# From the Laboratory to the Real World
## Understanding Community Impacts


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*Special Thanks to John Kargul*

# Topics:

1. Quick Tour of NVFEL's Testing Capabilities
2. The Marriage of Laboratory and Real-World Testing Yields More Data
3. Cleaner Air and Communities


# EPA's National Vehicle & Fuel Emissions Laboratory

OTAQ-NVFEL is a state-of-the-art test facility that provides EPA with the highest quality data to support Regulatory Policy-Development and Certification-Compliance, with a wide array of dynamometer and analytical testing & engineering services for EPA's motor vehicles, heavy-duty engine, and nonroad engine programs. *NVFEL is ISO 17025:2017 accredited and ISO 14001:2015 certified.*

**Establishing National Standards**
Technology-Forcing
Engines, Vehicles, Fuels

**Certification and Compliance**
Tailpipe pollution, GHG/ fuel economy
Fuels used in vehicles or mobile equipment

**Advanced Vehicle Technology Assessments**

**Support for States, Voluntary Programs and Communities**

# OTAQ-NVFEL's Standard Lab Test Capabilities are Vast…

- Conventional, hybrid, and battery vehicle testing
- Alternative fuel vehicle testing
  (e-, H2, CNG/LPG , alcohols, DME)
- High temperature LD car/SUV/pickup testing
- Cold temperature LD car/SUV/pickup testing
- LD Evaporative emissions testing
- Medium & heavy-duty diesel engine testing
- Small & medium gasoline engine testing/screening
- Heavy-duty truck & bus testing
- Fuel and fuels chemistry testing of all kinds (petroleum, bio, syn)
- On-highway & non-road testing with portable emissions equipment
- Battery testing (full-scale & vehicle) and E-motor efficiency testing
- 1-cylinder engine combustion research & catalyst bench testing
- Passenger car engine-only and transmission-only emissions/eff.

# ISO 17025:2017 Accreditation for testing and calibration laboratories

ANAB

**CERTIFICATE OF ACCREDITATION**

**ANSI National Accreditation Board**
11617 Coldwater Road, Fort Wayne, IN 46845 USA

This is to certify that

**EPA National Vehicle and Fuel Emissions Laboratory**
**Testing & Advanced Technology Division**
**2565 Plymouth Road**
**Ann Arbor, MI 48105**

has been assessed by ANAB and meets the requirements of international standard

**ISO/IEC 17025:2017**

while demonstrating technical competence in the field of

**TESTING**

Refer to the accompanying Scope of Accreditation for information regarding the types of activities to which this accreditation applies

AT-1658
Certificate Number

ANAB Approval

Certificate Valid Through: 04/30/2022
Version No. 006 Issued: 03/18/2020

ANAB

ilac-MRA

ANAB

This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2017. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (refer to joint ISO-ILAC-IAF Communiqué dated April 2017).

**Accreditation for these Exhaust Emissions procedures**

| Specific Tests and/or Properties Measured | Specification, Standard, Method, or Test Technique | Items, Materials or Product Tested |
|---|---|---|
| Exhaust Emissions: NOx, THC, $CH_4$, CO, $CO_2$, $N_2O$ & PM | 40 CFR Part 86 Subpart B & 40 CFR Part 1066 - FTP, HWY, US06, SC03 Test Procedures | Vehicle Testing: 1977 and Later Model Year Light-Duty Vehicles and Light-Duty Trucks |
| Exhaust Emissions: NOx, THC, $CH_4$, CO, $CO_2$ & $N_2O$ | 40 CFR Part 1065 Subparts A-H - Engine Test Procedures 40 CFR Part 1054 Subpart F – Test Procedures | Engine Testing: Nonroad Spark-Ignition Engines at or Below 19 Kilowatts |
| Exhaust Emissions: NOx, THC, $CH_4$, CO, $CO_2$, $N_2O$ & PM | 40 CFR Part 86 Subpart A & 40 CFR Part 1065 Subparts A-H – Cold & Hot FTP, RMC Test Procedures | Engine Testing: 1977 and Later Model Year New Heavy-Duty On-Highway Engines |
| Exhaust Emissions: NOx, THC, $CH_4$, CO, $CO_2$, $N_2O$ & PM | 40 CFR Part 1039 & 40 CFR Part 1065 Subpart A-H – Cold & Hot NRTC, RMC, 8 Mode Test Procedures | Engine Testing: New and In-Use Non-Road Compression Ignition Engines |
| Exhaust Emissions: NOx, THC, $CH_4$, CO, $CO_2$, $N_2O$ & PM | 40 CFR Part 1042 & 40 CFR Part 1065 Subpart A-H – E3 & E5 Test Procedures | Engine Testing: New and In-Use Marine Compression Ignition Engines |
| Exhaust Emissions: THC, CO & $CO_2$ | 40 CFR Part 86 Subpart C – Cold CO FTP Test Procedure | Vehicle Testing: 1994 and Later Model Year Light-Duty Vehicles and Light-Duty Trucks |
| Exhaust Emissions: NOx, THC, $CH_4$, CO, $CO_2$, $N_2O$ & PM: State of Charge | 40 CFR Part 86 Subpart B & 40 CFR Part 1066 Electric / Hybrid Electric Vehicle Testing Process | Vehicle Testing: 1977 and Later Model Year Light-Duty Vehicles and Light-Duty Trucks at or below 14,000 Pounds GVWR |
| Fuel Permeation Mass | 40 CFR Part 1060 Subpart F & I Fuel Line Permeation Test Procedure | Fuel Line Testing: Nonroad Spark-Ignition (SI) Engines |

