The challenge to emission controls and recent development of PEMS regulations for heavy-duty vehicles in China

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Research Participants

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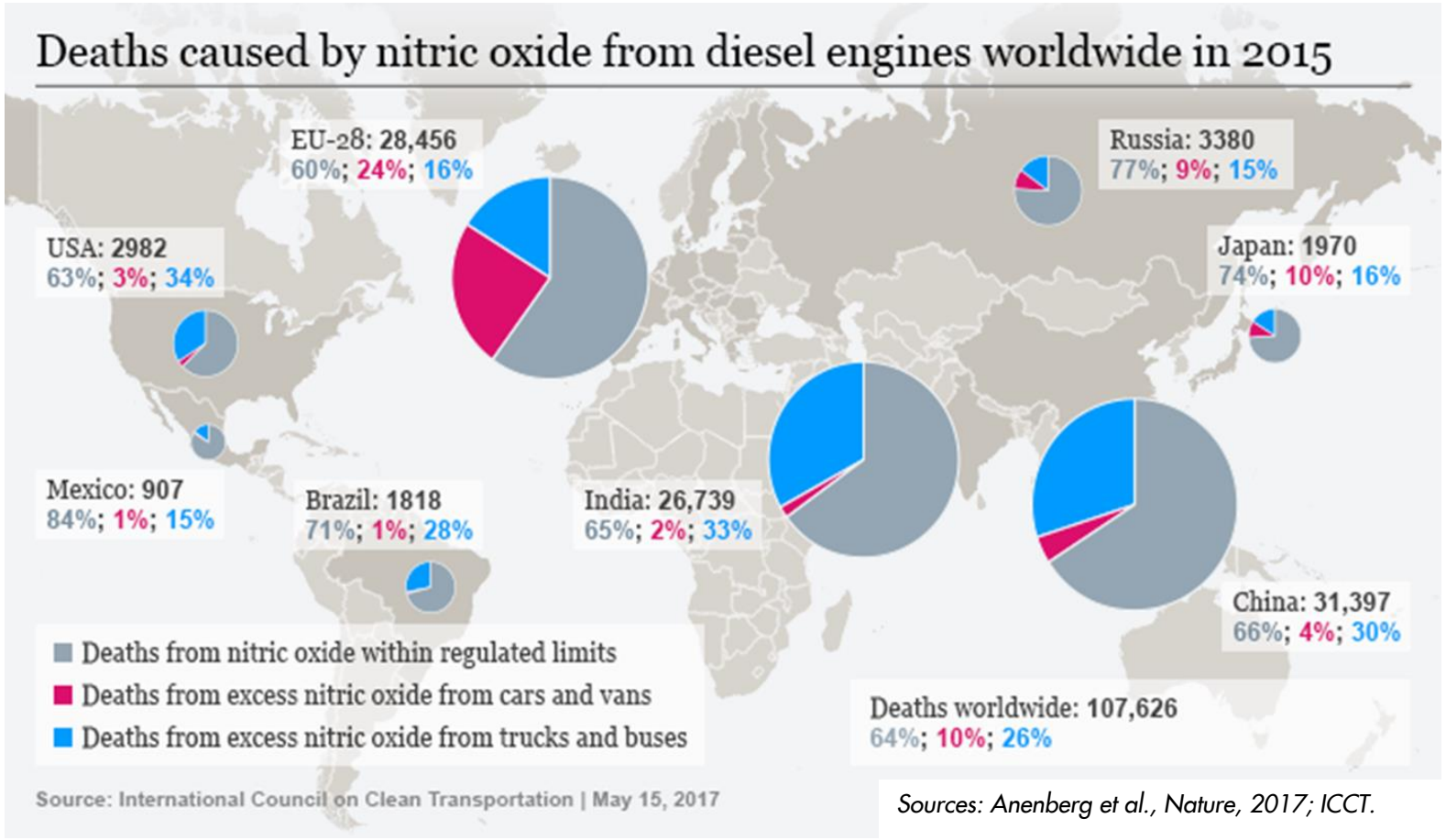
- **Chinese Research Academy of Environmental Sciences**
  - Jingnan Hu

Heavy-duty vehicles emissions pose serious challenges to air quality and public health



Sources: Anenberg et al., Nature, 2017; ICCT.

- **In China, heavy-duty diesel vehicles** dominate the premature deaths attributed to real-world diesel emissions.

One pioneer in PEMS research in China

- **Tsinghua University** has been working on real-world emission measurement by using PEMS since approximately 2005.
  - *Dr. Jingnan Hu* (Ph.D thesis, 2006) developed a simple version of PEMS to test gaseous emissions.
  - *Dr. Huan Liu* (Ph.D. thesis, 2010) employed commercial PEMSs (e.g., SEMTECH-DS) to measure diesel trucks and developed localized IVE model (in collaboration with UCR).
  - *Dr. Ye Wu* has led several studies to collect HDV emission factors in Beijing, Macau, and other Chinese cities (independently or in coloration with CATARC, CRAES, BIT and etc.).
  - PEMS data have supported the development of local emission models in China. For HDVs, emission factors are majorly constructed based on PEMS tests.
    - EMBEV series models (Beijing, Macau, Guangzhou, Nanjing, etc.)
    - The first trial version of National Emission Inventory Guidebook (transportation sector), released by the Ministry of Environmental Protection in 2015.

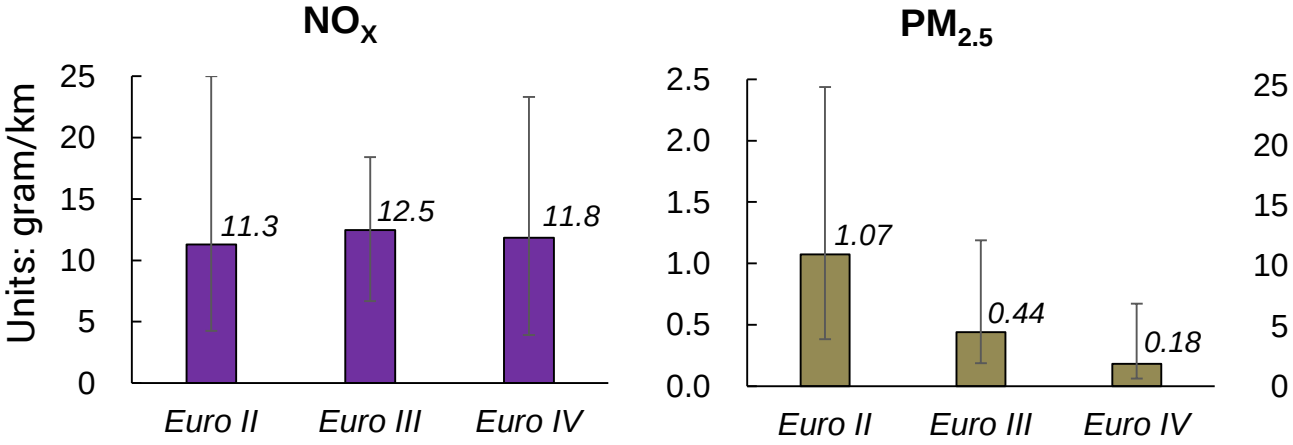
One significant issue from PEMS profiles: Real-world HDV NOx emissions

