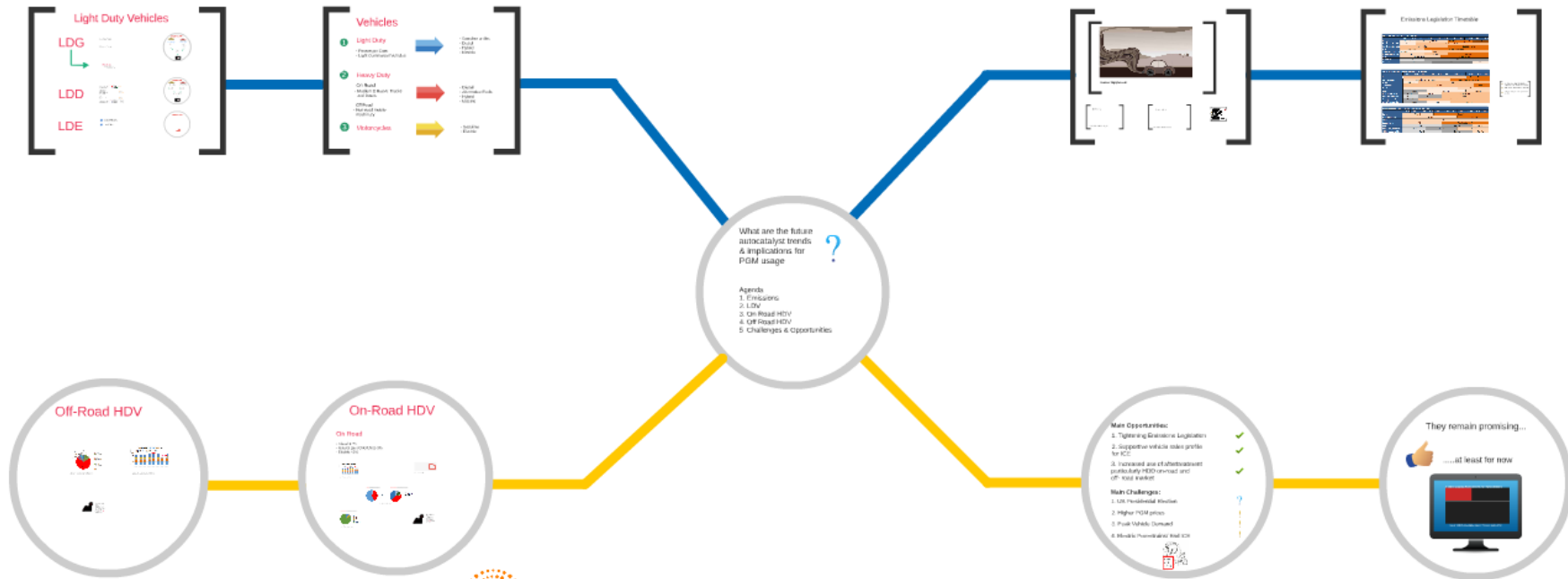
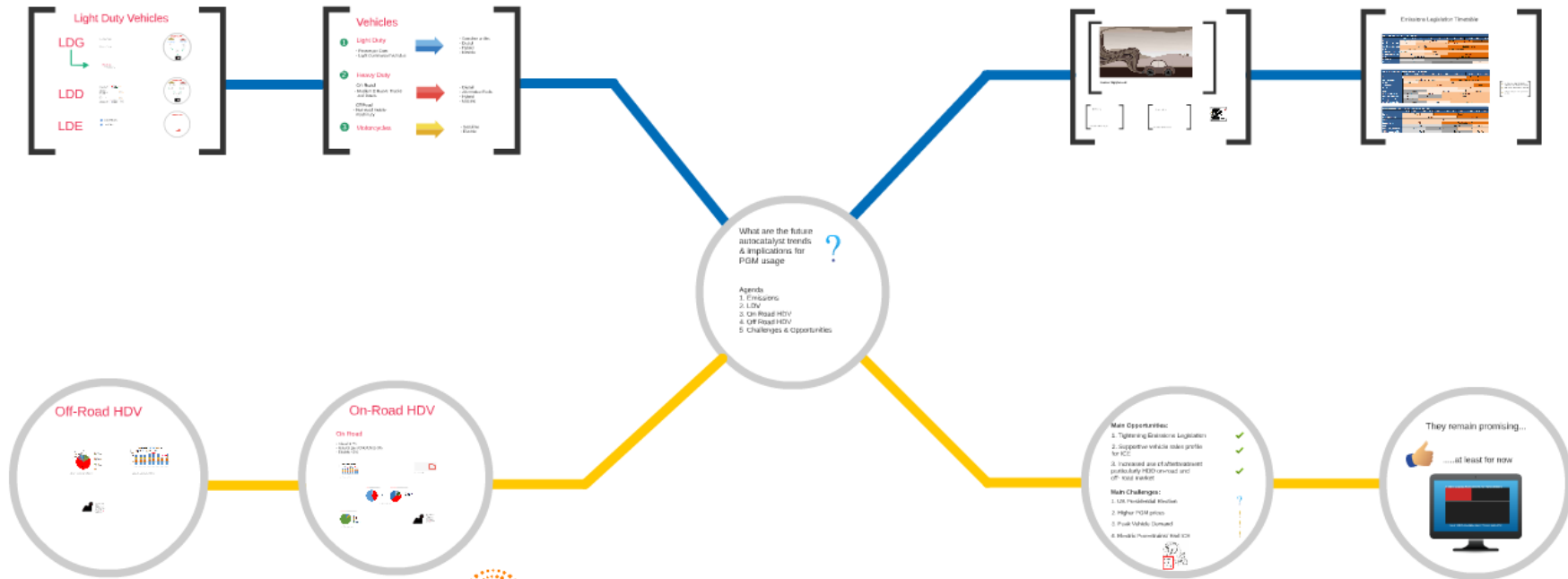
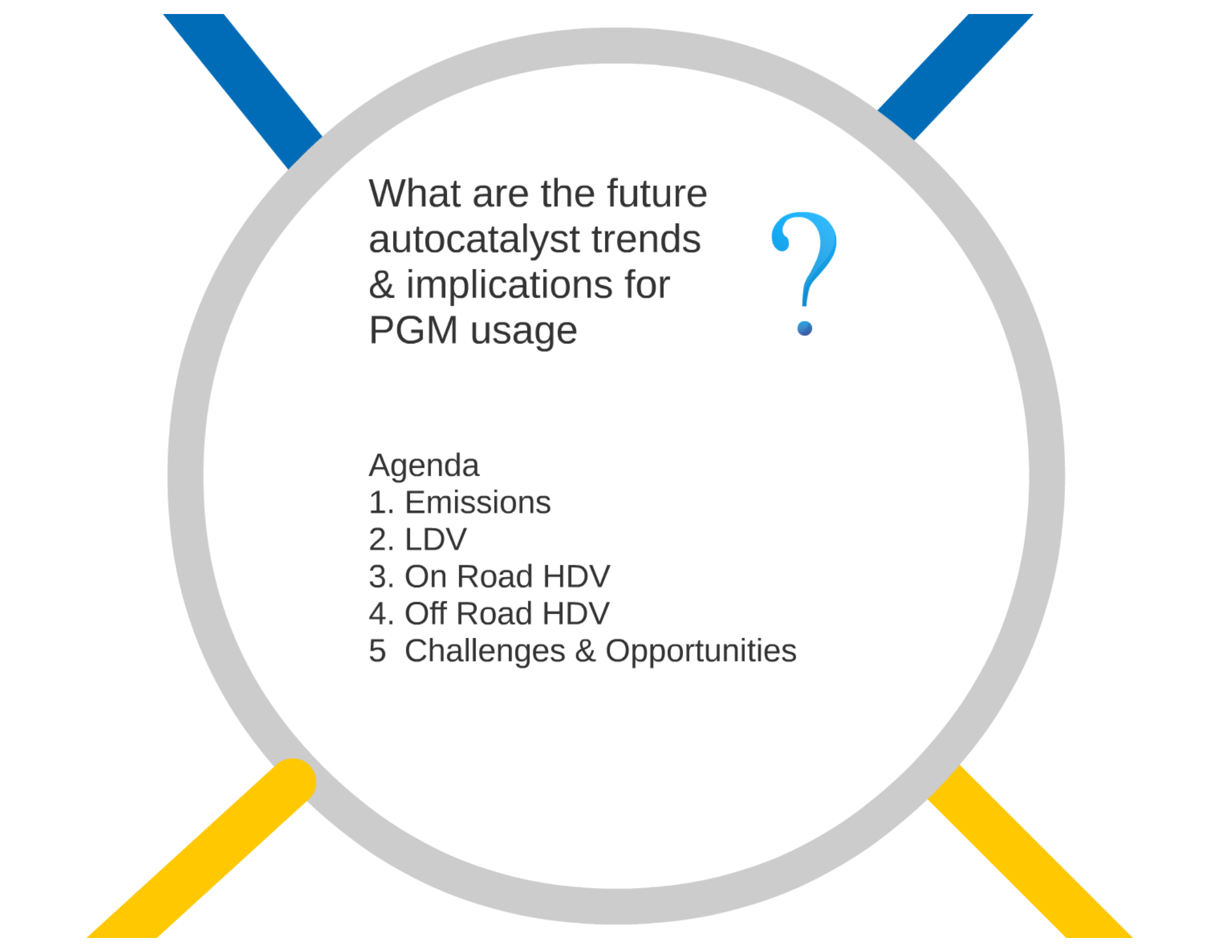


What are the future autocatalyst trends & implications for PGM demand?



What are the future autocatalyst trends & implications for PGM demand?



