Engine Control Systems

Retrofit Emissions Control in Mining

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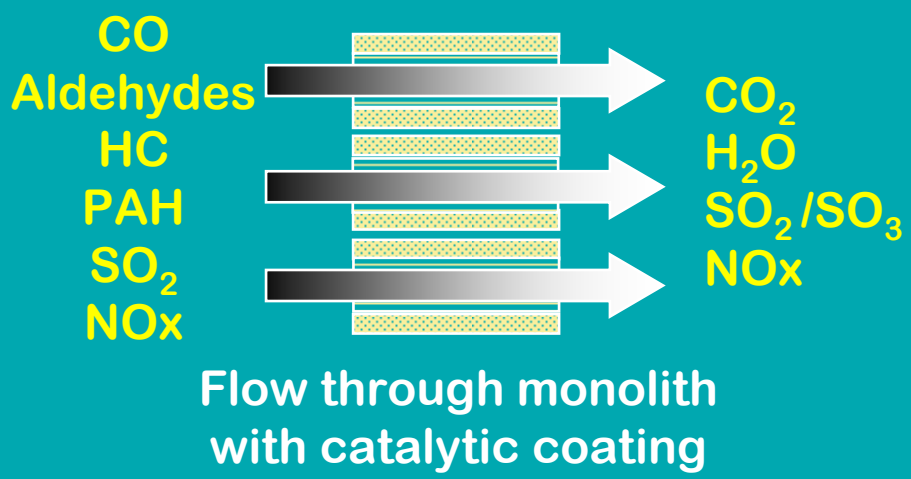
Retrofit Technology Options for PM Control

- Particulate Filters
- Oxidation Catalysts
- Flo-thru Filters
- Fuel Choice
  - Reduce Fuel Sulfur
    - ULSD
  - Bio-Diesel

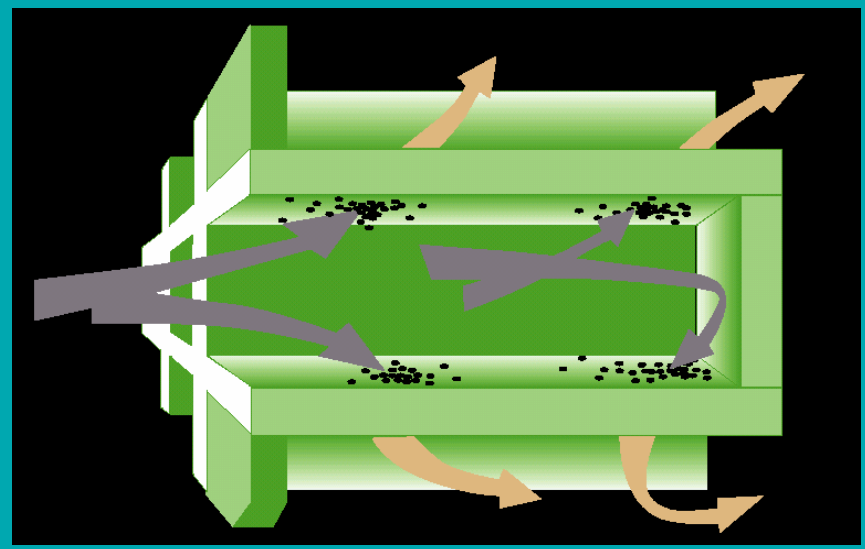
DOCs and DPFs: Two cornerstone technologies

Diesel Oxidation Catalysts



- 10-50% PM Reduction with <500ppm or ULSD
- Reduction in Toxics
- Nearly Universal Application with > 1 Million Retrofits Worldwide

Diesel Particulate Filters



- 85+% PM Reduction
- Large Reduction in Toxics
- > 200,000 Retrofits Worldwide
- > 1 Million OE Applications

DOC Advantages

- Cost effective
- Fuel Sulfur tolerant
- Compatible with an array of traditional and alternate diesel fuels (i.e. biodiesel, e-diesel, emulsions)
- Flexible design attributes
- Easiest Installation
- Durable
- Virtually Maintenance Free

