



Evolving Power Technologies: Lifting Equipment

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CRAC Annual Conference – June, 2014



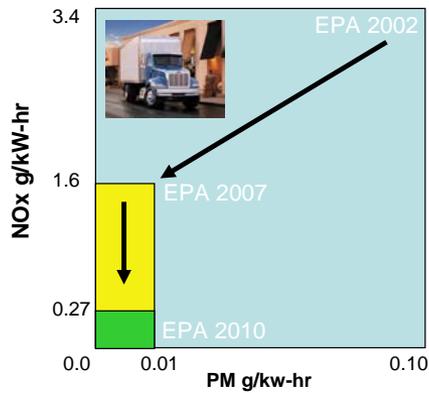


Today's Talking Points

- Diesel engine emissions regulations
 - ✓ Past, Present, & Future
- The “Tier 4 hurdle”
- How we meet today’s standards
- Exhaust aftertreatment technologies
- Analyzing your current equipment
 - ✓ Repair **vs.** Repower **vs.** Replace
- Q & A period

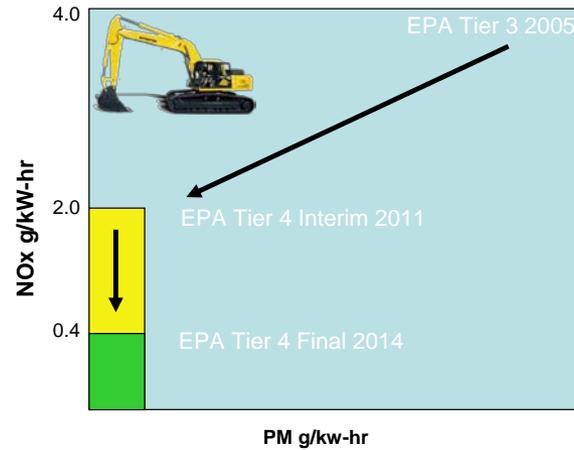
Emissions Alignment

On-Road



Off-Road

Most stringent emission levels shown for >49 hp (37 kW)



Marine



PowerGen



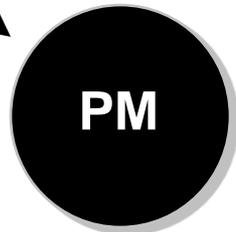
EPA is the Rule Maker

Diesel Emission Regulations

What is Regulated?



- oxides of nitrogen
- urban smog



- particulate matter
- health effects



What does Environment Canada Regulate?

Particulate Matter (PM)

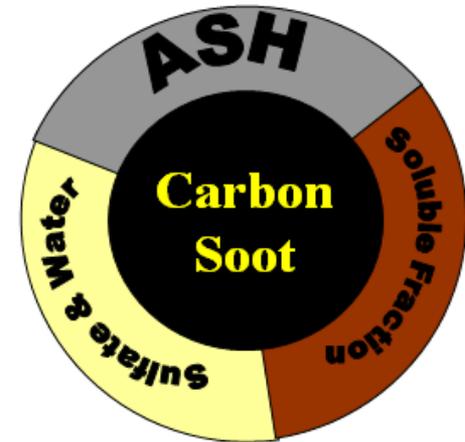
- Made up of Carbon Soot (C), Ash, Organic material & sulphates

Hydrocarbons (HC)

- Some have irritating odor, toxic and/or carcinogenic

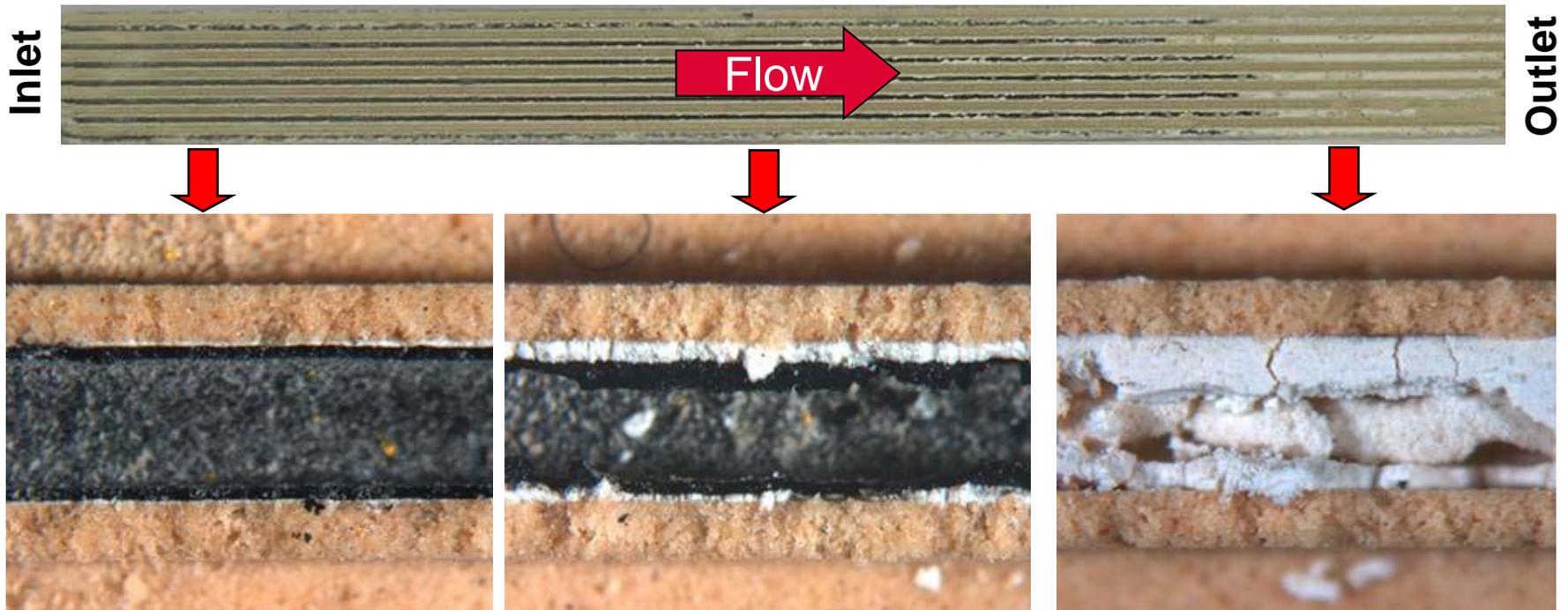
Carbon Monoxide (CO)