Nationwide implementation of HDV emission standards (for production conformity) in China

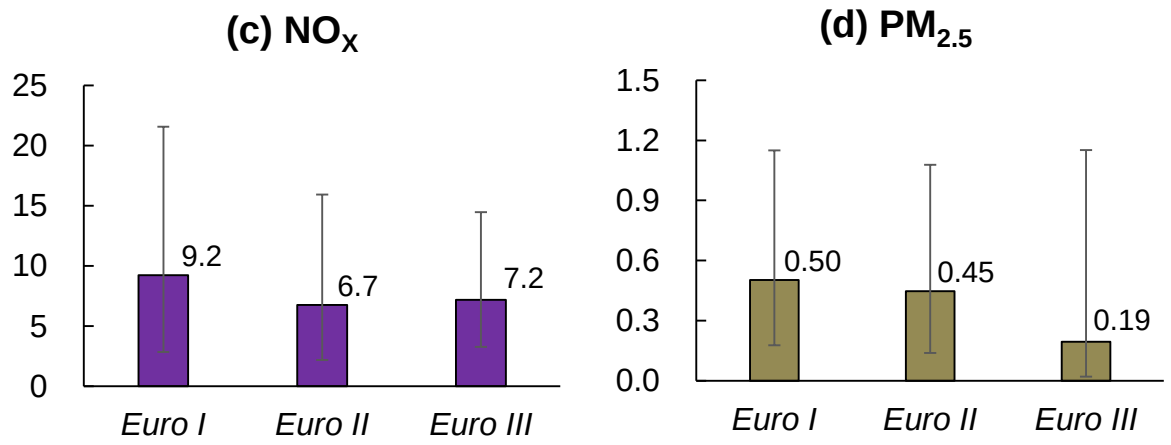
2001	2003	2005	2007	2009	2011	2013	2015	2017	2019	2021
China II		China III		China III			China IV	China V		China VIa

- PM emission factors of HDVs were reduced as emission standards got increasingly stringent. However, no significant improvement in NO_X emission factors were identified.

Diesel public buses (GVW~18 tons, 18 km/h)

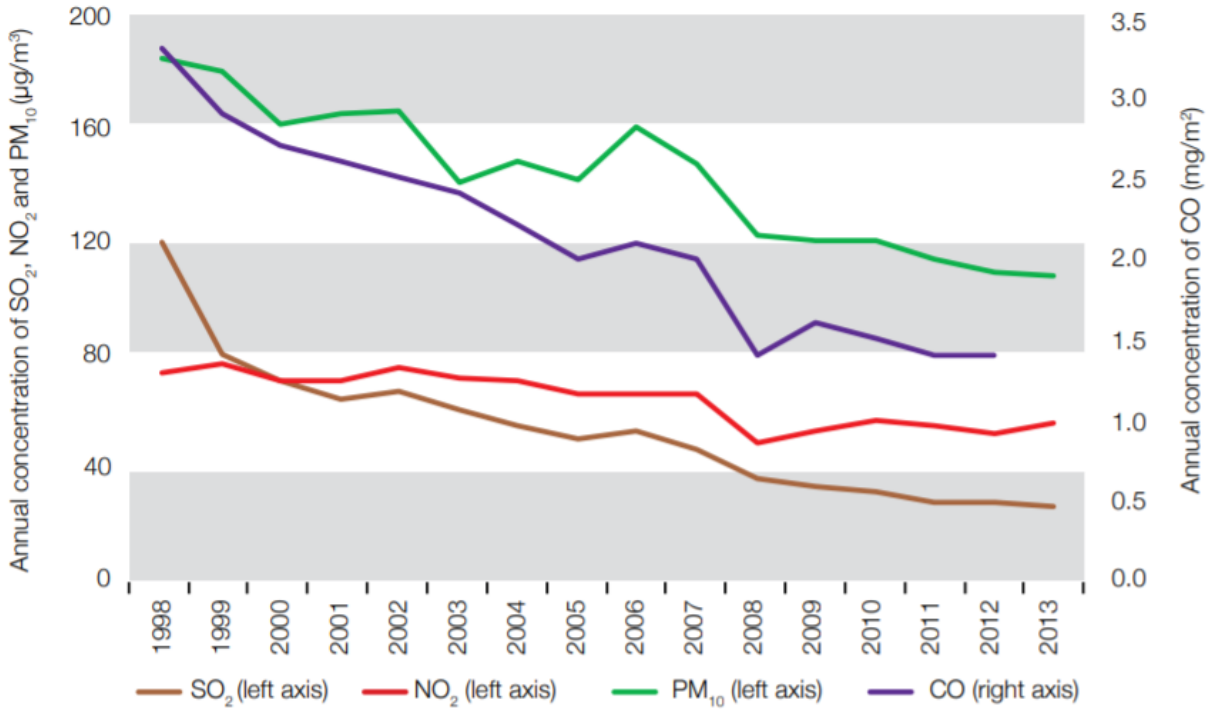


Diesel trucks (GVW>12 tons, 40km/h)

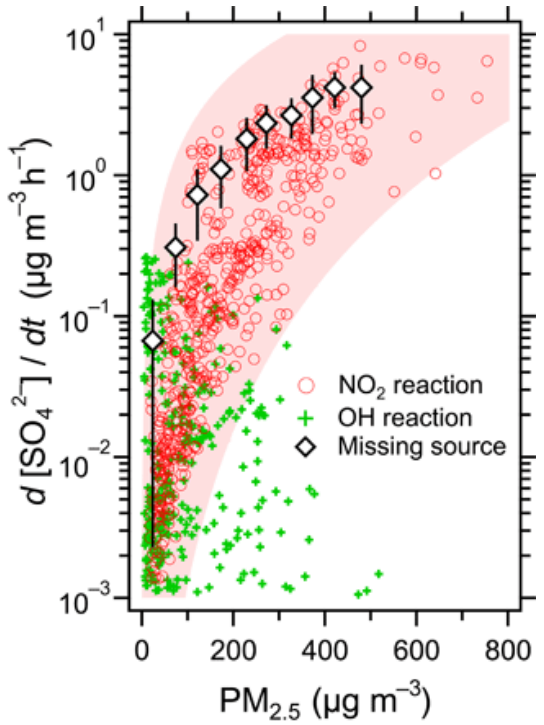


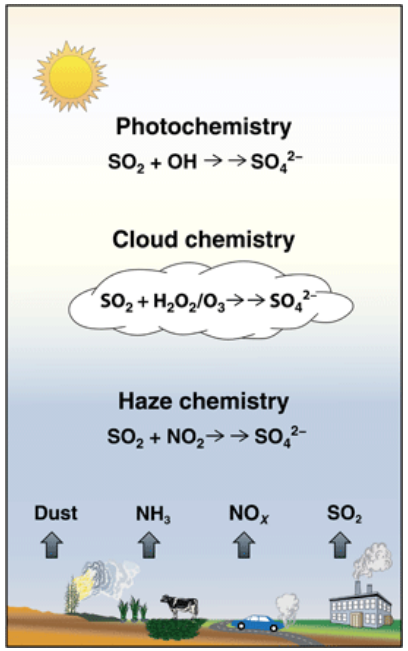
Source: Wu et al., Atmos. Chem. Phys., 2012.