Disadvantages: does not reduce significant amounts of elemental carbon, likely will not be enough for compliance

Elemental Carbon Combustion in Diesel Exhaust Aftertreatment

1) With soot ignition catalyst systems

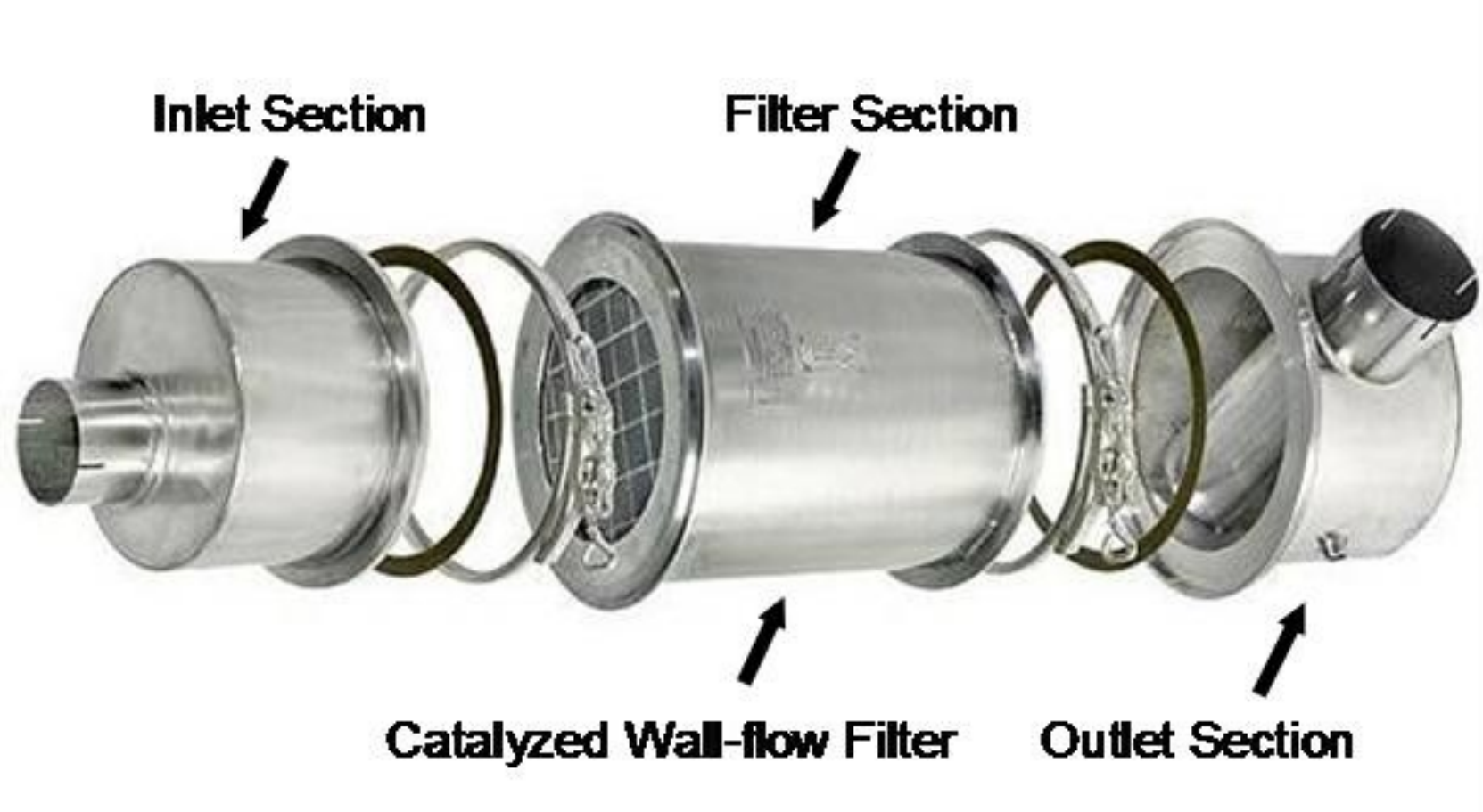
One or both of the following:

- 1a) Oxidized passively by nitrogen dioxide
  - as low as 200 Celsius claimed
  - Requires ULSD & has a NO_2 slip
- 1b) Oxidized passively by oxygen
  - >350 Celsius
  - Fuel sulfur tolerant & no NO_2 slip
  - Base metal DPF's and fuel additives

2) Alternatively, by external heat

- fuel burner or electrically heated in the presence of oxygen
  - >550 Celsius

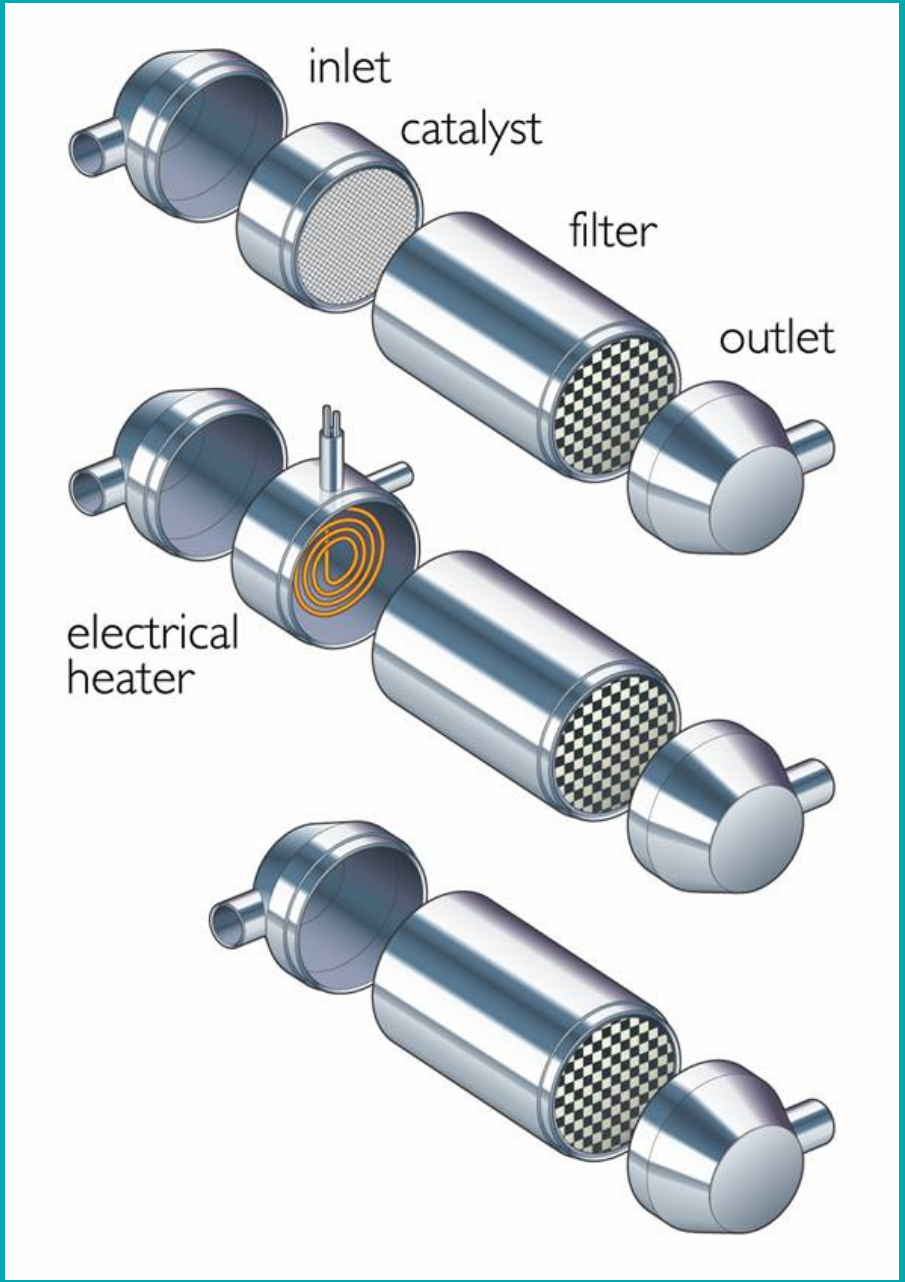
Diesel Particulate Filters



DPF Technology Configurations

Modular design allows a variety of configurations:

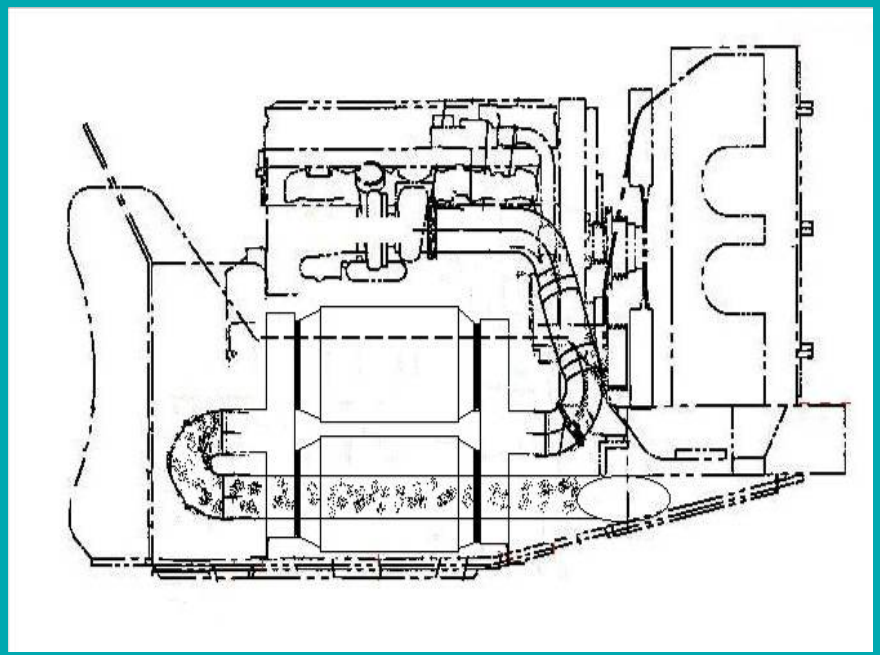
- DOC / DPF
  - also DPF / DOC
- Active DPF
- DPF



DPF Regeneration Types in Mining

Filter	Precious Metal containing Passive	Base Metal Passive	Active Electric
Fuel Required	ULSD	<500ppm S	any
Regeneration Temperature	280 – 320 C	380 – 420 C	Not Required
Regeneration Catalyst	Precious & Base Metal Coating	Base Metal Coating	Electrical Connection
Regeneration Downtime	None	None	60 minutes to 8 hours
Regeneration Method	Passive Filter Regeneration	Passive Filter Regeneration	Active Filter Regeneration

Base Metal DPF Durability Trials



Canadian DEEP Trials

Wagner ST8-B Loader; DDC S60 325 hp

- **4053 hrs total accumulation**
- **>25% above 380 ºC**
- **21.9% time at idle (887 hrs)**
- **One mine cave-in**
- **Now over 10,000 engine hours**

Source: SAE 2004-01-0077

Comparison of BM-DPF & PM-DPF from DEEP Program with <500 ppm Fuel Sulfur

	DEEP Series 60 Testing	
	PM Mass Reduction	
Mode / Exh. Temp	Base Metal DPF	Precious Metal DPF
1 / (371°C)	83%	67%
3 / (321°C)	85%	86%
5 / (464°C)	41%	-146%
7 / (376°C)	60%	11%