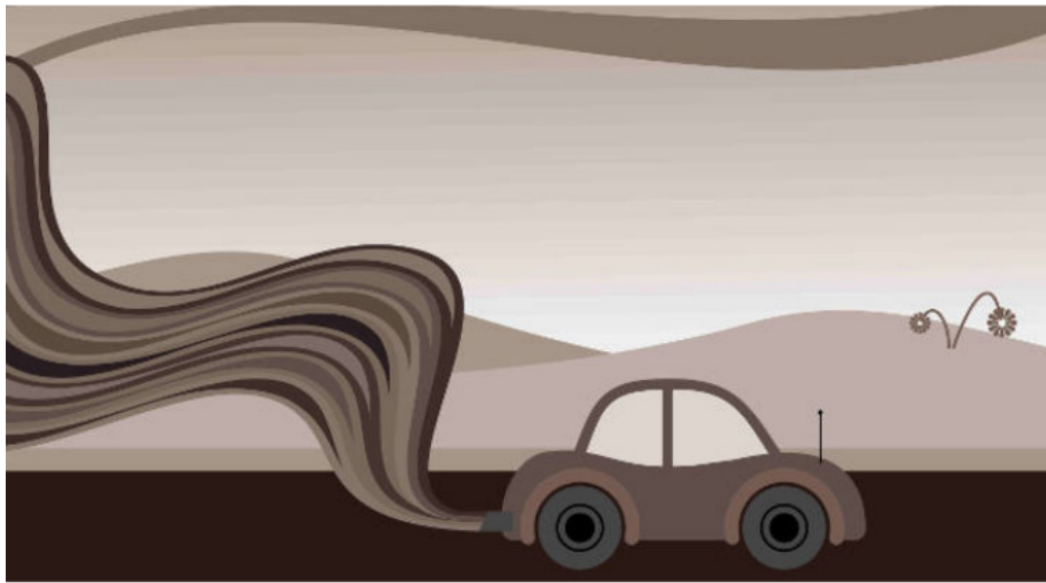


What are the future
autocatalyst trends
& implications for
PGM usage



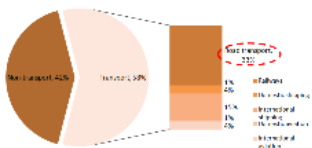
Agenda

1. Emissions
2. LDV
3. On Road HDV
4. Off Road HDV
5. Challenges & Opportunities

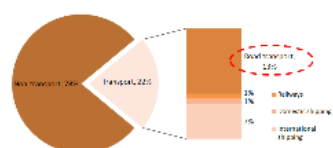


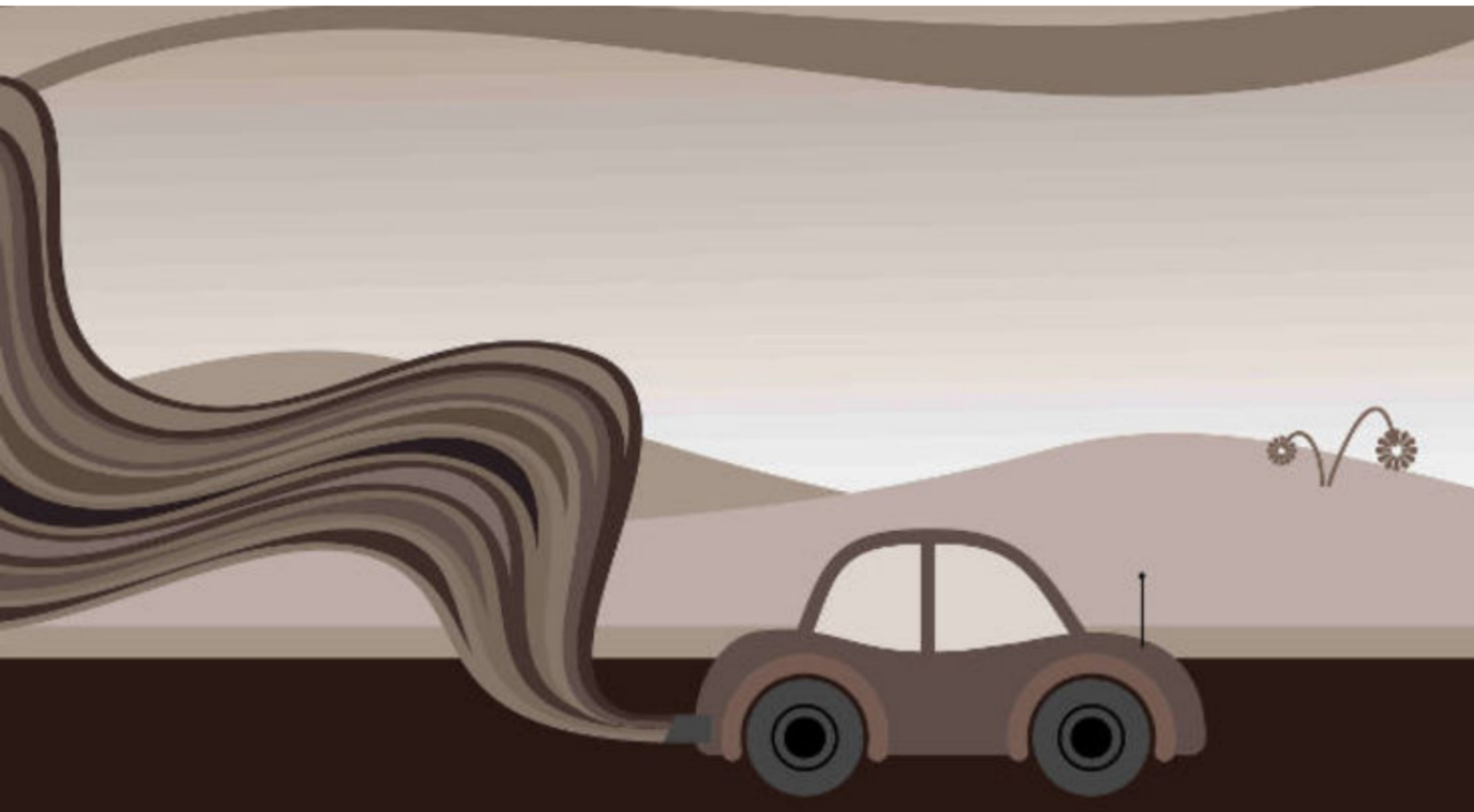
Source: Rappler.com

NOx Emissions



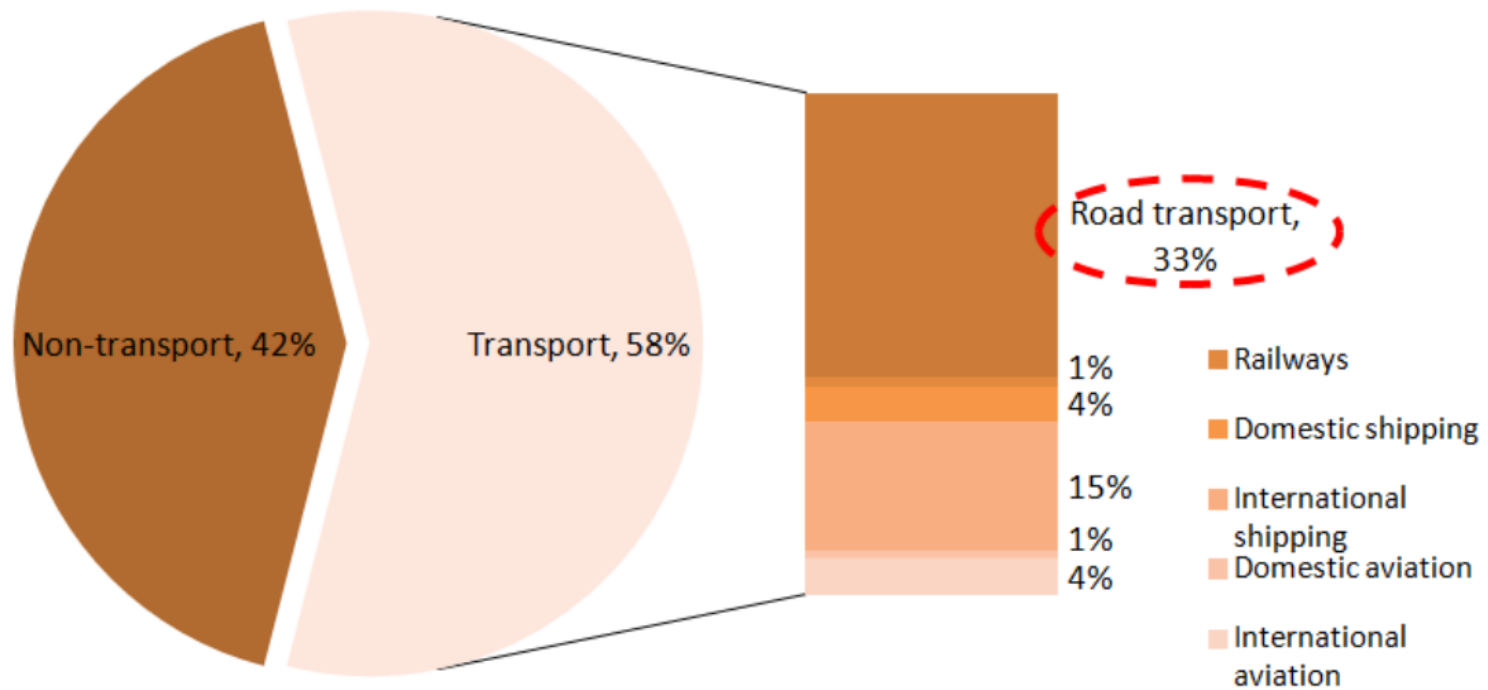
Particulate Matter





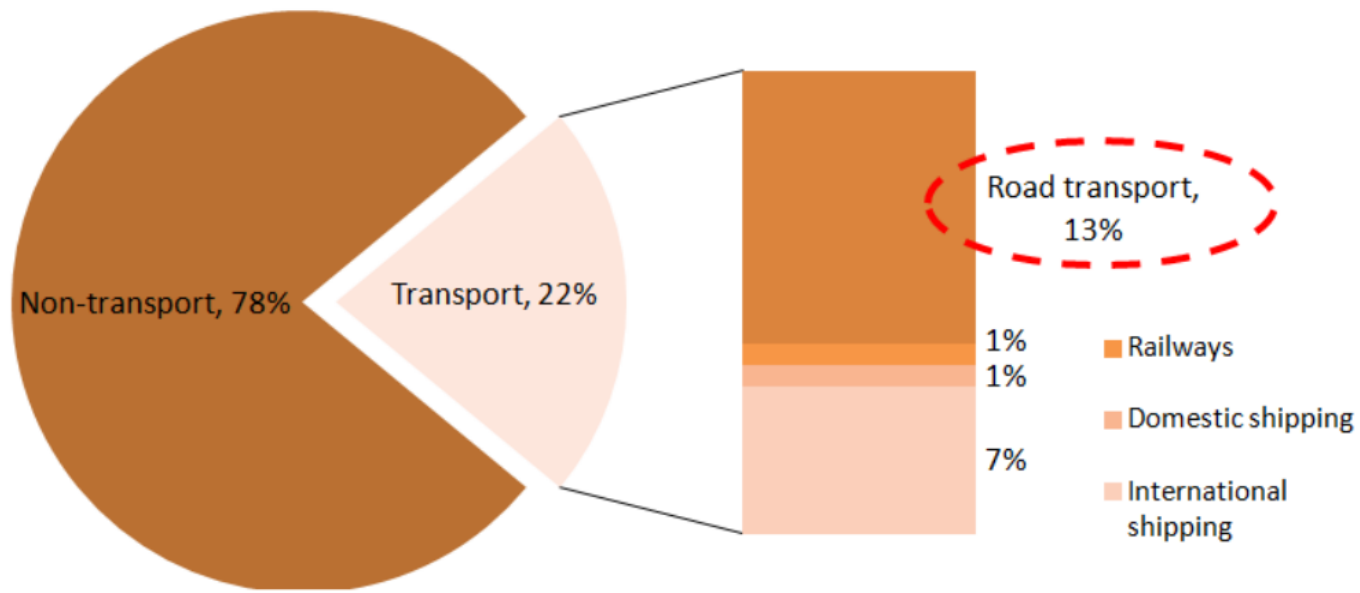
Source: Rappler.com

NOx Emissions



Source: European Environmental Agency

Particulate Matter



Source: European Environmental Agency






Emissions Legislation Timetable

Light Duty Vehicles Legislative Overview												
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	
Europe	Euro 6b		Euro 6c / RDE Phase 1			RDE Phase 2 / 95 g/km CO2		Possible Euro 7				
North America EPA	Tier 2		Tier 3 Introduction									
North America CARB	LEV III Phase in					LEV III Tightning						
Japan	Japan 09			Possible Japan 18								
South Korea (diesel)	Euro 6b				Euro 6c							
China (Nationwide)	China 4			China 5			China 6					
India	Bharat Stage 4					Bharat Stage 6						
Indonesia	Euro 2			Euro 4								
Thailand	Euro 4			Euro 5					Euro 6			

Heavy Duty Vehicles On-Road Legislation Overview												
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	
Europe	Euro VI								Possible Euro VII			
North America	Greenhouse Gas Phase 1						Greenhouse Gas Phase 2					
Japan	Japan 09		Japan 16									
South Korea	Euro VI									Euro VII		
Brazil	Euro V							Euro VI				
Russia	Euro IV			Euro V					Euro VI			
India (major cities)	Euro IV		Euro V			Possible Euro VI						
India (nationwide)	Euro III		Euro IV			Euro VI						