**Plus, accreditation for 23 Fuels and Chemistry procedures.**

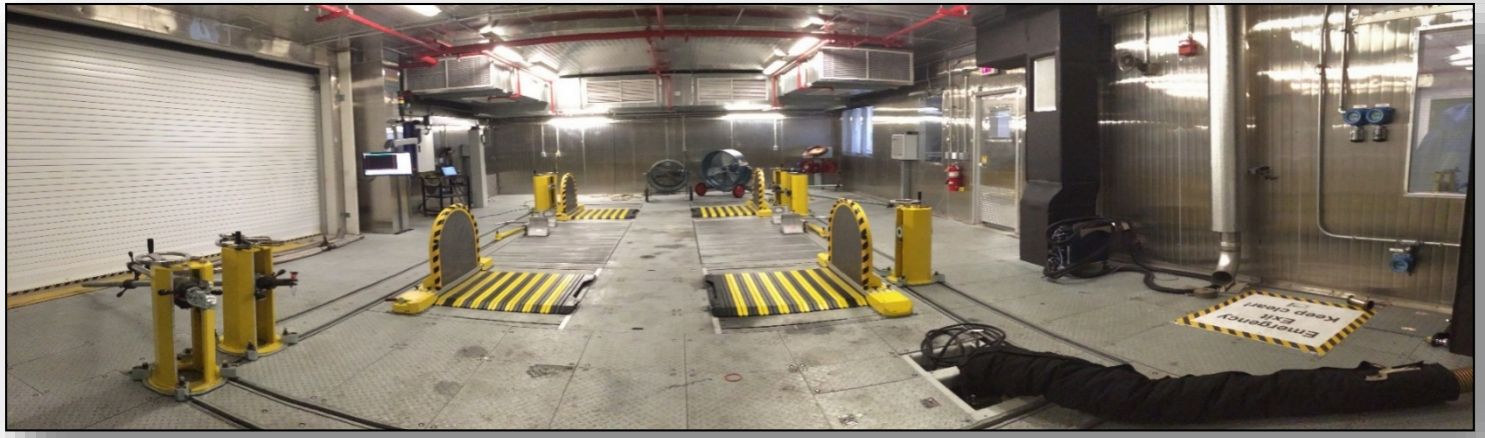
# Light Duty Vehicle Sites w/ 4WD Dynos

- Tier 3 / LEV III emissions capability, with particulate measurement
- Hybrid and BEV test capable, determining State of Charge / range testing
- 4-Wheel Drive - 48” twin roll dynos to 14,000 lbs inertia weight
  - 4WD reduces complexity (and voided tests) associated w/ testing on single axle dyno when ABS, traction control, etc. must be deactivated to get a valid test

# Cold Test Facility for Light-Duty Vehicles

**Environmental chamber verifies vehicles meet cold test temperature cycle emission standards and verify fuel economy under cold temperature test conditions for the 5-cycle fuel economy performance label.**

- Cold testing capability down to (20°F) -7°C
- Gas & diesel analytical capability
- Adjacent cold soak area for several vehicles
- Highly flexible master (host) test control system
- 4WD dyno, Tier 3 emissions



# Hot Test Facility for SC03 Light-Duty

**Environmental chamber verifies vehicles meet hot test temperature test cycle emission standards and verifying Air Conditioner impacts on fuel economy for the 5-cycle fuel economy label performance.**

- Simulation of solar loading using heat lamp banks
- Hot testing capability up to 95°F (35°C)
- Humidity 100 grains/lb
- Road speed simulation fan
- Gas & diesel analytical capability
- Highly flexible master (host) test control system
- 4WD dyno, Tier 3 emissions

# Variable Temperature Sealed Housing Evaporative Determination
## (VT SHED)

- Two Evaporative Emissions SHEDs measure evaporative emissions
- Diurnal temperature cycling and alcohol (E15-E20) capable

# Heavy Duty Truck Chassis Tests

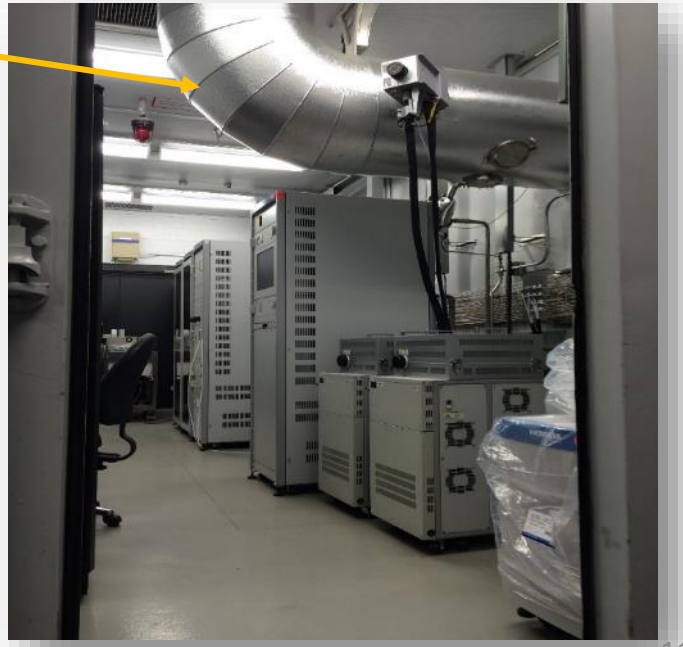
## Unique - HD Chassis Test Site for trucks and buses

