

# Retrofit Diesel Emissions Control System Providing 50% NOx Control

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# Background Information

# Advantages of a Diesel Fuel Processor for Lean NOx Trap (LNT) Operation

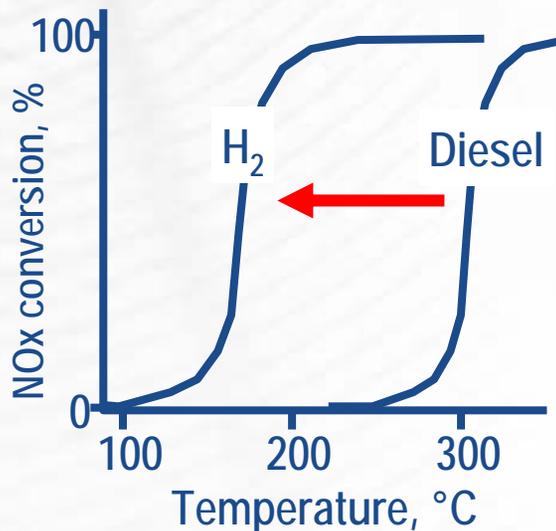
Fuel processor converts exhaust side diesel fuel to **reactive reductants**

## Benefits of Reactive Reductants

Regenerate the NOx trap at low temperatures  
H<sub>2</sub> shown to regenerate NOx trap at 150°C

Reactive reductants used very efficiently by NOx trap

Complete regeneration of NOx trap capacity allowing minimal LNT volume

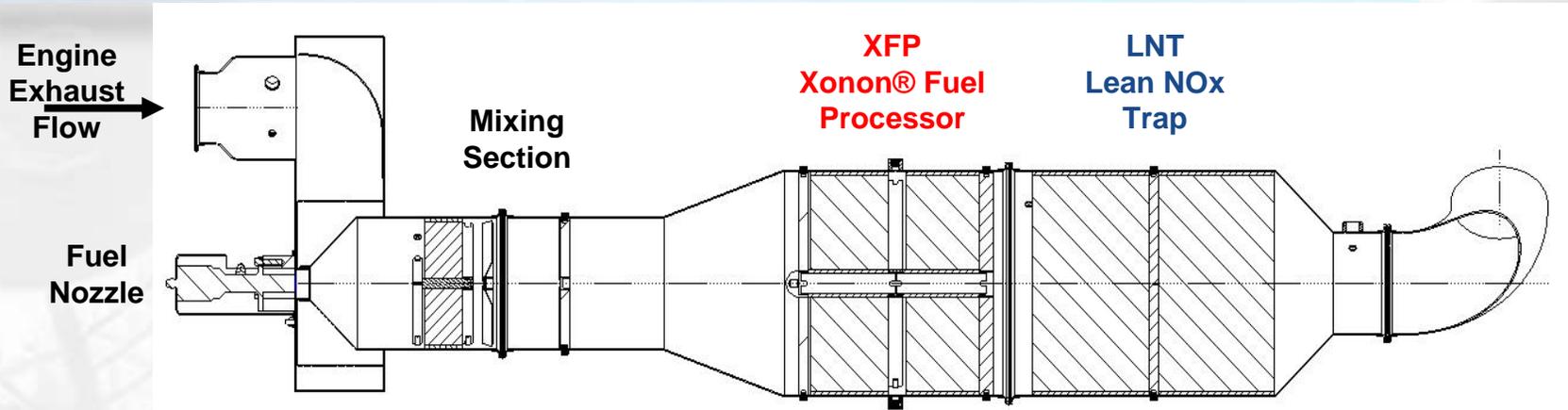


Theoretical reductant Requirements

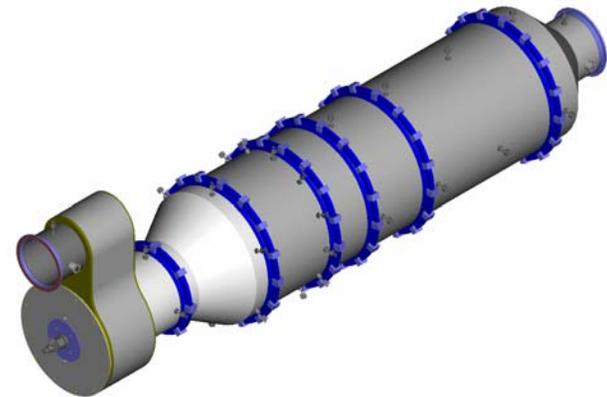
$$\frac{\text{H}_2 \text{ or CO}}{\text{NOx}} = 2$$

