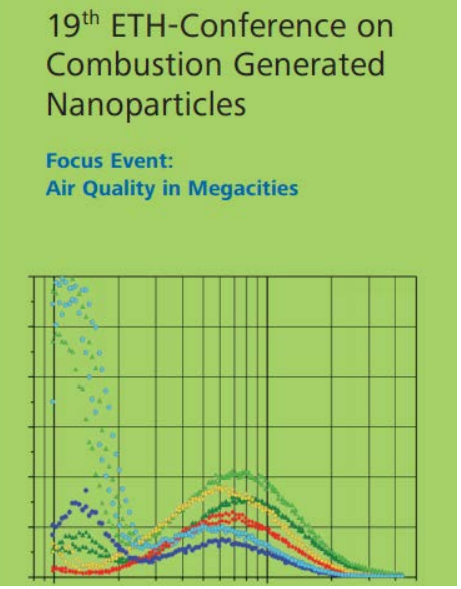

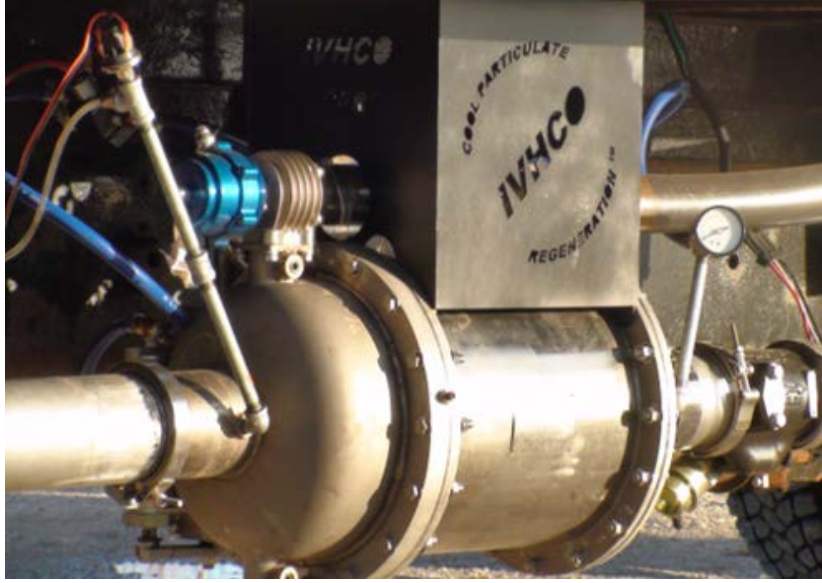

Global Emission Solution

Non-Thermal Active Particulate Filter Regeneration Technology

Cool Particulate Regeneration™ (CPR™)

Presented by:

Brett Bailey, President and CEO of IVHCO

19th ETH-Conference on Combustion Generated Nanoparticles

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Agenda:

- Motivation
- Non-Thermal Regeneration Fundamentals
- IVHCO R&D
- Particulate Matter Carbon Sequestration, Use as a Fuel and Incineration Options
- BACT for <19kW Diesel Engines
- Ash Removal
- Aftertreatment Combination/Simplification
- Main Mega City Options and Potential for Non-Thermal Regeneration
- Conclusions

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Motivation:

- **Low Cost Global Emissions Reduction**
  - Fuel Tolerant (ULSD Not Required)
- **Reduce or Eliminate Particulate Matter Incineration Energy and GHG**
- **Engine Independent Control System**
- **Low temperature**
- **Reduction or Removal of Ash Maintenance**
- **SCR/DPF Combinations**
- **Diesel Particulate Filter as Best Available Control Technology - <19kW Diesel Engine**

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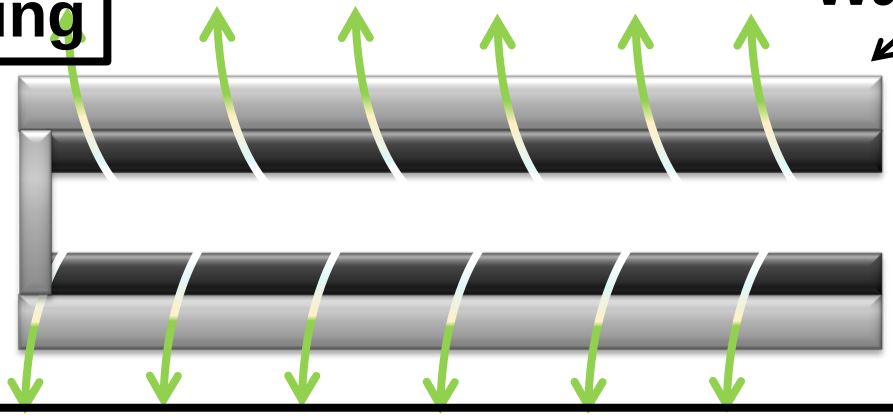
Non-Thermal Regeneration Fundamentals