Conclusions: Precious Metal DPF's will make sulfate, need ULSD

Source: Gangal et. al., MDEC Conference, 2002

DEEP program Results for BM-DPF

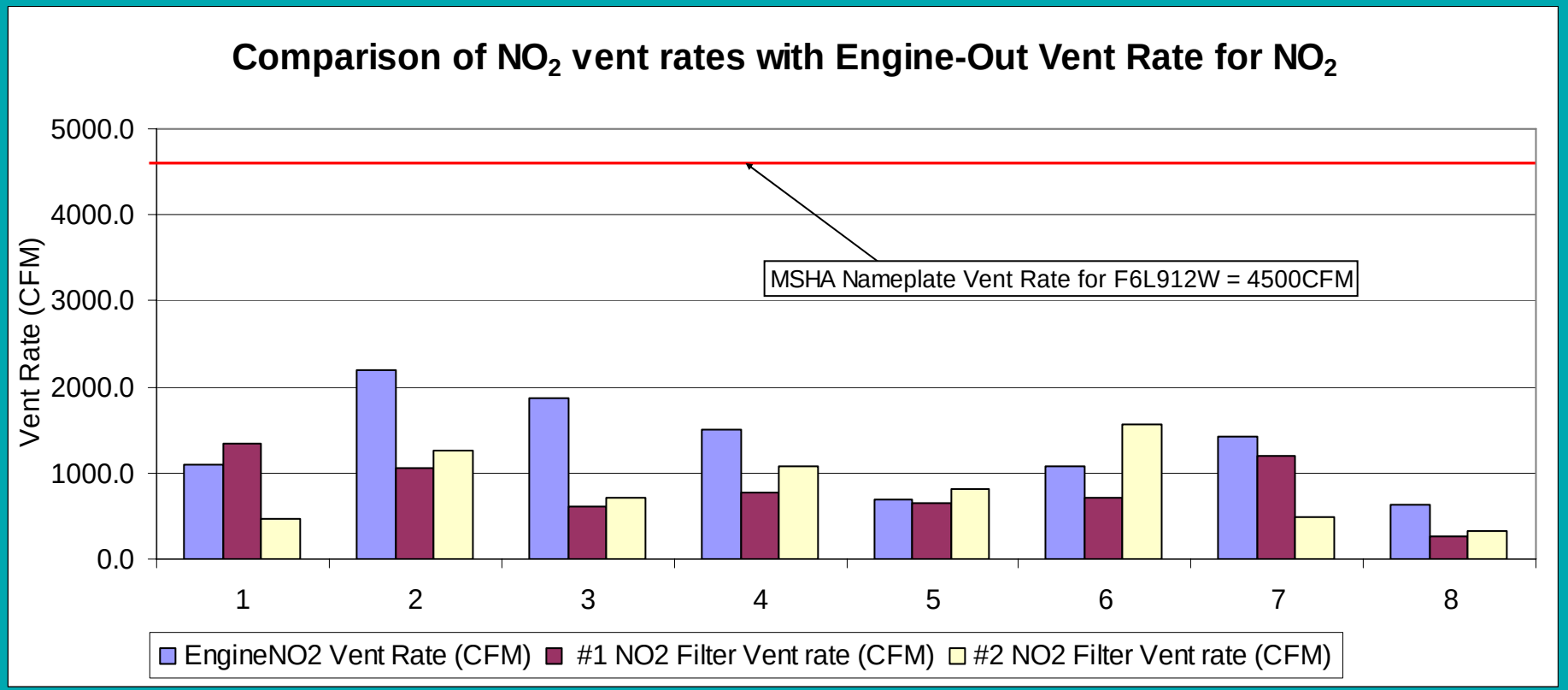
Tier 1 DDC Series 60 11.1L

ISO 8178 Mode / Exhaust Temp. (°C)	DPM Mass Reduction (%)	Particle # Based (%)	NO_2 Reduction (%)
1 (371)	83	99	76
3 (321)	85	92	80
5 (464)	41	93	70
7 (376)	60	94	81