China (major cities)	Euro IV		Euro VI									
China (nationwide)	Euro IV			Euro V			Euro VI					

Heavy Duty Vehicles Off-Road Legislation Overview												
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	
Europe	Tier 4b				Stage V							
North America	Tier 4b							CARB/EPA				
Japan	Tier 4b											
South Korea	Tier 4b					Possible Stage V						
Brazil	Tier 3				Tier 4a				Tier 4b			
China (major cities)	Tier 3			Tier 4a				Tier 4b				
China (nationwide)	Tier 3					Tier 4a					Tier 4b	

-  Limit Emissions Resulting from the Combustion Process (NOx, PM and PN)
-  Reduce CO2 by improving Fuel Economy
-  Complementary Real Driving Emissions testing



Limit Emissions Resulting from the Combustion Process (NO_x, PM and PN)



Reduce CO₂ by improving Fuel Economy



Complementary Real Driving Emissions testing

Vehicles

1

Light Duty

- Passenger Cars
- Light Commercial Vehicles



- Gasoline or der.
- Diesel
- Hybrid
- Electric

2

Heavy Duty

On Road

- Medium & Heavy Trucks and Buses

Off Road

- Non-road mobile machinery



- Diesel
- Alternative Fuels
- Hybrid
- Electric

3

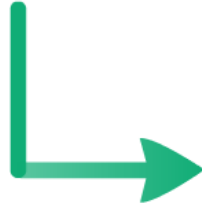
Motorcycles



- Gasoline
- Electric

Light Duty Vehicles

LDG



LDD

LDE

Two Way Catalyst 

Three Way Catalyst 

Hybrid Vehicles

- Mostly gasoline hybrid
- Diesel and hydrogen fuel cell
- Fuel cell cars to be approved and sold

Diesel Oxidation Catalyst (DOC) 

Pt

Catalyst Soot Filter (CSF)
Diesel Particulate Filter (DPF) 

Pt and some Pd

Lean Nox Trap (LNT) 

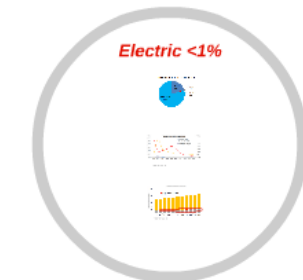
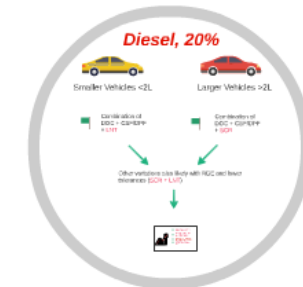
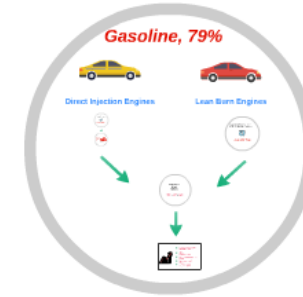
Pt and some Rh

Selective Catalytic Reduction (SCR) 