- Colorless, odorless and tasteless gas



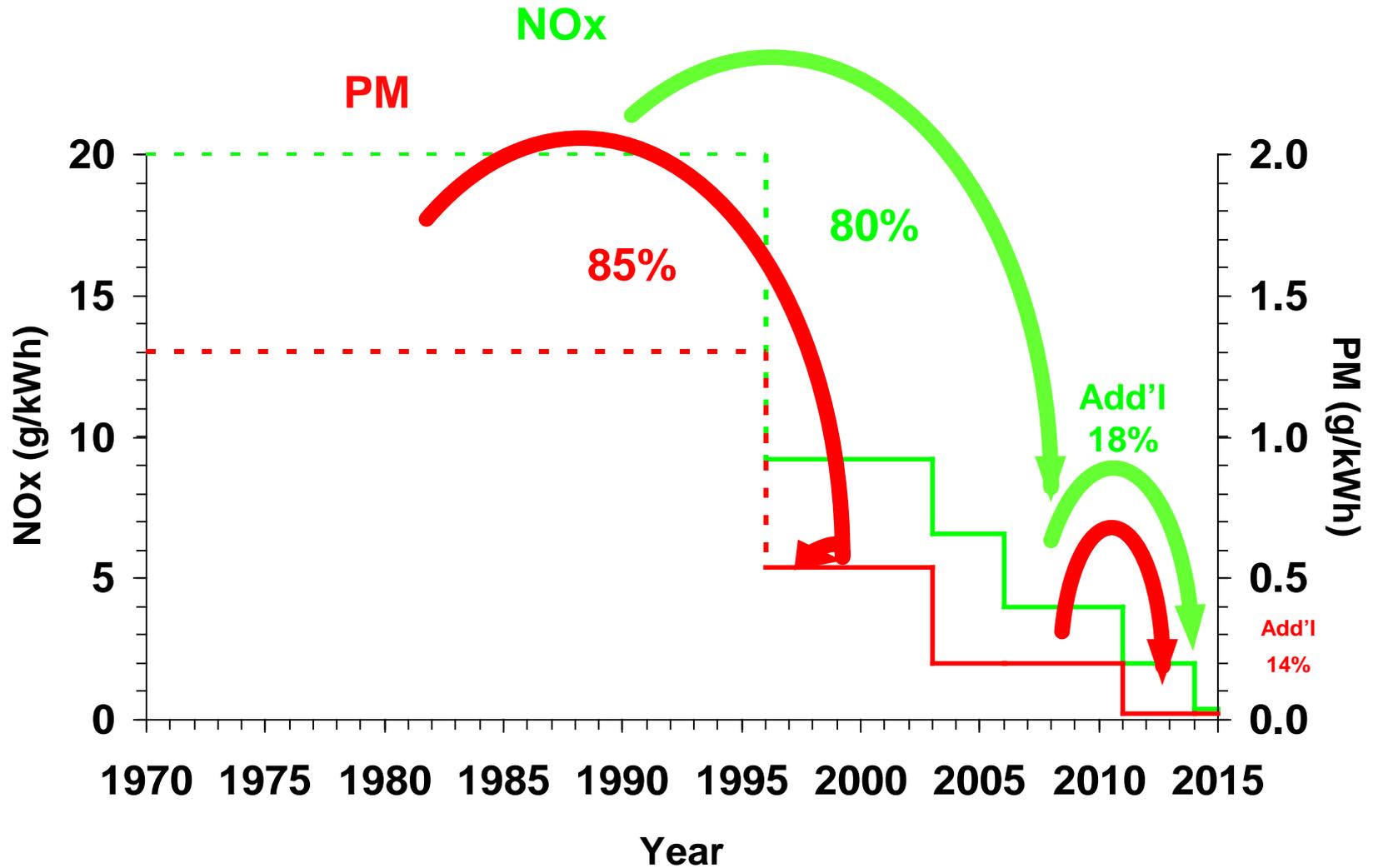
What Is Ash?

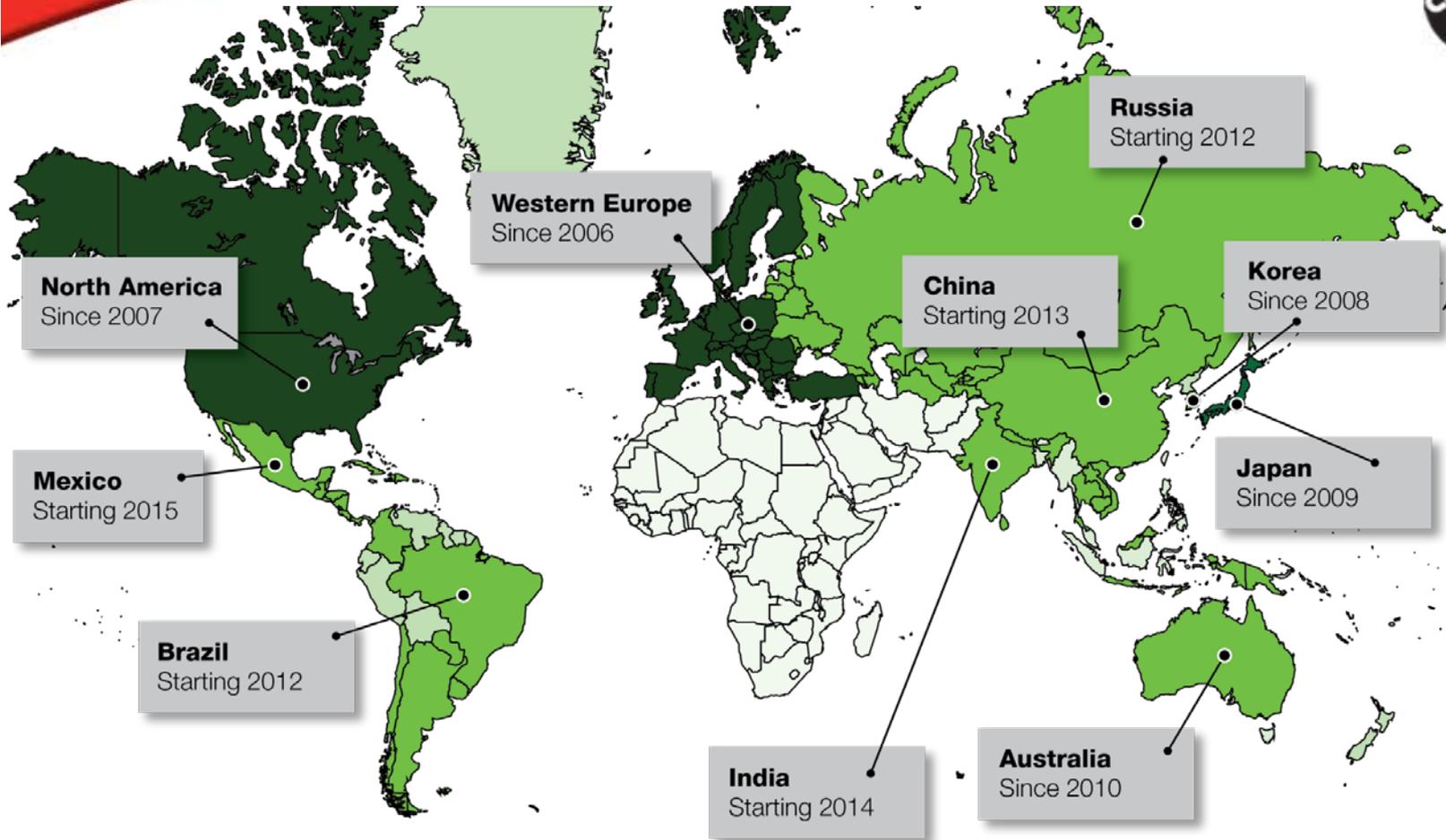
- Calcium, sulfur, zinc and phosphorous compounds (Ca, S, Zn and P)
- CaSO_4 , calcium sulfonate as anhydrite (60%)
- $\text{Zn}_2\text{P}_2\text{O}_7$, zinc pyrophosphate (20%)