Source: Gangal et. al., MDEC Conference, 2002

US MSHA Tests of Base Metal DPF

- **88% PM reduction over ISO 8 Mode on Deutz F6L912W**



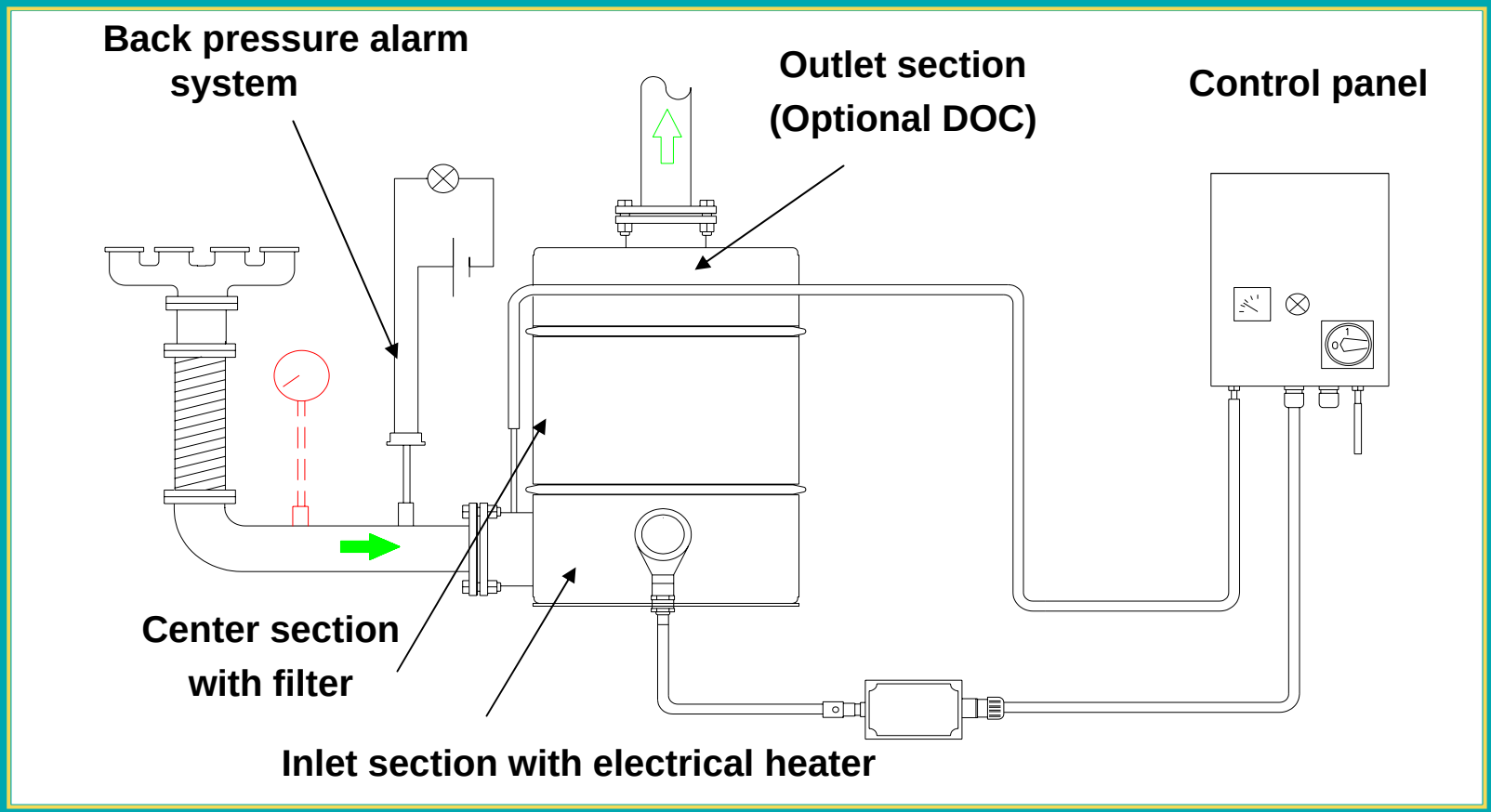
Base Metal and Un-catalyzed DPF's will lower NO2

Electrical Regeneration

Electrical (Active) Regeneration

- Not New – has been commercially available for 30 years
- Commonly used with un-catalyzed DPF's
- Can be regenerated on-board or off-board (exchange DPF's)
- Can be used periodically with catalyzed DPF's to
  - Deal with variable duty cycles
  - Deal with higher emitting engines
  - To insure low backpressure
  - To service DPF's on-board without removal