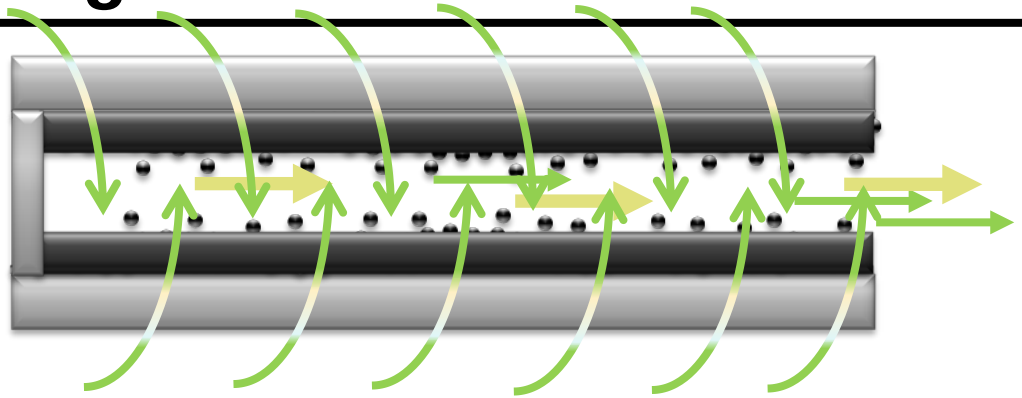
1. Filling



Engine Out Nano Particles Filtered by Diesel Particulate Filter Substrate

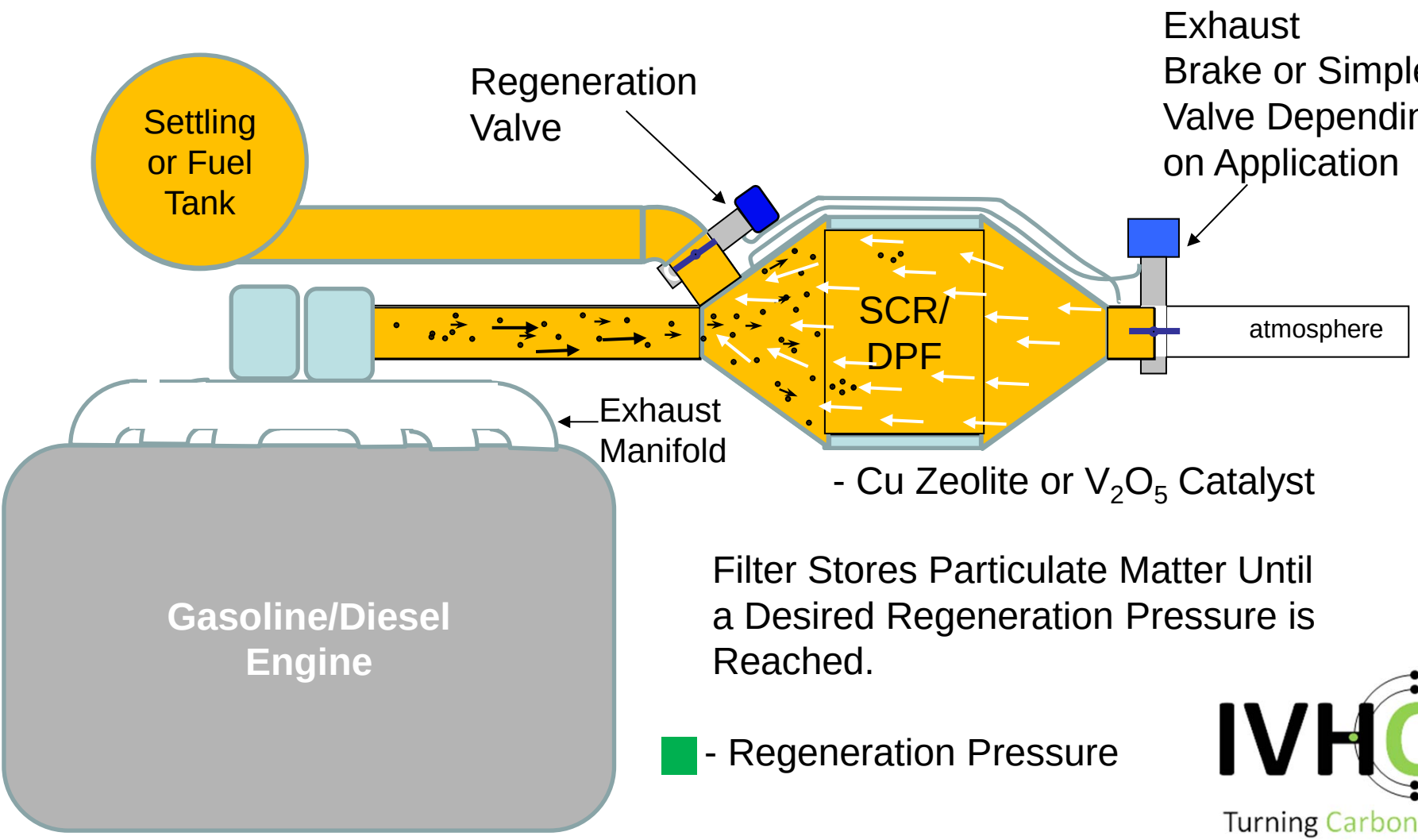
2. Pressurizing to Regeneration Set Point (Not Shown)