Controlling NOx emissions is critical to improve urban and regional air quality



In Beijing, the reduction in NO_2 concentration is less significant than other criteria pollutants (46 μg/m³ in 2017, exceeding the annual limit of 40).



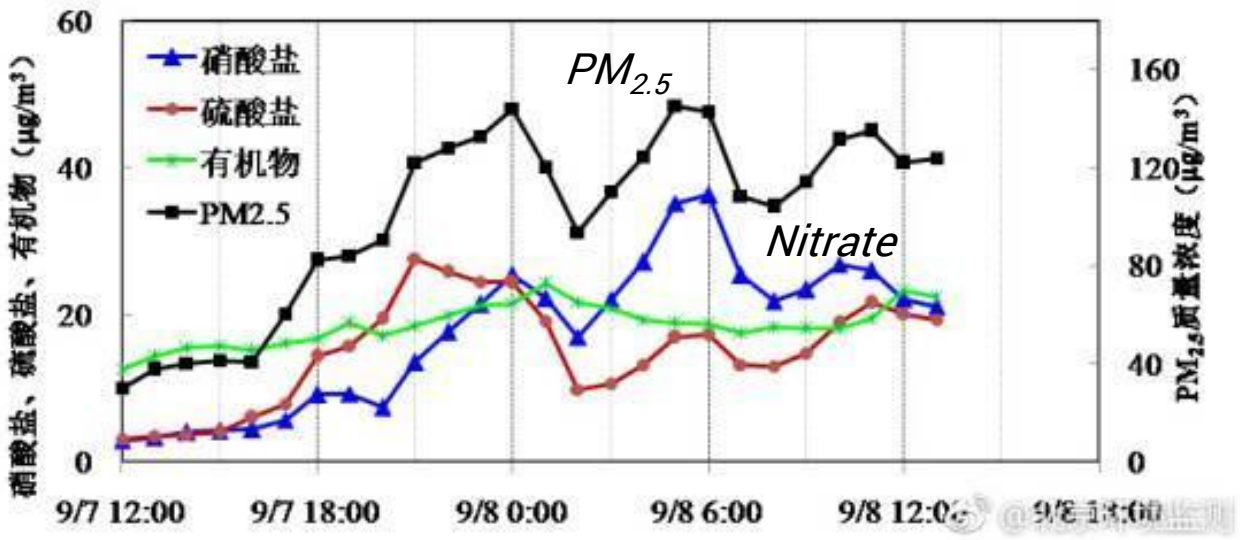


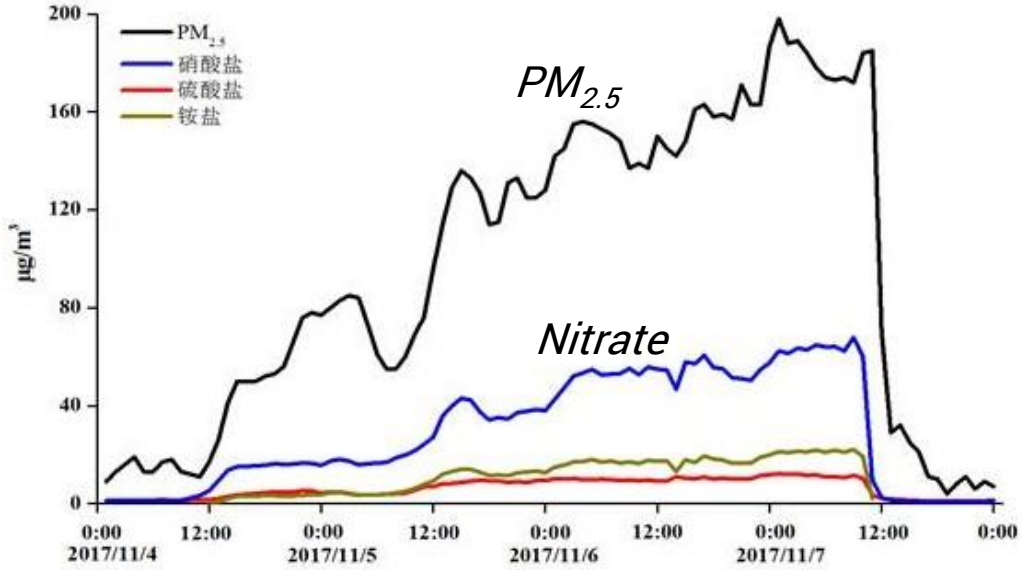
NO_2 oxidized SO_2 to sulfate (then most important PM component) at the aqueous phase (aerosol water) in 2013's haze episodes.

Sources: A Review of Air Pollution Control in Beijing, UNEP report, 2016; Cheng et al., Sci. Adv., 2016.

Controlling NOx emissions is critical to improve urban and regional air quality

- In 2017, nitrate has been more importantly responsible for local $PM_{2.5}$ concentrations (~30% to 40%) during Beijing summer and winter episodes.
- NOx emission control is critical to further improve air quality in China's polluted areas, and HDV emission mitigation is essential.





Source: Beijing EPB, 2017

HDV emissions control is one of the most prioritized environmental protection tasks