NO PGMs, but requires DOC to be higher quality

1 Battery Electric

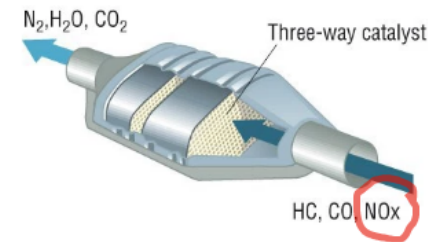
2 Fuel Cells



Two Way Catalyst



Three Way Catalyst



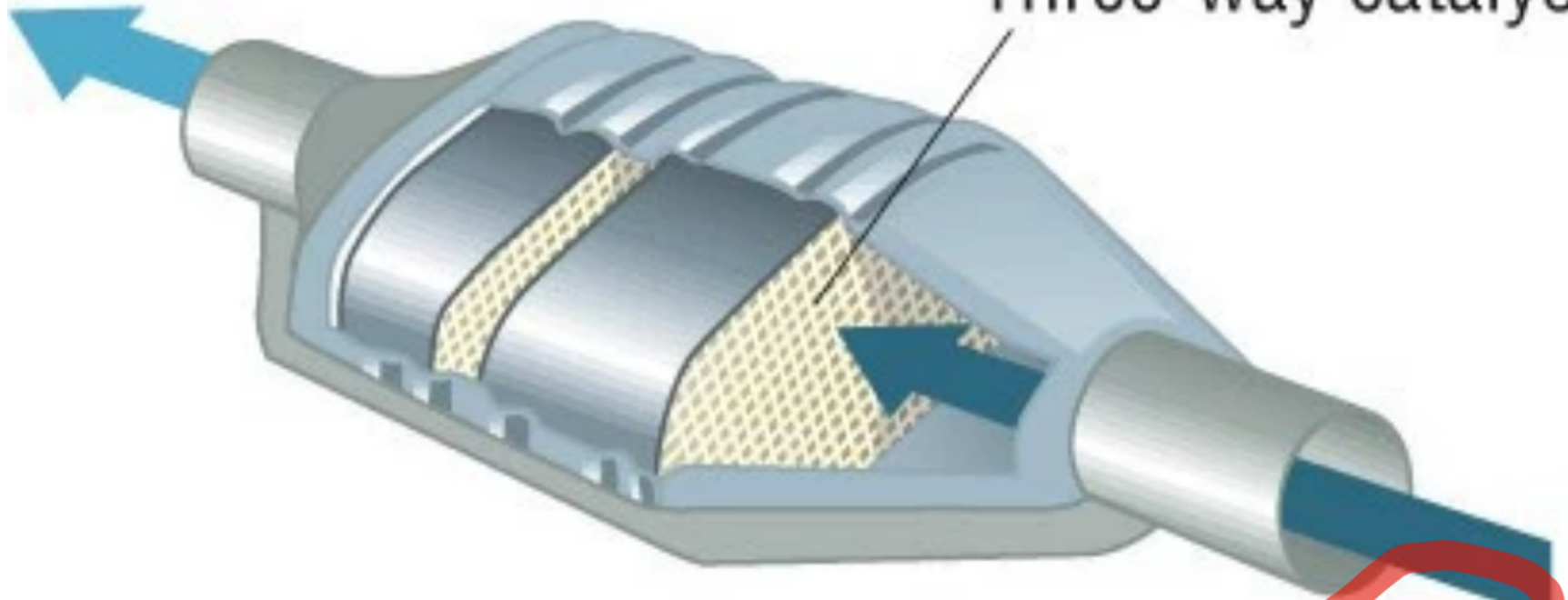


Oxidise
- CO -> CO₂
- HC -> CO₂

Source: thecatalyticconverter.wordpress.com

N_2, H_2O, CO_2

Three-way catalyst



HC, CO, NOx

Gasoline, 79%



Direct Injection Engines

Lean Burn Engines

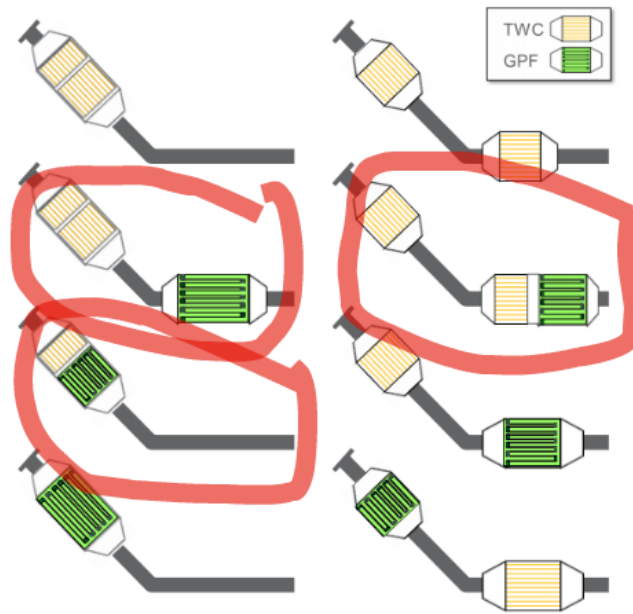


DI better fuel economy
but worse PM and PN



***Gasoline Particulate
Filter Applications***

- 1** *Reference Systems*
- 2** *Add on Systems*
- 3** *Integrated Systems*



Source: Corning Incorporated

Lean Burn Engines, high
NOx and PM also an issue



Lean NOx Trap



***Lean burn
Direct
Injection***

TWC + LNT + GPF



Both options will likely require more precious metals:



*TWC
or GPF
or an additional LNT*



Palladium favoured option, bit of rhodium



In some instances palladium only option

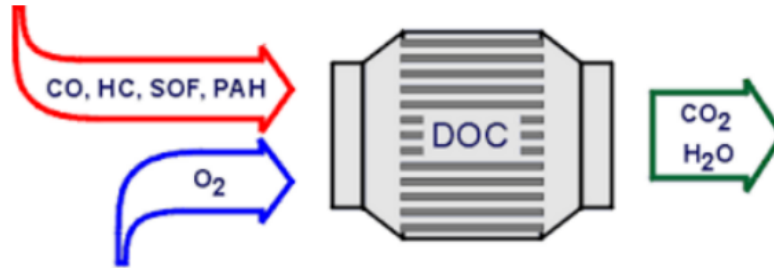


...as long as palladium is cheaper than platinum

Hybrid Vehicles

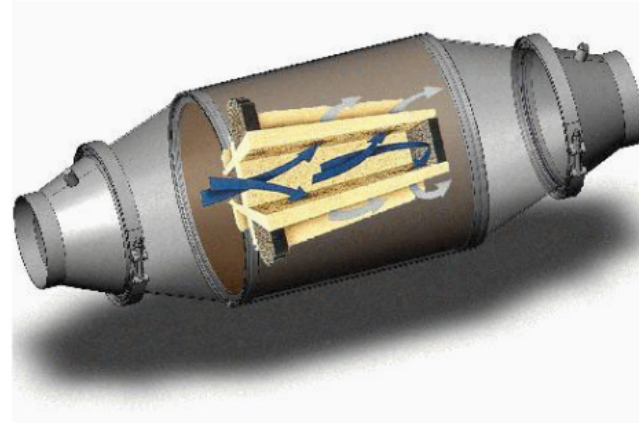
- Mostly gasoline hybrid
- Similar aftertreatment but higher loadings due to frequent cold start

Diesel Oxidation Catalyst (DOC)



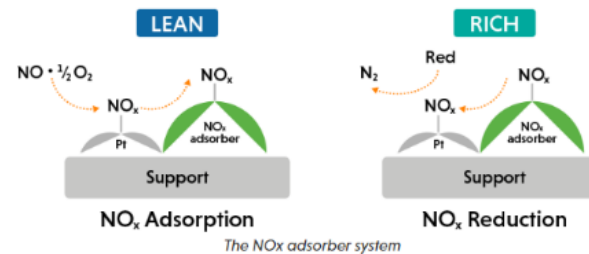
Pt

Catalyst Soot Filter (CSF) Diesel Particulate Filter (DPF)



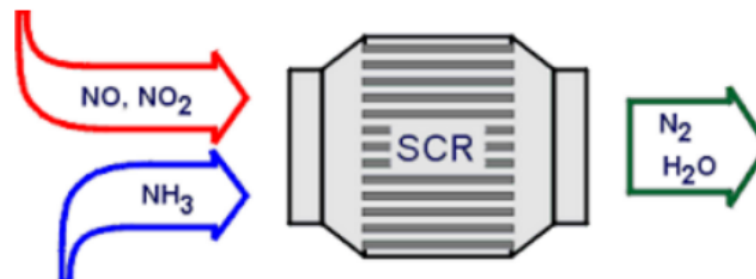
Pt and
some Pd

Lean Nox Trap (LNT)



Pt and
some Rh

Selective Catalytic Reduction (SCR)



No PGMs, but
requires DOC
to be higher
loaded

Diesel, 20%



Smaller Vehicles <2L



Larger Vehicles >2L



Combination of
DOC + CSF/DPF
+ LNT



Combination of
DOC + CSF/DPF
+ SCR

Other variations also likely with RDE and lower
tolerances (SCR + LNT)





Further emission tightening requires more filters



SCR is going to be dominant technology, but will require higher loadings on DOC



Smaller vehicles LNT but also more combinations (LNT+SCR)



