
ECT-2016
Contribution and Role of Off-road Industry towards Better Air Quality
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Emission Control Technology for Sustainable Growth
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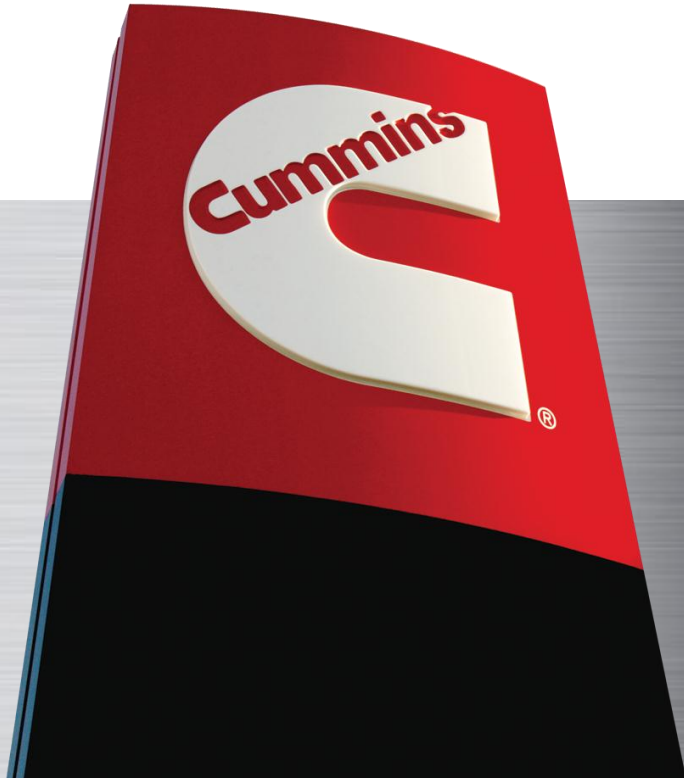
Role of Off-road Industry towards Better Air Quality