3. Upstream Release of Pressure Creating Reverse Pressure Wave



Agglomerated Particles Removed from Substrate

Non-Thermal Regeneration
How it works



- Cu Zeolite or V_2O_5 Catalyst

Filter Stores Particulate Matter Until a Desired Regeneration Pressure is Reached.

- Regeneration Pressure

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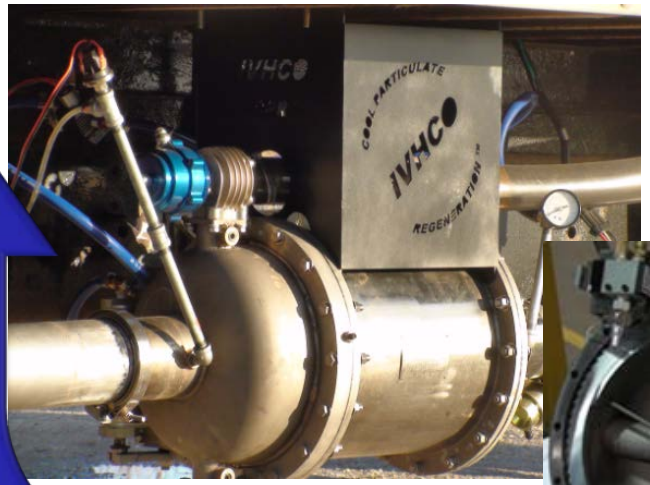
Regeneration Demonstration*

*** This Particulate Matter is Normally Captured in Settling Tank and NOT Released to Atmosphere**

IVHCO CPR R&D

- **CPR 2.0 Whole Trap**
  - 7.5kW Tier 0 Genset
  - High PM Emitting engine
  - Prove Scalability of Applicability of regeneration to <19kW Small Engine
  - Independent of Engine Control



- **CPR 1.0 Segment Design**
  - 167kW Medium duty Diesel engine testing

CPR Evolution

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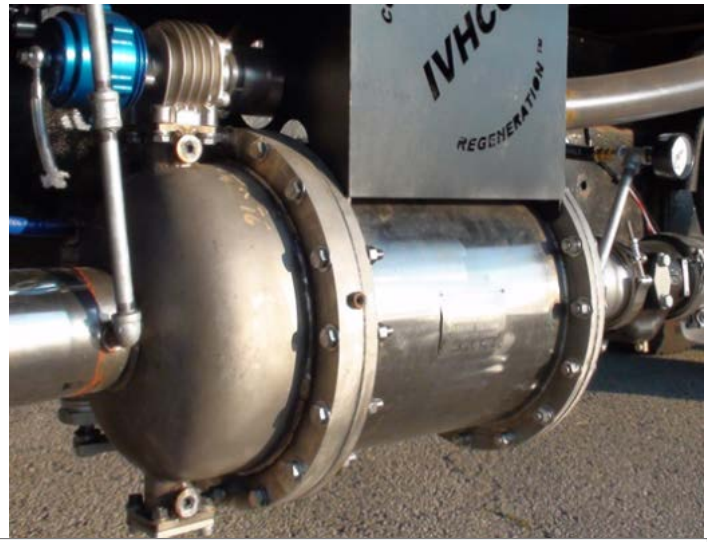
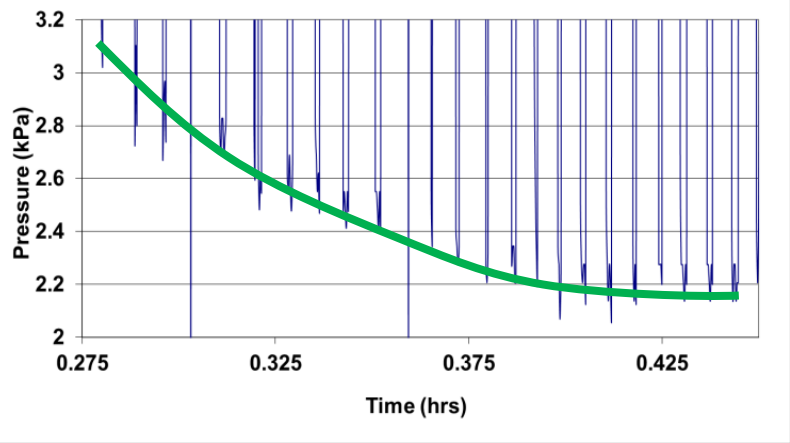
Non-Thermal Regeneration Segmented V1.0

