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# **Department of Energy Contract DE-SC04-01AL67526**

**Exhaust Aftertreatment and Low Pressure Loop EGR  
Applied to an Off-Highway Engine**

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John Deere Power Systems**

**DOE Project Officer- Steve Cooke**

**Subcontract with Michigan Tech**

# Goal

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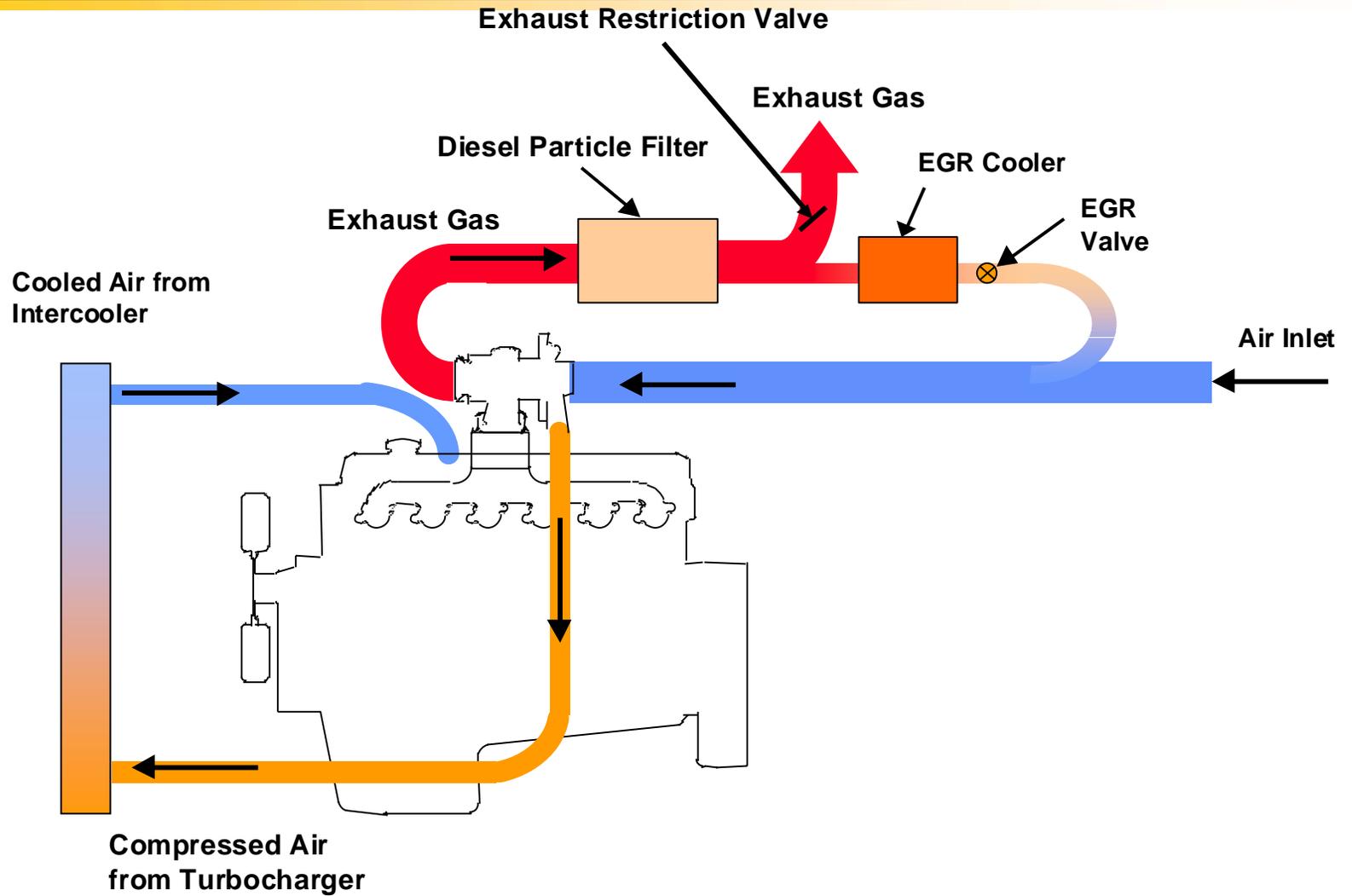
**Demonstrate that low pressure loop EGR incorporating a diesel oxidation catalyst (DOC) and a diesel particulate filter (DPF) can be applied to an off-highway engine to meet Tier 3 (Task I) and Interim Tier 4 (Task II) emissions standards.**

# Project Objectives

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- 1. Demonstrate Off-Highway NOx and PM levels can be achieved**
- 2. Measure exhaust particle size distributions.**
- 3. Perform steady-state loading curves to calibrate DPF model.**
- 4. Investigate regeneration strategies**

