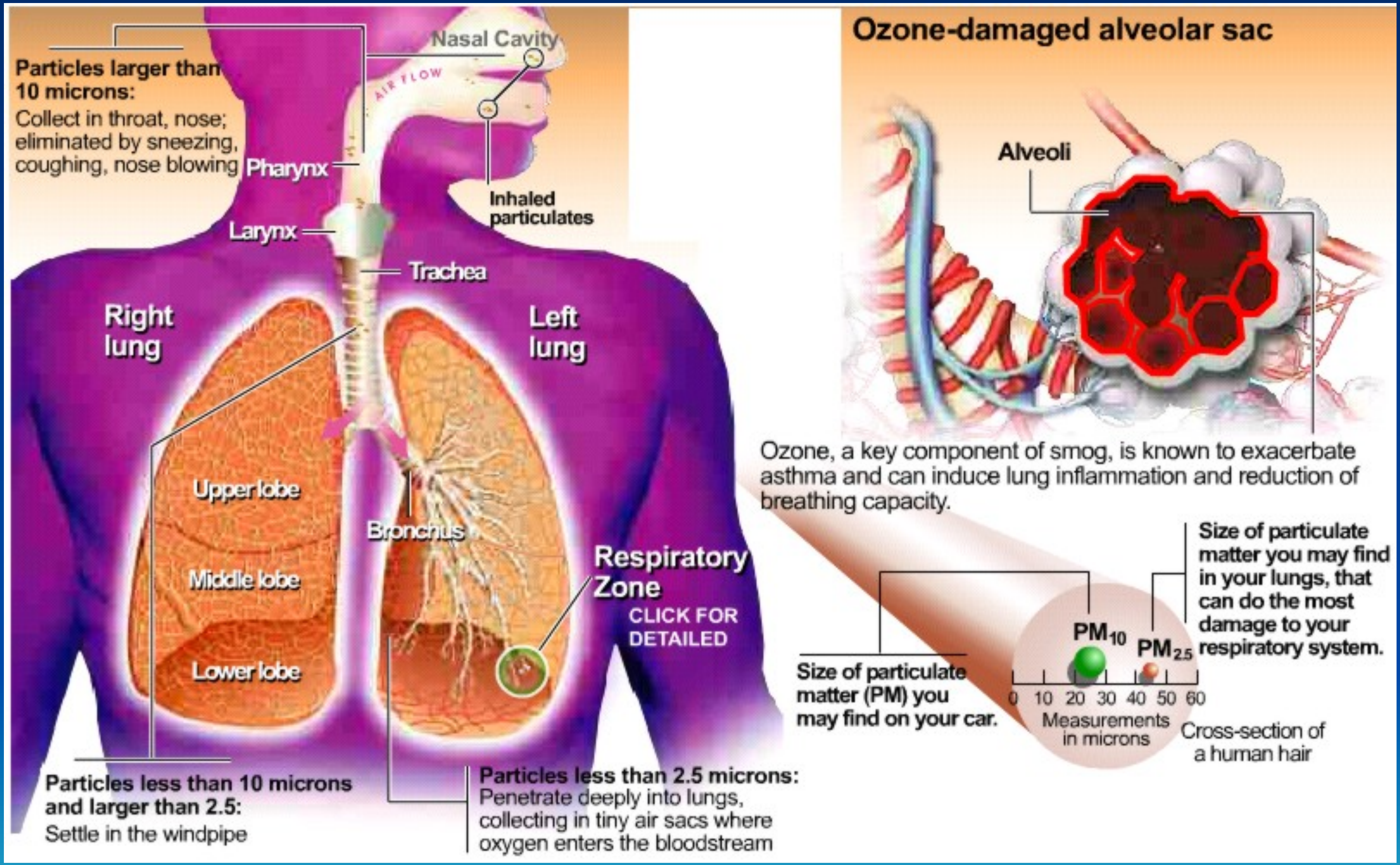
Reducing Air Pollution from Buses and Commercial Vehicles

Michael P. Walsh

Bangalore, India

July, 2012

OZONE AND PM CAUSE SERIOUS ADVERSE HEALTH EFFECTS INCLUDING PREMATURE DEATH



Health Impacts Clearly Linked To Traffic

- Over the past decade, dozens of studies from all over the world have shown that spending time in close proximity to heavy traffic, especially diesel truck traffic, is associated with a wide range of morbidity effects, as well as increased mortality
- Diesel exhaust particulate declared a toxic air contaminant by ARB in 1998; On June 12, 2012, WHO's IARC classified diesel exhaust as carcinogenic to humans