- Portion of Trap Regenerated at a Time (28 segments)
- 167kW Medium duty Diesel engine testing
- Over 8000 miles without failure
- Regeneration Conducted at Fuel Filling Intervals

GMC C6500 7.2L 3126B

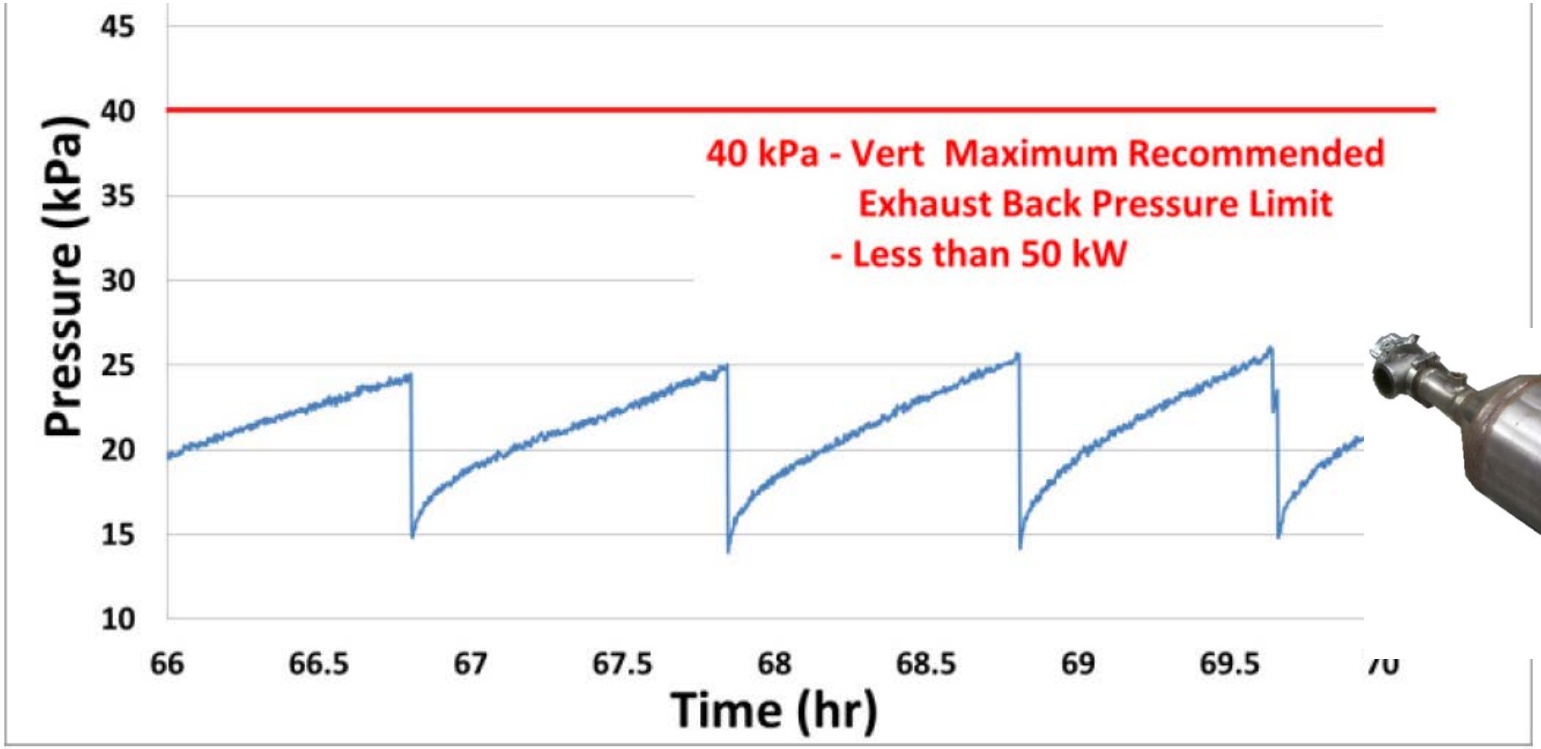




Whole Trap Engine Performance Tests

- **Equilibrium Operation**
- **Bare Uncatalyzed Cordierite Filter**
- **Over 100hrs of testing without Failure**