On-board regeneration



Off-Board Regeneration

- Allows all filters to be exchanged and regenerated off-board
- Reduces worker exposure to fine particles
- can be used to service passive filters

Active DPF Test Programs

Wagner ST-8 Loader
DDC Series 60
with Combifilter
Model 2xS18

- **regenerated daily**
- **operated over 2000 engine hrs**

DEEP Trials: Stobie Mine
(report available at www.deep.org)

Kubota Service Tractor
with Combifilter Model S10

- **regenerated as required**
- **operated over 500 engine hours and three years under DEEP program**

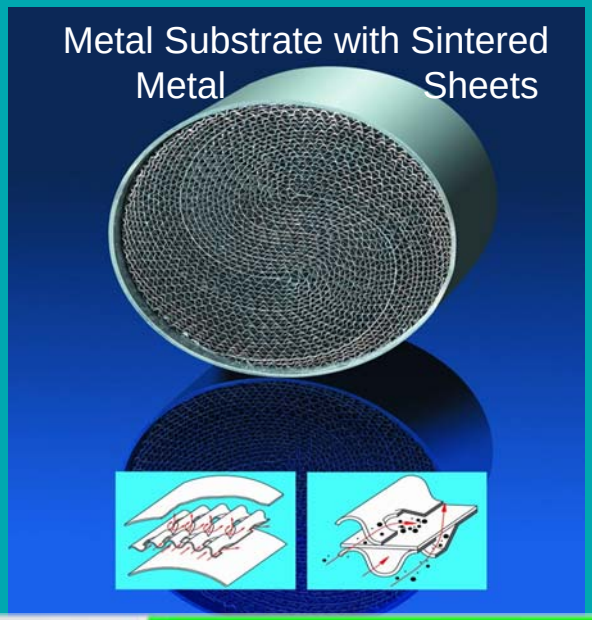
DPF Regeneration and Maintenance

Some machines combine regeneration and ash removal capabilities

Can be used to remove ash and hard carbon deposits from un-catalyzed and catalyzed filters

Cleaning frequency usually determined by manufacturers recommendation or more often if direct mine experience with specific equipment indicates it is necessary

"Flow-Thru" or "Partial" Filter Technologies are Emerging



Claims

- 50-80% PM reduction
- Can be catalyzed, used with a DOC, or a fuel-borne catalyst
- Have applicability on older engines
- Resistant to plugging

Flow Thru Filter (FTF) Technologies

- FTF technologies are emerging which afford >50 to 65% PM reduction
- Typically cost 85% of traditional DPF's
- These systems still have duty cycle requirements similar or identical to DPF's
- Duty cycles below minimum requirements, afford at best, DOC performance and increased risk of plugging or required maintenance
- Most FTF's operate under higher exhaust backpressures than DPF's
- FTF's employ NO2 at lower temperatures to oxidize elemental carbon
  - As such, they require ULSD and increase NO_2
  - They can be severely affected by higher sulfur fuels

Problems encountered to date

- Vehicle Operator / Maintenance Relationship
  - Lack of proactive operator education
  - Lack of reporting of problems to maintenance
  - Operator tampering
- Too much focus on aftertreatment diverts attention from obvious basic problems
  - Mis-fueling
  - Lack of preventative maintenance
    - especially air filters, injectors and turbochargers
    - basic inspection of installations
- Underestimating vibration
  - Not using high grade vibration isolators especially in track drive equipment

Problems encountered to date (cont'd)

- Not following installation instructions
  - taking short cuts to get machine done now
  - Owners demanding things done their way
- Not following manufacturer recommended preventative maintenance schedules
- The belief in magic silver bullets or lower cost options
  - Causes delay in dealing with the immediate issues
  - Trialing dubious products
  - Not dealing with a reputable manufacturer

Acknowledgements / Information

- DEEP trials (www.deep.org)
- Dieselnet (www.dieselnet.com)
- MSHA (www.msha.gov/01-995/dieselpart.HTM)
- MECA (www.meca.org)
- EPA (www.epa.gov/otaq/retrofit/retroverifiedlist.htm)
- ARB (http://www.arb.ca.gov/diesel/verdev/verdev.htm)