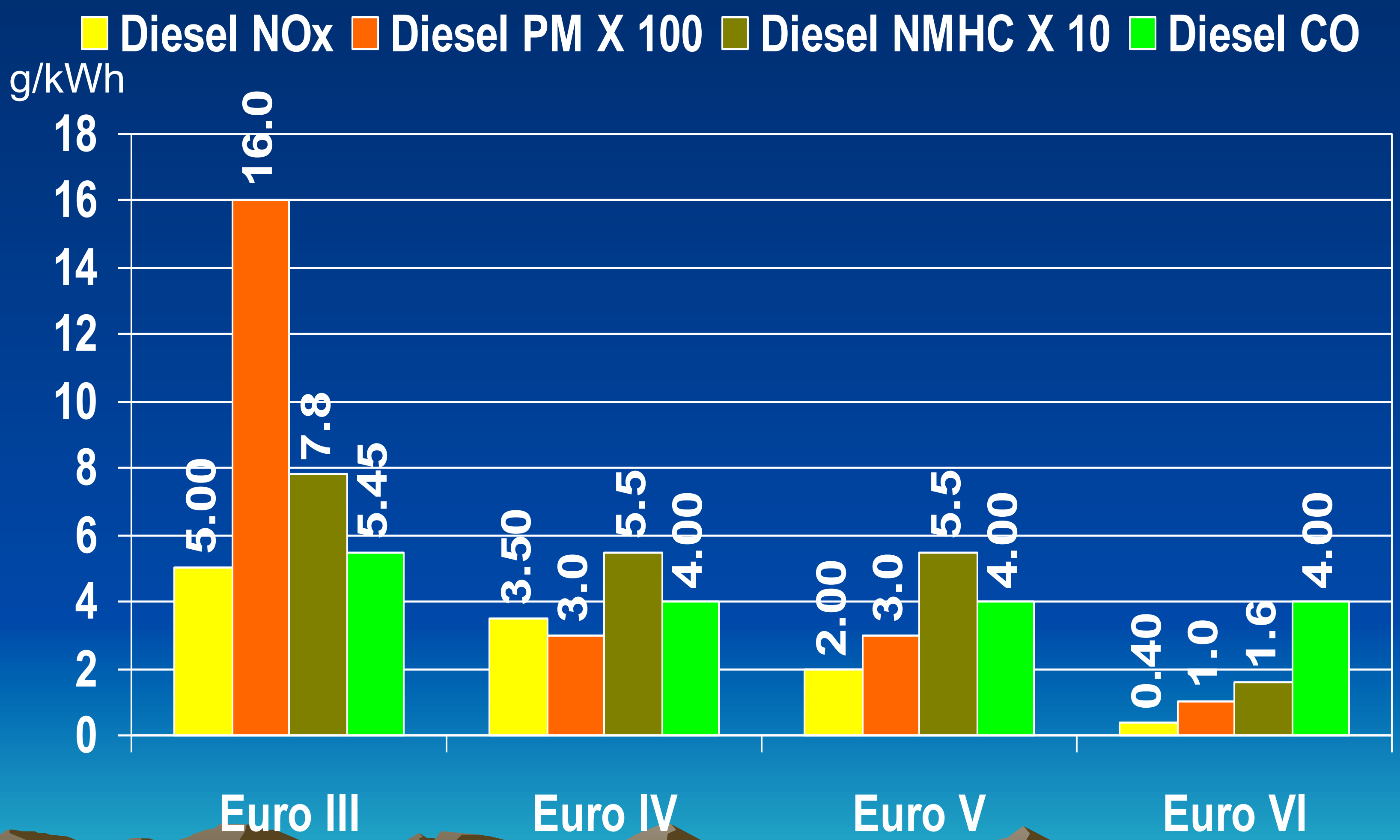
hindustantimes

"India Air Among World's Deadliest"

Monday, February 27, 2012

- Lowest score of 132 nations
- Particulate levels 4 times above India standard
- India per capita AQ-related mortality exceeds China's
- Delhi has 3,000 deaths per year related to air pollution