- Simulated road testing of Class 4 to Class 8 vehicles, 2-wheel drive or 4-wheel drive
- Twin 72” rolls, with either roll capable of tandem drive axles absorption
- Each roll capable of 80,000 lbs (36k kg) inertia weight, plus additional up and down grade loading
- Movable rear roll allows for different vehicle wheelbases
- Analytical emissions (gas & diesel) measurement per most stringent requirements (40CFR Part1066)
- 250 HP road speed fan provides engine compartment wind cooling simulation
- Concurrent soak of an additional truck

# PART 1065 Engine Testing-Large, Medium and Small

## Different sites for different engine power

- Large diesel engine: 150kW – 450kW
- Medium diesel or gas engine: 30kW – 150kW
- Small gas engine: 2-19kW, vertical & horizontal shaft
- Emissions per EPA 40CFR Part 1065
- Medium & Large - Full Flow Dilution Tunnels for diesel sampling
- Bag and modal emission gas sampling & particulate sampler
- Two small handheld engine dynos
- Small engine 2-stroke and 4-stroke benches

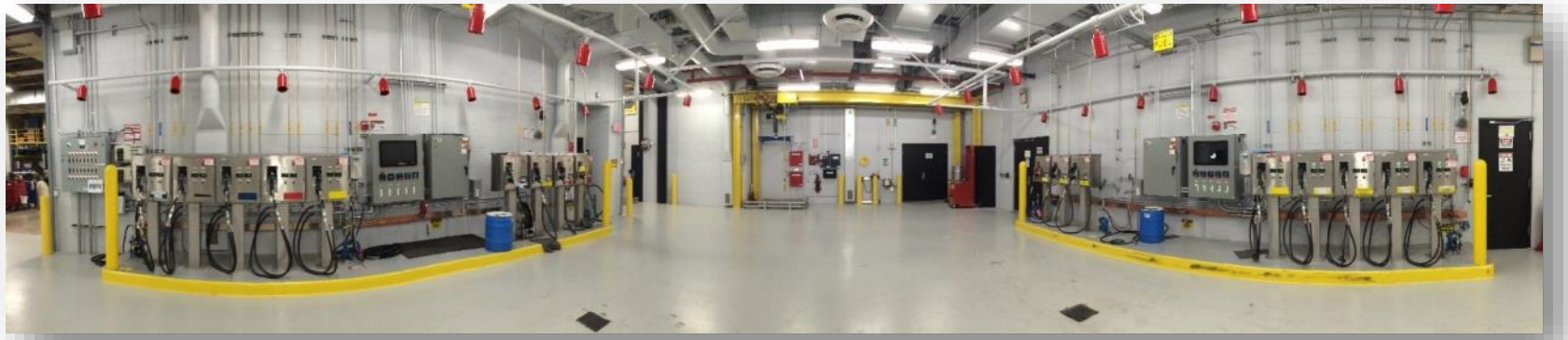
# Chemistry Lab & Fuels Dispensing

## CHEMISTRY LAB

- Approx. 60 instruments
  - Physical Properties of Fuel: distillation, density, RVP, net heating value, viscosity, flash point
  - Chemical Properties of Fuel and Exhaust: GC-FID, GC-TCD, HPLC, SFC, GC-MS, CHN Analyzer, WD-XRF, ED-XRF, Sulfur Analyzer, FTIR, UV-Vis, HPLC-MS, Q-TOF, GC-QQQ, ICP-QQQ, Magnetic-Sector Mass Spectrometer
- Analytical Capabilities
  - Approx. 80 running methods including ASTM, ISO, and EN, for the analysis of fuel and exhaust composition
  - Routine analyses include: sulfur in fuels, olefin content, aromatics composition, oxygenates content, glycerides, carbonyls
  - Development and Specialized: ethylene oxide emissions, $N_2O$ in exhaust, DHA, hydrocarbon speciation, metals analyses

## FUEL DISPENSING

- Conditioning fuel dispensing for 16 fuels, and underground and barrel/tote storage/dispensing for dozens more liquid fuels for regulatory development or as mandated by EPA regulations



# Metrology Lab & Gas-Standards Lab

## Metrology Lab →

- **Provides standard calibrations for over 250 devices**
  - **Pressures & Temperatures**
  - **Humidity & Flow & Weights**
  - **Frequency, Voltages & Currents**

(O-Scopes, Power Quality Analyzers, Precision Resistors)

## ← Gas-Standards Lab

- **Provides NIST & ISO traceable calibrations, including error analysis**
- **Master Bench Gas blending and standard naming of analyzer span gases**
- **Monitoring and supply house gases**