EPA Emission Standards: Off-Hwy



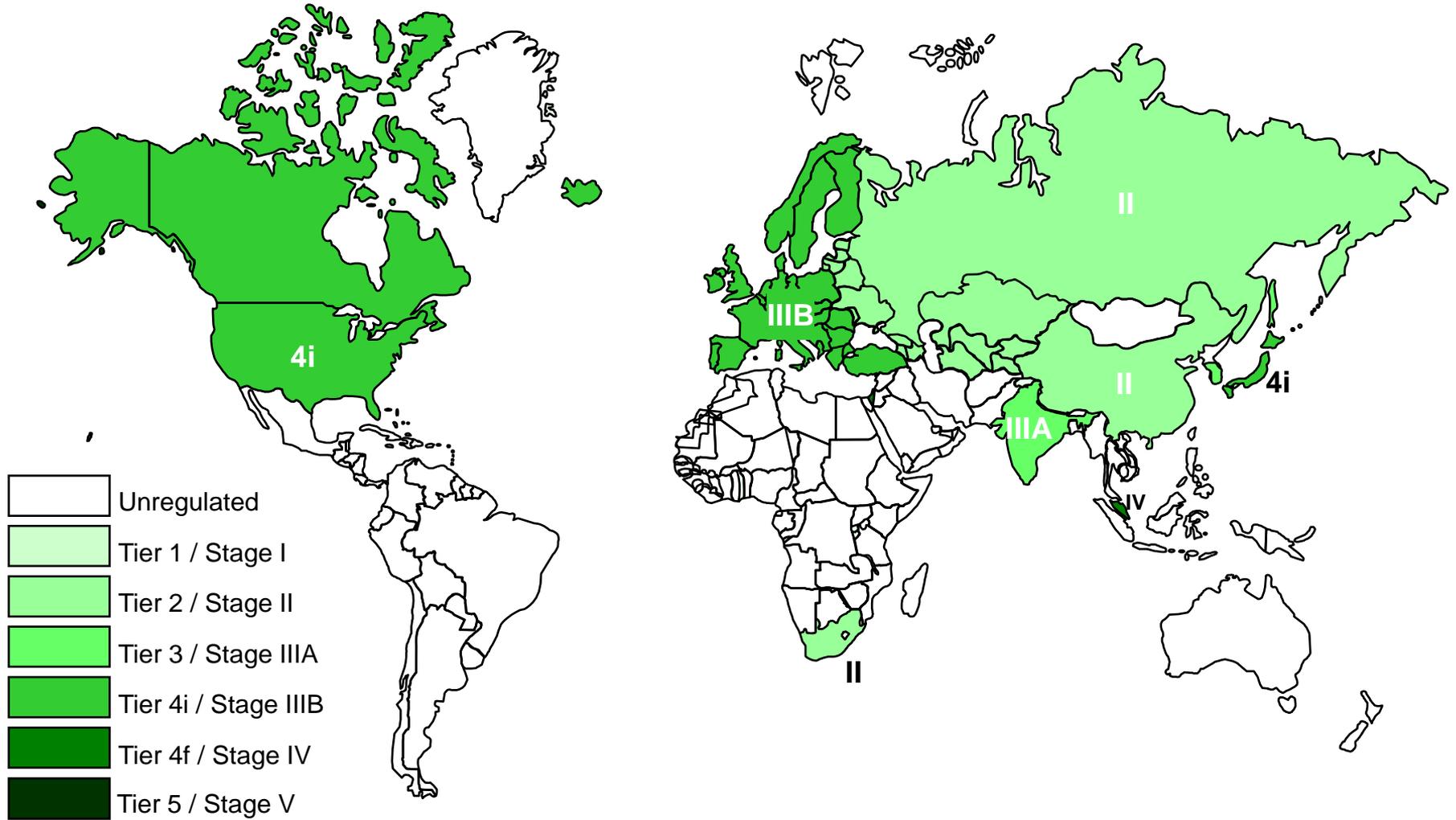


Global Emission Regulations Expanding

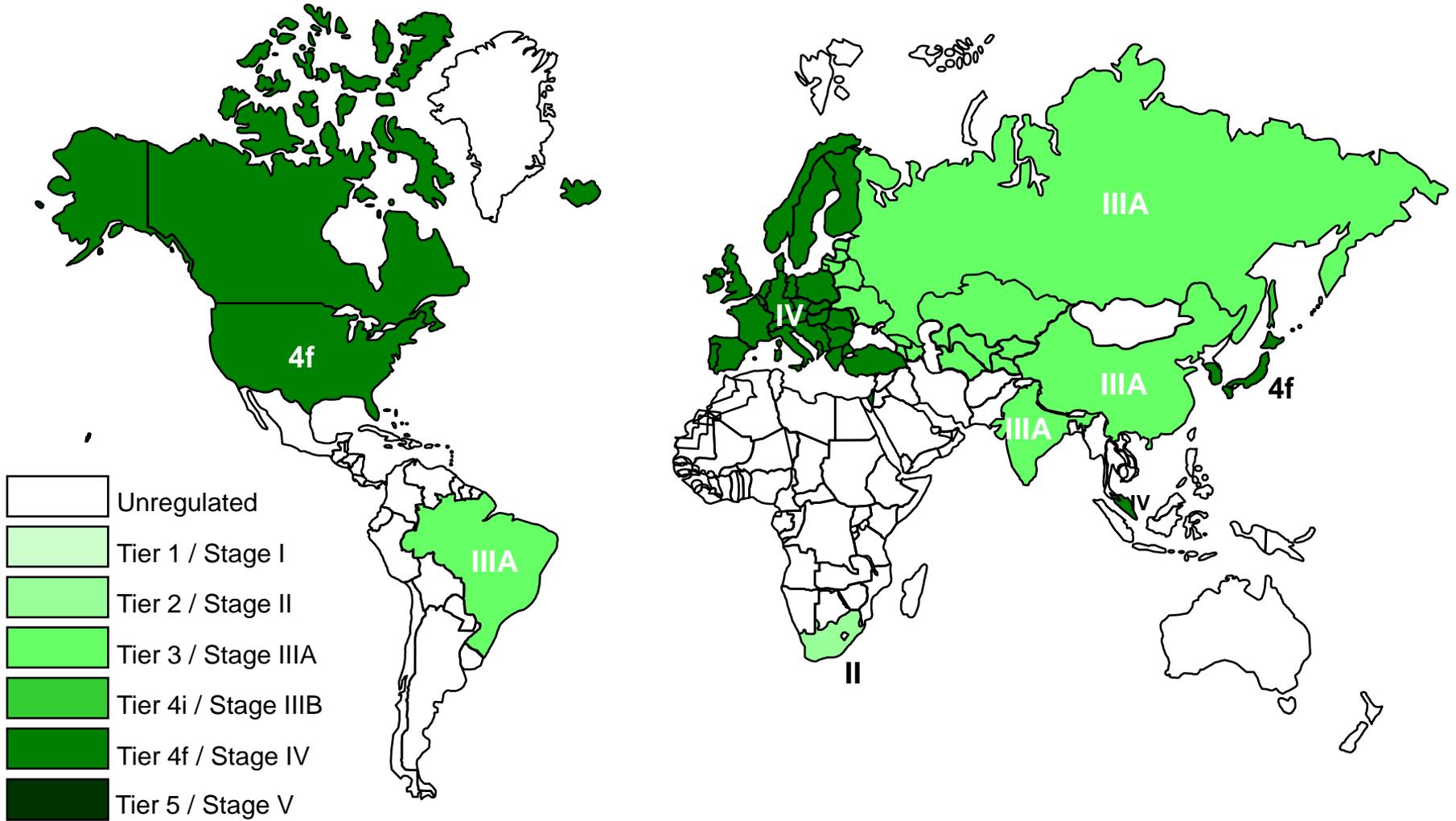
Leading Emissions Lagging Emissions



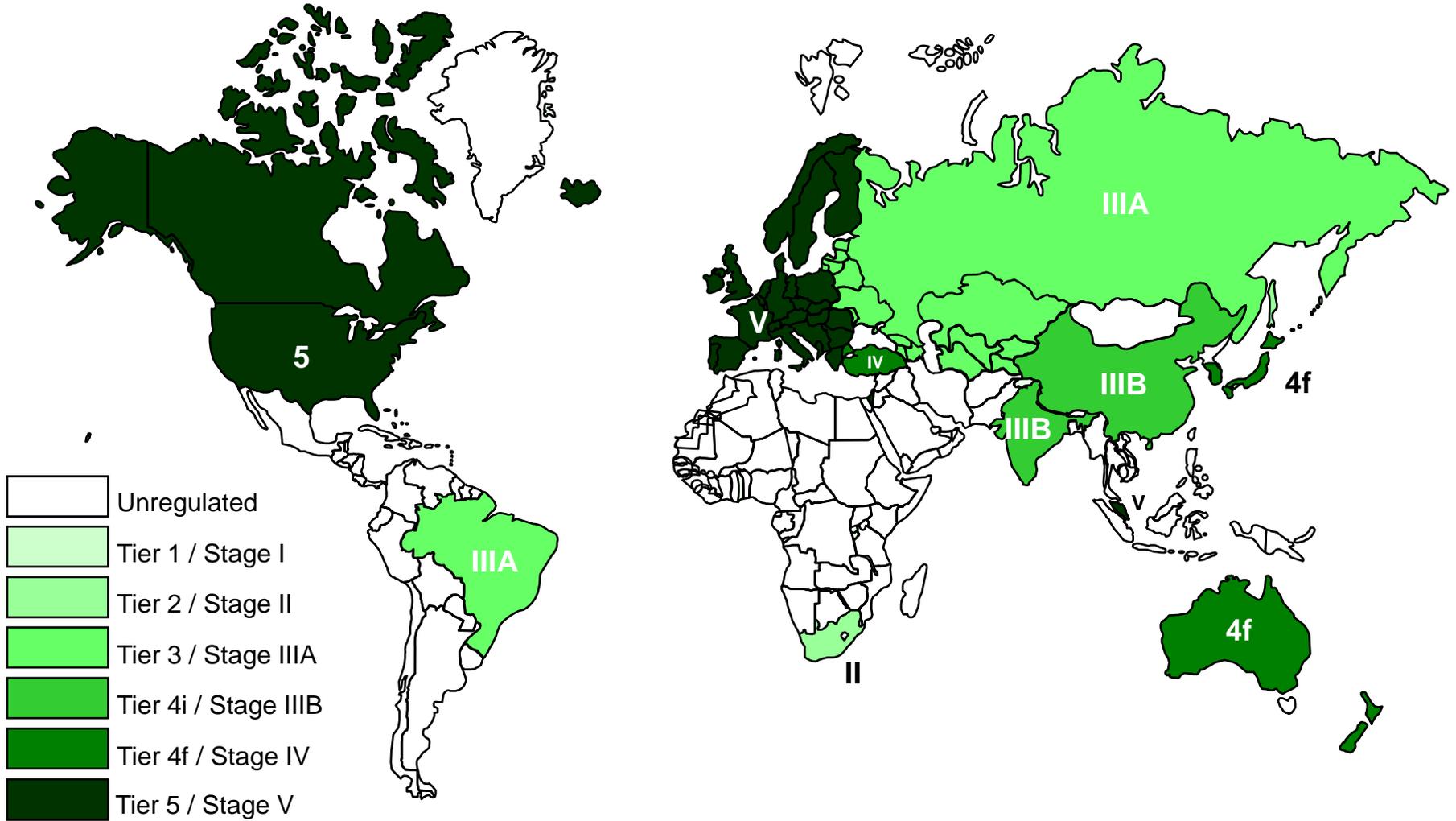
Worldwide Emission Regulations



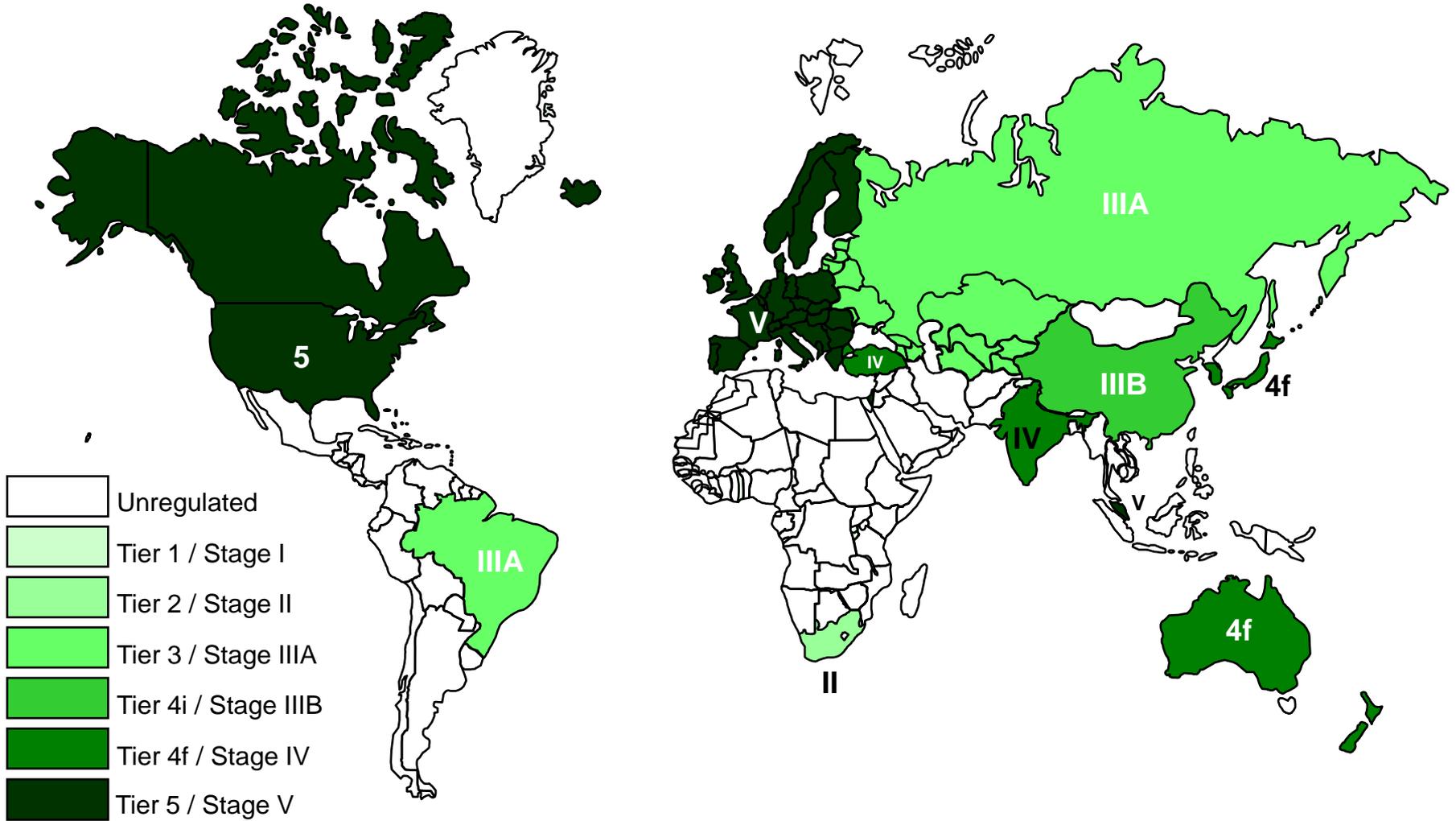
2015 Projection



2020 Projection



2025 Projection



Tier 4 Regulations

- Two-phase introduction of INTERIM & FINAL
- For above 173 hp category:
 - INTERIM began 1/1/2011
 - FINAL began 1/1/2014
- 15-ppm Ultra Low Sulfur Diesel fuel will be mandated to enable emissions compliance
- US, Canada, EU & Japan are broadly aligned