Onan 7.5kW Quiet Diesel Generator					
Engine RPM	3600	rpm			
Engine Displacement	0.719	l	43.88	cu in	
Cylinders:	3				
Bore	67	mm	2.64	in	
Stroke	68	mm	2.68	in	
Compression Ratio	23 to 1		23 to 1		
Power (max) @3600 rpm	12.4	kW	16.6	hp	
Fuel Injection Pump	Bosch MD type				
Combustion Chamber:	Spherical (TVCS)				



Non-Thermal Active Regeneration 2.0 Whole Trap Design

- **2.3 Second Total Regeneration Time**
- **Rapid Sequential Pneumatic Control Valve Operation**

Onan 7.5kW Quiet Diesel Generator				
Engine RPM	3600	rpm		
Engine Displacement	0.719	l	43.88	cu in
Cylinders:	3			
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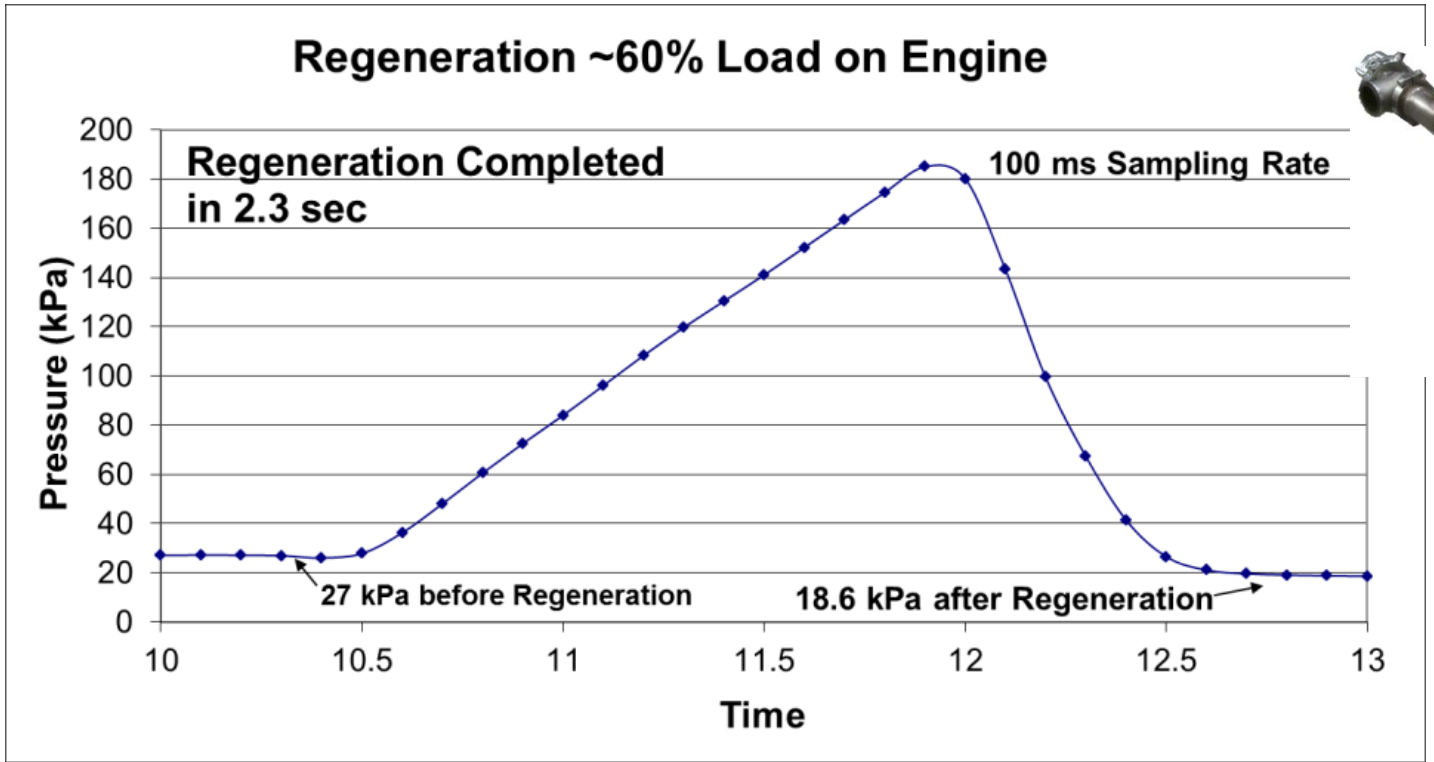