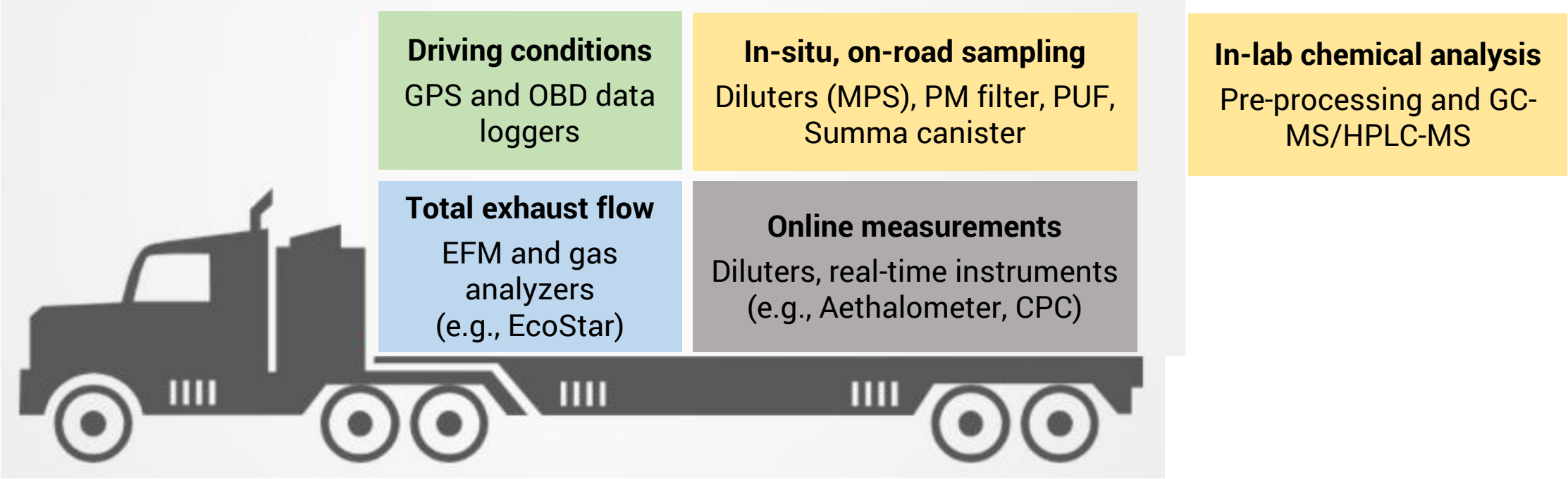
- In 2017, the ***Prier Minister***'s office issued a ***Special Fund*** to improve the regional air quality in the Jing-Jin-Ji region (2+26 cities; i.e., Beijing, Tianjin and 26 other cities in surrounding provinces).
- Controlling HDV emissions are essentially listed in the prioritized tasks.
- Key areas:
  - Advanced NOx (and PM) diesel emission control technologies, including demonstration and retrofit programs;
  - Multi-method inspection technologies to control high emitters;
  - Regional transportation mode optimization and urban logistic solutions (i.e., first and last mile for city freight transport);
  - Interdisciplinary ("traffic-emissions-air quality"), big-data informed management systems for diesel fleets;

China accelerates to fertilize real-world vehicle emissions research

- Tsinghua University (**Projects PI: Ye Wu**) has been recently funded by Ministry of Science and Technology (MOST), National Natural Foundation of Sciences Foundation of China (NSFC), Prier Minister's Special Fund and other funding agencies.
  - To develop advanced PEMS methods to characterize key pollutant species of environmental, climate and health concerns.
  - To develop and utilize multiple measurement approaches (PEMS, chasing, remote sensing) to establish large-sized profiles of real-world emissions in China.
    - E.g., to deploy PEMS-validated chasing method to cover fleet-level, real-world measurements. (MOST's International Program, U.S. partners: EPA and Cornell University, 2017-2019, ￥5 million).
    - E.g., to accumulate at least 1000 PEMS tests (in collaboration with CATARC, CRAES, Shanghai and Sichuan's environmental research academies, BIT, and etc.) and 5000 chasing tests in several regions of China (MOST's Key Research and Development Program, 2017-2020, ￥27.7 million).
  - To integrate with traffic big data and transport demand models to improve policy decisions.

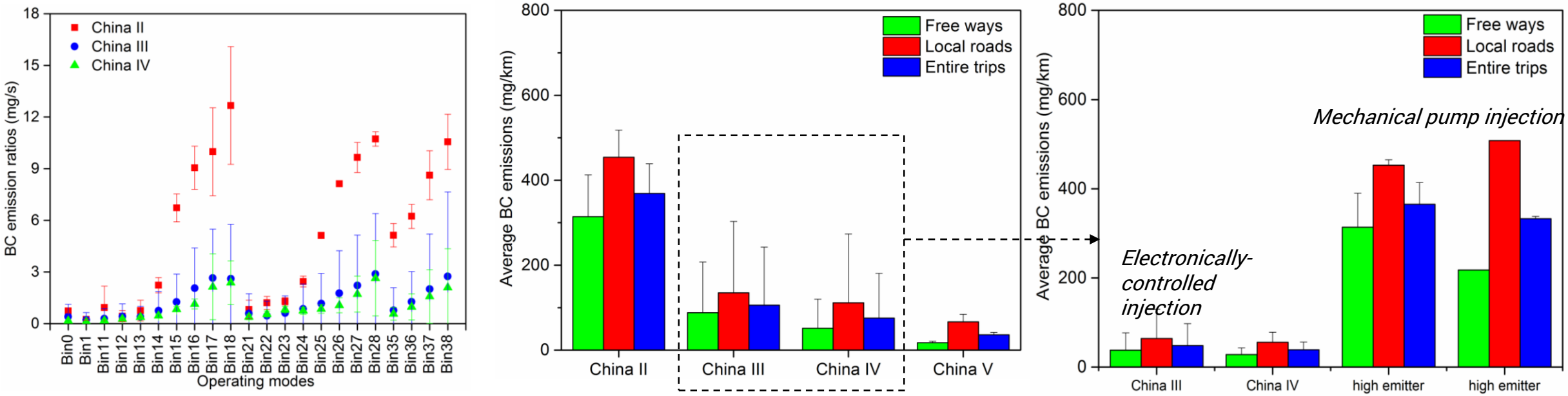
Specie-resolved measurements of organic compounds based on a PEMS platform

- Incorporated **in-situ, on-road sampling** (PEMS/MPS/PM filter & Summa canister) and **in-lab chemical analysis** (GC-MS/HPLC-MS) to characterize species-resolved organic compounds.



PEMS measurements of black carbon (BC) emissions from HDVs

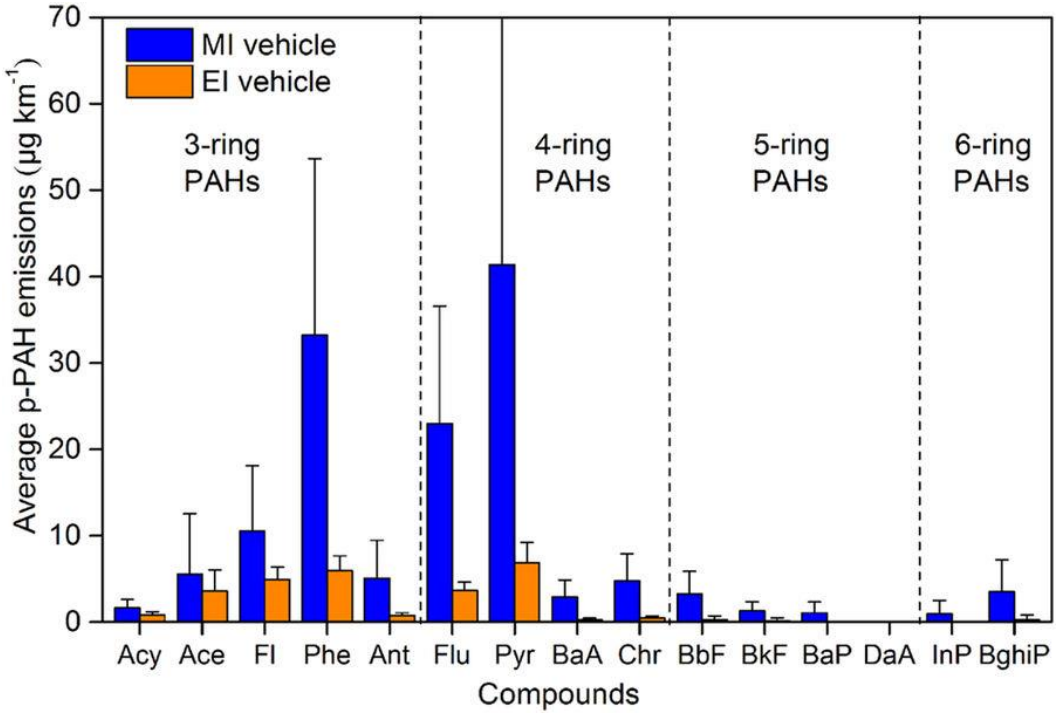
- Incorporated aethalometers (AE-33 or AE-51) and Micro Proportional Sampling (MPS) system to measure instantaneous BC emissions.
- BC emission rates are developed based on the op-mode approach.
- BC emission factors are generally reduced by stricter emission standards. However, high emissions are observed due to fraudulent engine use.