# Low Pressure Loop EGR with a Diesel Particulate Filter



# Engine Hardware

	Task 1	Task 2
Model	Tier 2 John Deere 6081H	Tier 2 John Deere 6068H
Type	4 stroke 2 valve	4 stroke 4 valve
Cylinder	6, in-line	6, in-line
Aspiration	Turbocharged, Aftercooled	Turbocharged, Aftercooled
Displacement	8.1 liters	6.8 liters
Rated Power	175 kW @ 2200 rpm	187 kW @ 2200 rpm
Peak Torque	1060 N-m @ 1400 rpm	1000 N-m @ 1650 rpm
Timing	Variable (Electronic Control Unit)	Variable (Electronic Control Unit)
Injection System	Standard HPCR	Advanced HPCR
EGR System	Cooled LPL EGR	Cooled LPL EGR with increased quantities

# Aftertreatment / EGR Hardware and Fuel Specifications

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## Exhaust Aftertreatment:

**Johnson Matthey CRT™ and CCRT™**

- **Diesel Oxidation Catalyst (DOC)**  
10.5” D x 6” L 300 cpsi and 400 cpsi
- **Catalyzed Diesel Particulate Filter (CDPF)**  
Corning DuraTrap® 10.5” D x 12” L 200 cpsi
- **Uncatalyzed Diesel Particulate Filter (DPF)**  
10.5” D x 12” L 200 cpsi and 100 cpsi

## EGR System:

**STT Emtec DNOx<sup>r</sup>**

## Diesel Fuel:

**<15 ppmS**

# Particle Size Distribution Instrumentation

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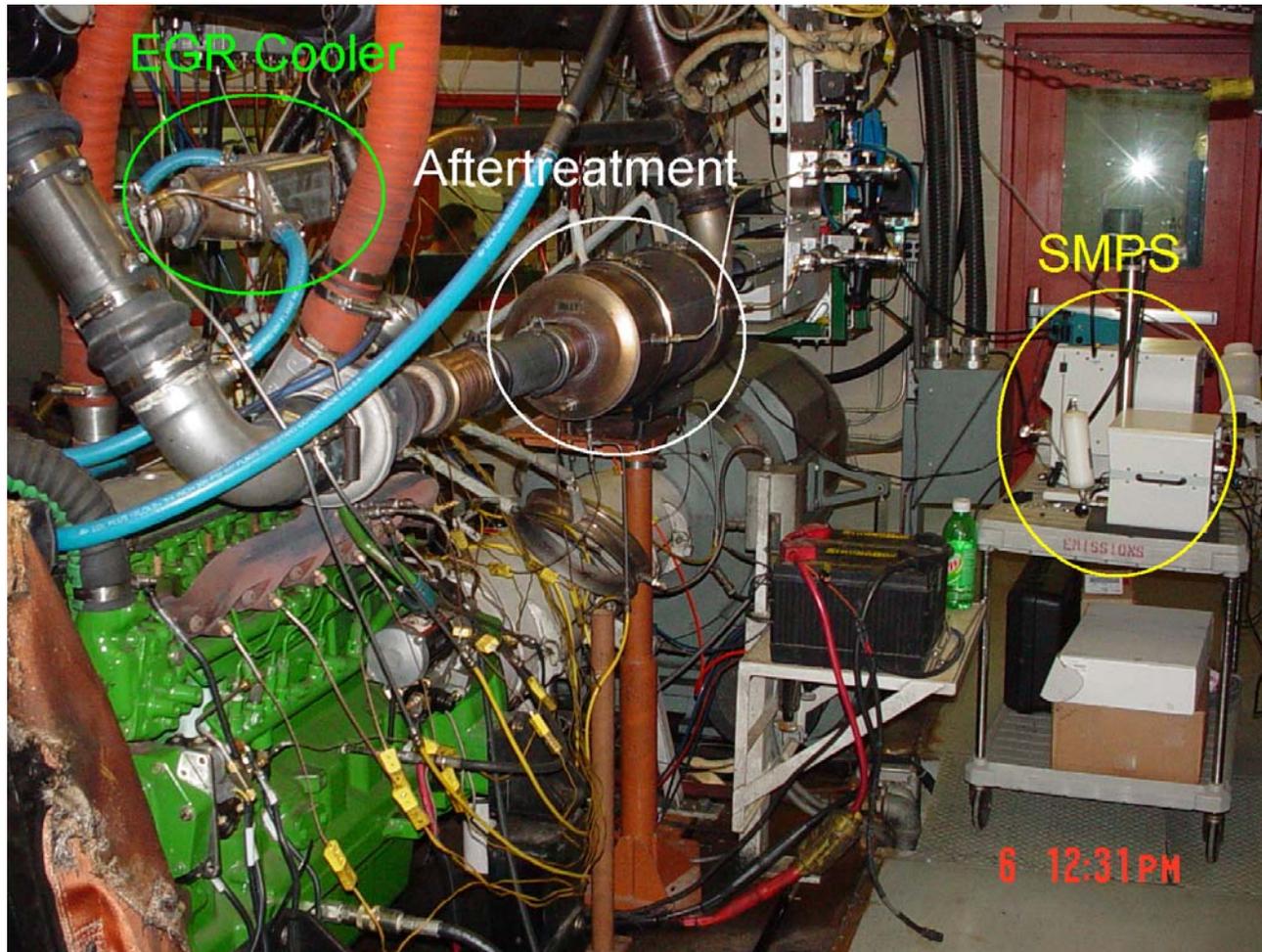
**TSI Model 3936NL25 Scanning Mobility Particle Sizer (SMPS)**