Dr. Anuradda Ganesh

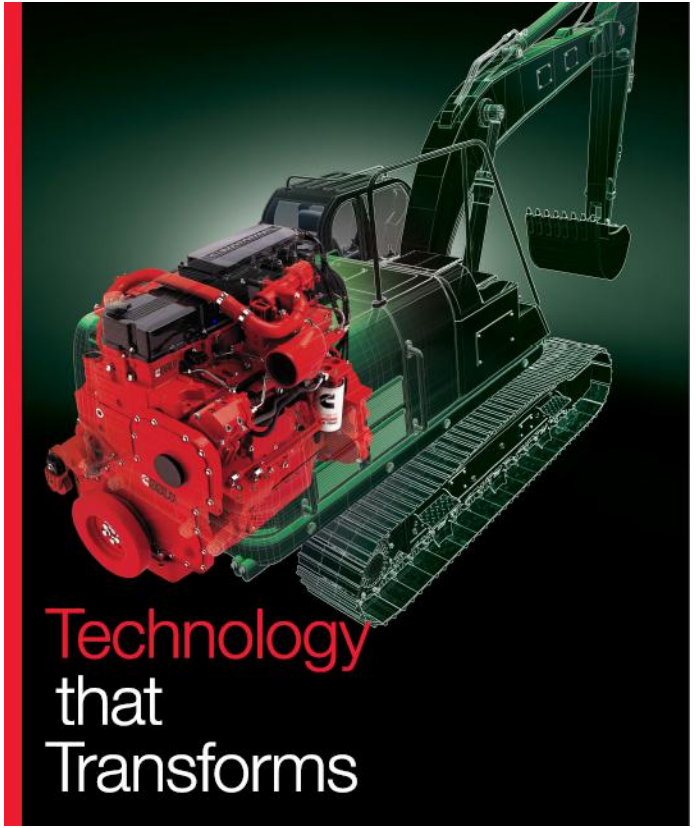
10th November 2016

Data Classification: Public

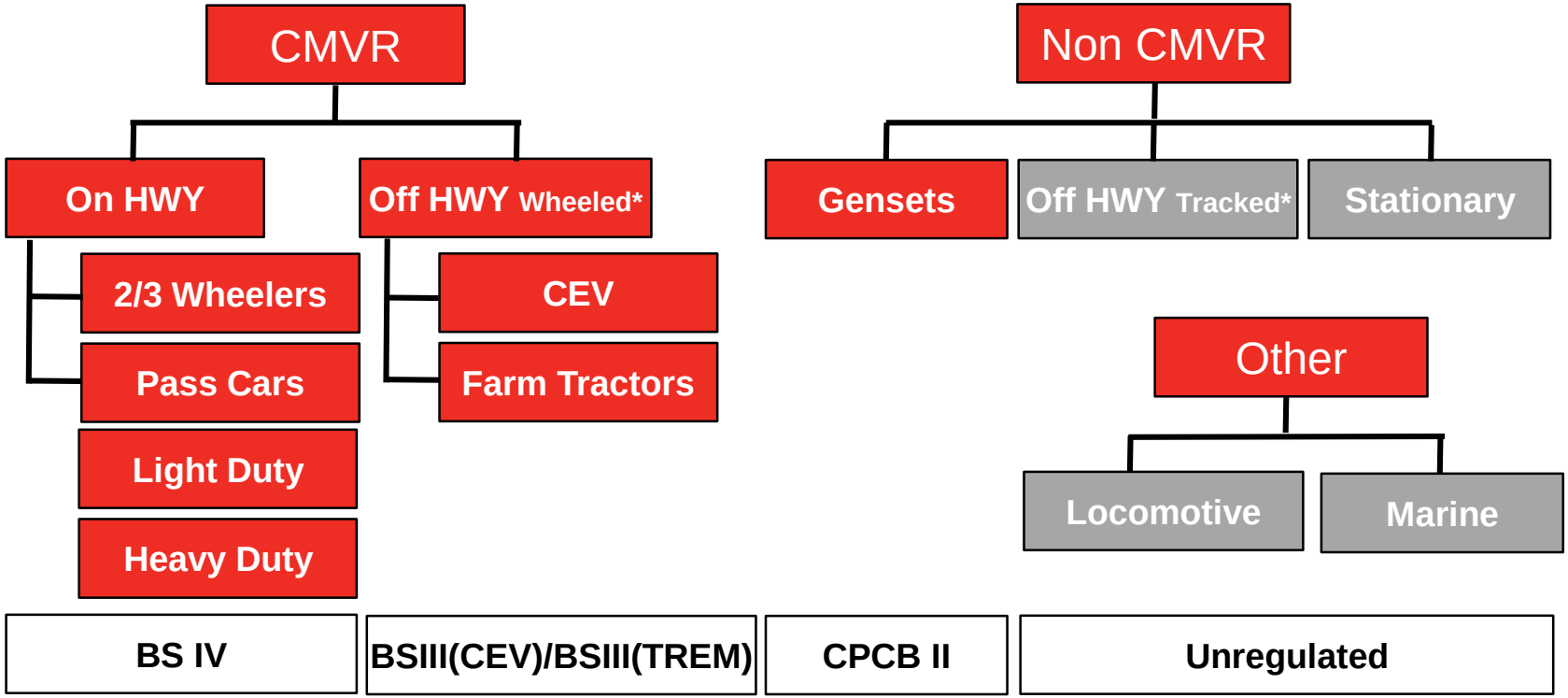


Content:

- Off HWY scenario – Global and in India
- Global Off HWY emission norms
- Cummins Emissionised products
- Architectural Options
- Conclusion

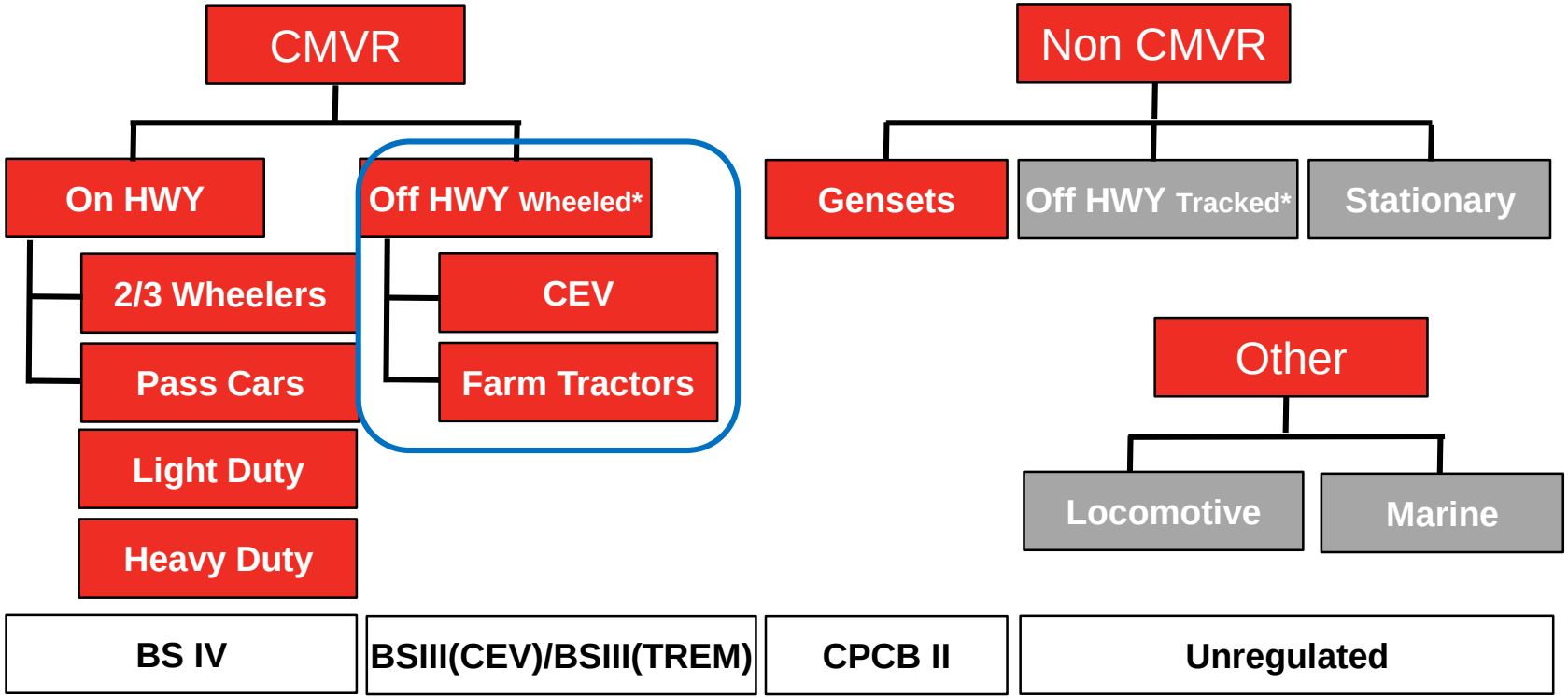


India Off HWY Emission Categories:



* Although broadly defined as wheeled and tracked, emission exemption applicability may differ

India Off HWY Emission Categories:



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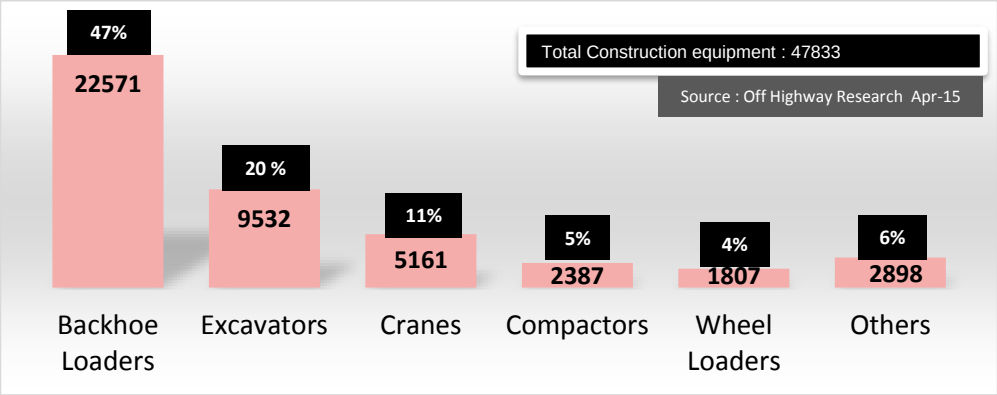
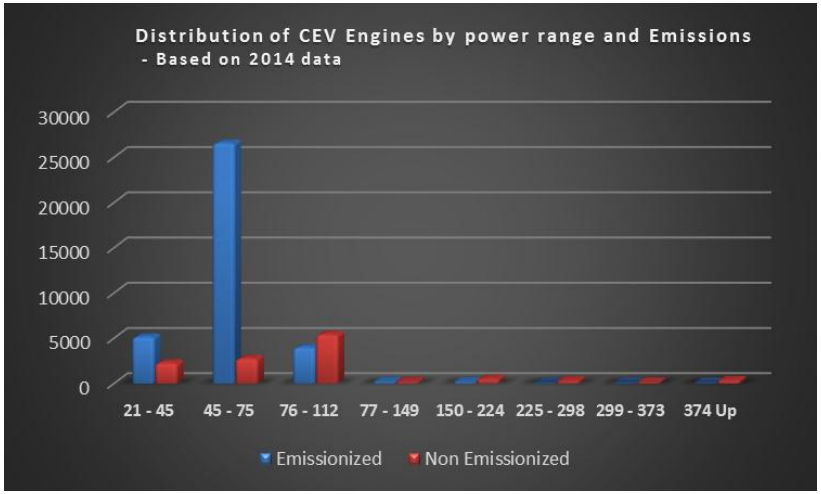
CEV Market Statistics:

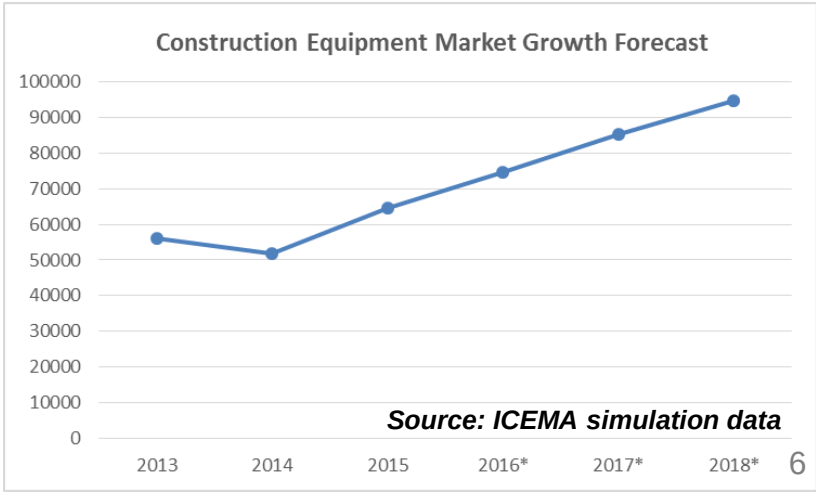
(includes Compact Construction)



- Backhoe Loader continues to be the largest sub-segment in 2015, dominated by players who prefer captive engines.
- Excavators, Wheel Loaders & Cranes are the growing sub-segments.

Based on 2015 fiscal year data

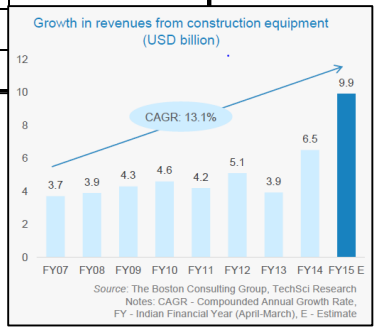




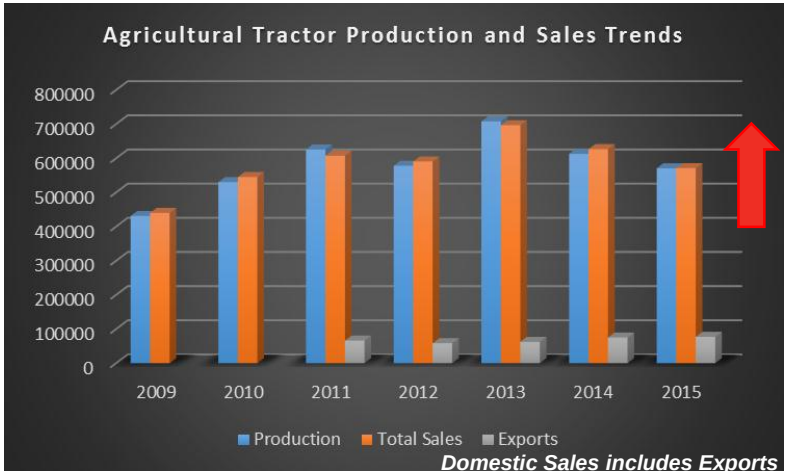
CEV Applications Share:

Category	Product Family	Overall Share	Emissionized Eqp. Share
CEV's (Emissionized)	Backhoe Loaders	52.2%	69.3%
	Mobile Cranes	10.4%	13.9%
	Compaction Equipment	5.6%	7.5%
	Wheeled Loaders	3.8%	5.0%
	Asphalt Finishers	1.7%	2.2%
	Skid-Steer Loaders	0.9%	1.2%
	Motor Graders	0.6%	0.8%
	Wheeled Excavators	0.0%	0.0%
Non CEV's (Non Emissionized)	Crawler Excavators	21.9%	0
	Crawler Dozers	0.9%	
	Mini Excavators	1.1%	
	Rigid Dump Trucks	0.7%	
	Articulated Dump Trucks	0.0%	
	Crawler Loaders	0.0%	

Based on 2014 product mix



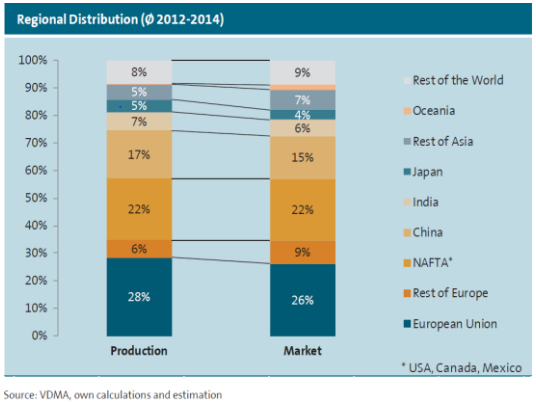
Agricultural Tractors:

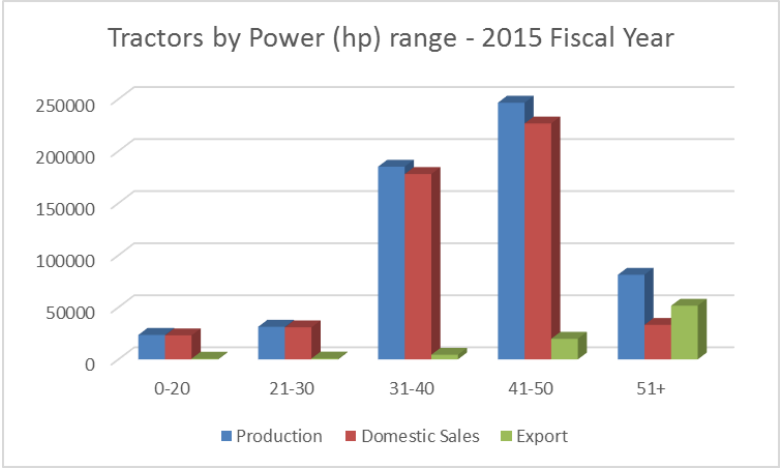


Data Source: Tractor manufacturers Association (http://tmaindia.in/consolidated-monthly-reports.php)

Image courtesy - TMA

Image courtesy - TMA





Global On & Off HWY Future Emissions:

Cummins View on Future Emissions:

United States
EPA17 GHG Phase I

India
BS IV Nationwide

Beijing
Jing V

Beijing
NS VI Select Apps

Mexico
Euro VI-A

Beijing
NS VI All Apps

China *
NS VI

Europe
Euro VI OBD-D

Australia
Euro VI-C

India
BS VI

Brazil
Euro VI

2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022

Europe
Off-Hwy Stage V (130kW to 560kW)

China @
Inland Stage I

Europe
Off-Hwy Stage V (56kW to < 130kW)

China @
Off-Hwy Stage IV

China @
Stationary Stage I

United States
EPA21 GHG Phase II

India #
BS IV CEV

India #
CPCB III

China
Inland Stage II

Off Highway Emissions Comparison

US	Canada	EU	Japan	Korea	China	India		Brazil	
						Industrial	Powergen	Industrial	Powergen
Tier 1	Tier 1	EU Stage I	Tier 1		CS I		CPCB I		
Tier 2	Tier 2	EU Stage II	Tier 2	Tier 2	CS II				
Tier 3	Tier 3	EU Stage IIIA	Tier 3	Tier 3	CS III	BS III CEV	CPCB II	MAR 1 (2017)	
Tier 4i	Tier 4i	EU Stage IIIB	Tier 4i		CS IV (2019+)				
Tier 4F	Tier 4F	EU Stage IV	Tier 4F	Stage IV		BS IV CEV (2021+)	CPCB III ?		
		EU Stage V (2019)		Stage V (Likely by 2020)					

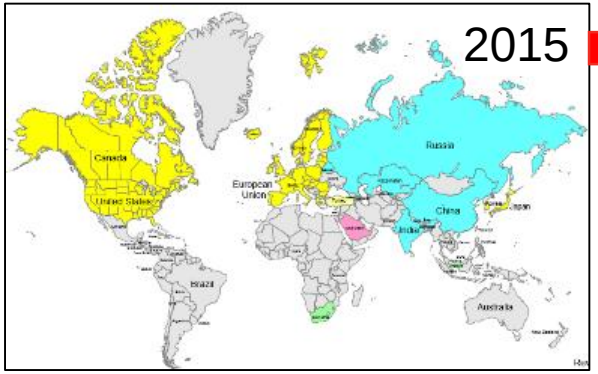
Pattern indicates the current applicable regulations in the region