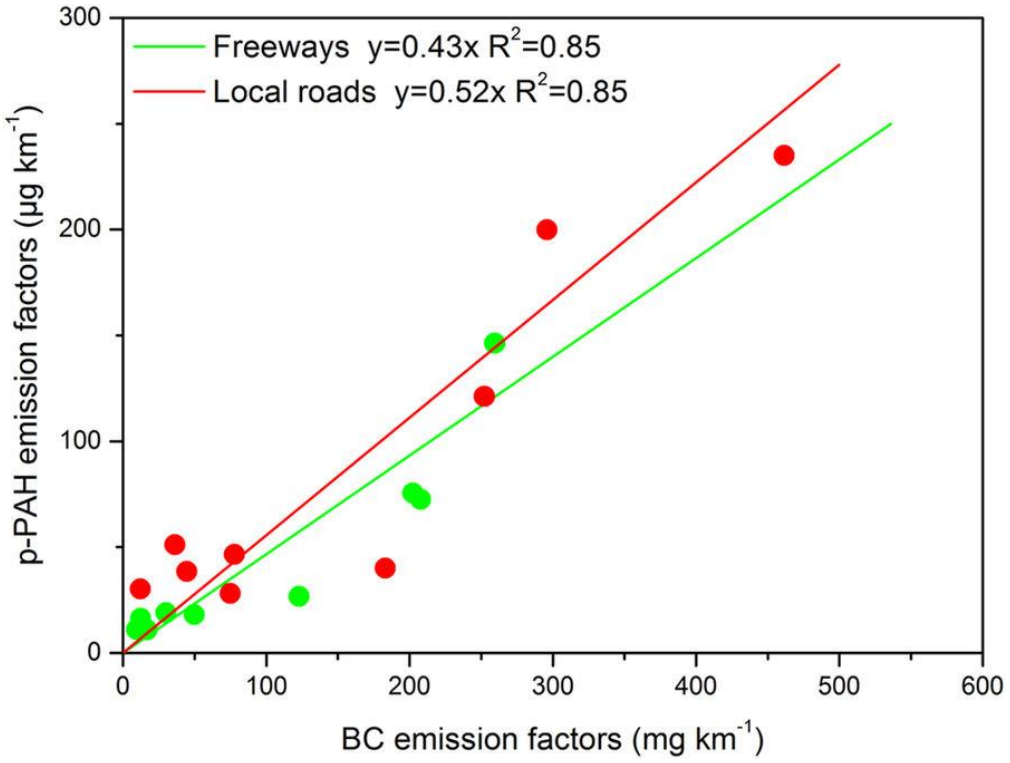


Source: Zheng et al., Env. Sci. Techno., 2015.

Specie-resolved measurements of organic compounds based on a PEMS platform

- Application case: particulate polycyclic aromatic hydrocarbons (p-PAH).
  - 15 EPA priority PAH compounds except for Naphthalene (highly evaporative).

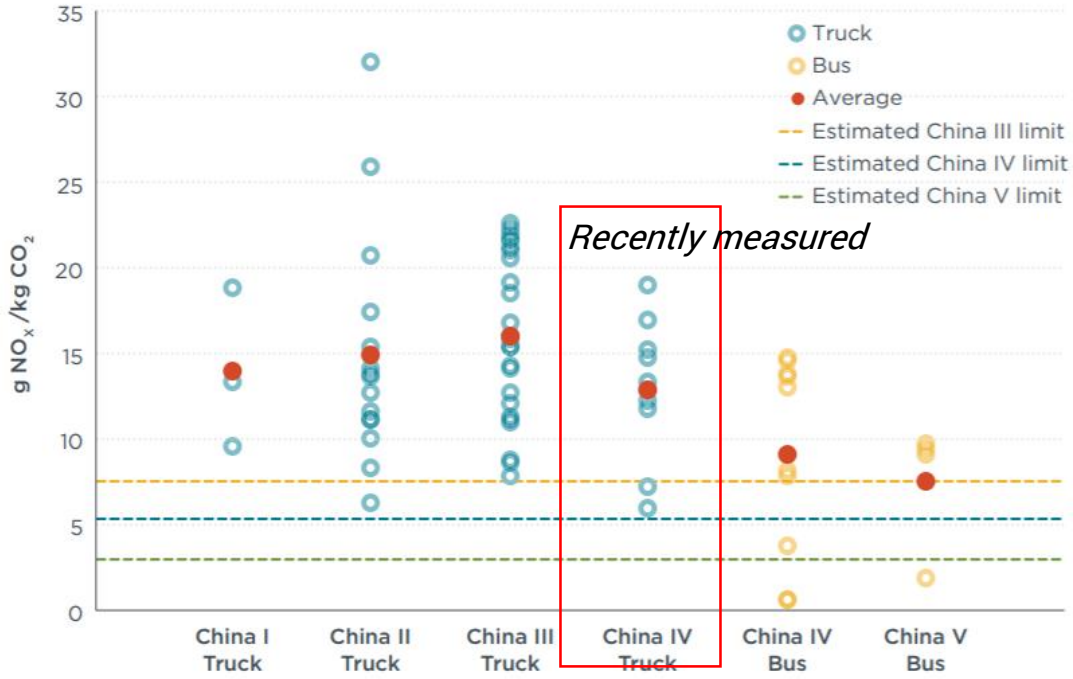




Source: Zheng et al., Scientific Reports, 2017.

Unalleviated challenge to NO_X emission controls for HDVs in China

- The recent PEMS tests indicate that NOx emission factors of **China IV diesel trucks** have not been improved as expected.
  - This observation is different from the European trend, where SCR systems could assist to reduce NOx emissions by 40% to 50% for Euro IV trucks.