Will favour platinum and palladium and some rhodium too

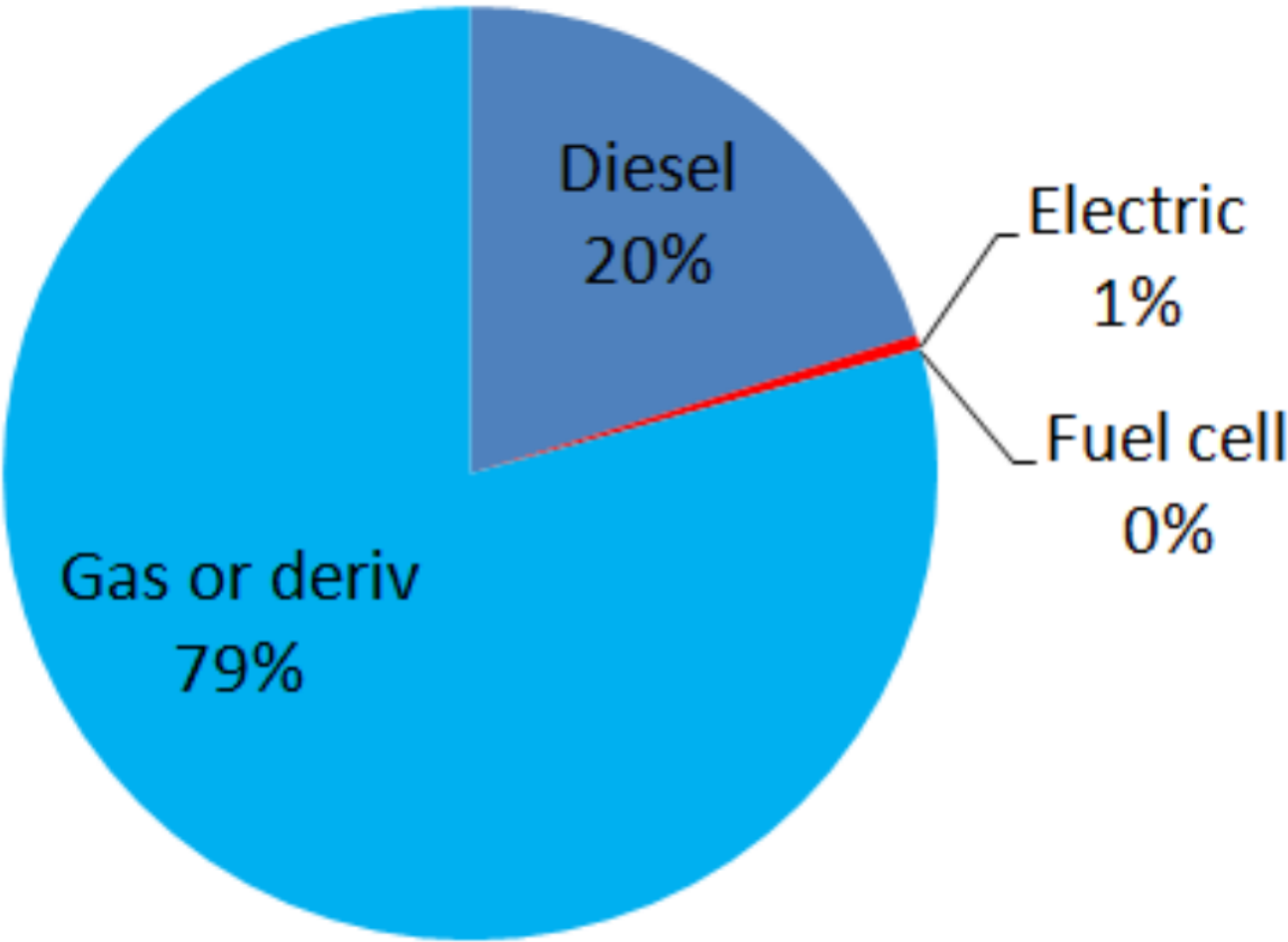
1

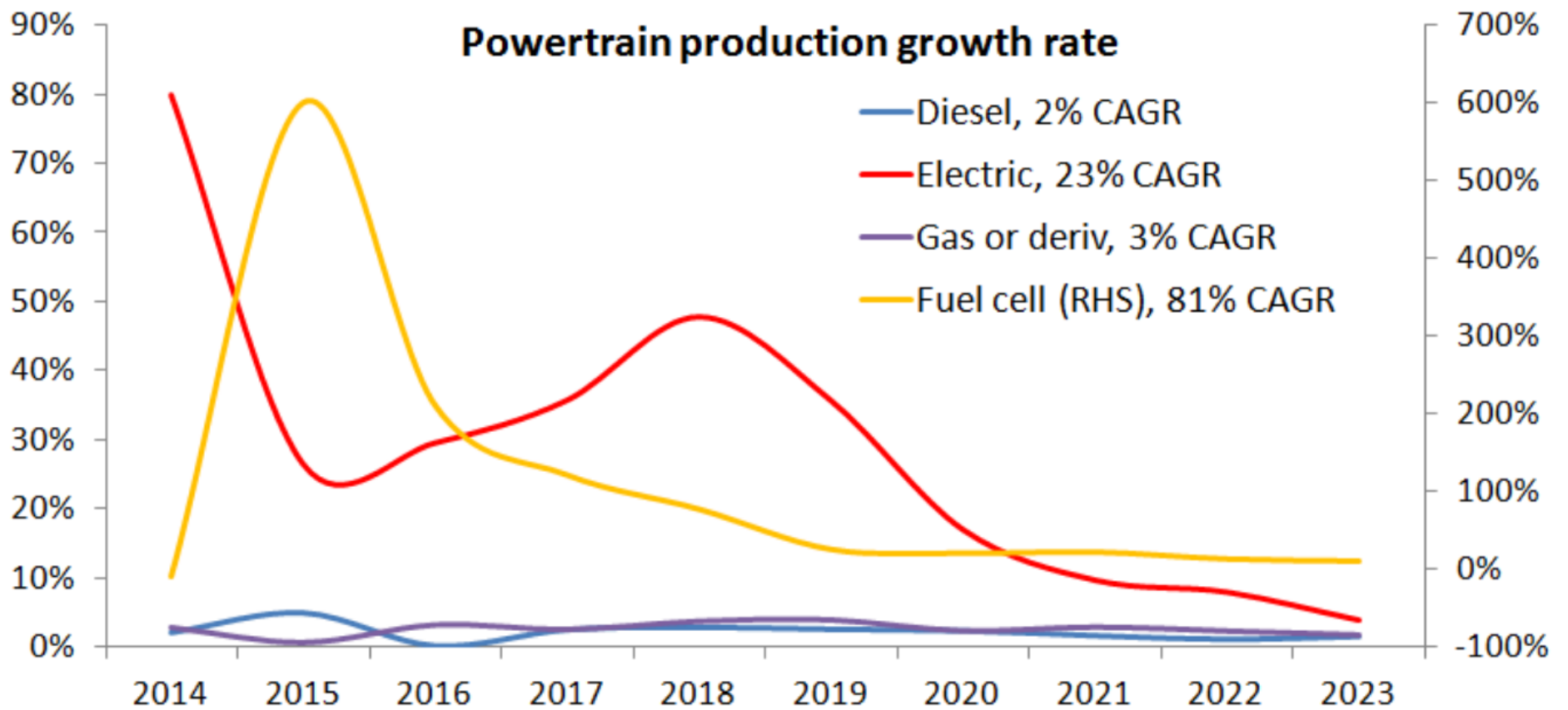
Battery Electric

2

Fuel Cells

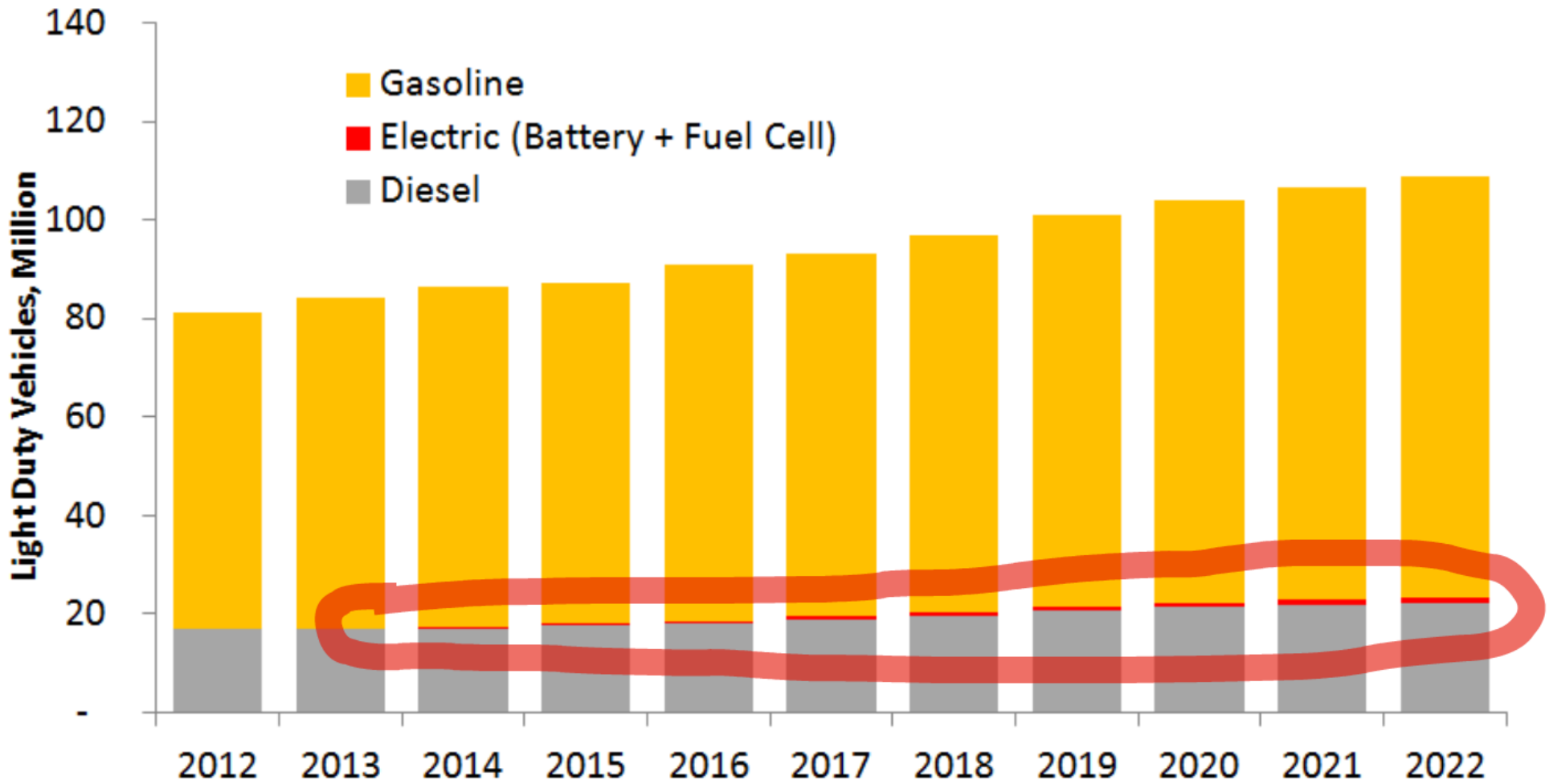
Global Light Vehicle Production in 2016





Source: LMC Automotive

Vehicle Production Forecast

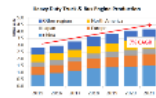


Source: LMC Automotive

On-Road HDV

On Road

- Diesel 97%
- Natural gas (CNG/LNG) 3%
- Electric <1%

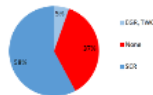


Source: FICG, Government of Punjab



Source: LUDHIANA CONTROL SYSTEM

China installed aftertreatment



Source: FICG, Government of Punjab

Other Regions installed aftertreatment



Major vehicle manufacturers



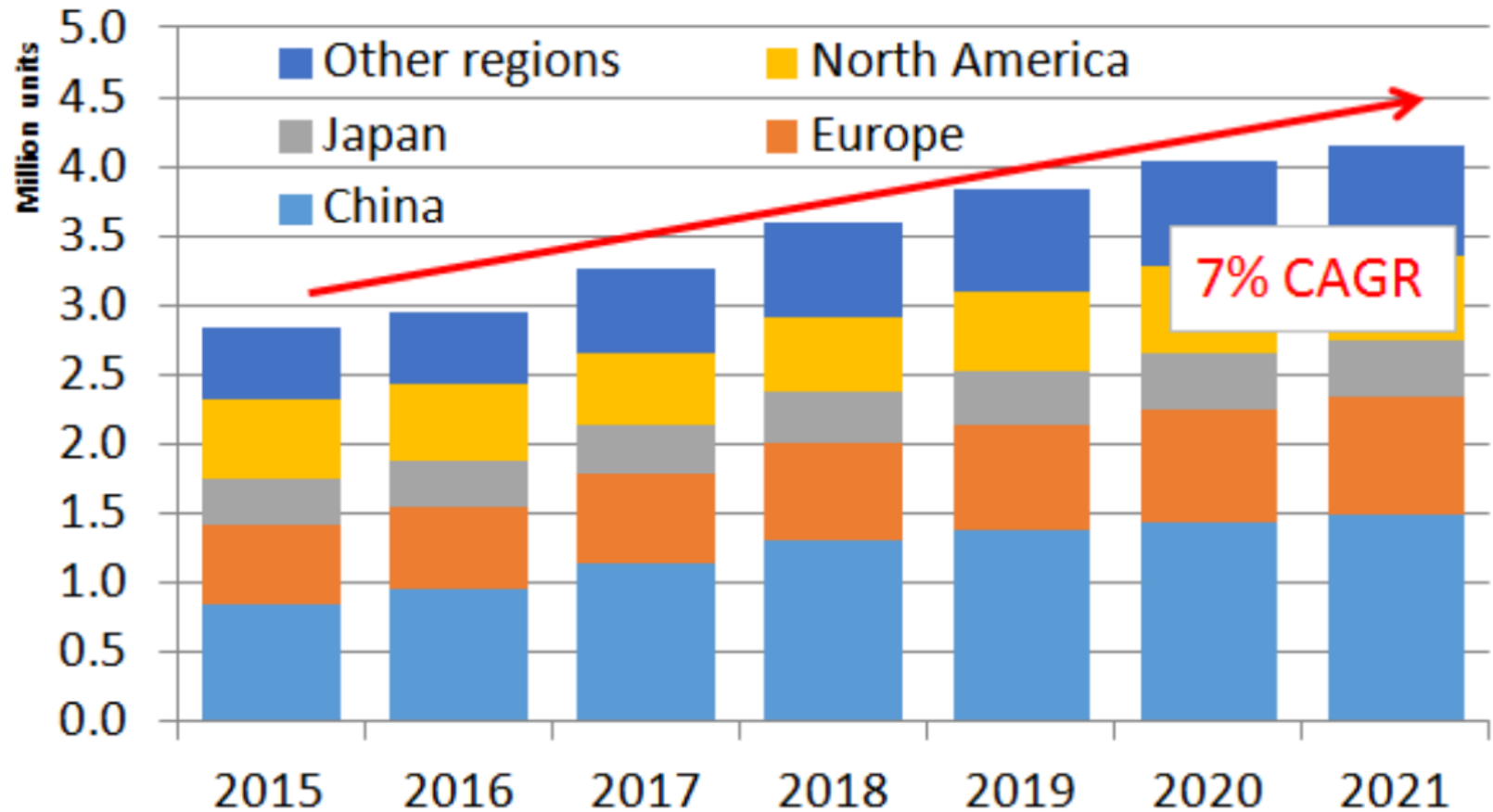
Source: FICG, Government of Punjab



- Vehicle production growth
- Stricter emissions regulation
- A lot of room for more application of and PDI controlling aftertreatment