Large NOx trap capacity over wide temperature range

# Technology Approach – XononD™

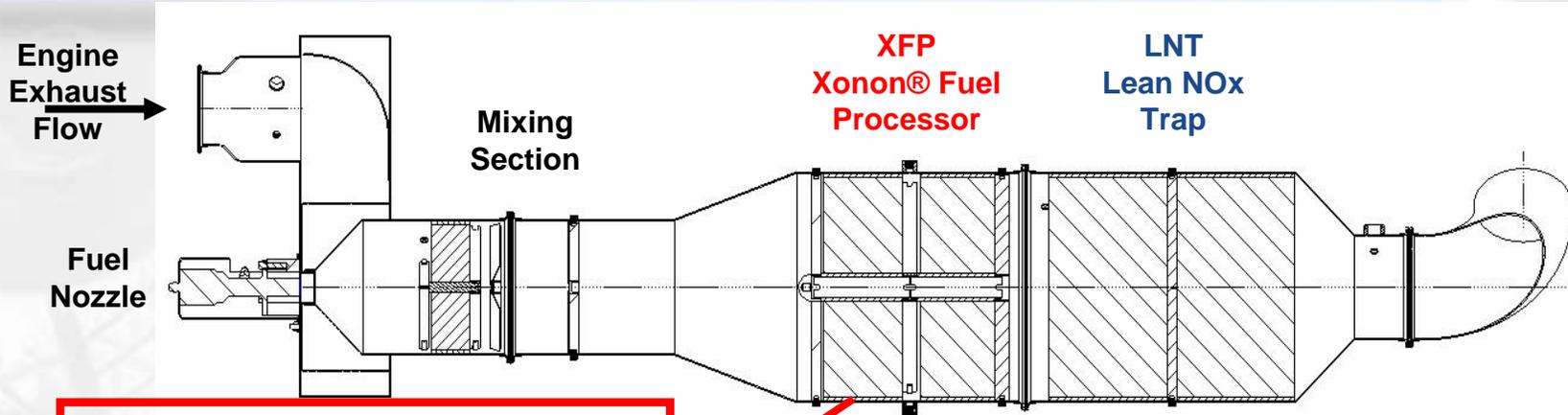


- Key Features:
  - Simple single leg design
  - Low temperature LNT regeneration
  - Minimal LNT volume
- Easy Retrofit Application:
  - No modification to engine
  - No engine control required
  - Bolt-on design replaces existing muffler

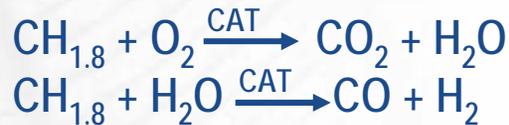


Target: EPA Verification - 50% NO<sub>x</sub>, 50% HC and 50% CO reduction

# XononD™ – How it Works



## Regeneration cycle



## NOx Adsorber reactions

- Lean NOx trapping reaction (typical component is BaO/BaCO<sub>3</sub>)



- Regeneration cycle



[red] = reducing agent, e.g. H<sub>2</sub> or CO

XFP fuel flow



XFP Outlet O<sub>2</sub> level



# Performance Targets

## XononD™ Single Leg Configuration

- Steady state performance targets on AZ-Dyno Test Facility
  - > 50 % NOx reduction in AVL-8 mode
  - < 8% Fuel penalty
- Transient performance targets for field tests
  - > 40% NOx reduction for FTP cycle
  - < 8% Fuel penalty
  - Life > 1k hrs
- Verification performance targets
  - > 50% NOx reduction for FTP cycle
  - > 90% PM reduction
  - < 6% Fuel penalty
  - Life > 150k mi (5k hrs)