# Topics:

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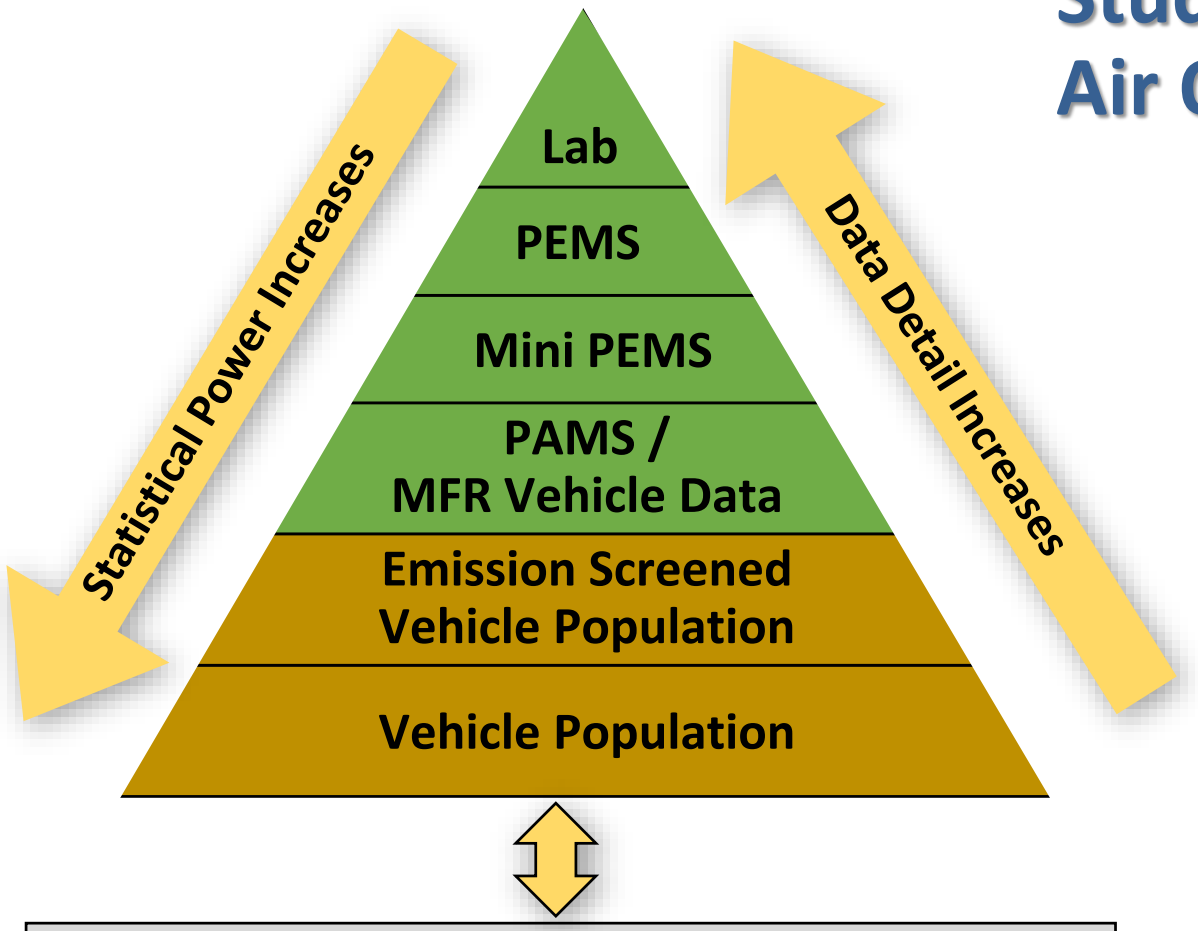
2. The Marriage of Laboratory and Real-World Testing Yields More Data
3. Cleaner Air and Communities

# It Takes a Suite of Discovery Tools!


**Some things are well hidden and require special examination!**

# Studying, Modeling and Enforcing Air Quality Requires Ample Data

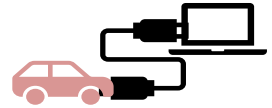



NVFEL capabilities

Data we partner to obtain

**Laboratory Testing Data:**
- Obtain detailed emissions data over different types of driving cycles

**Portable Emission Measurements (mini-PEMS & PEMS):**
- Obtain activity, emissions, and temporal allocation



**Portable Activity Measurements (PAMS) Data:**
- Hundreds of vehicles measured over several weeks to months in real world
- Obtain activity and temporal allocation

**Emission Screening of Vehicle Population Data:**
- Remote Sensing tools: HEAT, Portable tent
- Random population evaluated for days to months
- Obtain emission "snap shots" to evaluate distribution of emissions

**Vehicle Population Data**:
- Department of Motor Vehicles
- Port Gate Data
- Fleet Data
- Obtain population and temporal allocation

# Using the Whole Suite of Tools!

1. **Historical LD Test Procedure Changes:** we have learned that on-road driver behaviors and choices impact results seen from standard EPA-cycle emission tests alone *(EPA's move from 2 to 5 cycles for fuel economy testing).*
2. **Evaluating Current Test Procedures:** NVFEL uses on-road test data to evaluate & validate lab test procedures.
3. **Searching Other Datasets:** On-road datasets can give all of us early warning data of possible vehicle compliance concerns.
4. **Evaluating Vehicle Emissions using PEMS:** NVFEL uses routine on-road driving to obtain more data about vehicle emissions.
5. **Researching Vehicle "Signatures":** Looking for changes in a vehicle operating "signatures" – both on-road & on-dyno.