**Size Range: 3 to 1000 nm**

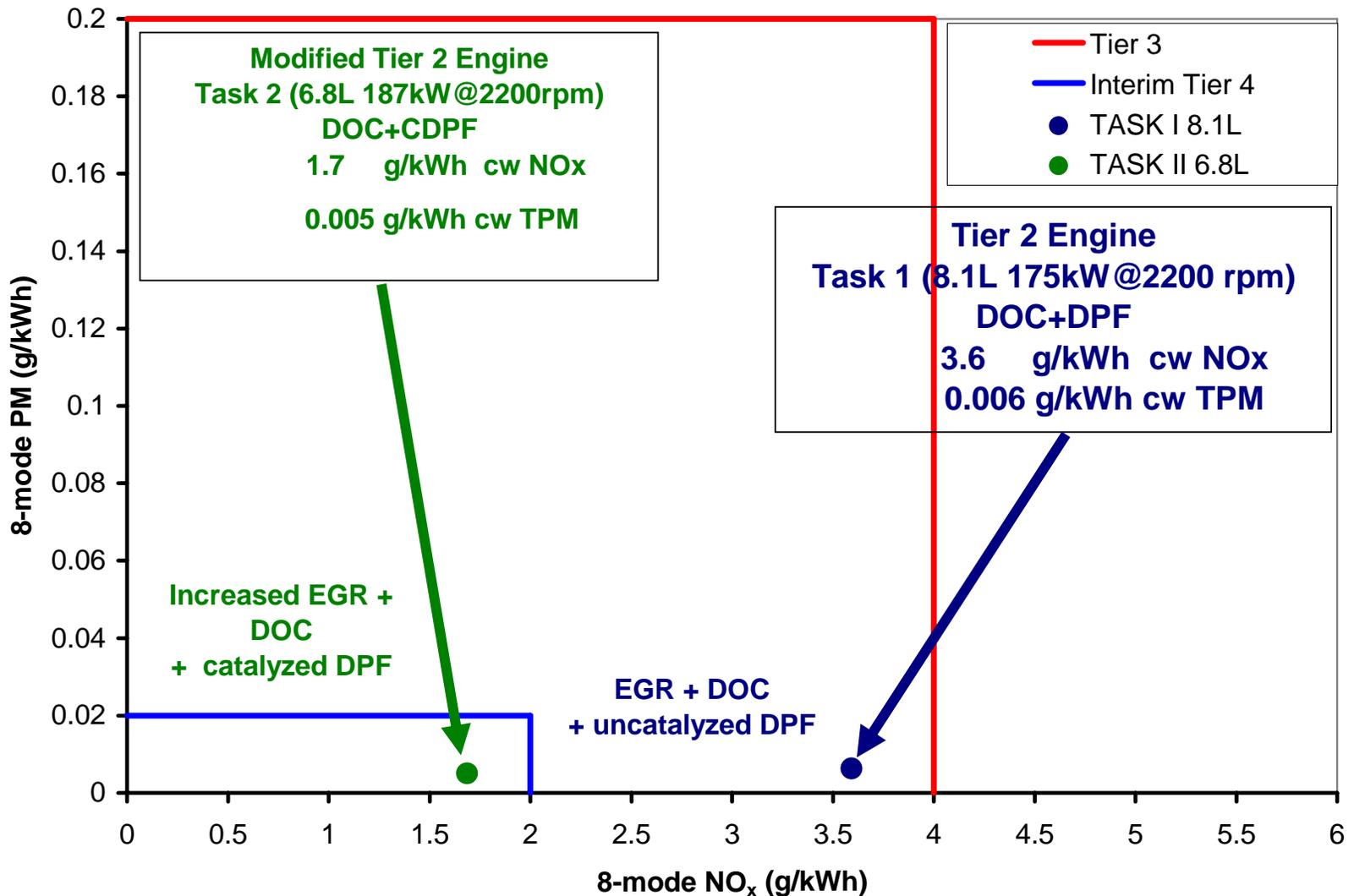
**Concentration: 20 to  $10^7$  particles/cm<sup>3</sup>**