Regulation by HP Range

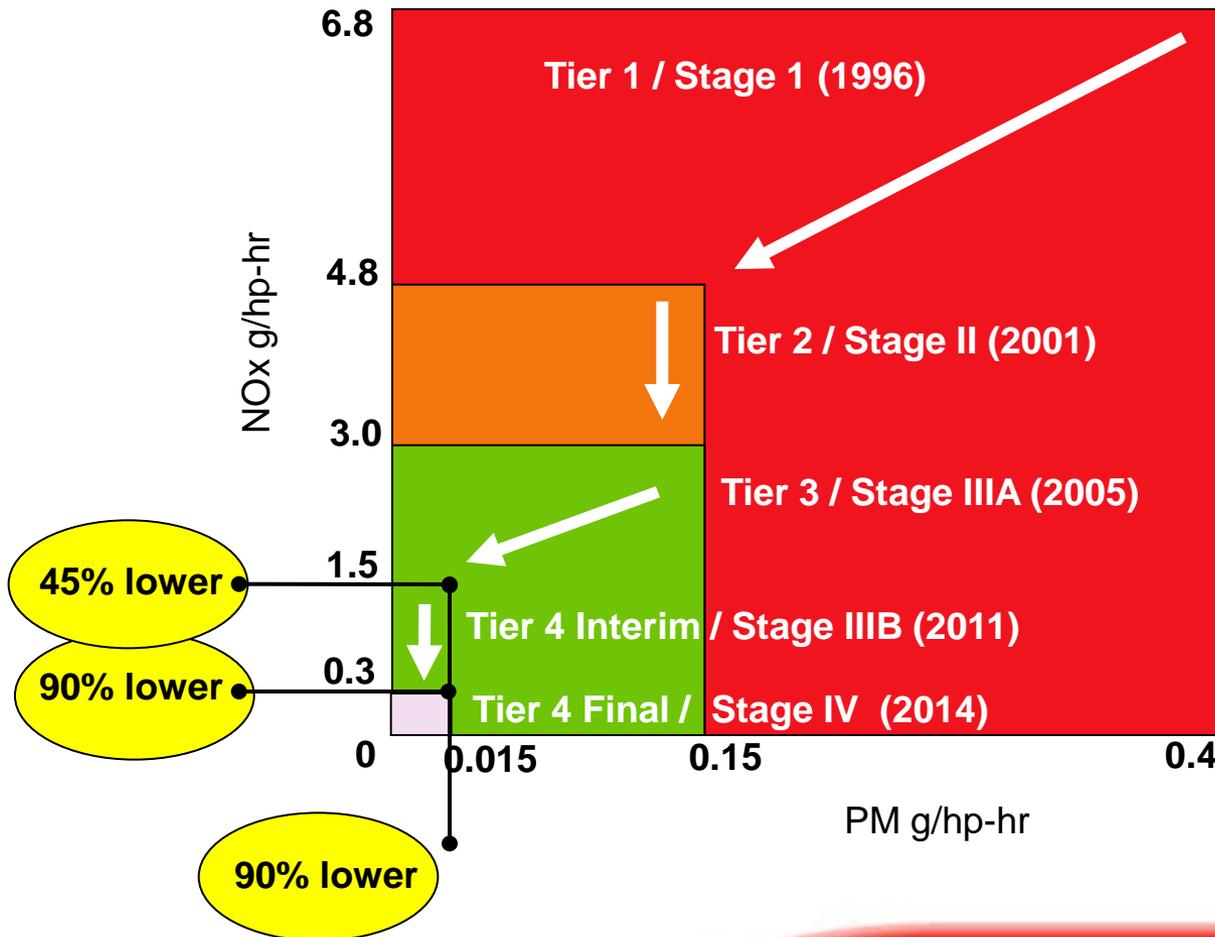
✓ Equipment OEMs will have to meet T4 next year



| kW | (HP) | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-----------|-------------|-------------------------|------|------|------|-------------------------|------|------|------|----------------------|------|----------------------|------|--------------------------------|---------------------------------------|--------|-------------------------|----------------------|---------------------------------------|--------------------------|------|------|------|
| 0 - 7 | (0 - 10) | | | | | (10.5) / 8.0 / 1.0 | | | | (7.5) / 8.0 / 0.80 | | | | (7.5) / 6.6 / 0.40 | | | | | | | | | |
| 8 - 18 | (11 - 24) | | | | | (9.5) / 6.6 / 0.80 | | | | (7.5) / 6.6 / 0.80 | | | | | | | | | | | | | |
| 19 - 36 | (25 - 48) | | | | | (9.5) / 5.5 / 0.80 | | | | (7.5) / 5.5 / 0.60 | | | | (7.5) / 5.5 / 0.30 | | | | (4.7) / 5.0 / 0.03 | | | | | |
| 37 - 55 | (49 - 74) | | | | | 9.2 / -- / -- / -- | | | | | | (7.5) / 5.0 / 0.40 | | Opt T4i 0.30 PM: 37-55 kW | | Note 6 | | | | | | | |
| 56 - 74 | (75 - 99) | | | | | | | | | | | (7.5) / 5.0 / 0.40 | | (4.7) / 5.0 / 0.40: 37-74 kW | | | | | | | | | |
| 75 - 129 | (100 - 173) | | | | | 9.2 / -- / -- / -- | | | | | | (6.6) / 5.0 / 0.30 | | (4.0) / 5.0 / 0.30 | | | 3.4 / 0.19 / 5.0 / 0.02 | | | 0.40 / 0.19 / 5.0 / 0.02 | | | |
| 130 - 224 | (174 - 301) | 9.2 / 1.3 / 11.4 / 0.54 | | | | | | | | (6.6) / 3.5 / 0.20 | | (4.0) / 3.5 / 0.20 | | | | | | | | | | | |
| 225 - 449 | (302 - 602) | 9.2 / 1.3 / 11.4 / 0.54 | | | | | | | | (6.4) / 3.5 / 0.20 | | (4.0) / 3.5 / 0.20 | | | 2.0 / 0.19 / 3.5 / 0.02 | | | | 0.40 / 0.19 / 3.5 / 0.02 | | | | |
| 450 - 560 | (603 - 751) | 9.2 / 1.3 / 11.4 / 0.54 | | | | | | | | (6.4) / 3.5 / 0.20 | | (4.0) / 3.5 / 0.20 | | | | | | | | | | | |
| >560* | (>751)* | | | | | 9.2 / 1.3 / 11.4 / 0.54 | | | | | | (6.4) / 3.5 / 0.20 | | | 3.5 / 0.40 / 3.5 / 0.10 | | | | 3.5 / 0.19 / 3.5 / 0.04 | | | | |
| | | | | | | | | | | | | | | | 0.67 / 0.40 / 3.5 / 0.10 ^a | | | | 0.67 / 0.19 / 3.5 / 0.03 ^b | | | | |
| | | Tier 1 | | | | Tier 2 | | | | Tier 3 | | | | Tier 4 Interim | | | | Tier 4 Final | | | | | |



Tier 4 Challenge



TPEM / FLEX



- Transition Program for Equipment Manufacturers
- Allows installation of engine from previous Tier
- Provides a window of time for re engineering
- Either % of production or absolute volume of engines

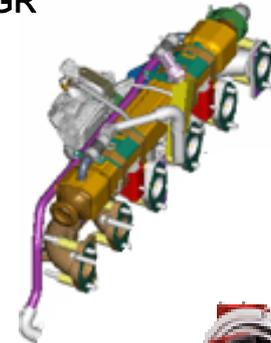


Evolution of the Diesel Engine

HPCR



Cooled EGR



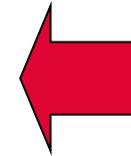
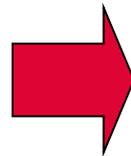
VGT