# 1 Historical LD Test Procedure Changes

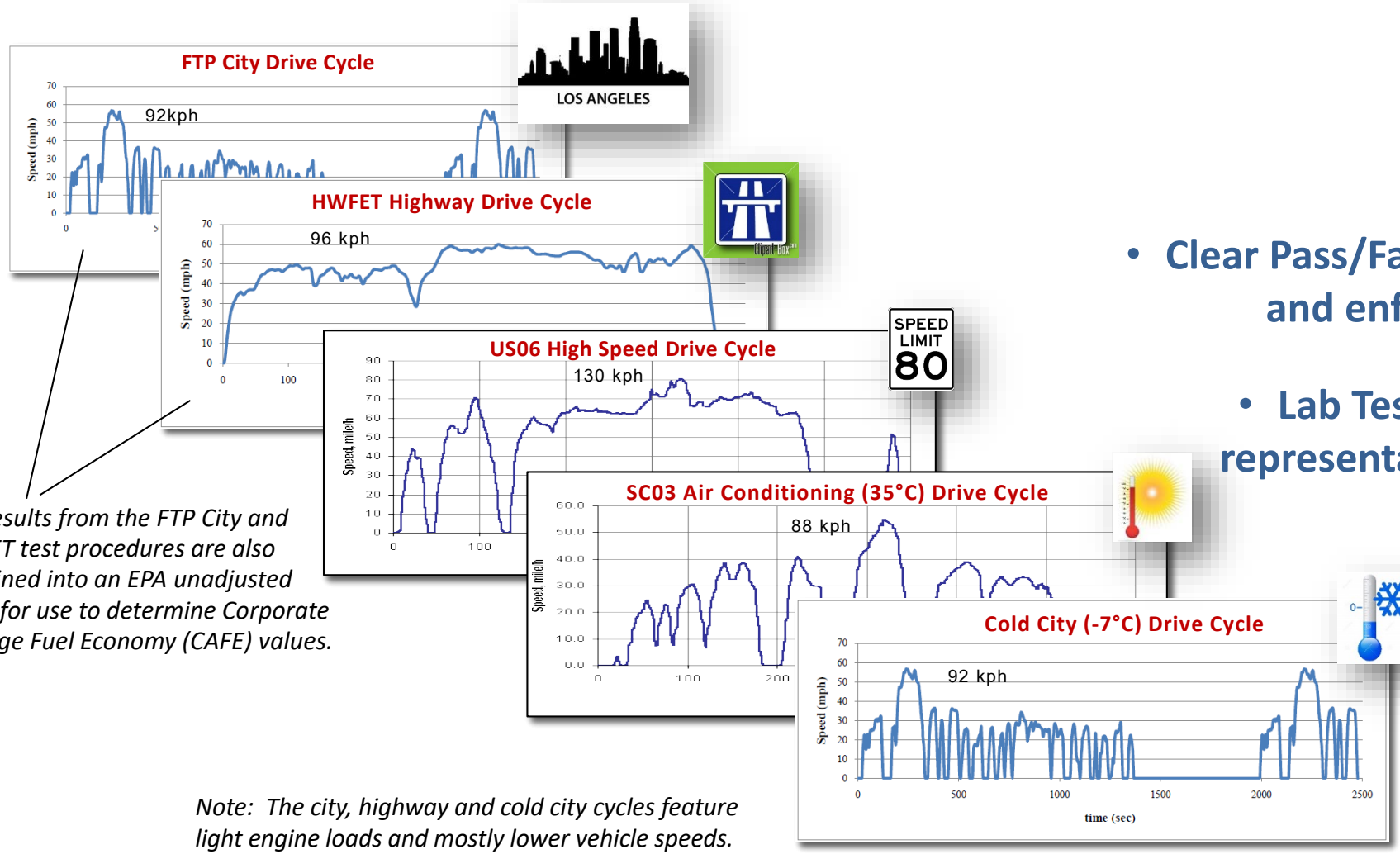
## Driver behaviors and technology choices impact results from standard EPA-cycle emission tests

| | Driving Behavior | + | Vehicle Design | + | Utilization of Vehicle Fleet | + | Emission Makeup |
|---|---|---|---|---|---|---|---|
| **Already adapted to these changes** | • 55 → 70 → 80+ mph<br>• Faster acceleration<br>• Heavier braking | | • Air-conditioning<br>• ABS brakes<br>• All-wheel drive<br>• Stability control | | • Drive cycle weighting<br>• Car / truck mix | | • Renewable fuels<br>• Greenhouse gases<br>• Tier 2 → Tier 3 fuels<br>• In-use testing (PEMS) |

**Our goal is to make lab emissions testing representative, repeatable, reliable & fair, and also to adapt to changes that affect real-world emissions.**

# We have had to add new test cycles to get more data!

## Light-Duty Vehicles are now tested on 5 Standard Test Procedures




*The results from the FTP City and HWFET test procedures are also combined into an EPA unadjusted value for use to determine Corporate Average Fuel Economy (CAFE) values.*

*Note: The city, highway and cold city cycles feature light engine loads and mostly lower vehicle speeds.*