European Union Heavy-Duty Engine Transient Cycle Emission Standards

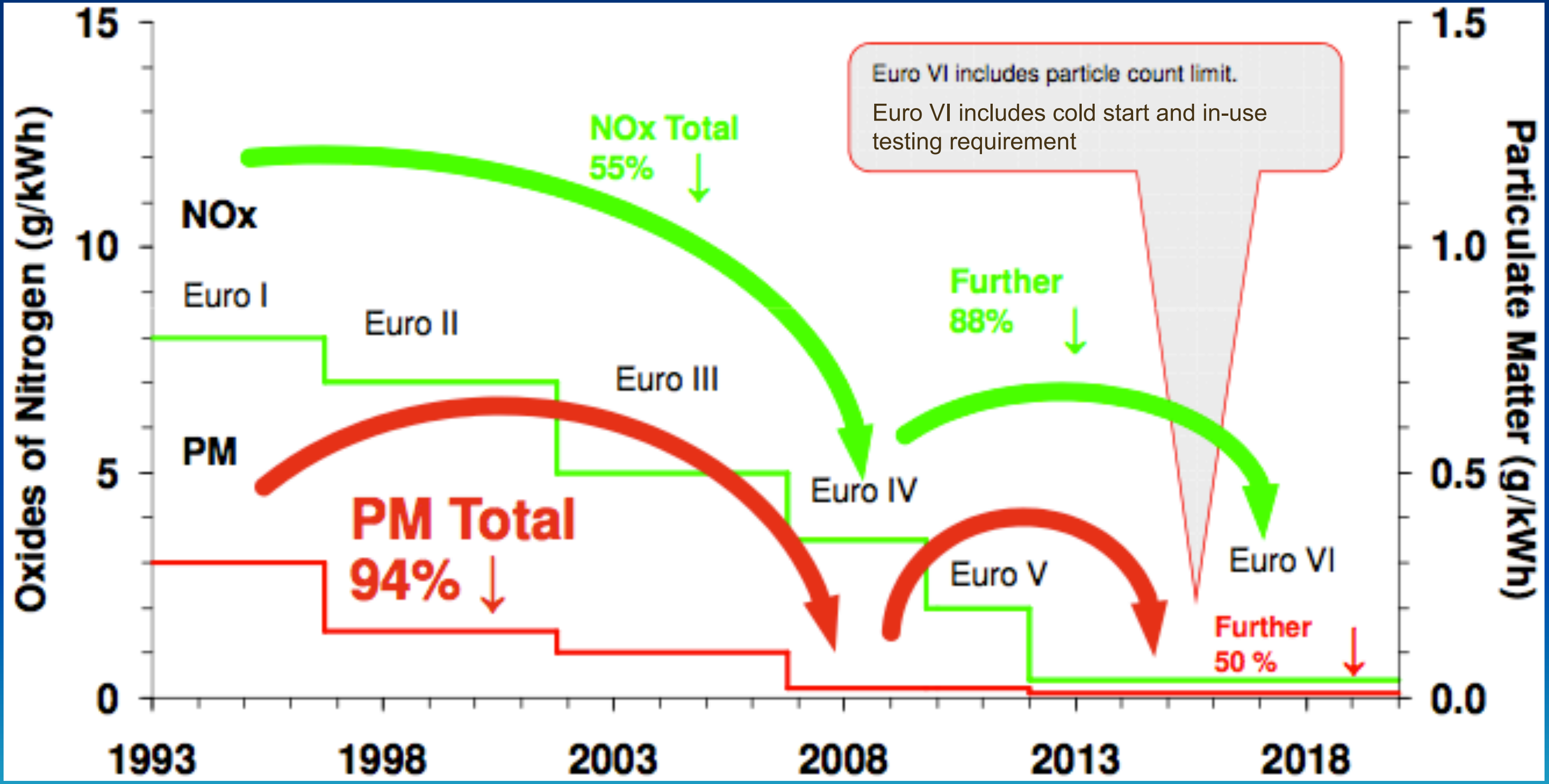


Euro VI includes particle number limit

Note: Euro VI uses THC rather than NMHC

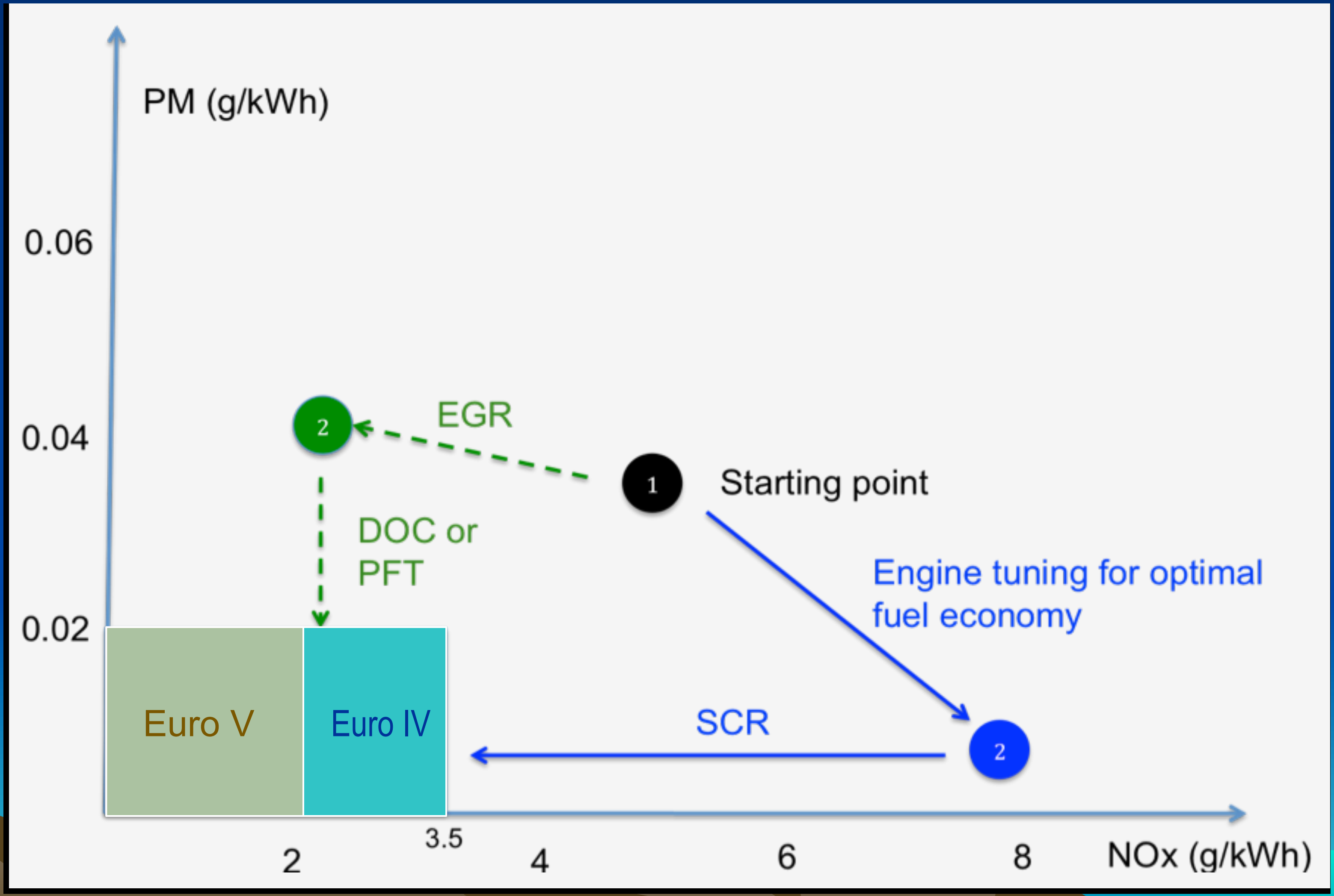
NOx and PM standards for HDVs

Euro IV -> V: 43% NOx reduction; Euro V-> VI: 80% NOx reduction
Euro IV -> V: 0% PM reduction; Euro V-> VI: 50% PM reduction



Source: Jonathan White, HD Emissions Technology – Beyond China Stage IV – Presentation at China Diesel Conference. Feb 22, 2011.

Two Common Pathways For Meeting Euro IV And V Emissions Standards

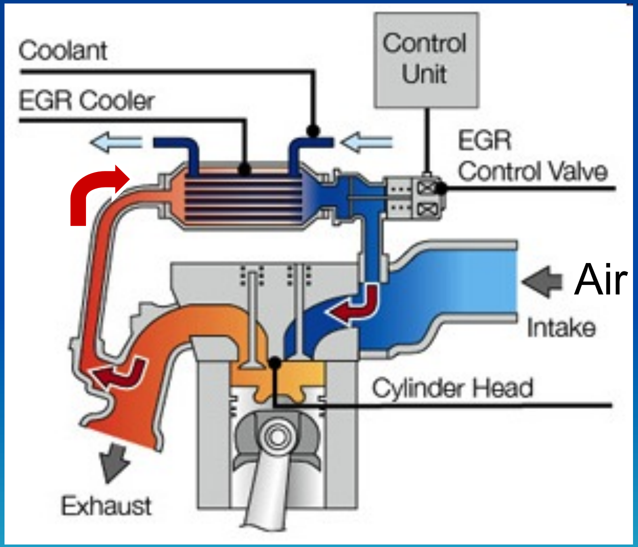


How the two pathways work?

In cylinder NOx control: EGR
PM aftertreatment: DOC or DPF

- Exhaust Gas Recirculation (EGR):
  - Reduce peak combustion temperature, thus avoiding high temperatures where NO_x is formed
  - Reduce concentration of O_2 available for NO_x formation
  - Reduces up to 80% NOx at higher load demands

- Diesel Oxidation Catalyst (DOC) or Diesel PM Filter
  - DOC:
    - Reduces 20-50% PM, but does not cut black carbon
  - DPF:
    - Reduces > 90% PM
    - Large ultrafines reduction
    - Large Black Carbon reduction
- Pros: No need for user intervention
- Cons:
  - ~ 2% fuel penalty