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Removed Particulate Matter Options

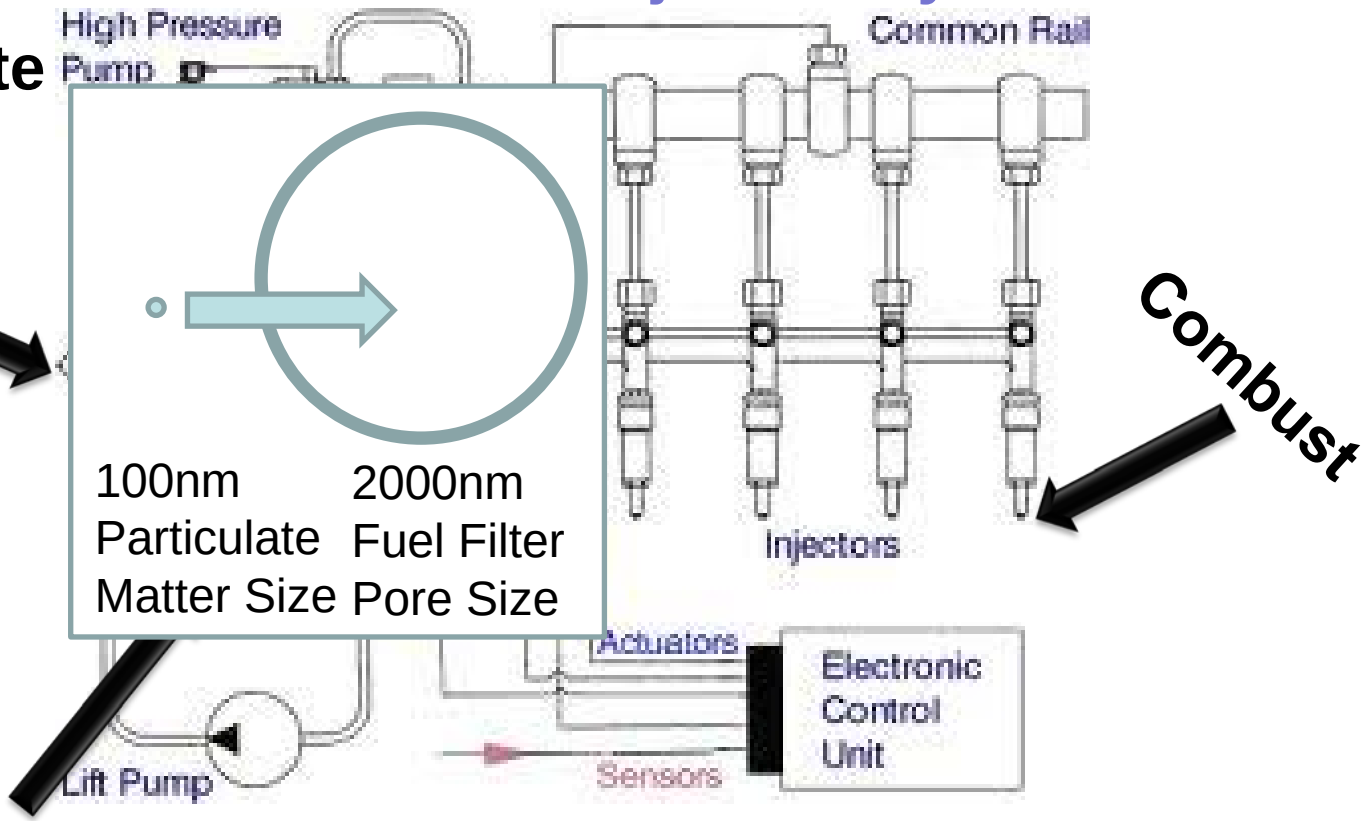
- **Carbon Sequestration**
  - PM stored between Oil Changes (Recycled with oil) or for the Life of the Vehicle Depending on PM generated (GDI & possibly next generation Diesel)
  - By-product (i.e. asphalt melting point enhancement)
- **Particulate to Power**
  - Combusting particulate as a Colloidal fuel
- **Incineration of Particulate Matter**
  - Waste Exhaust Manifold Energy Utilization
  - Direct Electrical Oxidation

Particulate to Power

Waste Particulate Recycled into Fuel

- **Deagglomerate Particulate Matter to Original Size (10-100nm)**
- **Mix w/ Fuel**
- **Pass through Fuel Filter**

Common Rail Fuel Injection System



Fuel Tank is Potential Settling Tank

Particulate to Power!