- **Clear Pass/Fail Tests provided compliance and enforcement surety/confidence**
- **Lab Test cycles were intended to be representative of real-world operation** – broad & expanded tests
- **Stringent lab tests and greater measurement precision**

# We don't expect technology choices and driver behaviors to stop changing, so we keep looking…

| | Driving Behavior + | Vehicle Design + | Utilization of Vehicle Fleet + | Emission Makeup |
|---|---|---|---|---|
| **Already adapted to these changes** | • 55 → 70 → 80+ mph<br>• Faster acceleration<br>• Heavier braking | • Air-conditioning<br>• ABS brakes<br>• All-wheel drive<br>• Stability control | • Drive cycle weighting<br>• Car / truck mix | • Renewable fuels<br>• Greenhouse gases<br>• Tier 2 → Tier 3 fuels<br>• In-use testing (PEMS) |
| **Examples of changes that could be coming** | • Smoother autonomous driving<br>• Optimize connected driving (anticipate stoplights) | • Adaptive cruising<br>• No pedals<br>• Optimized for platooning<br>• Optimized for single occupant<br>• Hybrid system synergies | • Shared mobility<br>• Increases in VMT<br>• Self-parking<br>• Delivery tasks (last mile delivery)<br>• Personal pickup / delivery (Chicago pizza) | • More fuel used for powering electronics<br>• BEVs emit at the powerplant |

**Our goal is to make lab emissions testing representative, repeatable, reliable & fair, and also to adapt to changes that affect real-world emissions.**

# 2 Evaluating Current Test Procedures

## Using On-Road Tests to Evaluate & Validate EPA Lab Test Procedures

***Focusing on what is needed to improve and enhance laboratory test procedures***

**General Principle:** The more we know about in-use vehicle driving and emissions behavior (during on-road and on-dyno driving relative to lab-based testing), the better we will be able to ensure clean air from our regulations by identifying gaps in lab test procedures & infrastructure.

- There is an increasing focus of on-road emissions (within OTAQ, CARB, environmentalists and globally).
- Helps us detect issues seen on-road, looking at how relevant and accurate lab testing is now.
- In-use data should come from both **EPA** and **outside** sources (national labs, CARB, 3rd parties like AAA, Verizon, etc.)
- Enables us to creatively think of what the lab testing can do to better reflect real world on-road conditions.

*https://www.treehugger.com/strange-roads-you-can-actually-drive-4869235*

*https://autotechreview.com/cover-stories/real-driving-simulation-on-a-high-altitude-climate-roller-dynamometer*

# Differences between lab on-dyno and real-world on-road

## Laboratory (on-dyno)

- Humidity and temperature are controlled
- Values like calibrated torque easier to measure
- Calibration standards regularly checked in controlled environment.
- Effects of grade are controlled
- Tests are highly repeatable from a test cell perspective.
- Fuel make up and temperature highly controlled
- Complex equipment like fuel meters for engines are easier to utilize
- Drive cycles easier to precisely repeat
- Evaporative SHED testing is easier and more controllable
- Laboratory grade instruments generally the most accurate and precise.
- CVS tunnel

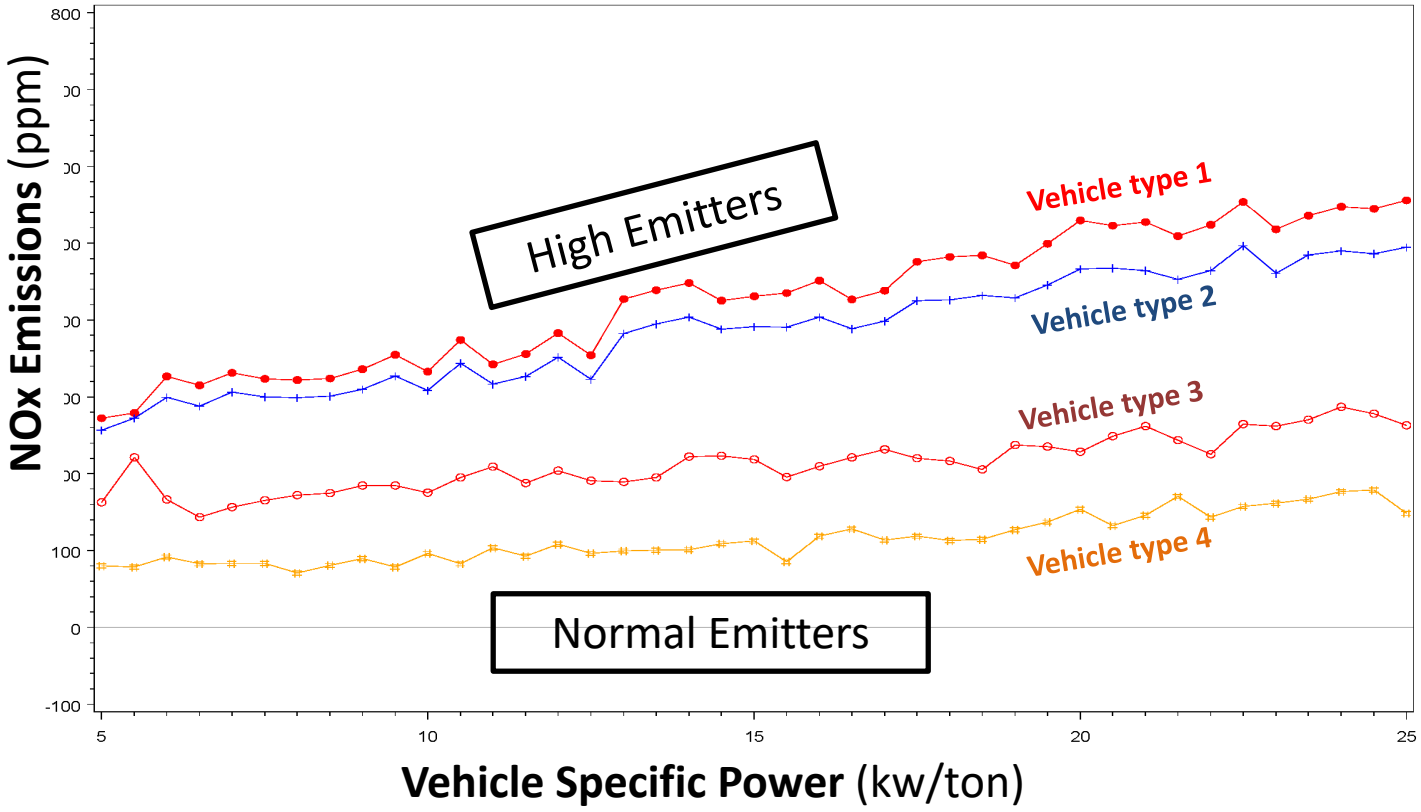
## Real-World (on-road)