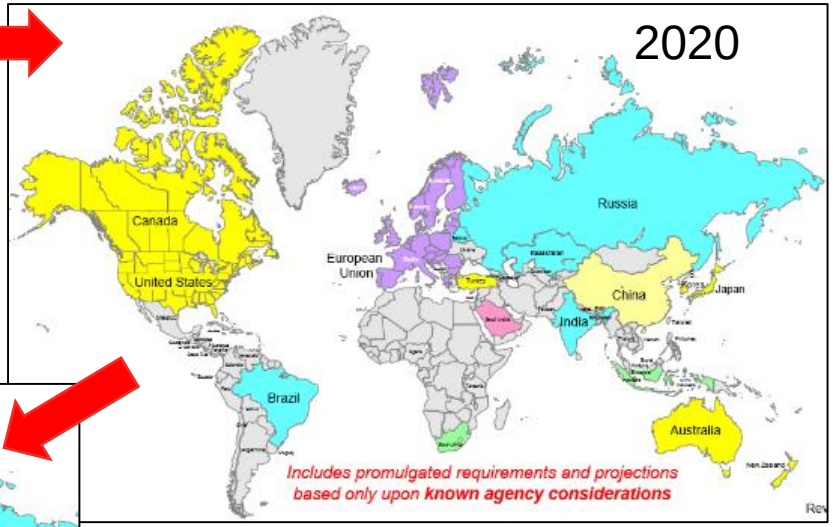
Based on visibility and limited understanding of future emission norms

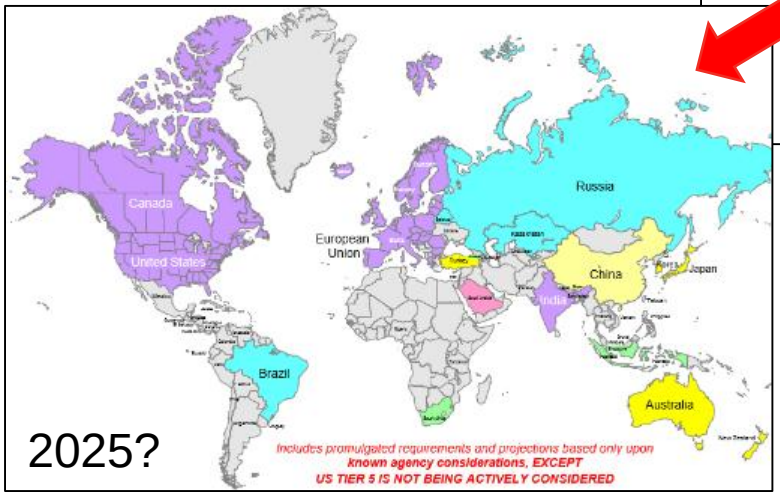
** Draft dated 17th October 2016*

 # Under discussions

Non-road Emission Regulations (49-751 hp)







Euro Stage	US Tier
I	1
II	2
IIIA	3
IIIB	4i
IV	4f
V	*5*

Global Non-Road Emissions:

EUROPEAN UNION (EU)

NOx / THC / CO / PM (g/kWh) / [PM count/kWh] (NOx+**THC**) / CO / PM (g/kWh) / [PM count/kWh]

kW	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
kW < 8										*(7.5) / 8.0 / 0.40 (0.6 PM for certain hand-startable engines)*						
8 ≤ kW < 19										*(7.5) / 6.6 / 0.40*						
19 ≤ kW < 37	(7.5) / 5.5 / 0.6									*(4.7) / 5.0 / 0.015/ [10^12]*						
37 ≤ kW < 56 (a)	(4.7) / 5.0 / 0.4 (a)			(4.7) / 5.0 / 0.025												
56 ≤ kW < 130 (b)	(4.0) / 5.0 / 0.3 (b)		3.3 / 0.19 / 5.0 / 0.025			0.4 / 0.19 / 5.0 / 0.025					*0.4 / 0.19 / 5.0 / 0.015 / [10^12]*					
130 ≤ kW ≤ 560	(4.0) / 3.	2.0 / 0.19 / 3.5 / 0.025			0.4 / 0.19 / 3.5 / 0.025					*0.4 / 0.19 / 3.5 / 0.015 / [10^12]*						
kW > 560										*3.5 / 0.19 / 3.5 / 0.045 (c)*						
	Stage IIIA	Stage IIIB			Stage IV					*Stage V*						

(a) The power category for Stages I-IIIA was 37 ≤ kW < 75 kW

(b) The power category for Stage I-IIIA was 75 ≤ kW < 130 kW

(c) Non genset standards shown. Genset standards will align with US genset standard of 0.67 / 0.19 / 3.5 / 0.035

Constant-speed engines: All were at Stage IIIA by 2012 and will remain at Stage IIIA until they align with variable speed at Stage V

See table on Europe tab for EU member countries

Stage V dates and emission limit values apply to variable speed and constant speed engine. Until Stage V constant speed engines remain at Stage IIIA

UNITED STATES, CALIFORNIA AND CANADA

kW	(hp)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0-7	0-10	(7.5) / 8.0 / 0.40	Single power category for TPEM														
8-18	11-24	(7.5) / 6.6 / 0.40															
19-36	25-48	(7.5) / 5.5 / 0.30			(4.7) / 5.5 / 0.03	Single power category for TPEM									*(4.7) / 5.0 / 0.015 / [10^12]*		
37-55	49-74	*Optional T4i 0.30 PM*			(4.7) / 5.0 / 0.03												
56-129	75-173	Tier 3		3.4 / 0.19 / 5.0 / 0.02			0.40 / 0.19 / 5.0 / 0.02								*0.40 / 0.19 / 5.0 / 0.015 / [10^12]*		
130-560	174-751	Tier 3	2.0 / 0.19 / 3.5 / 0.02			0.40 / 0.19 / 3.5 / 0.02									*0.40 / 0.19 / 3.5 / 0.015 / [10^12]*		
> 560	> 751	Tier 2	3.5 / 0.40 / 3.5 / 0.10 *0.67 / 0.40 / 3.5 / 0.10 (a)*				3.5 / 0.19 / 3.5 / 0.04 *0.67 / 0.19 / 3.5 / 0.03 (b)*								?		
		T2	T3	Tier 4 Interim			Tier 4 Final								*Tier 5*		

(a) Applies to portable power gen engines > 900 kW (> 1207 hp)

