- Durability is still a significant challenge
- Phosphorus effect should not be neglected, not easily reversible
- Phosphorus can have a significant effect on long term catalyst performance
- More focus needed to understand long-term performance degradation
- Ashless lubricants would be a major benefit to NOx adsorbers and other aftertreatment devices