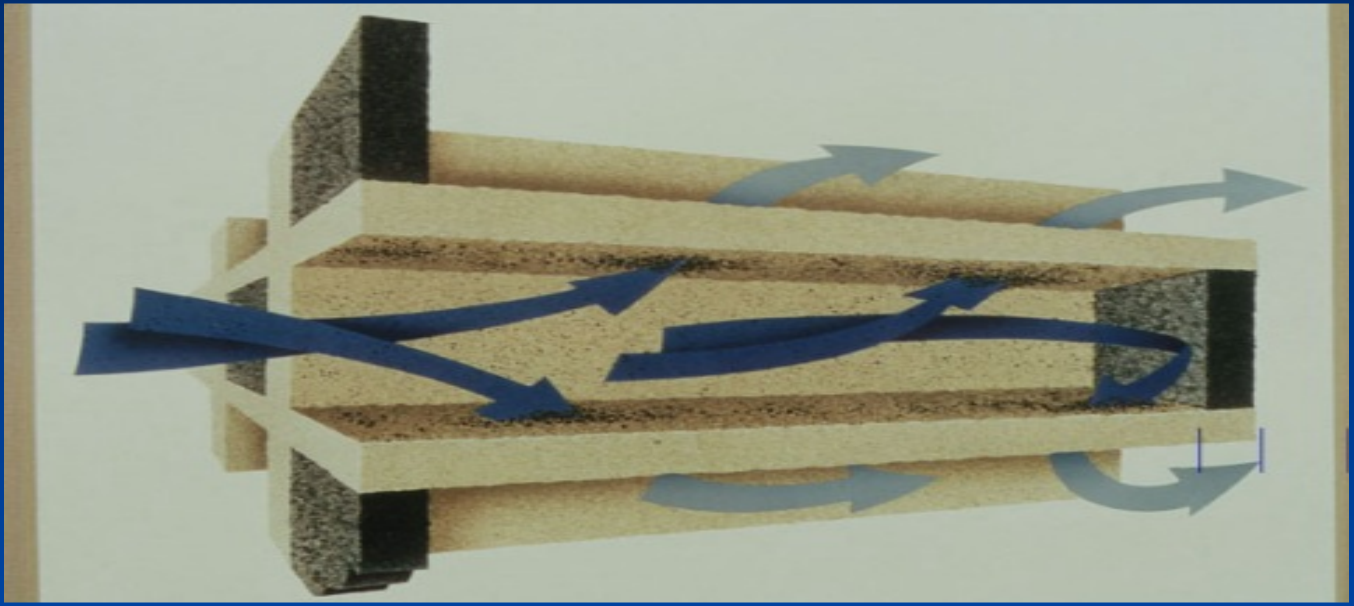


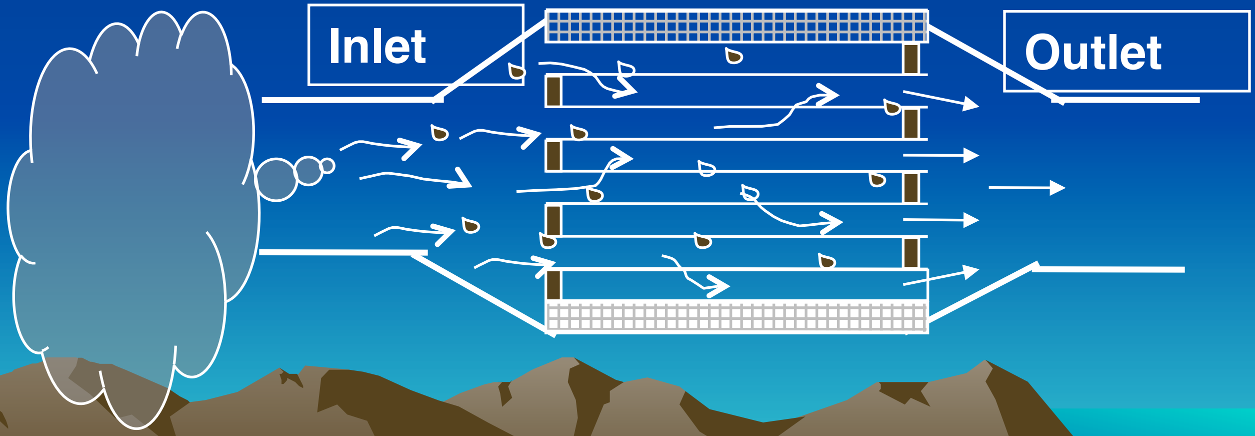
Schematic of an EGR

Source: http://www.hcmsa.co.za/global/products/excavator/medium/zx225usr-3/feature_1.html