(b) Applies to portable power gen engines > 560 kW (> 751 hp)

Includes Puerto Rico and US Virgin Islands

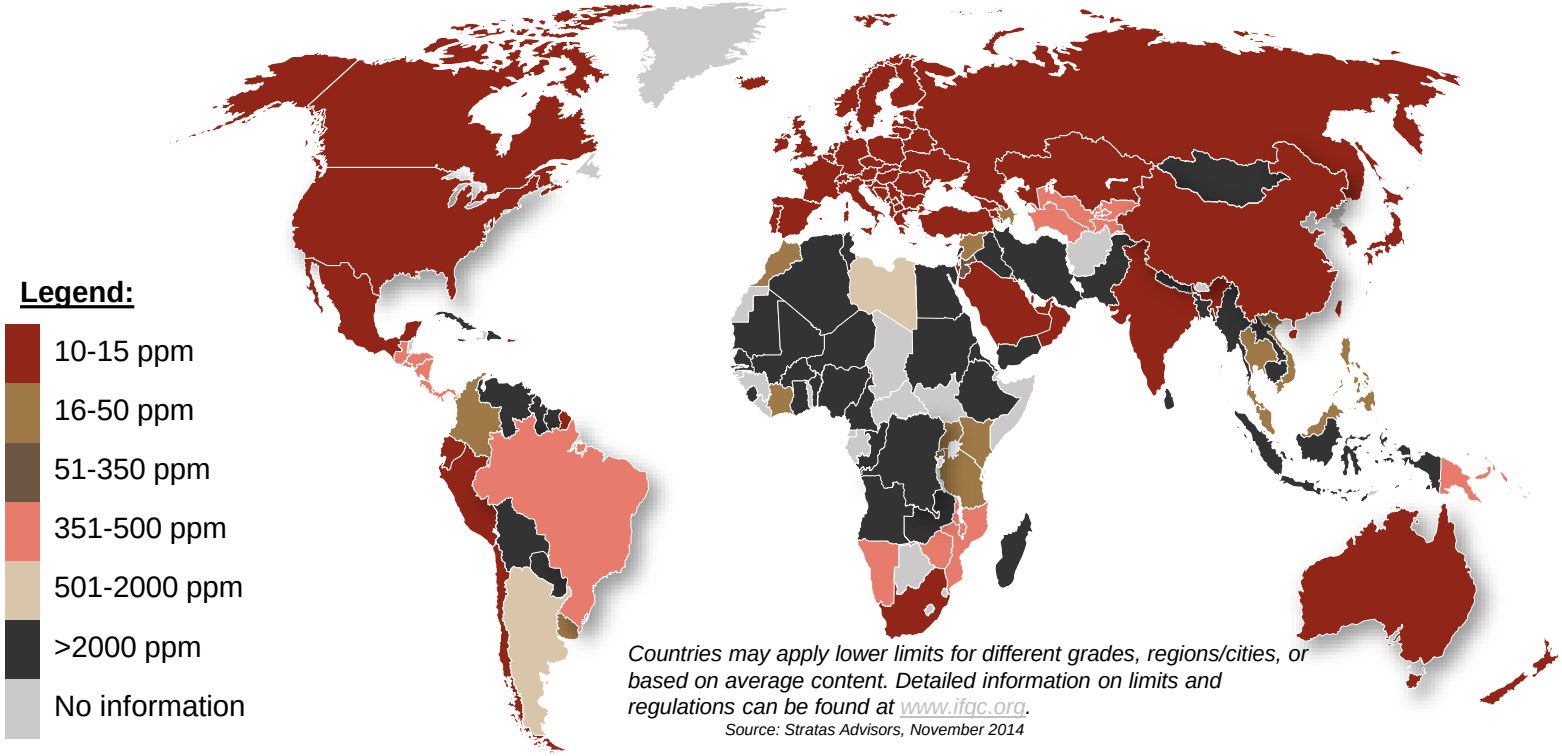
Canadian Tier 4 standards came into effect January 16, 2012

California nonroad standards are the same as the 49-state EPA nonroad standards

Significant Reduction in NOx and PM

Max Sulfur Limits in On-Road Diesel, 2020

China, India, South Africa and Ukraine moving to 10 ppm by this time



Countries may apply lower limits for different grades, regions/cities, or based on average content. Detailed information on limits and regulations can be found at www.ifqc.org.

Source: Stratas Advisors, November 2014

BSVI fuel under single fuel policy will be enabler for advance Off HWY norms

STRATASADVISORS
A HART ENERGY COMPANY

Emissions Share:

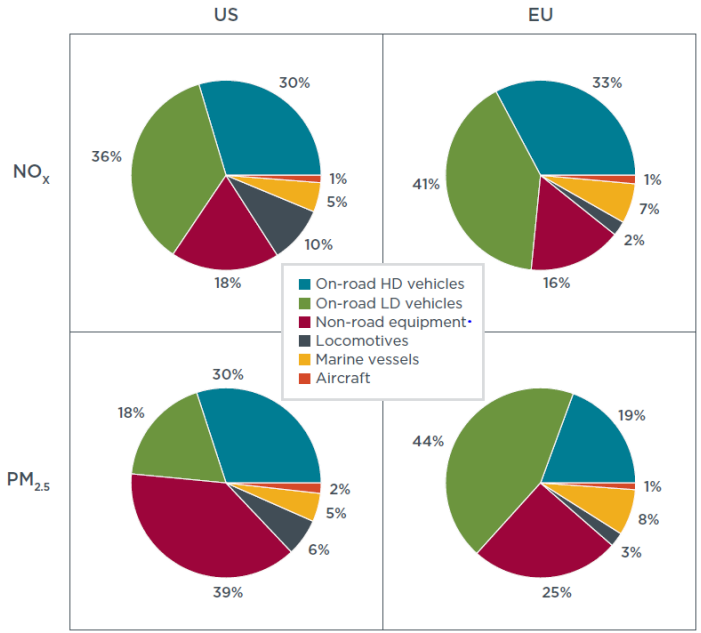


Figure 2. Relative contributions of individual source categories to mobile-source NO_x and $PM_{2.5}$ emissions in the United States and European Union for 2011 (EPA, 2015a; EEA, 2015)