Electronics



Advanced Combustion



Tier 3 base platform



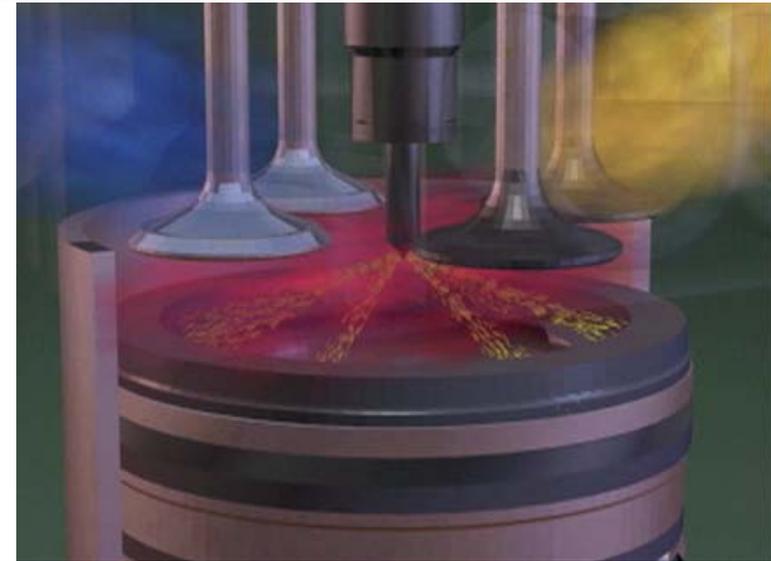
Crankcase Filter



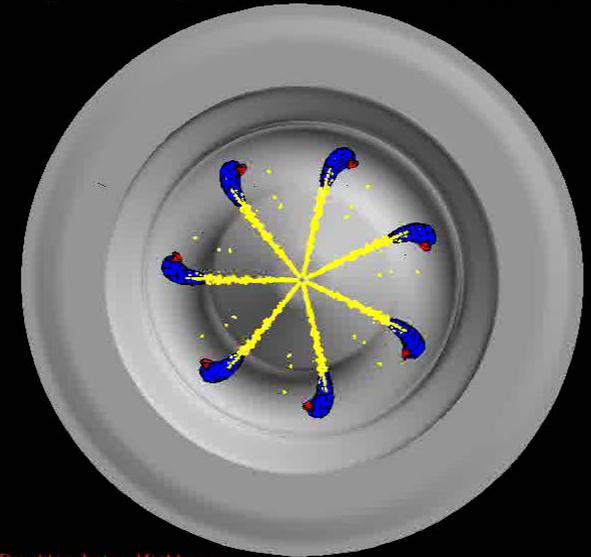
Particulate Filter

Advanced Combustion

- Tier 2 emissions levels require further optimization of combustion
- Avoid risk of mechanical stress by:
 - managing piston speed & cylinder pressure
 - achieving uniform ring temperature
 - applying piston cooling techniques



Pegasus Engine Combustion Simulation



Red - Particulate Matter

Blue - Fuel Rich Region

White - NOx

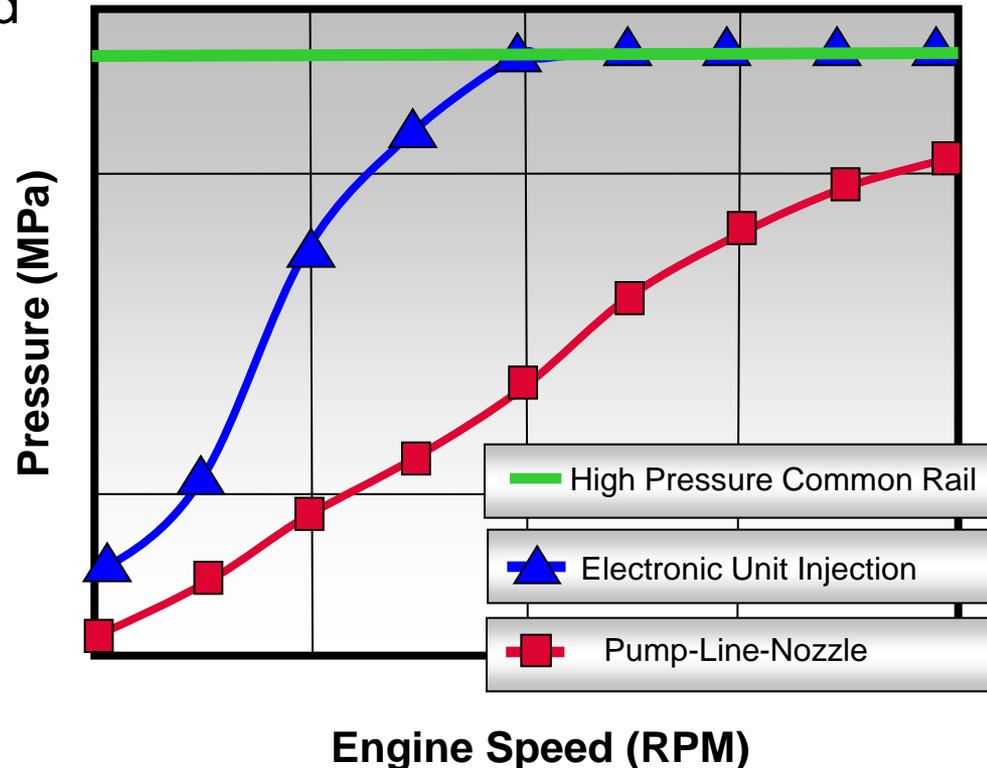
Yellow - Liquid Fuel

Crank Angle = 365 (TDC 360)