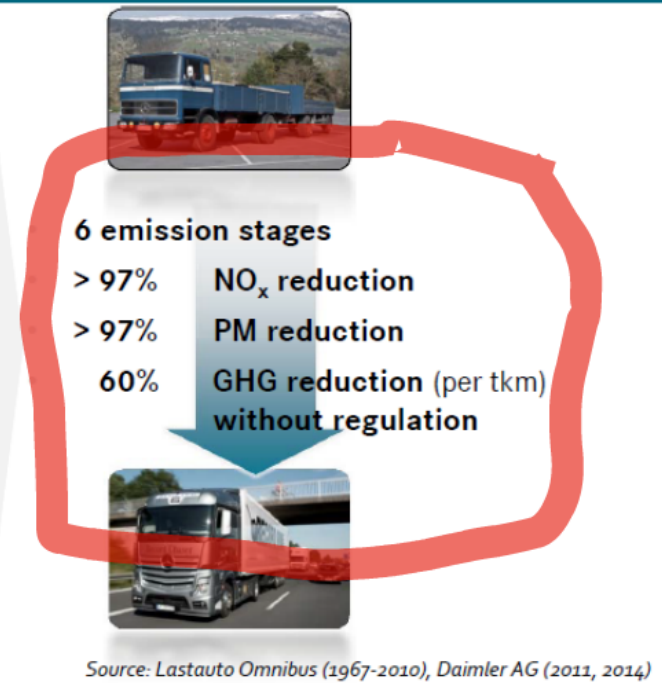
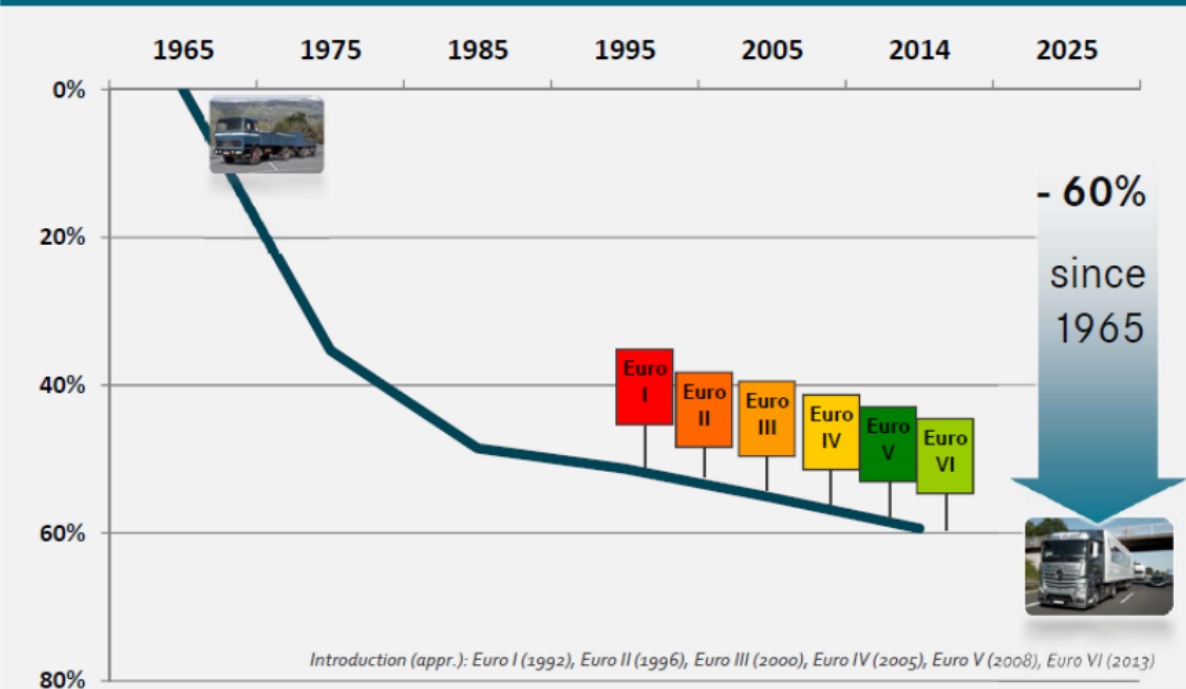


Heavy Duty Truck & Bus Engine Production



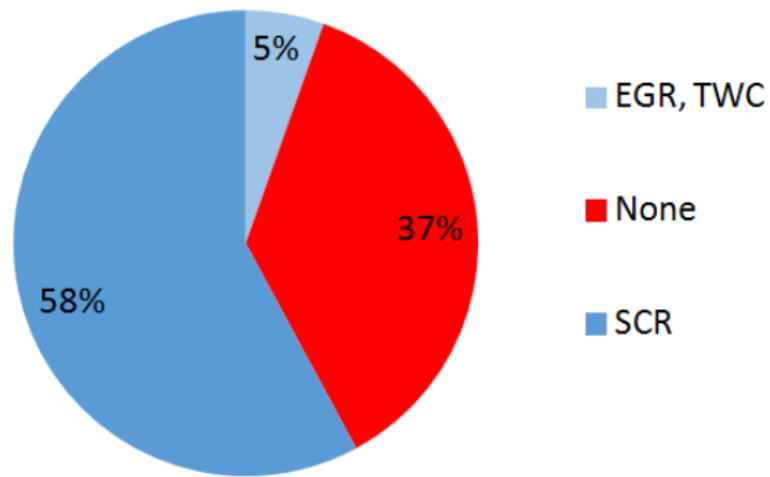
Source: Knibb, Gormezano & Partners

Fuel consumption reduction of new HDVs in the EU [tkm]