Source: Yang, L. Real-world emissions in China: A meta-study of PEMS data. ICCT white paper, 2018

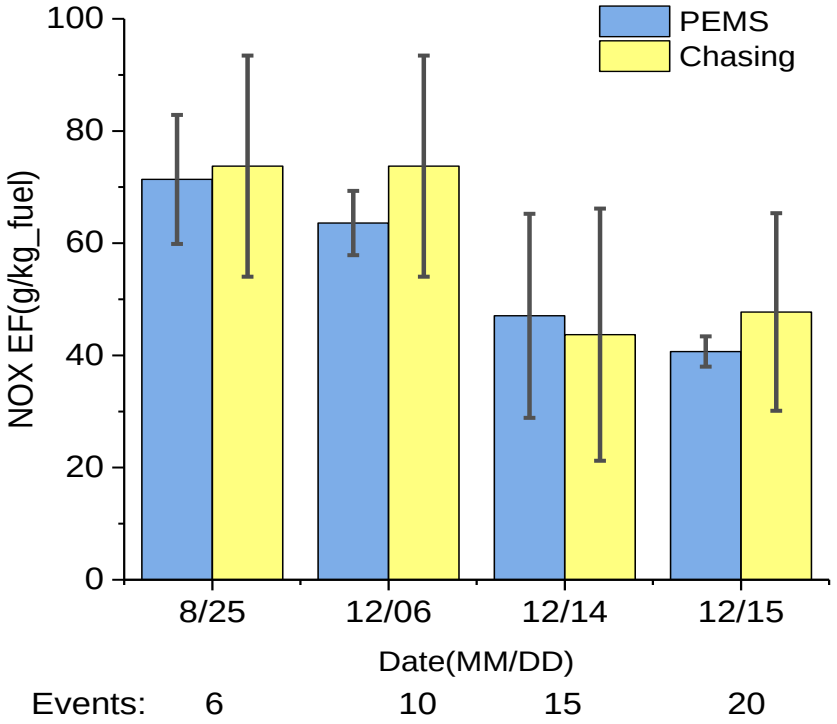
Notes:

1) PEMS tests of China IV trucks were conducted by Tsinghua and CRAES.

2) The China IV trucks with low NOx emission factors were measured before the standard adoption, which were candidates provided by manufacturers for China's RDE rule design.

Chasing confirms the widespread NOx control problems among China IV HDVs

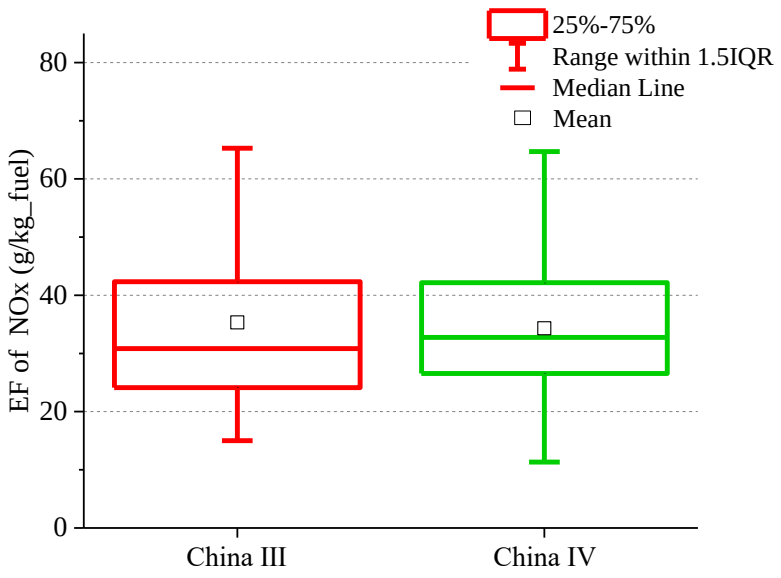
- Comparative (PEMS vs chasing) on-road experiments are conducted to validate the capability of chasing for measuring NO_X emission factors.
  - NOx analyzers: SEMTECH-EcoStar (PEMS) vs. EcoPhysics CLD66 (Chasing)

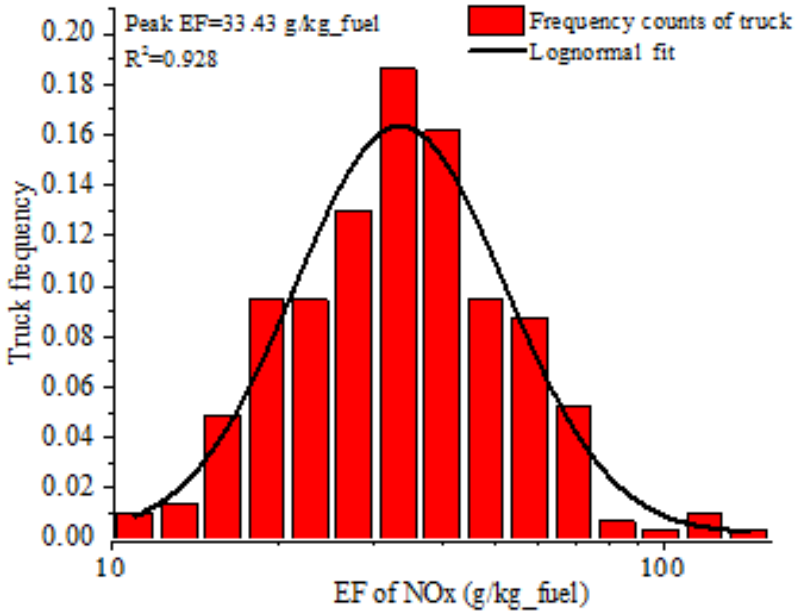


Chasing confirms the widespread NOx control problems among China IV HDVs

- In 2017 and 2018, nearly 1000 highway trucks are measured by chasing in China (chasing locations: Beijing, Tianjin, Hebei, Sichuan, Shanxi, Henan).
- No improvement in fleet-wide NO_X emission factors for China IV trucks (claimed to have adopted SCR) compared with China III trucks.

NOx emission factors for chased trucks in Beijing, Tianjin and Hebei





Note:

Nearly 400 diesel trucks in this region were chased in July to August, 2017.

Unpublished data, DO NOT disclose.

Conjecture of causes for high NOx emissions

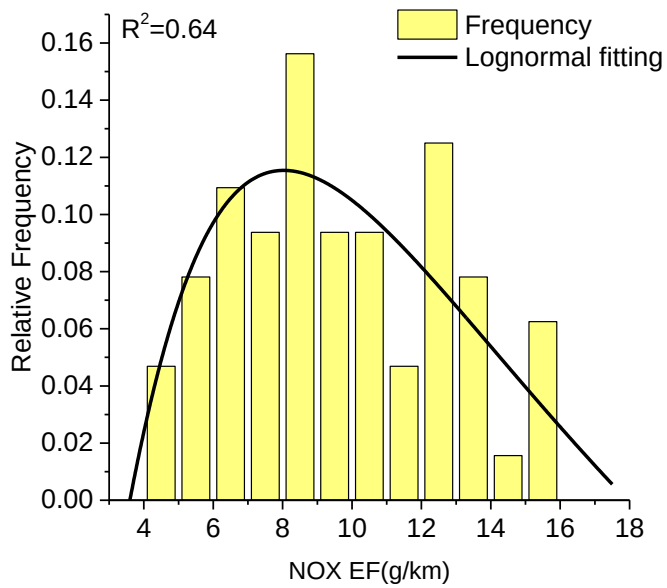
- Mostly China IV HDVs rely on SCR devices to achieve NO_X compliance.
- The unsatisfactory performance of SCR systems could be typically attributed to three categories of causes：
  - 1. Unfavorable operating conditions: low-temperature, low-speed, low-load conditions and considered as the main reason for high NO_X emissions for urban buses. However, average speeds of chased trucks were approximately 60 km/h.
  - 2. ***Failure to refill urea tanks***.
  - 3. ***Tampering of SCR systems***, such as removal or defeat of SCR (e.g., AdBlue killer).