**TSI Model 3065 Low Flow Thermodenuder**

# 6068H Engine and DPF in Test Cell



# 8-mode ISO-8178 Test Cycle test results



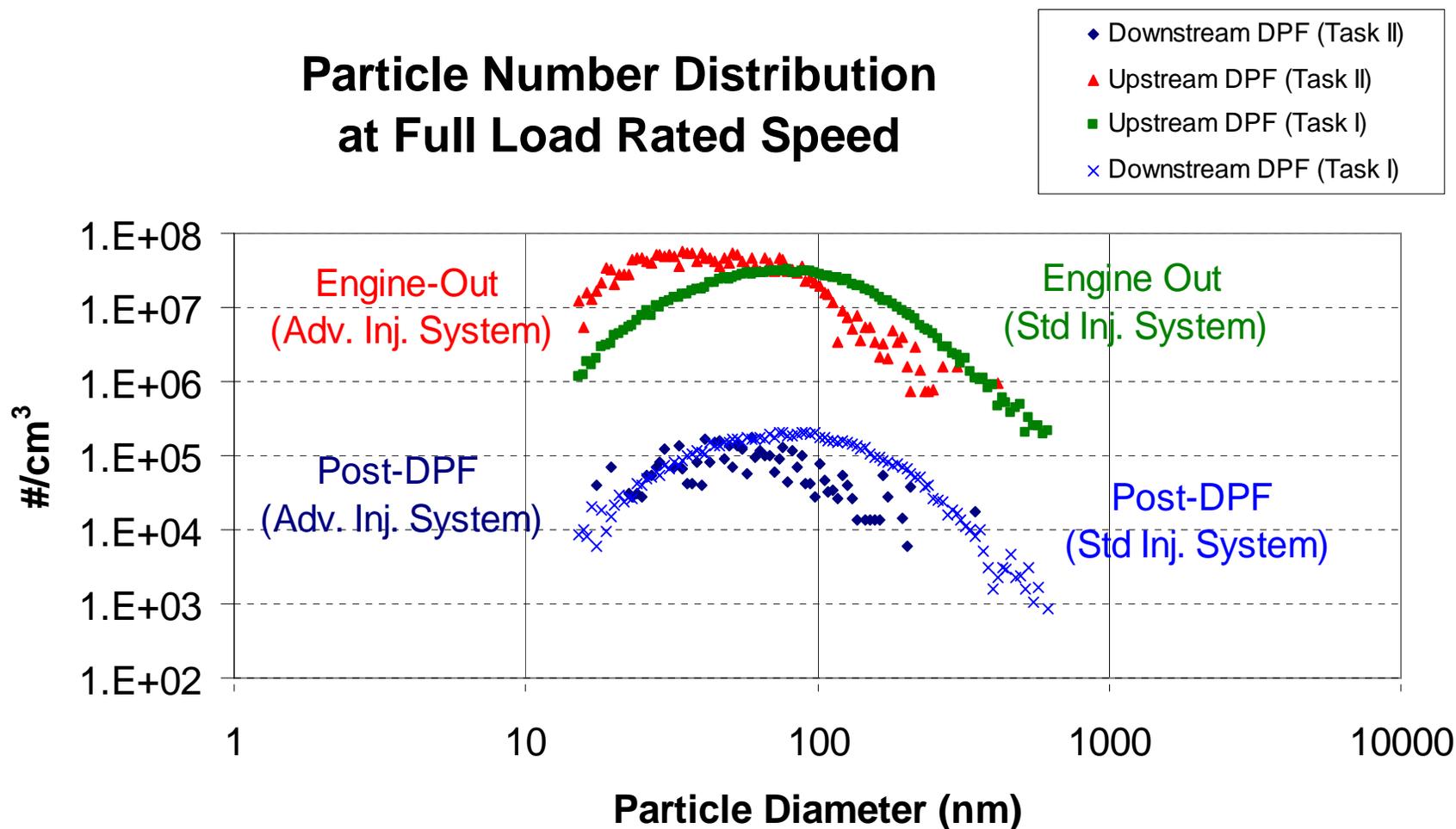
# Fuel Economy Comparisons

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<b>Baseline-Tier 2</b>	<b>100 %</b>
<b>Task 1 LPL EGR DOC+DPF – Tier 2 engine</b>	<b>101-102 %</b>
<b>Task 2 LPL EGR DOC+CDPF - Modified Tier 2</b>	<b>103-105 %</b>