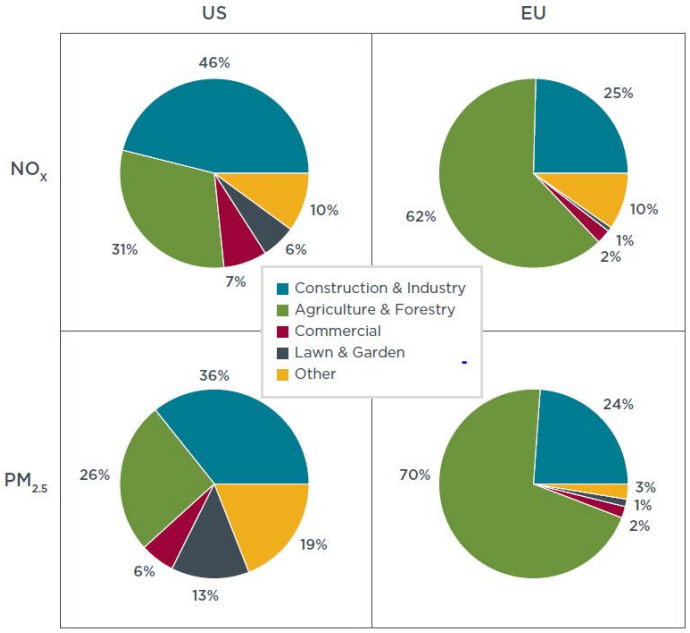


Figure 3. Relative contributions to non-road vehicle and equipment NO_x and $PM_{2.5}$ emissions in the United States and European Union by end-use sector for 2011 (EPA, 2015a; EEA, 2015)

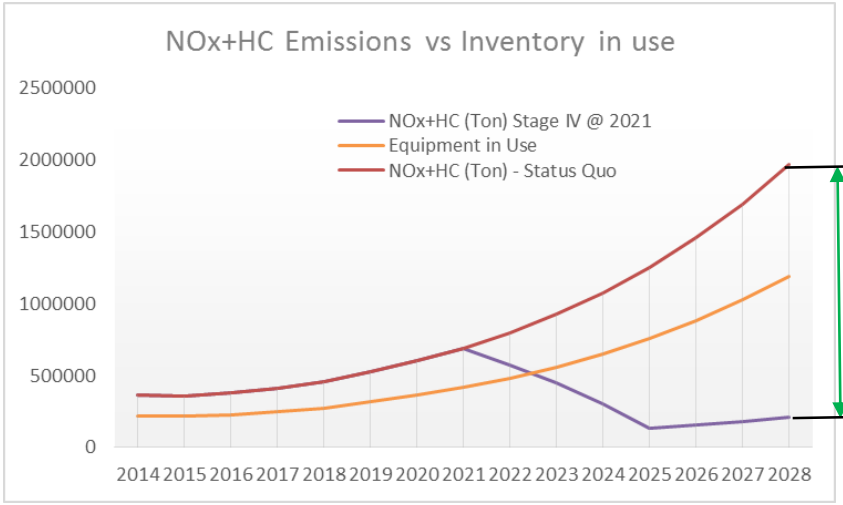
US and EU share of emission by Categories

US and EU share of emission within Non Road applications

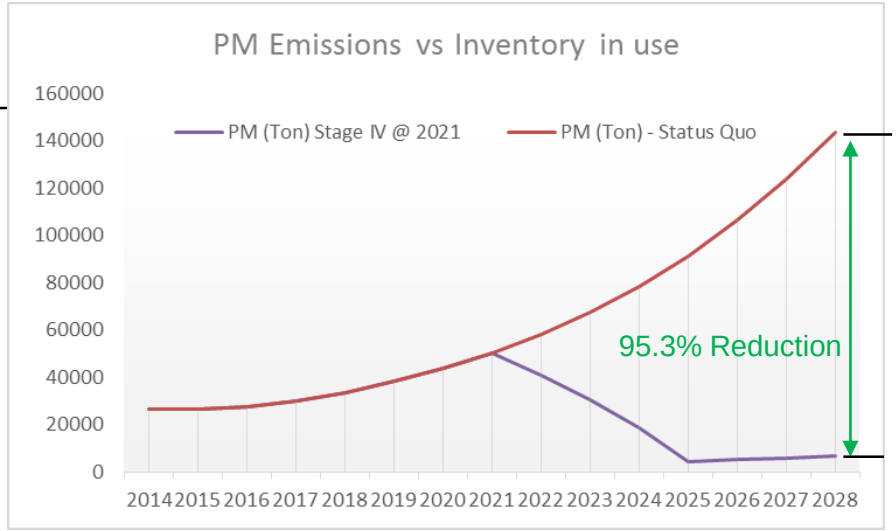
With infrastructure growth plan, India would exhibit similar trends as in EU

Source: ICCT White paper-Sept 2016

CEV Emissions Impact with and Without Stringent upcoming Emissions:



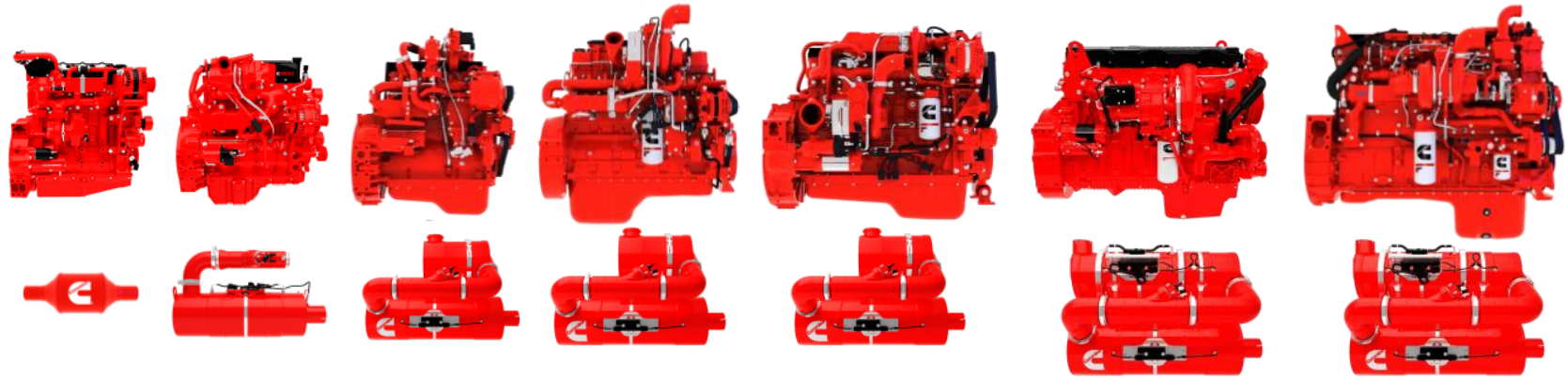
Simulation only to illustrate impact of 'Stage IV' norms applicable across all CEV categories beginning 2021.



Emissions inventory data simulation based on certain assumptions:

- Equipment Life cycle of 4 years and 12 hours of use per day @ 250 days operation totaling 12000 Hrs
- Product mix ratio same as 2014 data assumed for extrapolation
- 16.1% CAGR beyond 2018 (same as average growth in 2014-2018 (E)
- Excluded RTLTs due to data availability

Cummins Global Products:



QSF2.8 QSF3.8 QSB4.5 QSB6.7 QSL9 QSG12 QSX15

49 hp → **675 hp**

- **Tier4 Final and Stage IV compliant Engine + Aftertreatment solutions.**

Cummins CEV offerings in India

60-80 HP
B3.3

75-102 HP
4B

130 HP
QSB4.5

125-169 HP
6B

230-260 HP
6C

220 HP
QSB6.7

280 HP
QSL8.9

QSM11

N14

- Optimised Fuel and Lube oil consumption
- Compact and Low weight
- Low noise level
- Standardisation of engine platform
- Built tough for the most demanding conditions like high heat, humidity, dust and cold, all conditions that can compromise the productivity of your equipment
- Guaranteed availability, higher equipment uptime through customised service contracts and parts support

Emissionsied products for CEV applications

Cummins Products:

- Aftertreatment System Solutions:

Compact Box

Next Gen ATS

Introduced with Euro VI

Typical Off HWY Switchback system

DOC+SCR configuration shown

Selective Catalytic Reduction (SCR) Systems

Over 1,168,000 units

61.3B miles,

2.21B hours

Diesel Particulate Filter (DPF)

Over 1,468,000 units

71.91B miles, 2.60B hours

Single Module

Compact and Next Gen ATS

Being Introduced with EPA 2017 norms

2010 – 2013 Technology (DOC+ DPF + SCR)

Over 586,000 units

27.13B miles, 980M hours

Architectural Options:

Base Engine Technology:

Parameter	Technology / Solution	Impact
Fuel system Fuel Injection parameters and controls	High Pressure common rail or unit injector systems or equivalent. Multiple injection events. Dynamic Timing control.	Better atomization and mixing. Better controlled combustion Better control on NOx & PM emissions in wide operating range
Air handling System	Electronically controlled variable geometry turbines or equivalent solution. Better air flow estimates and control through capable sensors.	Better control of air/fuel ratio. Better and flat torque characteristics. Better fuel economy over wide engine operating zone. Helps in emission reduction.
In cylinder NOx reduction	Low or high EGR solutions with EGR coolers or internal EGR for in-cylinder NOx control strategy.	High EGR: Lower NOx at cost of PM or Low / internal EGR: Low PM and moderate NOx - to be treated through aftertreatment solutions.

Architectural Options:

After treatment Devices:

Parameter	Technology / Solution	Impact
PM Reduction	DOC: PM, HC and CO reduction DPF: PM reduction through Passive and Active soot regeneration	DOC converts only Soluble Organic Fraction (SOF) part of PM. Good reduction in HC and CO. DOC is essential for passive and active regeneration of PDF.
NOx Reduction	Vanadia SCR. Zeolite based SCRs - Cu-Z/Fe-Z Urea dosing system Ammonia Oxidation Catalyst (AMox)	NOx reduction: 80 – 95% efficiency Ammonia slip control through aftertreatment system
ATS Controls and OBD	Closed loop controls along with catalyst models. High accuracy Temperature sensors, NOx Sensors, Delta ‘P’ sensors, PM Sensors	Optimal Ammonia dosing. Ultra high efficiency NOx conversion. Better soot load management. Aftertreatment system protection. Effective conversion efficiency over lifecycle.

Conclusion:

- **World harmonized norms such as ‘Stage IV’ should apply to CEVs and agricultural tractors including currently exempted categories not too delayed from BSVI implementation.**
- **CPCB III norms can be aligned with proposed CEV emissions leveraging technology and common development efforts.**
- **Stationary applications should be brought under emissions regime inline with global emissions initiatives.**
- **Marine norms are also critical to be looked at and regulated, particularly ‘inland’ category owing to government initiatives of utilizing waterways more effectively.**
- **Non road machines have significant potential to curb air pollution further.**

Need Tough, Clear and Enforceable emission Norms