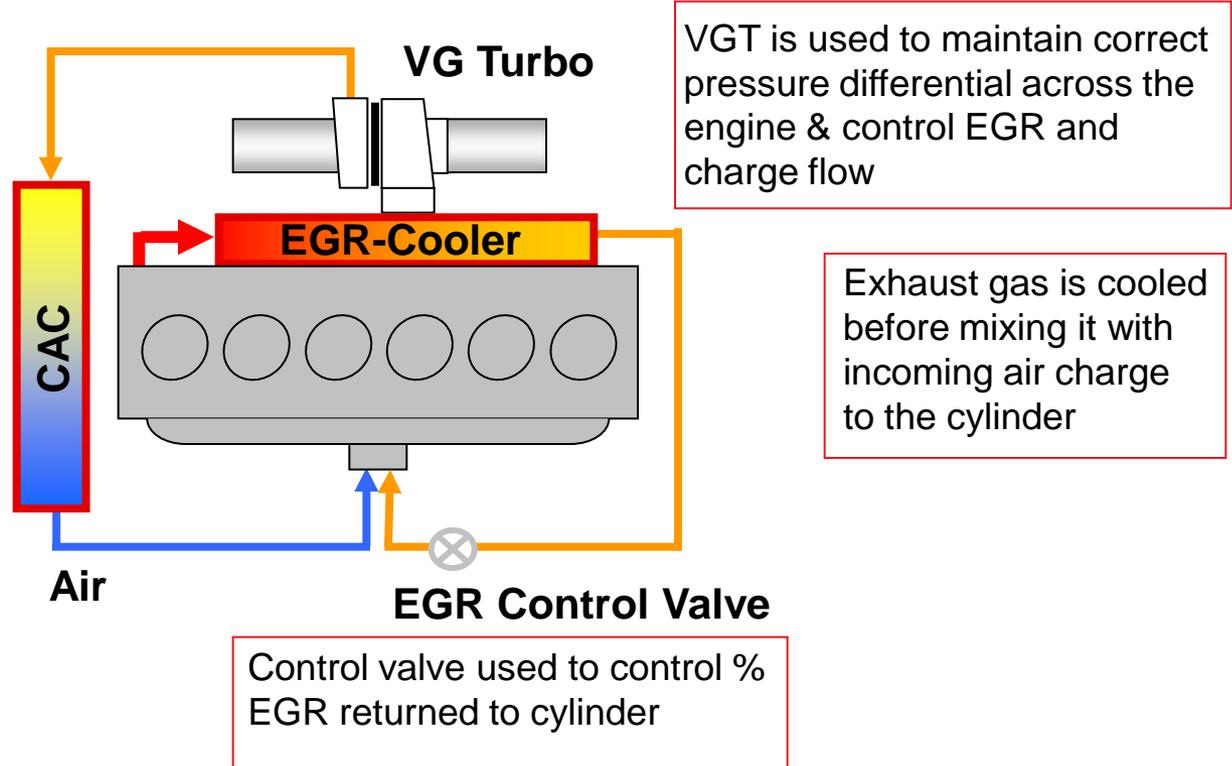
HPCR Fuel Systems



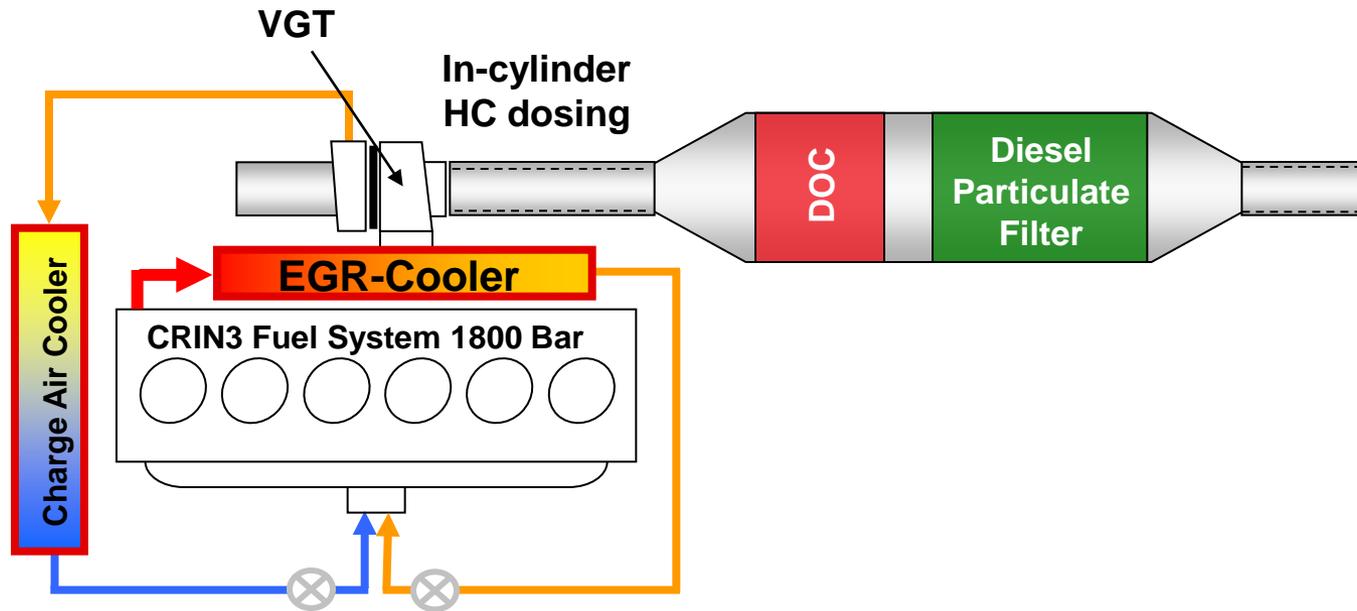
- Higher fuel injection pressure
 - Very fast response with multiple injection events
 - Precise control of fuel metering timing
- Not connected to engine speed or load conditions
- Multiple injection events
- Improves cold start, idle stability & engine response
- Reduces noise & vibration



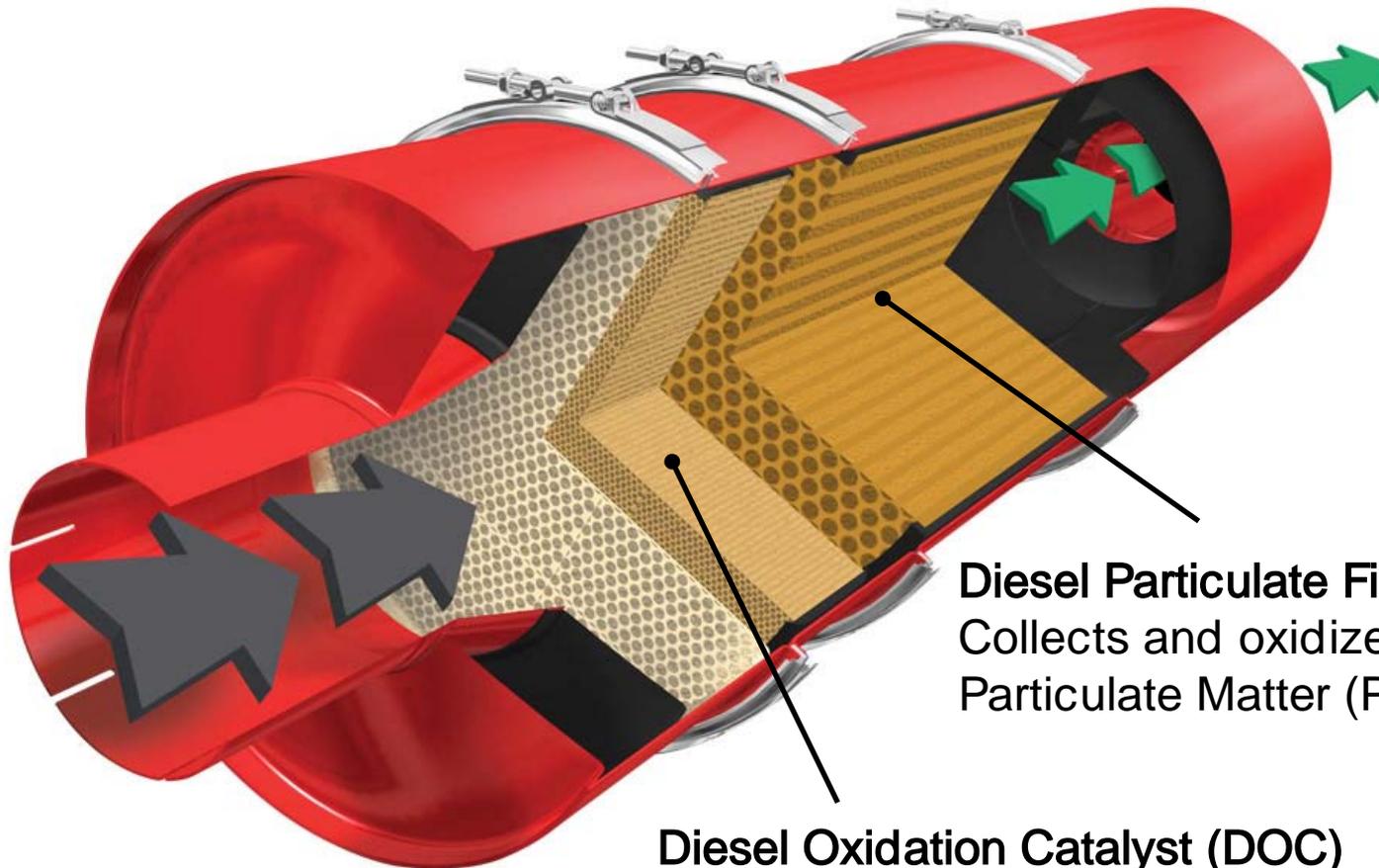
How CEGR Works



Typical Tier 4 interim System



Particulate Filter



Diesel Particulate Filter (DPF)
Collects and oxidizes carbon to remove Particulate Matter (PM) from the exhaust

Diesel Oxidation Catalyst (DOC)
Increases oxidation of carbon in the DPF and improves passive regeneration for improved fuel efficiency

What is a DOC?

- PM reduction product via catalyst

Flow-through substrate

- Made of cordierite or metal
- No maintenance necessary

Substrate is coated with precious metals

- Platinum (Pt) and Palladium (Pd)
- Enhances combustion of diesel fuel in the exhaust stream to generate heat for active regen of DPF



*Light seen through
substrate paths*

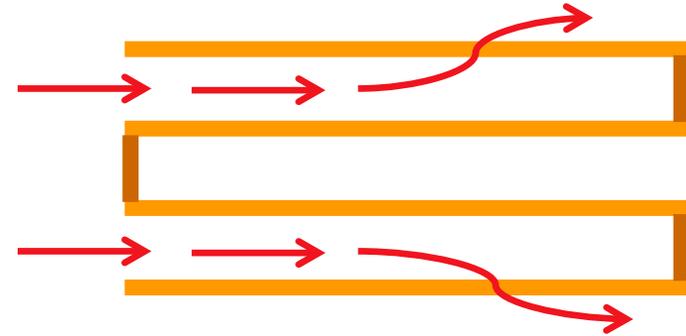
What is a DPF?