# Tasks 1 and 2 Particle Size Distribution Data

## Particle Number Distribution at Full Load Rated Speed



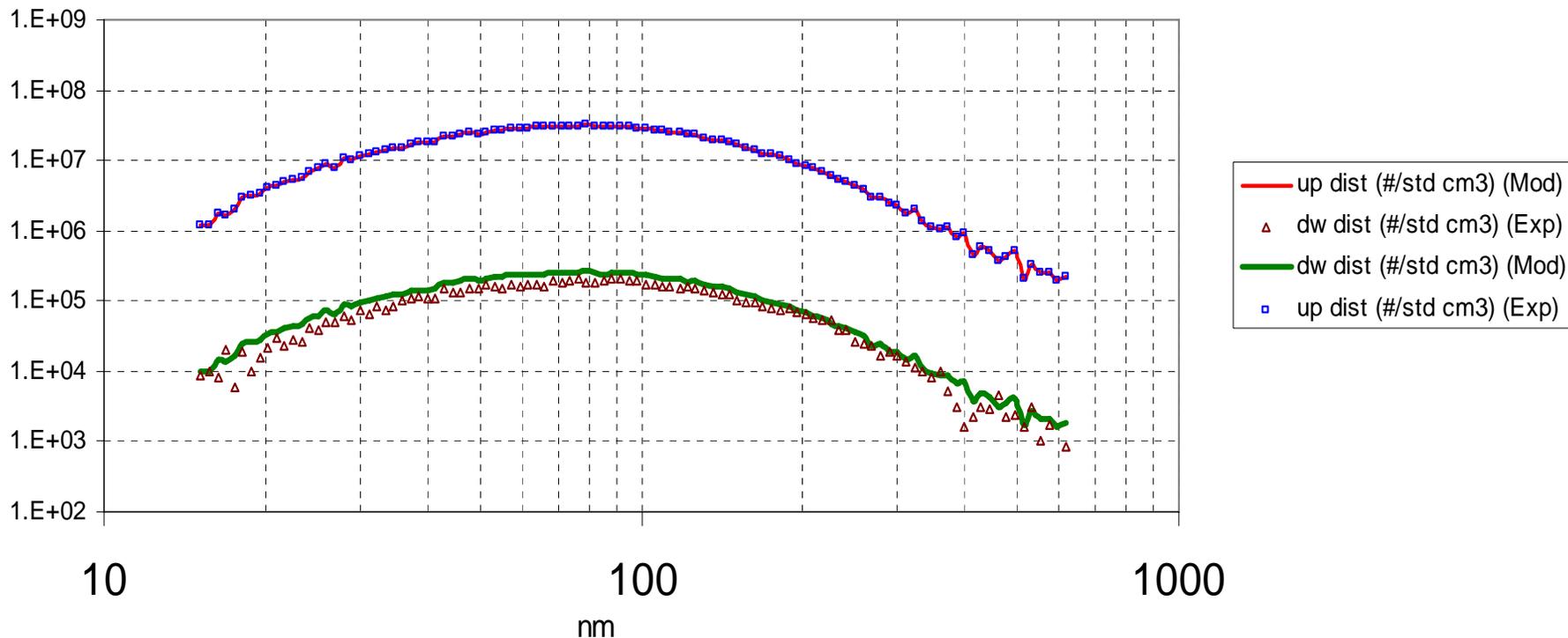
# Task 1 - DPF Model Particle Size Distribution Prediction