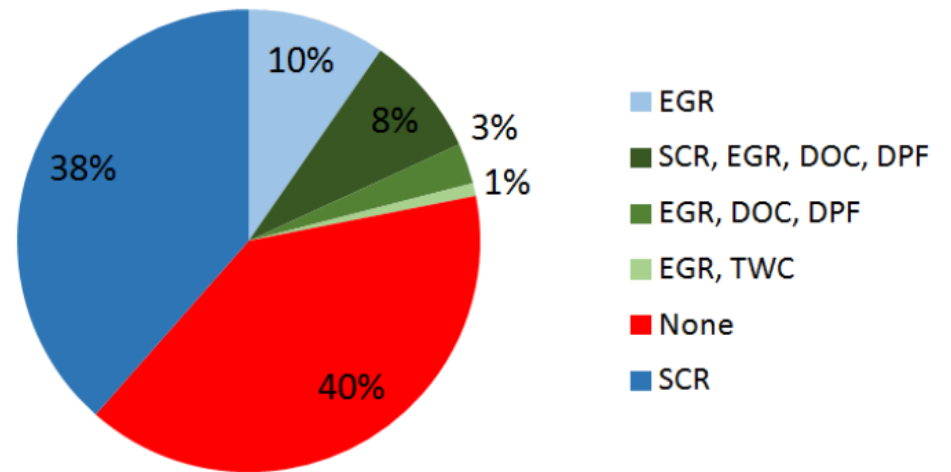


Source: Lastauto Omnibus, Daimler

China Installed Aftertreatment

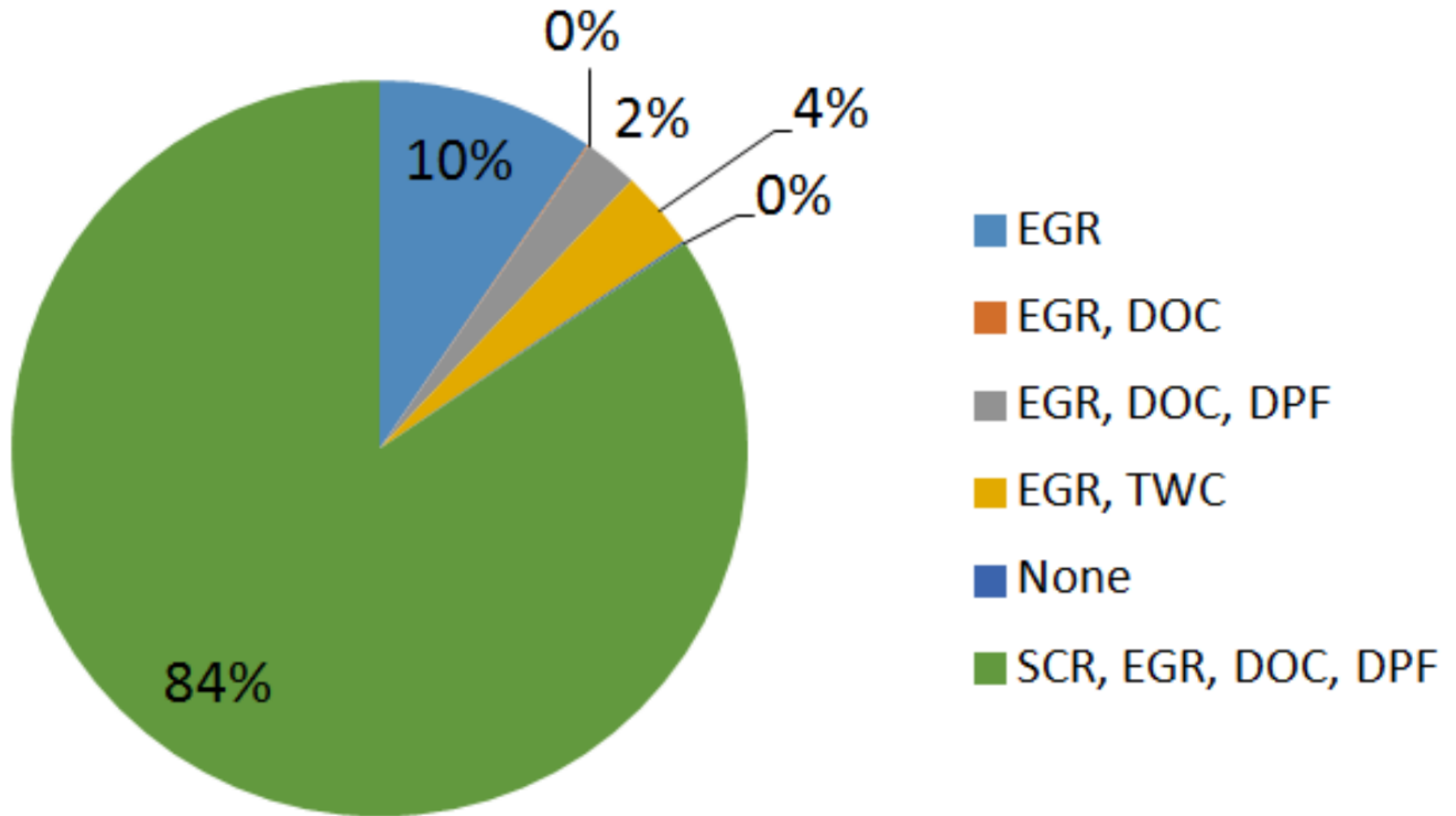


Other Regions Installed Aftertreatment



Source: Knibb, Gormezano & Partners

North America Installed Aftertreatment

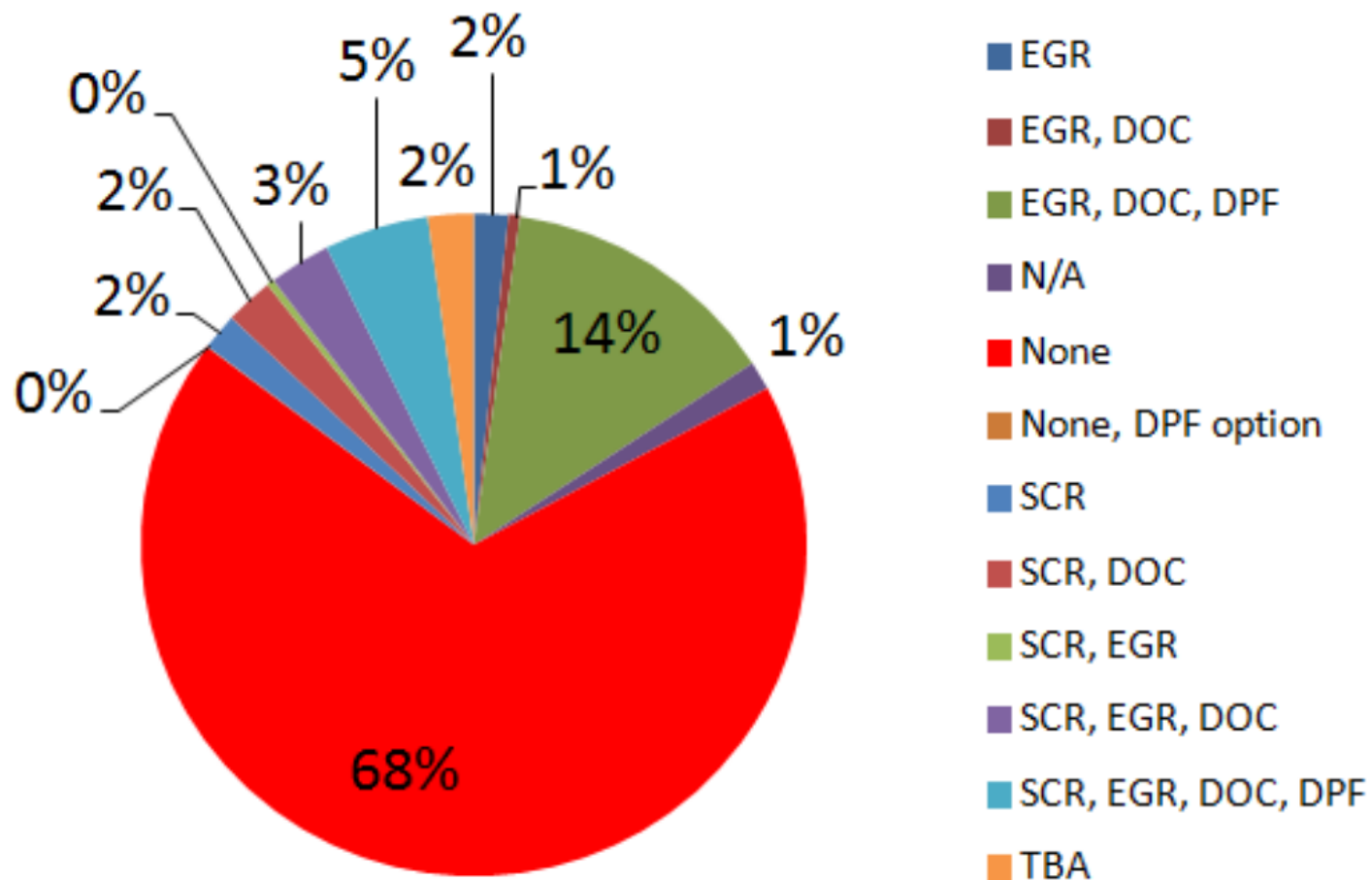


Source: Knibb, Gormezano & Partners



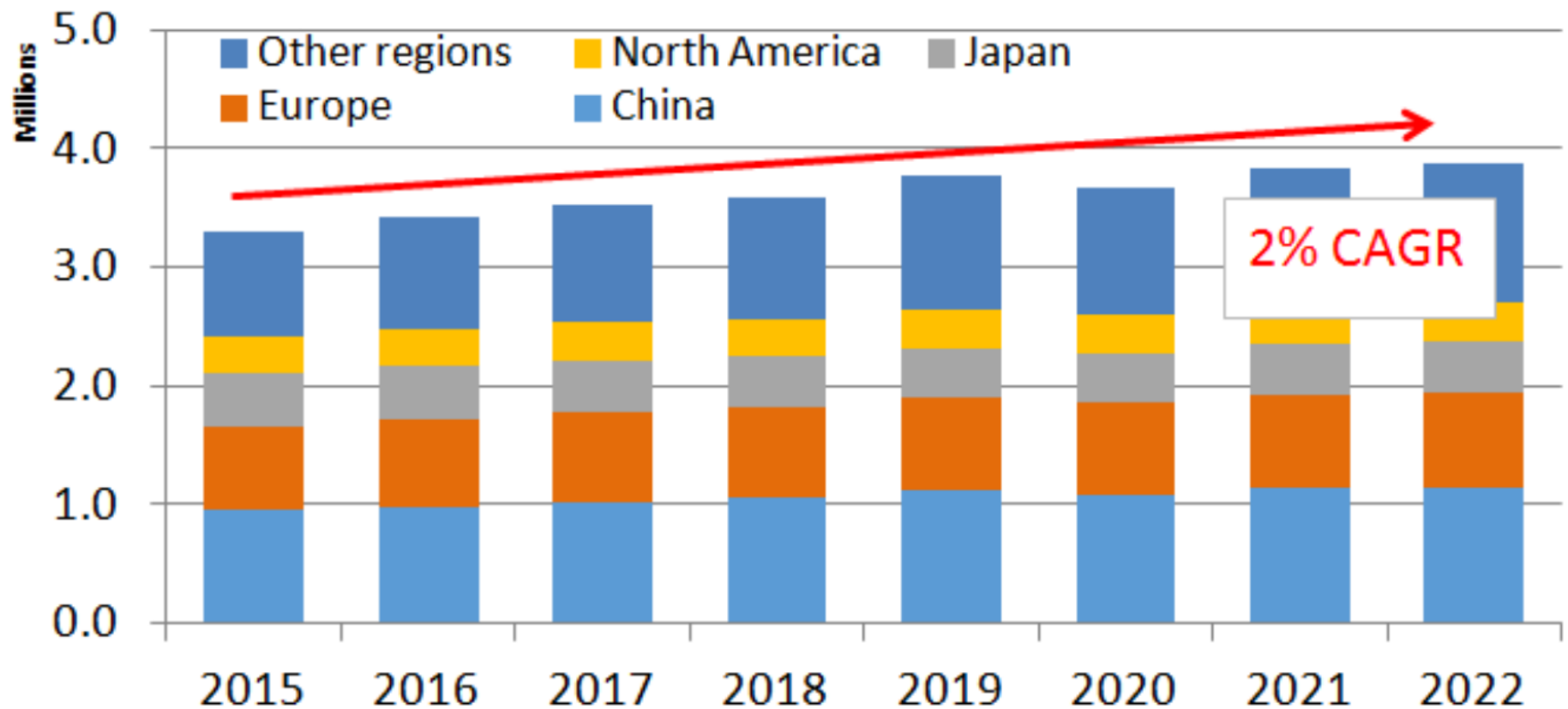
- Vehicle Production growth
- Stricter emission legislation
- A lot of room for more sophisticated Pt and Pd containing aftertreatment