Diesel Catalysed Soot Filters

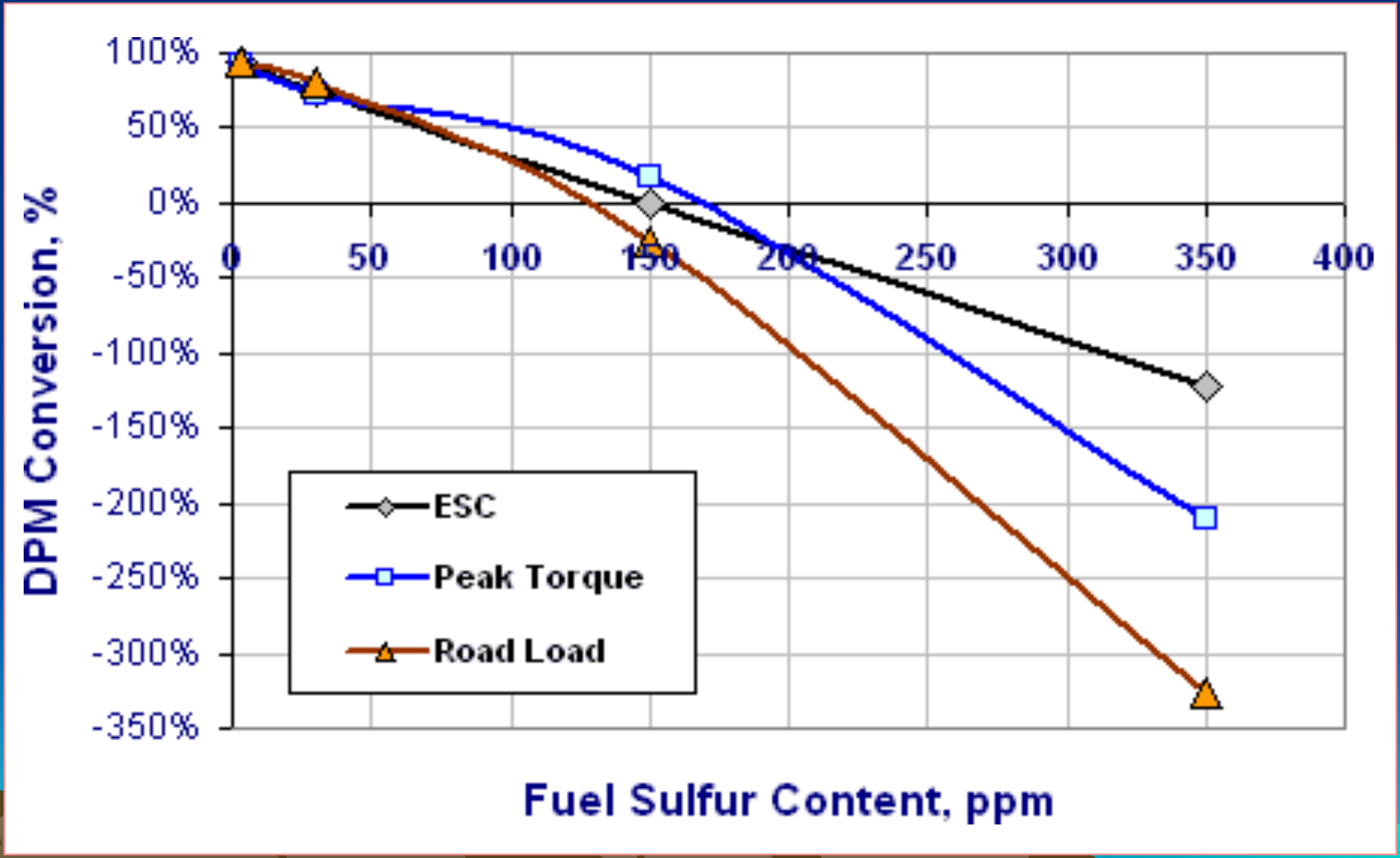
Function





Low Sulfur Fuel is Critical to Get Maximum Benefits From DPFs

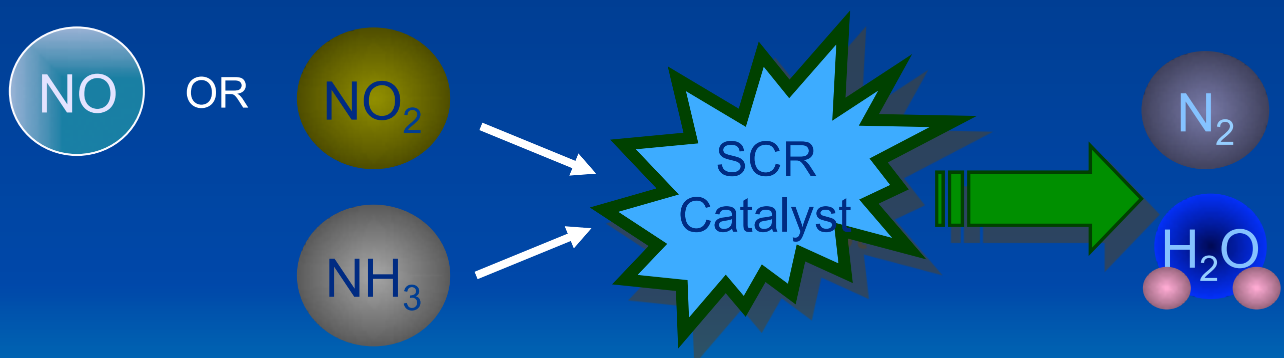
Sensitivity to Sulfur With Catalyzed Soot Filters



How the two pathways work?

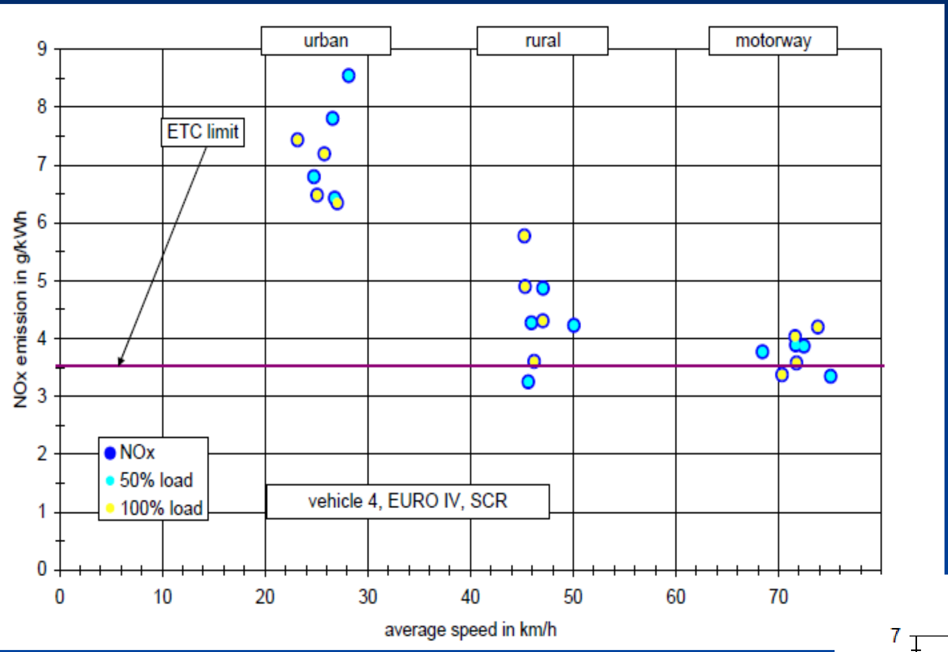
In cylinder PM control: Engine control to cut PM (but high NOx)
NOx aftertreatment: SCR

- In cylinder PM control:
  - Engine tuned to low PM emissions (hence high efficiency) and high NOx
- Selective Catalytic Reduction (SCR):
  - Ammonia (NH_3) carried onboard in the form of urea
  - Reduces 55-90%+ NOx, depending on system design and duty cycle