2200 rpm 100% Load

200 cpsi DPF

## DPF Model Prediction of Downstream Particle Number Distribution

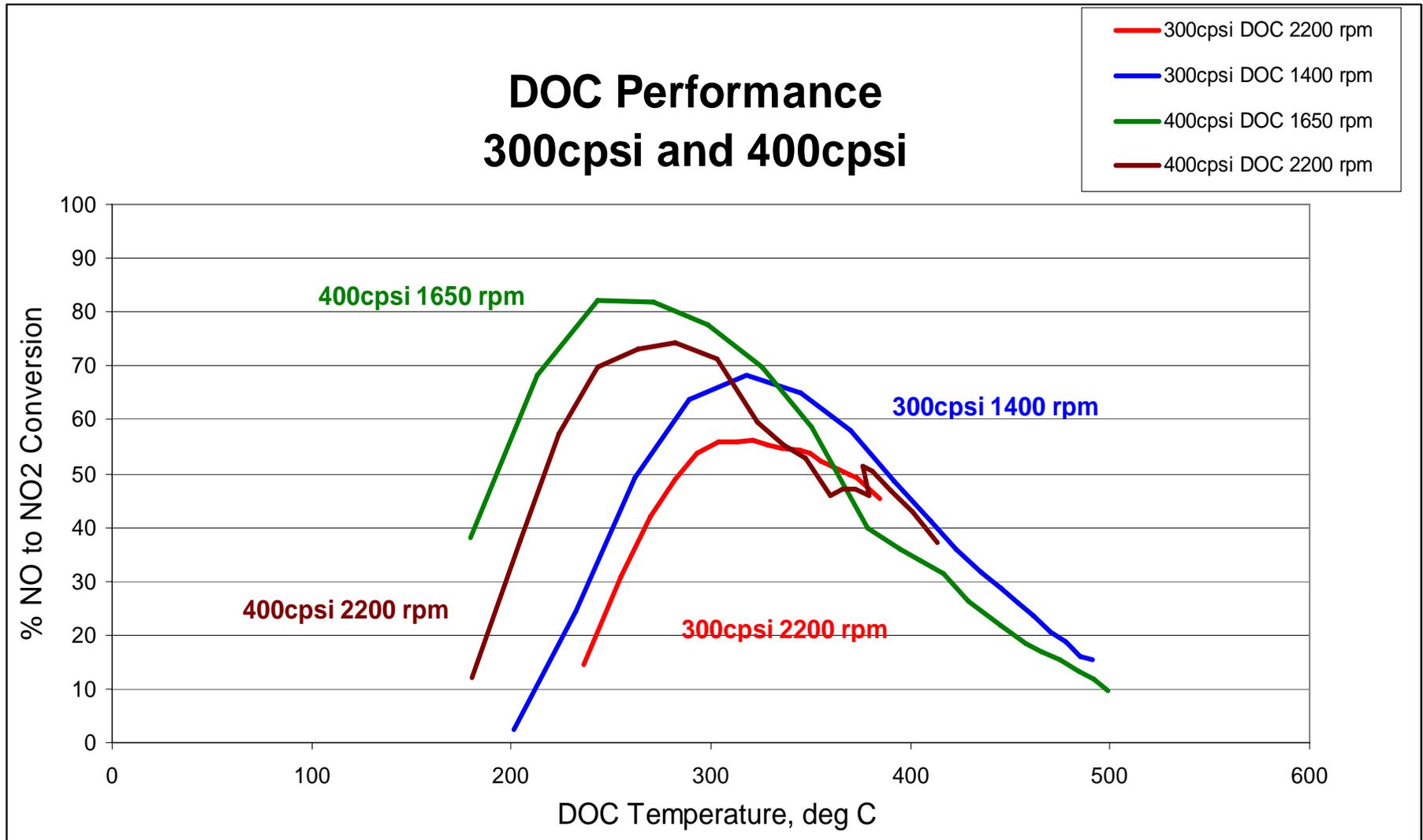
# / std cm<sup>3</sup>



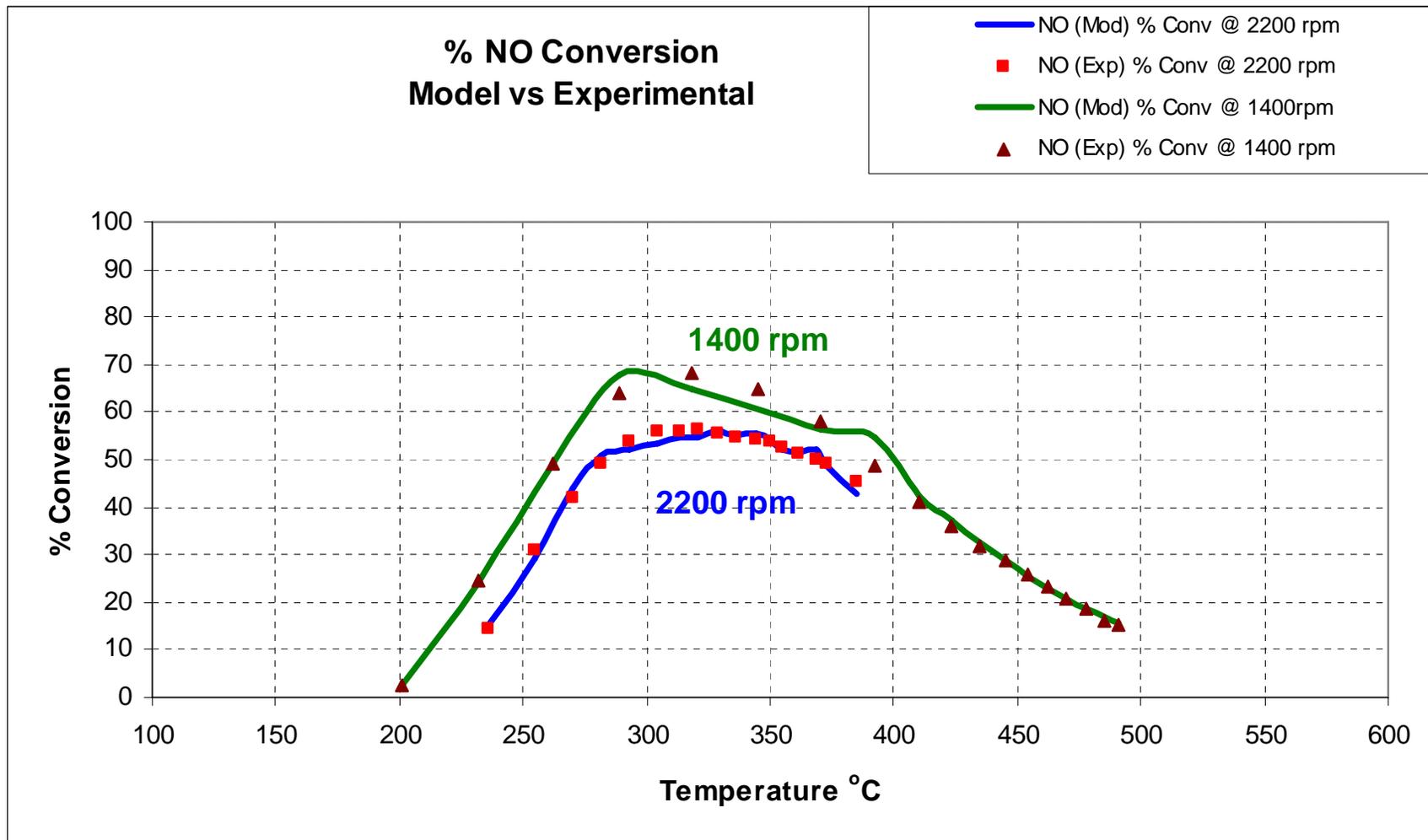
# DOC Performance Evaluation

Task 1 - 300cpsi DOC

Task 2 – 400cpsi DOC

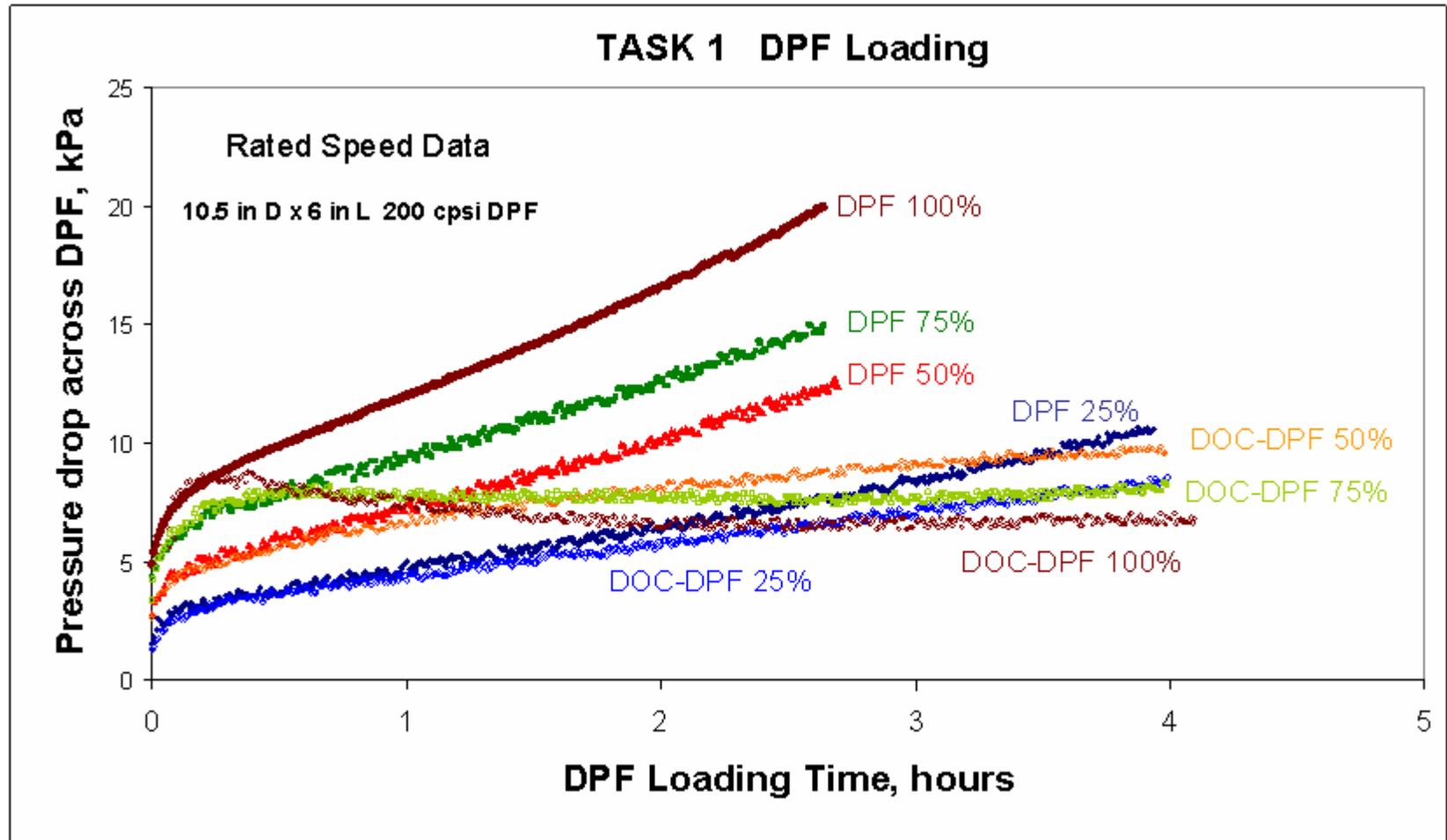


# Task 1 - DOC Model Calibration



# TASK 1

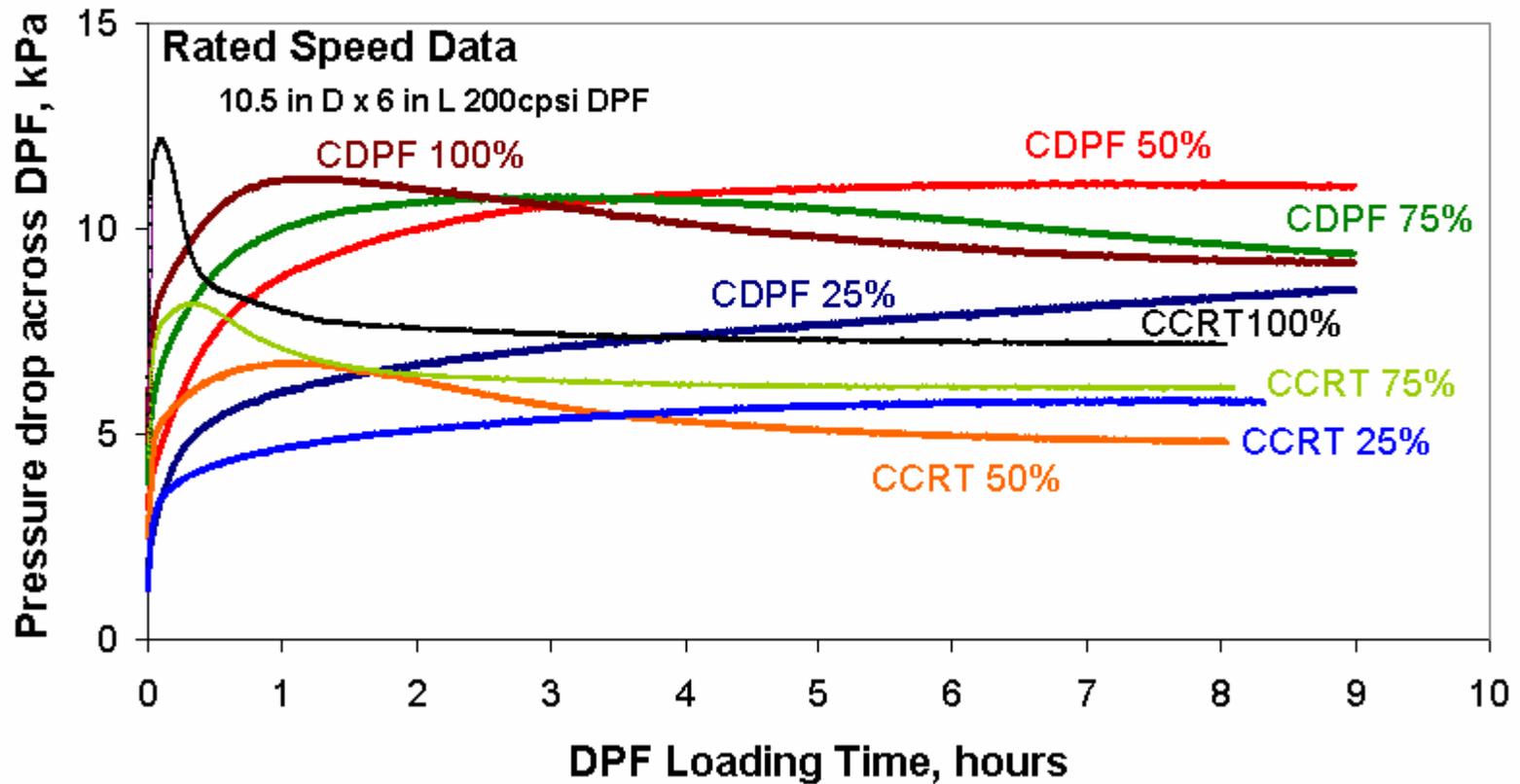
# DPF soot loading tests



# TASK 2

# DPF soot loading tests

## Task 2 DPF Loading Curves



# Tasks 1 & 2 PM Loading: Baseline, EGR, and DPF

## Task 1

Mode	6081H Baseline (Std Inj. Syst.)		with EGR		with EGR DOC and DPF
	PM %	NOx/PM	PM %	NOx/PM	PM %
1	100	68	255	21	4
2	100	30	132	19	4
3	100	19	143	9	2
5	100	30	161	13	1
6	100	26	191	9	1