# Performance Status

# Dynamometer Test Facility



# AVL-8 Mode Dynamometer Results

	Dyno Settings		Device Inlet			Totals	
Pt	Speed (rpm)	Torque (ft-lbf)	Temp (°C)	Flow (slpm)	NOx <sup>1</sup> (ppm)	NOx Reduct	Approx Fuel Penalty
1	701	5	89	2,250	183		
2	899	94	159	2,950	678		
3	1,078	266	315	3,600	1295		10.4
4	1,276	424	443	4,800	1591		4.8
5	2,489	56	236	8,700	325		8.7
6	2,409	209	322	10,350	780		8.7
7	2,409	359	385	13,300	1038		5.3
8	2,301	505	436	15,350	680		3.8
Weighted Sums =						80%	5.7% <sup>2</sup>

**Target NOx conversions and fuel penalty demonstrated**

<sup>1</sup> California Analytical Model 400S-HCLD NOx analyzer

<sup>2</sup> OEM application tests with engine control has consistently demonstrated less than 3% fuel penalty with XFP

# FTP Mode Dynamometer Results

- Typical FTP cycle results

Engine Status	Engine Out NOx (g/hp-hr) <sup>1</sup>	XononD™ Out NOx (g/hp-hr) <sup>1</sup>	NOx Conversion	Fuel Penalty
Cold	5.96	2.60	56%	5.8%
Warm	5.20	1.75	66%	6.4%
Warm	5.03	2.04	59%	7.4%
Warm	5.09	1.58	69%	7.6%
Weighted Sum			64%	7.0% <sup>2</sup>

Target NOx conversions and fuel penalty demonstrated

<sup>1</sup> California Analytical Model 400S-HCLD NOx analyzer

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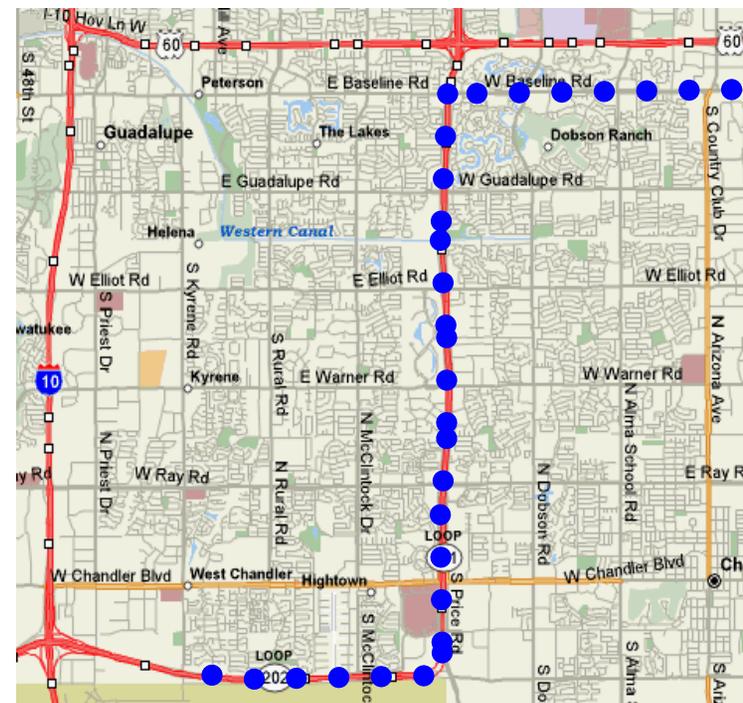
# First XononD™ Retrofit Vehicle



# Retrofit Vehicle On-road Results

Drive Cycle	Engine Out NOx (g) <sup>1</sup>	XononD™ Out NOx (g) <sup>1</sup>	NOx Conversion	Fuel Penalty
Combined City & Highway	137	39	71%	6.3% <sup>2</sup>

- Inaugural on-road test with transient control system
- Drive cycle in Chandler, AZ includes:
  - 6 miles surface streets (~45 mph)
  - 18 miles of highway (~60 mph)
- NOx conversion and fuel penalty based on integrated measurements from the entire trip



<sup>1</sup> Horiba MEXA-720NOx sensor & analyzer units

<sup>2</sup> OEM application tests with engine control has consistently demonstrated less than 3% fuel penalty with XFP

# Field Demonstration Vehicles



Field demonstration vehicles provided by the City of Denton, Texas.