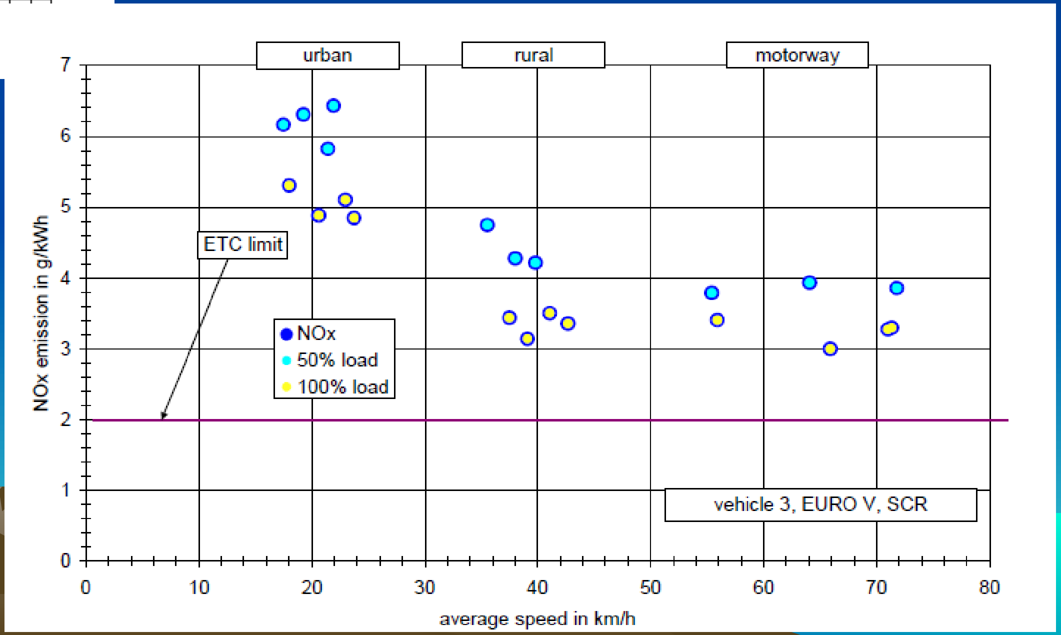
- Pros:
  - ~3-5% fuel saving, though savings partially offset by urea cost
  - Flexible in meeting multiple standards
- Cons: Excess emissions likely unless key set of criteria met

The Problem: High Off-cycle NOx Emissions In Urban Applications



In-use PEMS testing of Euro IV and Euro V trucks in The Netherlands found emission well above standard in urban driving

Source: Kleinebrahm 2008



The Technical Reason: SCR's Poor Low Temperature Performance

- For most Euro-compliant SCR systems, catalyst activity falls off sharply below approximately 280°C, and urea cannot be injected below approximately 200°C because it will not convert to ammonia
- One driver is the SCR catalyst composition
  - Most EU SCR catalysts are Vanadium based, low cost and sulfur tolerant but with poor low temperature performance

The Technical Reason: SCR's Poor Low Temperature Performance (2)

CHARACTERISTIC	CATALYST MATERIAL		
	VANADIUM	CU-ZEO	FE-ZEO
Primary market	Euro IV	United States, from 2010	Japan, from 2005
Optimum operating temperature (deNOx)	300°– 450°C	225°– 500°C	300° – 500° + C
Cold-start performance	Poor	Good	Poor
Fuel sulfur tolerance	2000 ppm	50 ppm	50 ppm[1]
Cost	~$2,200 US	~$3,200 US	~$2,700 US
Resistance to HO poisoning	Higher	Lower	
Thermal stability	Poor[2]	Good	
Other issues	Difficult to integrate with active DPF	Low temperature performance sensitive to NO_2/NOx ratio	

[1] Can be used with 350 ppm sulfur fuel if catalysts are periodically regenerated above 600°C
[2] Decreased deNOx efficiency, V_2O_5 emissions possible above 500°C

*Sources: Johnson (2009); Cheng (2009); MECA (2007); Hodzen (2010).[24]

The Root Cause: Limitations Of The Euro IV/V Type-Approval Process

- ESC/ETC test cycles do not represent low load applications
- No cold start testing
- Weak in-use compliance provisions
  - Usually interpreted as twice the ETC limit
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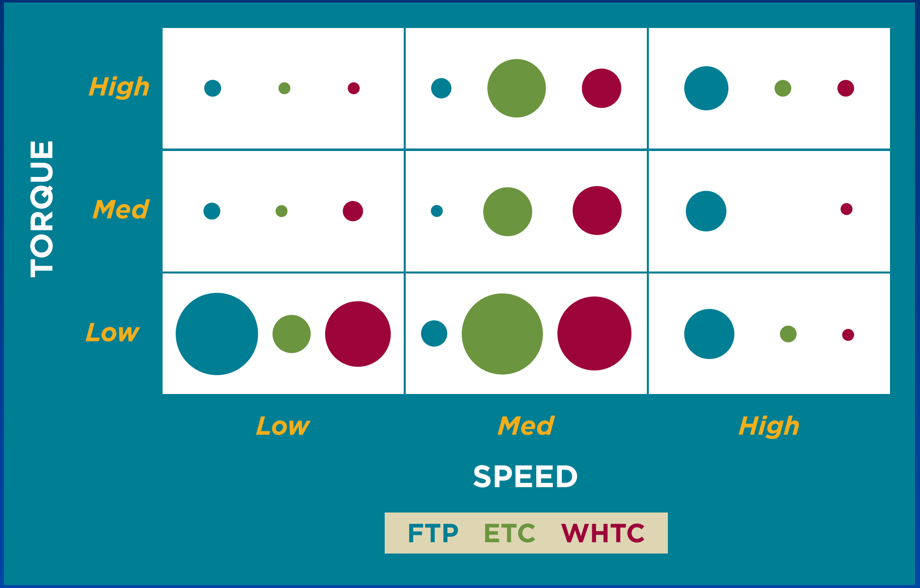