## Task 2

Mode	6068H Baseline (Adv. Inj. Syst)		with EGR		with EGR DOC and DPF
	PM %	NOx/PM	PM %	NOx/PM	PM %
1	19	353	33	59	8
2	12	270	18	70	6
3	26	70	19	50	2
5	27	170	27	43	4
6	11	380	15	102	4

\* All PM Loading % based on 6081H Baseline

# DPF, CDPF, CRT™, and CCRT™ comparison

## Soot Loading Comparison

50% load @ 2200 rpm

T<sub>in</sub>, °C

NO<sub>x</sub>/PM

NO<sub>2</sub>/C

solid PM deposited, g

Pressure drop across DPF, kPa

Loading time, hours

## Soot Loading Comparison

50% load @ 2200 rpm

T<sub>in</sub>, °C

NO<sub>x</sub>/PM

NO<sub>2</sub>/C

solid PM deposited, g

Pressure drop across DPF, kPa

Loading Time, hours

## 6081H 175kW @2200 rpm

DPF	CRT™
366	372
4.9	5.2
0.3	2.8
126	126
14.5	10 *
2.7	4.0

## 6068H 187kW @2200 rpm

CDPF	CCRT™
343	350
44.0	44.0
21.0	45.0
21	8
11.0	5 *
9.0	8.0

\* DPF only

# Conclusions

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- **Adding EGR increases PM levels and decreases the NO<sub>x</sub>/PM ratio.**
- **The NO<sub>x</sub>/PM ratios were not favorable for maintaining continuous regeneration for Task 1.**
- **Using an advanced injection system (Task 2) in conjunction with higher EGR quantities, a more efficient DOC and a catalyzed DPF demonstrated that Off-highway Interim Tier 4 standards can be met with a low fuel penalty. The filter can regenerate continuously at most engine operating conditions.**
- **Particle size distributions shifted to smaller particles when using higher injection pressures and the overall mass was reduced by more than 80%.**