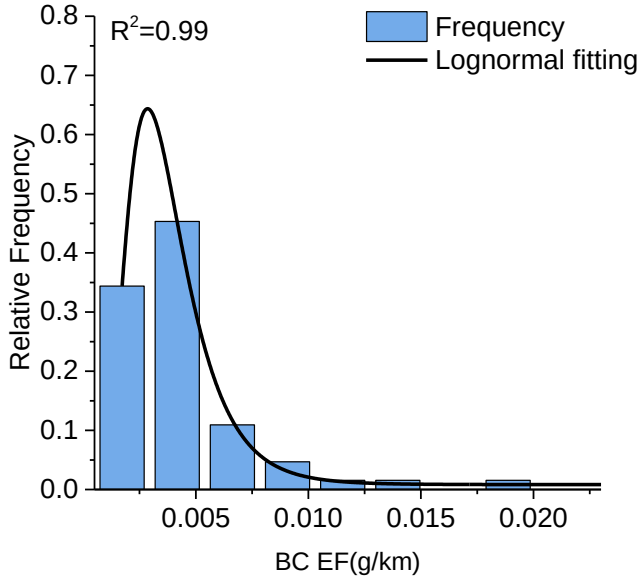
- Failure to refill urea tank and tampering of SCR are highly suspicious.

Nature gas vehicles also have high real-world NO_X emission factors

- In 2018, 64 CNG/LNG public buses in Chengdu, China were chased (average NOx emission factor of 9 g/km; lean-burn engines without NOx aftertreatment devices).

Distributions of NOx and BC emission factors of natural gas buses

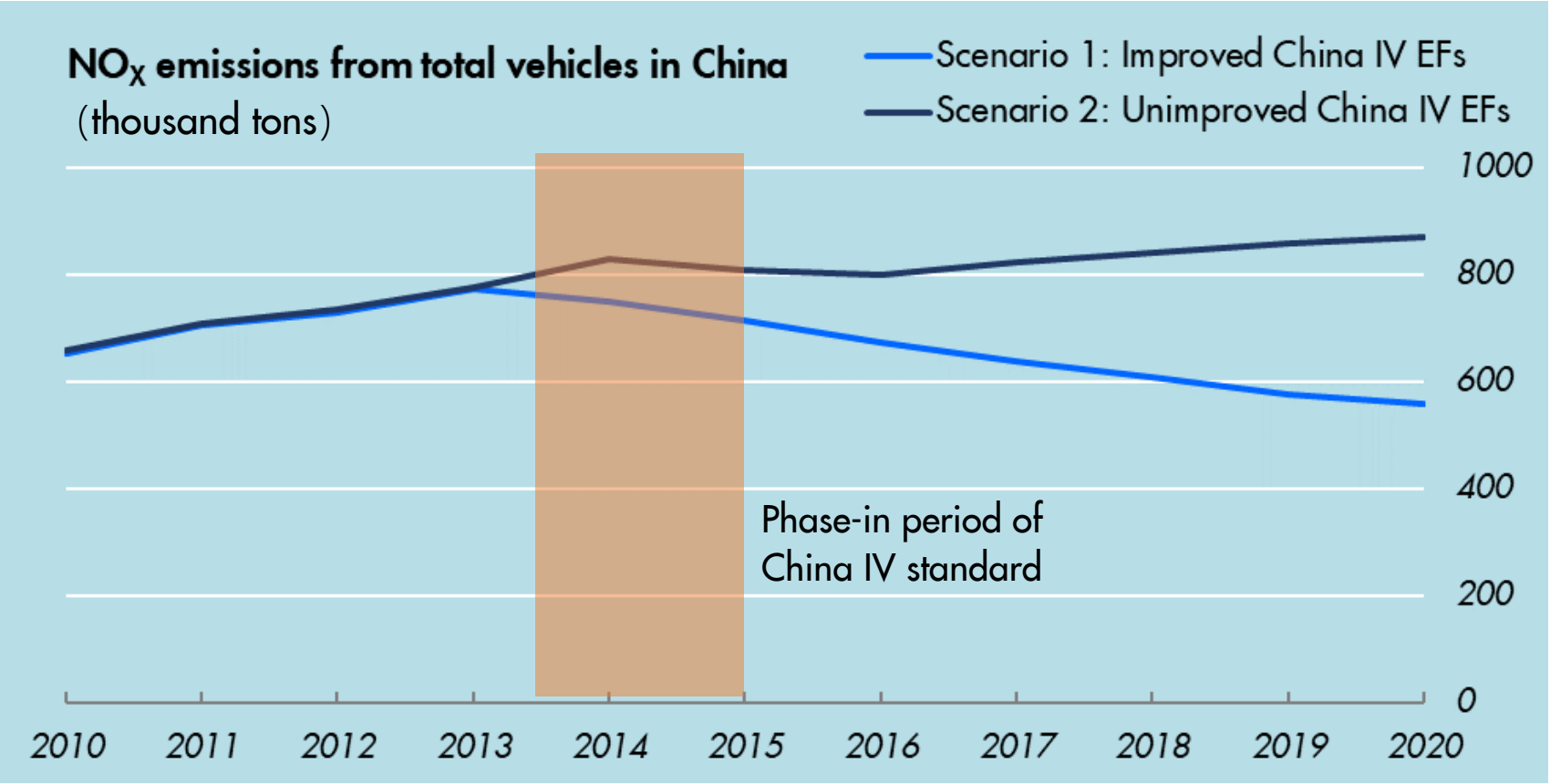




Unpublished data, DO NOT disclose.

- High NOx emission factors of CNG taxis are also founded, which is associated with poor calibrations of spark-ignition engine and three-way catalyst system.

Near-term total vehicle emission trend with the case of unimproved NOx emission factors



Note:

Methodology is referred to China's NEI guidebook (Wu et al., 2017).

In Scenario 1, NOx emission factors (EFs) of China IV HDVs are estimated to be reduced by approximately 40% relative to China III EFs, except for urban buses.

- Scenario analysis poses great concerns regarding NO_X emission factors of China IV HDVs.

Policy recommendations and recent development of PEMS regulations.