Comparison of ETC, US FTP, and WHTC test cycles

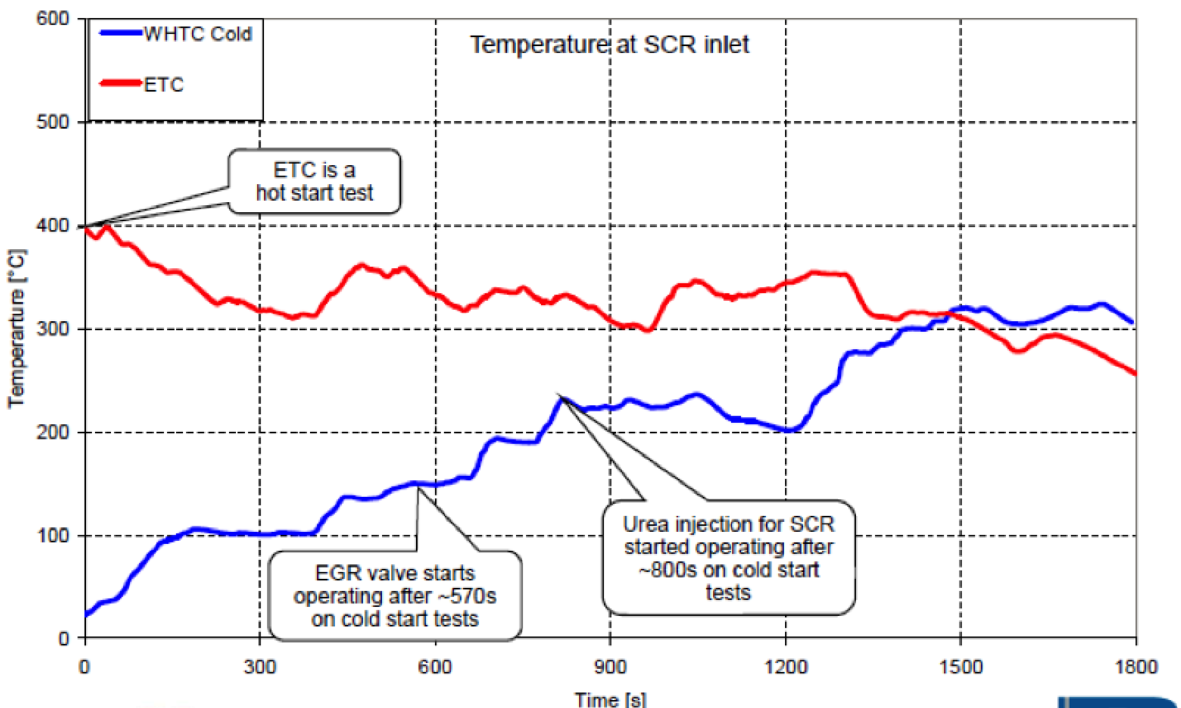
Technical Solutions

- Improve urea decomposition
  - Heated urea injector, mixer or decomposition catalyst
- Improve SCR catalyst activity
  - Lower light off temperature and low temperature conversion
  - Add DOC ahead of SCR
  - Use Cu-zeolite catalyst
  - Optimized urea dosing
  - Larger SCR catalyst volume and improve substrates
- Alternative systems or supplemental reductants
  - Lean NOx trap and SCR
  - Solid ammonia cartridge (e.g. adAmmine)
  - Second reductant (e.g. Ammonium Nitrate)
- Exhaust thermal management
  - In-cylinder post injection of fuel
  - Air intake and/or exhaust throttle
  - Fuel injection into exhaust across a catalyst
  - Exhaust heater
- Higher EGR rate during cold start and light load

Technical Solutions (2)

- Manufacturers are likely to implement a combination of several technology option (i.e. improved thermal management + Cu-zeo catalyst)
- Some options could be implemented as retrofits to existing vehicles if a robust certification program for after-market devices is in place
  - Retrofits often require customization to specific vehicle configuration
- Costs expected to be less than transition from Euro V to Euro VI, up to $5,000 on the high end, lower in countries with low labor costs

Regulatory Solutions: Improved Test Cycles



Association for Emissions Control by Catalyst AISBL

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- The test procedures for Euro VI address many of the issues with Euro IV/V
- The World Harmonized Transient Cycle provides a better coverage of low load condition than the ETC
- The cold start testing and no allowances for preconditioning emphasize low temperature operation

Regulatory Solutions: Improved In-use Requirements

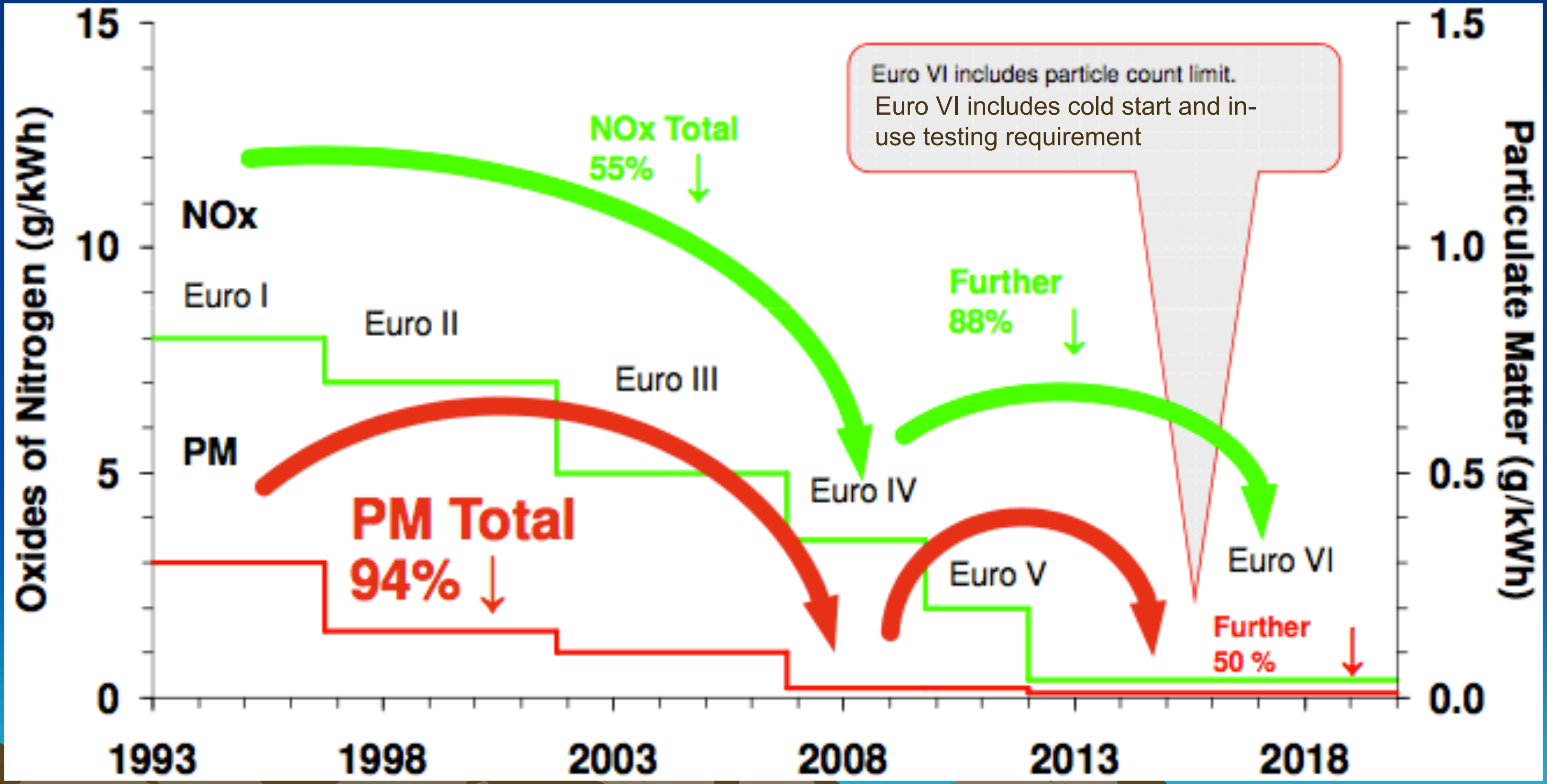
- In-use requirements ensure:
  - Compliance in the full range of driving conditions
  - Legal basis to address excess in-use emissions
- Best practice in-use requirements include
  - In-use emissions limits (and conditions where they apply)
  - Prohibition of defeat devices
  - Testing requirement to demonstrate in-use limits
  - Penalties for non-compliance
- Euro VI specifies emission shall be effectively limited under all in-use conditions
  - Establishes a not-to-exceed limit at 1.5 times the standard over the WHTC
  - Establishes a PEMS in-use testing program