- Equipment generally less expensive
- Can test articles that can't easily be tested in a dynamometer i.e., locomotive, bulldozer, marine ships.
- May experience conditions not easy to replicate, temperature, humidity, altitude.
- Since the equipment is less expensive, broader testing is more cost effective.
- Easier to obtain representative cross section of the population of interest.
- Does not require disassembling the test article to test it.
- Longitudinal data more easily obtained
- Real life situations that are unplanned or unexpected are discoverable
- Easier to test generate variable test conditions like, e.g., altitude

# 3 Searching Other Datasets

## Some emission concerns are detected in real-world testing

**Remote sensing tests have the potential to find "high-emitters" by grouping the emission data by MY, make, model, engine size, fuel used, and then plotting using vehicle specific power and emission concentrations.**




**Tool-set utilized:**

- **Remote Sensing Data** (RSD) noticed high NOx emitters
- **PEMS on-road** testing used to confirm vehicles problems
- **LAB on-dyno** testing to create forensic datasets

4

# Evaluating Vehicle Emissions Using PEMS

## Searching for indicators of possible high emissions during on-road driving

**A goal of EPA's Real-World driving tests is to determine if a car-SUV-pickup behaves the same (or differently) in the chassis dyno during emissions test compared with operation on public roads during "Real World" driving.**

- The vehicle emissions system effectiveness and behaviors during everyday road driving should be consistent with emissions during EPA's 5 standard test procedures.

**Another goal is to identify modes of operation or areas of emissions that could be better represented in our standard emissions testing.**

- It isn't uncommon to discover modes of operation, and emissions characteristics with PEMS that aren't always readily apparent during standard dynamometer testing.


On-road PEMS testing

# Using PEMS to study new technologies and varying vehicle operation is generating data used to study and model air quality

- Robust air quality modeling requires a deep understanding of vehicle population, real-world vehicle use and emission profiles.
- Screening all types of vehicles for emission levels
- Any compliance actions for current and future regulations require rigorous laboratory testing.



**Future diverse engines, powertrains, HEVs, PHEVs, EVs, autonomous vehicles, different fuels, etc. have made monitoring and modeling of real-world activity and use for today's vehicles much more challenging and complex.**

# 5 Researching Vehicle "Signatures"

## Looking at vehicle emission behaviors _between on-road driving and on-dyno tests

**Technical Paper on Signature Device** 2020-01-0372 Published 14 Apr 2020

SAE INTERNATIONAL

Motor Vehicle Emission Control Quality Monitoring for On-Road Driving: Dynamic Signature Recognition of $NO_x$ & $NH_3$ Emissions

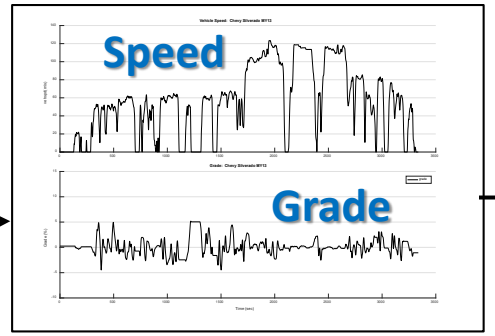
**Xiaoguo Tang, John Kargul, and Dan McBryde** US Environmental Protection Agency

***Citation:*** Tang, X., Kargul, J., and McBryde, D., "Motor Vehicle Emission Control Quality Monitoring for On-Road Driving: Dynamic Signature Recognition of $NO_x$ & $NH_3$ Emissions," SAE Technical Paper 2020-01-0372, 2020, doi:10.4271/2020-01-0372.