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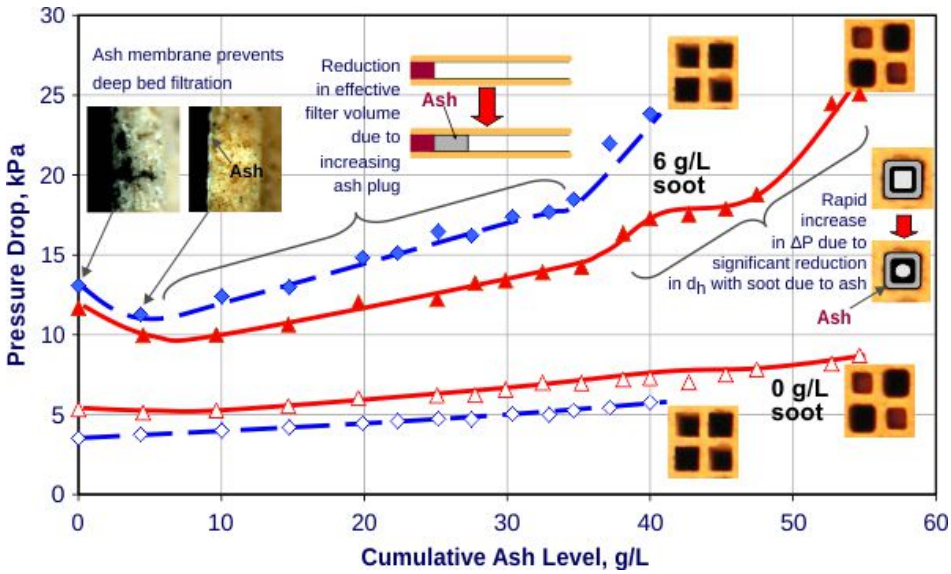
Non Thermal Regeneration DPF Best Available Control Technology (BACT)<19kW Small Engine Segment

- **Segment Technical Challenge that have Restricted Emissions Regulations Adoption**
  - **High PM generation**
  - **Low Exhaust Temperatures**
  - **Lack of Electronic Controls**
  - **Cost Constrained**

- **Non Thermal Regeneration**
  - **Low Cost and High PM Tolerant**
  - **Simple Pneumatic Controls (Independent of engine)**
  - **Particulate Combusted In-cylinder**

Ongoing Ash Removal (each Regen)

- **Regeneration Expected to Remove Ash & PM**
- **Ash Backpressure and Fuel Economy Penalty Reduced or Eliminated**
- **Long-term Testing Required**



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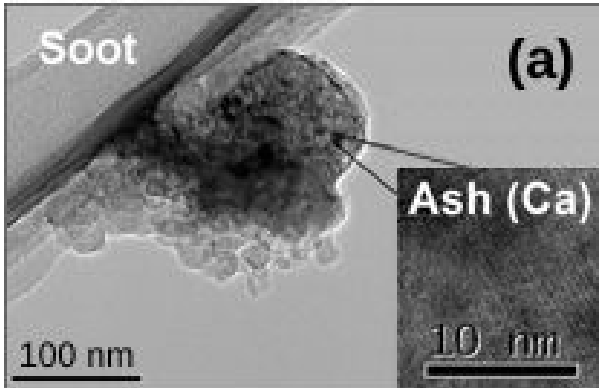