- To strengthen PEMS regulations.
  - For LDVs, the **China 6 emission standard** will include a ***Real Drive Emission (RDE)*** rules to enhance type-approval and in-use compliance requirements: fuel and technology neutral (e.g., MPFI, GDI, diesel), but cold start excluded.
  - For HDVs, Chinas' PEMS regulations majorly follow the European standards. Beijing is the first city to have released a RDE regulation for China V HDVs, and the local PEMS regulations for China VI are also announced.
  - China VI PEMS regulation for HDVs has been proposed now, which is expected to include cold start emissions.
- Modification of retrofit programs of urban HDVs; Technical guidance of retrofit is needed.
- Strong focus on in-use surveillance programs.
  - Multi-method in-use testing and penalty for non-compliance.

A international comparison of PEMS standards for HDV emissions

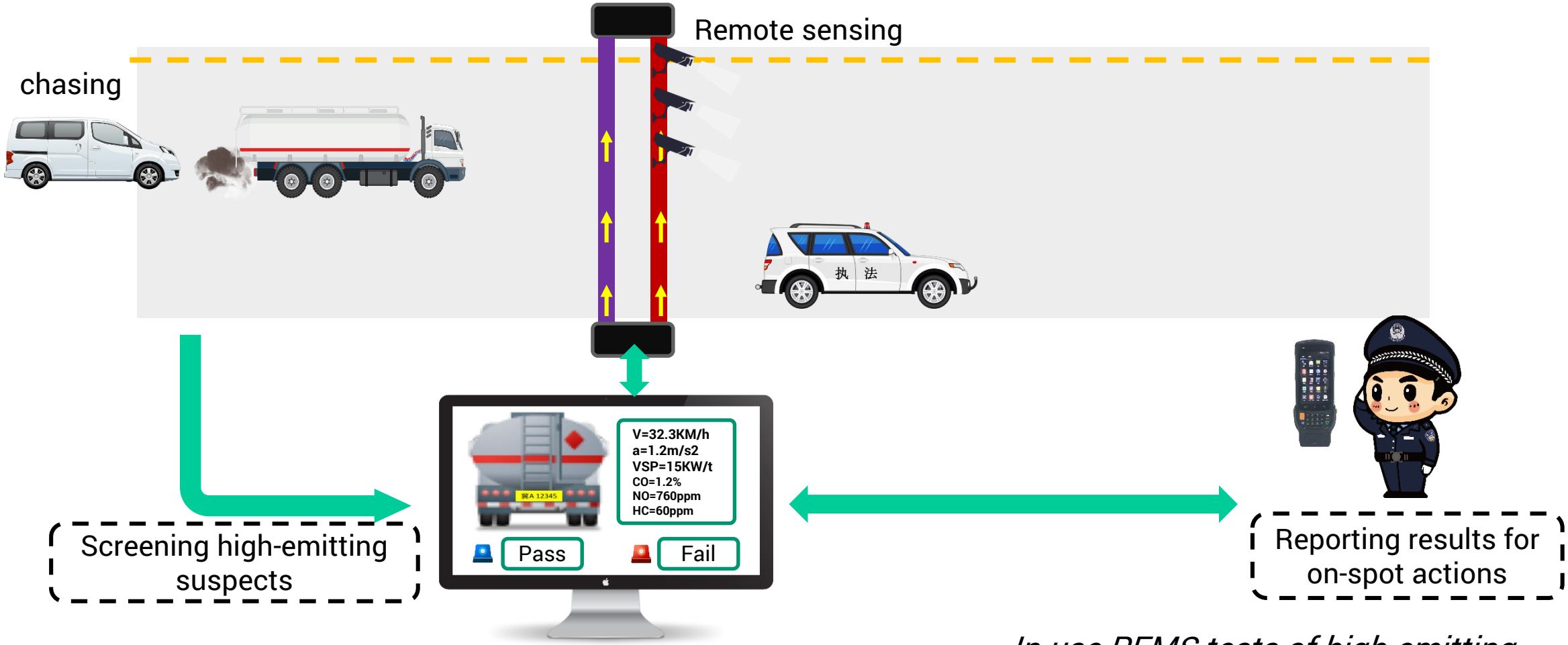
		U.S. 2010	Euro VI	China VI proposal	China V	Beijing V/VI
Implementation		2007	2014	2020 for China VIa 2023 for China VIb	2017	2017 (Amended)
Application		In-use	Newly produced and in-use	Type test, newly produced and in-use	Type approval and in-use	Type test, newly produced and in-use
Data analysis		Not to exceed (NTE)	Moving average window			
CFs	NOx	1.5	1.5	1.5	2.0	2.0 for Beijing V 1.75 for Beijing VI
	PN	N.A.	Limit marking	2.0 for diesel in China VIb	N.A.	N.A.
	CO	1.5	1.5	1.5	1.5	1.5
	THC	1.5	1.5	1.5 for gas-fueled vehicles	N.A.	N.A.
Instantaneous NO_X emissions		N.A.	N.A.	500 ppm *	900 ppm *	N.A.

* 95% of instantaneous NOx emission concentration data should comply with the limits.

A international comparison of PEMS standards for HDV emissions (cont'd)

		U.S. 2010	Euro VI	China VI proposal	China V	Beijing V/VI
Ambient temperature range		≤38°C (100°F)	-7°C ~38°C	-7°C ~38°C	2°C ~38°C	-7°C ~40°C
Altitude		≤1676m (5500ft)	≤1,700 m	≤1,700 m in China VIa ≤2,400 m in China VIb	≤1,000 m	N.A.
Cold start		No. Gas temperature above 250℃.	Yes since 2018.	Yes	Yes	No.
Road shares (% of time)	Urban	Normal driving	20~70	20~70	10~70	20~70
	Rural		25~33	25~33	10~30	25~33
	Motorway		0~55	0~55	0~80	0~55
Payload		Normal	10%~100% since 2018	50%~100% in China VIa 10%~100% in China VIb	50%~100% for bus 75%~100% for truck	40%~60%
Test length		One valid NTE event	4~7 times of WHTC since 2018	4~7 times of WHTC since 2018	5x work of WHTC (for urban vehicles) 3x work of ETC (for other categories)	5 times of WHTC since 2018

A conceptual, multi-method surveillance networking to pursue full-fleet compliance



In-use PEMS tests of high-emitting suspects can be followed!

Summary

- The serious air pollution characteristics in China call for stringent NO_X emission controls for HDVs in China.
- In the past two decades, China has rapidly implemented more and more engine emission standards (e.g., China I to China V) for HDVs.
- However, recent PEMS and chasing measurements both indicate that real-world NOx emission factors from HDVs in China have not been significantly improved.
- The widespread high NO_X emission problems are found among current China IV diesel truck fleets. Failure to refill urea tanks and tampering of SCR device are highly suspected.
- PEMS regulations are developed in China to enhance type-approval and in-service emission conformity for China V/VI HDVs.
- Chasing measurement, remote sensing, and stringent OBD provisions could be used to enhance full-fleet inspection and in-use compliances.

Thanks for you time !

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