Recommendations

- Establish a roadmap to early Euro VI implementation
- Strengthen existing national program
  - Modify type-approval process: more representative test cycle (i.e. WHTC) and cold start testing
  - Establish stringent in-use compliance requirements:
- Local supplemental emission requirements should be considered especially if national program improvements will take time
  - Can be incorporated in large urban fleet new bus purchasing requirements

Adopt Euro VI As Early As Possible

- Improved test cycles: cold start and World Harmonized Test Cycle
  - More effectively control of in-use emissions
- 80% lower NOx limit, 50% lower PM limit; PN limit to force the use of DPF for better control of ultrafines



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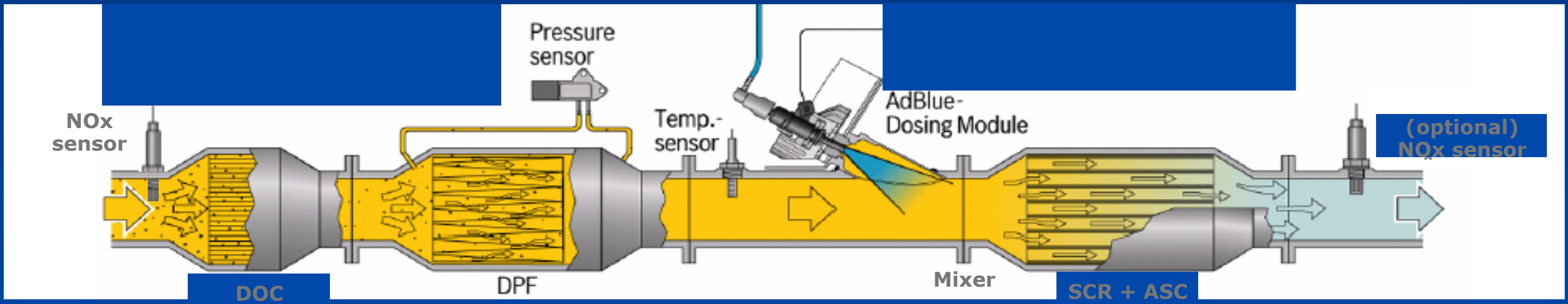
Emissions Control System For Euro VI

Oxidation catalyst (DOC), catalyst-based particulate filter and urea-SCR with ammonia slip catalyst (ASC).



Roadmap For The Next Decade Is Missing In India

- Auto Fuel Policy of 2003 recommended revision every five years
  - Need to continue to treat vehicle and fuel as a system, fuel quality improvements critical for next phase of standards
- Long term roadmap needed quickly to give industry adequate lead-time
  - Technology already in the market, but on limited models in India
- One Country, One Vehicle, One Fuel

Thank You!

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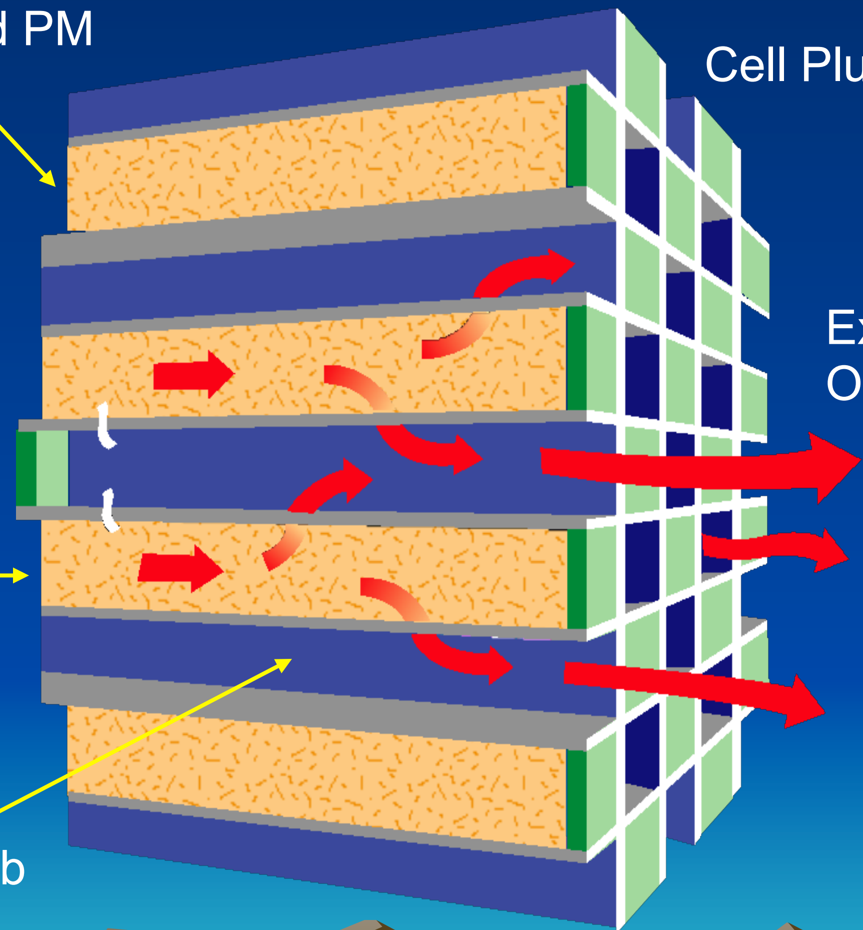
Backup Slides

Diesel Particulate Filters



Reductions:

- -80 to 95% PM
- -80-100% HC, CO
- -80%+ toxins

Issues to balance:

- sulfate formation
- regeneration and back pressure
- Fuel Economy

Estimated Cost To Comply With Euro Standards For Vehicles With Different Engine Sizes