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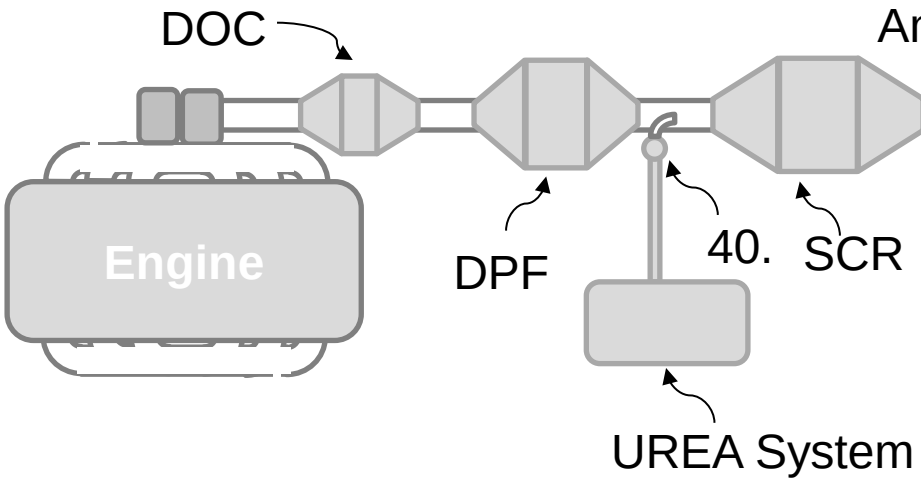
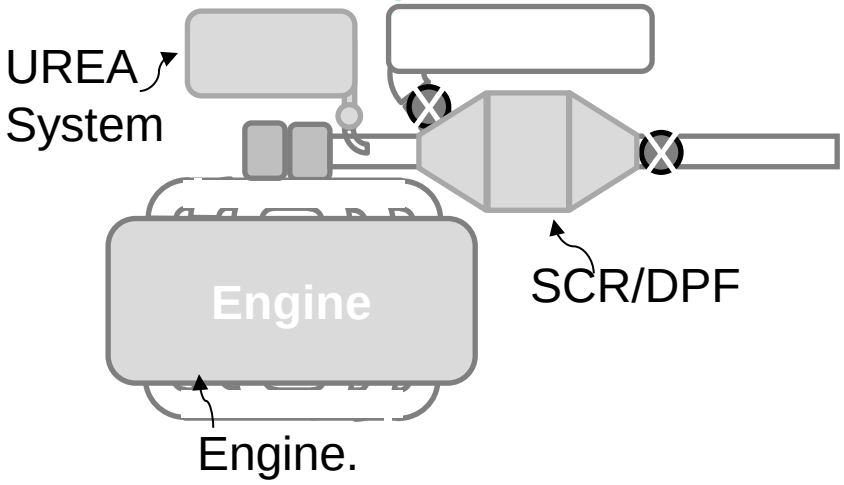
SCR/DPF Combination

Typical Current Solution:



SCR Catalyst Coated DPF

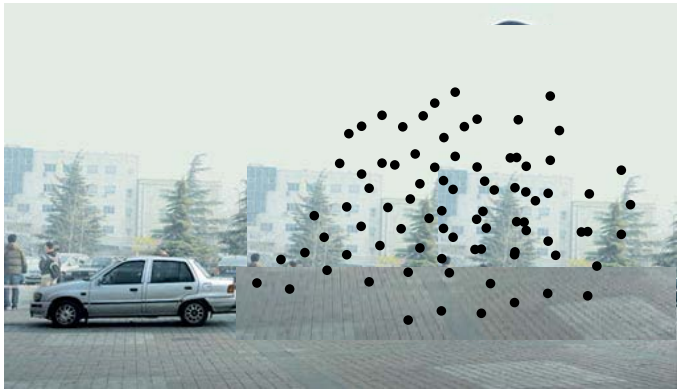


Advantages:

- V2O5 SCR Catalyst Capable (Fuel Tolerance)
- Closed Coupled for Real World Emissions Reductions
- Decoupled for Low Temp SCR Capable
- Cost and Complexity Reduction
- Durability/Reliability Improvement

Emission Reduction for Mega City Air Today Options:

- **Replacing of Vehicles with New Lower Mass Particulate Generating Vehicles**
  - Increases the Quantity of Fine and Ultra Fine Particulate Unless New Vehicle is Fitted with a DPF
- **Retrofitting of Vehicles with Particulate Filters**
  - Greater than 85% and Approaching 99% Reduction in PM (Fine and Ultra-fine)
  - Lower Cost Near Term Solution



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Emissions Reduction in Mega City Air Today Non-Thermal Active Regeneration

- **Effective and Efficient at Controlling High PM**
- **Low Cost and Mass Production Potential**
- **Fuel Tolerant to Low Grade Fuels (High Sulfur)**
- **Independent of Engine Control Module (ECM)**
- **Limited Modifications (Bolt-on) to the Vehicle**
- **Potential for 2-Stage Implementation.**
  - 1st PM Coated with Vanadium Pentoxide (V_2O_5)
  - 2nd NOx reduction with addition of NOx sensor and UREA system

Conclusions:

- **Non-Thermal Regeneration Demonstrated**
- **Innovative Particulate Removal Options Demonstrated and Introduced**
- **Global Emissions Solution**
  - Potential to export to Developed Markets with Stringent Emissions
- **Combining of Aftertreatment Modules Potential**

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Thank You for Your Time

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