Global Installed Aftertreatment



Source: Knibb, Gormezano & Partners

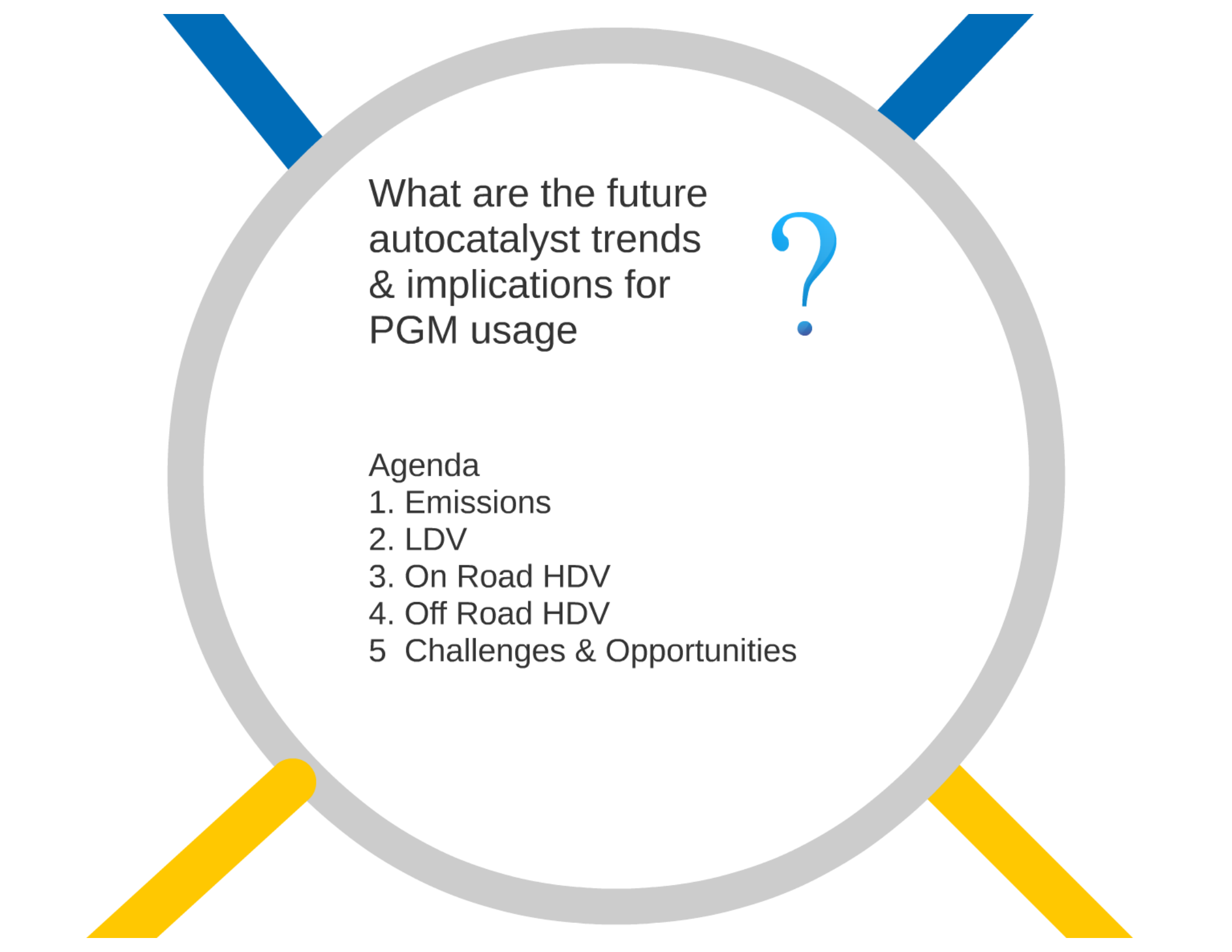
Heavy Duty Off Road Mobile Machinery



Source: Knibb, Gormezano & Partners



- 70% no aftertreatment globally
- China and Other 98% vs 86% no aftertreatment at all
- Even Europe and Japan room for growth
- Positive for **Pt** and **Pd** containing filters



What are the future
autocatalyst trends
& implications for
PGM usage



Agenda

1. Emissions
2. LDV
3. On Road HDV
4. Off Road HDV
5. Challenges & Opportunities

Main Opportunities:

1. Tightening Emissions Legislation
2. Supportive vehicle sales profile for ICE
3. Increased use of aftertreatment particularly HDD on-road and off- road market



Main Challenges:

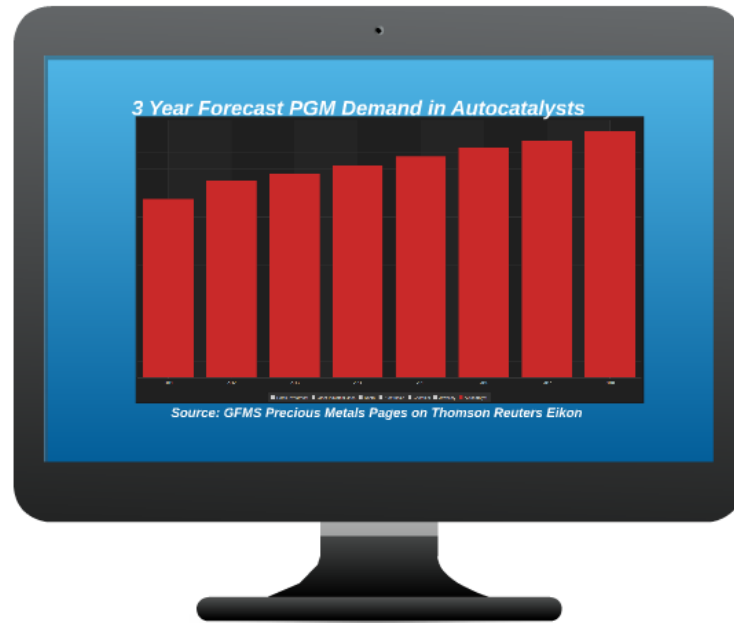
1. US Presidential Election
2. Higher PGM prices
3. Peak Vehicle Demand
4. Electric Powertrains/ End ICE



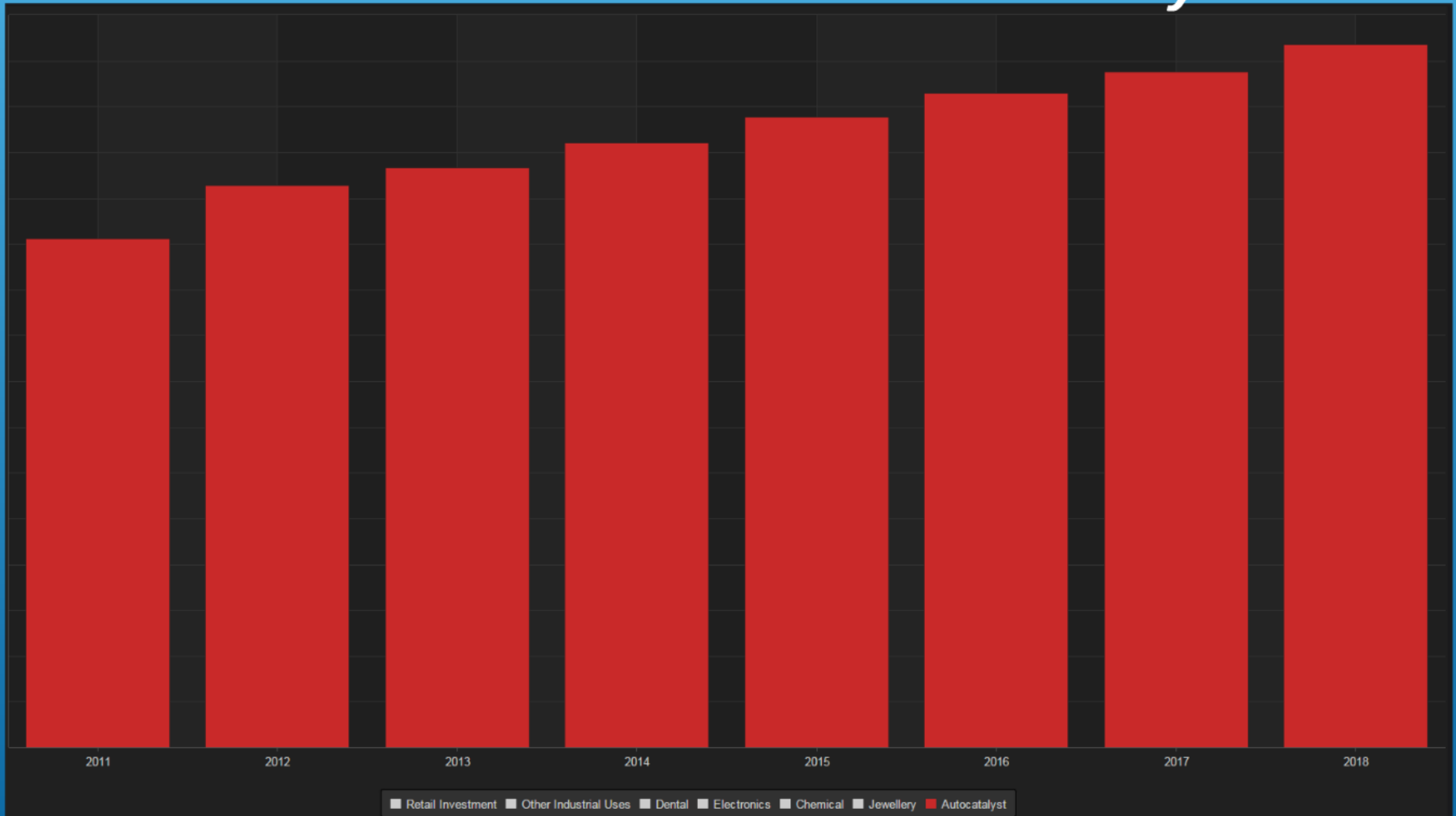
They remain promising...



.....at least for now



3 Year Forecast PGM Demand in Autocatalysts



Source: GFMS Precious Metals Pages on Thomson Reuters Eikon



Thank you for your attention!

ross.strachan@tr.com