# Neighborhood Field Demo Results

Engine Out NOx (g) <sup>1</sup>	XononD™ Out NOx (g) <sup>1</sup>	NOx Conversion
4404	2626	40%

- Neighborhood drive cycle in Denton, TX during normal refuse pick-up
  - Lower NOx conversion indicative of lower temperature duty cycle
- NOx conversion based on cumulative measurements over several weeks
  - > 580 cumulative on-road hours on XononD™
- Estimated fuel penalty ~ 4 to 7% <sup>2</sup>

<sup>1</sup> Horiba MEXA-720NOx sensor & analyzer units

<sup>2</sup> OEM application tests with engine control has consistently demonstrated less than 3% fuel penalty with XFP

# Loop-288 Field Demo Results

Date	Engine Out NOx (g) <sup>1</sup>	XononD™ Out NOx (g) <sup>1</sup>	NOx Conversion
6/29	303	124	59%
7/27	342	156	54%
8/3	179	75	58%
8/10	409	133	67%

- Repeatable loop 288 drive cycle in Denton, TX
- NOx conversion based on integrated measurements from multiple back-to-back cycles
- Estimated fuel penalty ~ 4 to 7% <sup>2</sup>

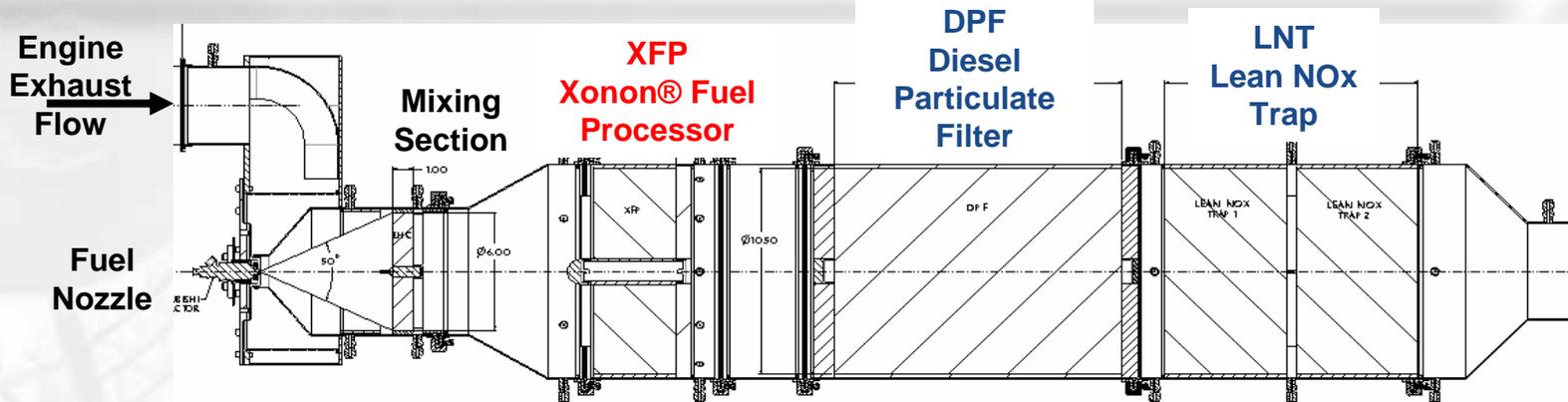


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# Looking Ahead

# Diesel Particulate Filter (DPF) Integration



- DPF provides thermal mass to “shield” LNT from thermal spikes during regeneration
- During each regeneration, XFP temperature spikes to  $>600^{\circ}\text{C}$  for 2 to 10 s
  - DPF temperature may be 10 to  $50^{\circ}\text{C}$  higher resulting in improved “passive” DPF regeneration
- XFP provides active regeneration of DPF up to  $700^{\circ}\text{C}$
- Can combine LNT desulfation and DPF regeneration cycles

# Summary

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- CESI has developed a single leg exhaust after-treatment diesel fuel processor and NOx adsorber system for retrofit applications
- > 50% NOx reduction achieved for AVL-8 mode and FTP transient cycle tests
- On-road field demonstrations tests achieve 40 to 67% NOx reduction
- Retrofit fuel penalty varies from ~ 4 to 7%
  - OEM application tests with engine control has consistently demonstrated less than 3% fuel penalty with XFP
- Particulate filter integration planned for future verification product

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