Ceramic Wall flow filter

- Every other channel is closed, forcing exhaust gas through walls of filter
- Made of cordierite or silicon carbide

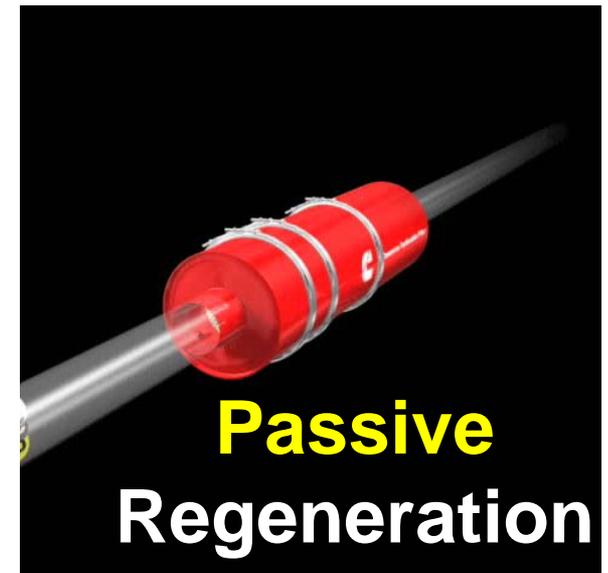
Porous ceramic walls capture soot and ash from exhaust

- Soot is removed by periodic regeneration (active / passive)
- Ash accumulates, requiring DPF removal and maintenance



What is Regeneration?

- Carbon (soot) converted to carbon dioxide at a faster rate than the filter is collecting
- Passive regeneration is about self-cleaning – the system naturally takes care of itself



What is Regen?



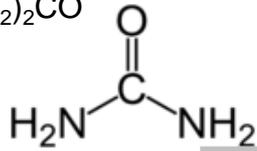
- Occurs when the filter loads up with soot (carbon)
- Delta P increases to a certain level & ECM knows passive regeneration is not removing the soot

Selective Catalytic Reduction Fundamentals

1

DEF Injection

- Small quantity of DEF injected
- Proportional to NOx rate
- 32.5% solution in water, freezing point = -11°C
- Stored in heated tanks
- $(\text{NH}_2)_2\text{CO}$



2

Hydrolysis

- DEF breaks down by hydrolysis to form ammonia
- NH_3

3

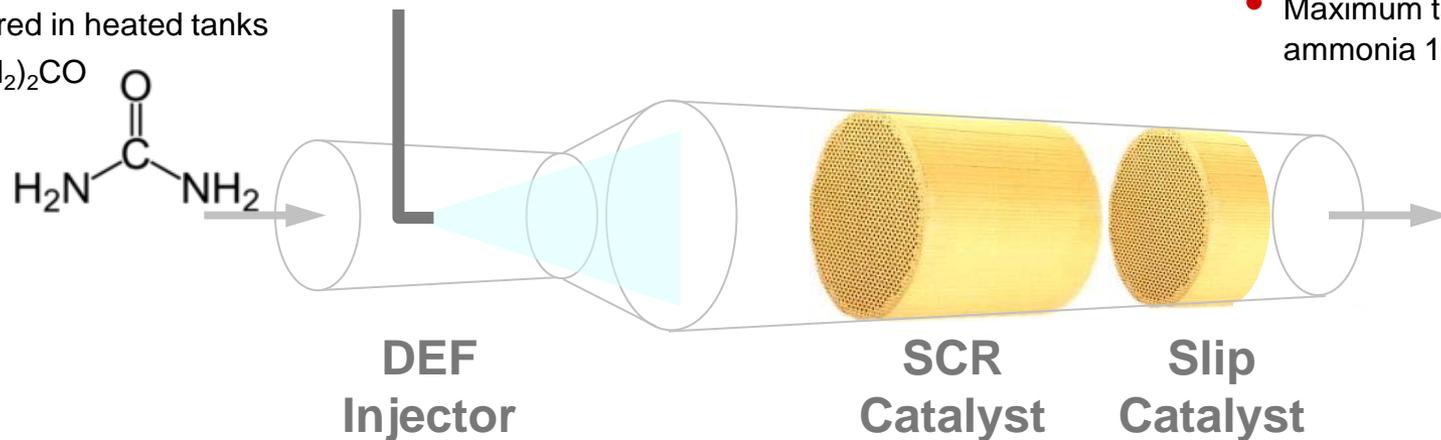
NOx Catalysis

- NO and NO_2 react with ammonia over a catalyst to form nitrogen and water vapor

4

Ammonia Slip

- Any trace amounts of ammonia remaining after reaction with NOx is broken down to nitrogen
- Maximum tailpipe ammonia 10PPM



What is Urea or Diesel Exhaust Fluid?

- Non-toxic solution of 32.5% Urea and 67.5% Water
- Concentration ratio with lowest freezing point (-11°C)
- Eutectic solution – concentration does not change with freezing / thawing



CC2567

Plastic 55 Gal Drum



CC2586

Disposable 275 Gal Tote



CC2585

Plastic 330 Gal Tote



CC2584

Bulk

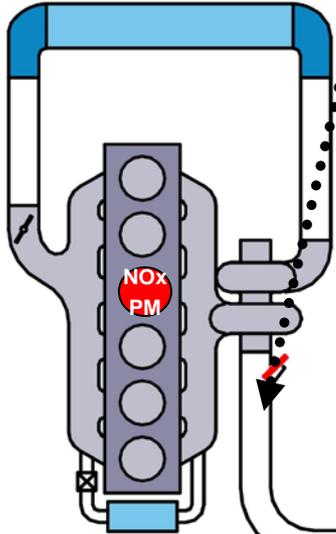
Exhaust leaves the engine with the pollutants NOx and PM

● = Exhaust

○ = Diesel Exhaust Fluid (DEF)

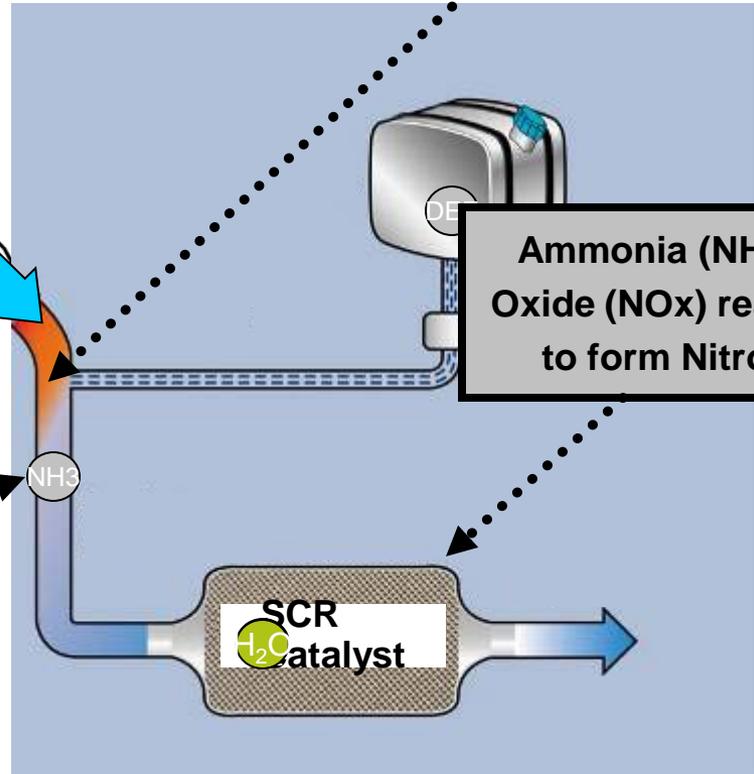
Particulate Matter (PM) is trapped in the Diesel Particulate Filter (DPF)

DEF injected into the exhaust stream



Ammonia (NH₃) and Nitrogen Oxide (NO_x) react in the catalyst to form Nitrogen and Water

DEF solution 'hydrolyzes' into ammonia gas (NH₃) which mixes with the exhaust



Equipment Analysis



REPAIR

- Running engine hrs
- In-frame estimate
- Relation to certified service outlet



REPOWER

- Regulations in region
- Availability of ReCon
- Tier 3 Engine options

REPLACE

- Low value asset
- Additional driveline work
 - Resale market



Independent Survey Results

- Tier IV final prices expected + 10% - 25%
- Operating costs of Tier IV Interim are up 10%
- Lease and rental rates expected to increase
- Decrease in residual values expected to increase demand for rentals
- Tier IV Final will increase need for dealer service
- Fleet age to increase

* Source: Manfredi & Associates and AEM