## START with Driving Trip on the Road

Collect Signature Device Data * On Public Roads

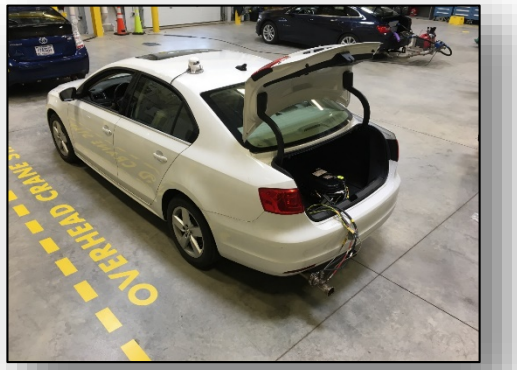
Recreate exact Vehicle Drive Trace Using Road Speed and Grade




## Replicate Driving Trip on the Dyno

**Collect Signature Device Data On Dyno**

**Collect Emission Analyzer Data from Dyno**




*Small lower-cost mini-PEMS*

Compare NOx **Concentrations & Timing** Road versus Dyno

**The CHECK**

**If both comparisons are not consistent, then investigate and diagnose:**

- Is the difference an on-road measurement artifact (false positive)?
- Is the difference associated with defect in the emissions control system?
- Is the difference associated with an AECD?

* NOx, O2, *tailpipe exhaust gas temp and log GPS (speed, time, distance, elevation)*

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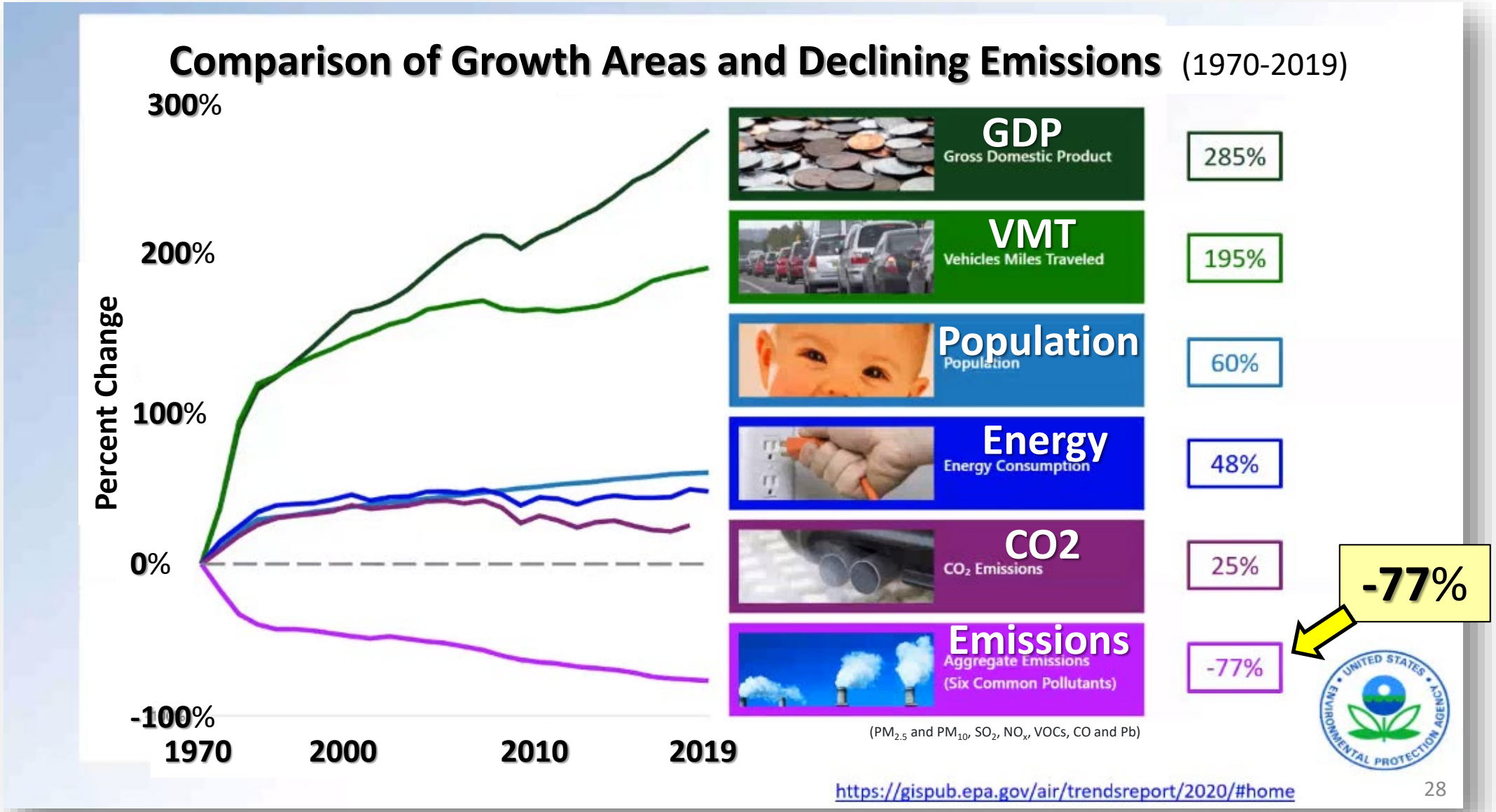
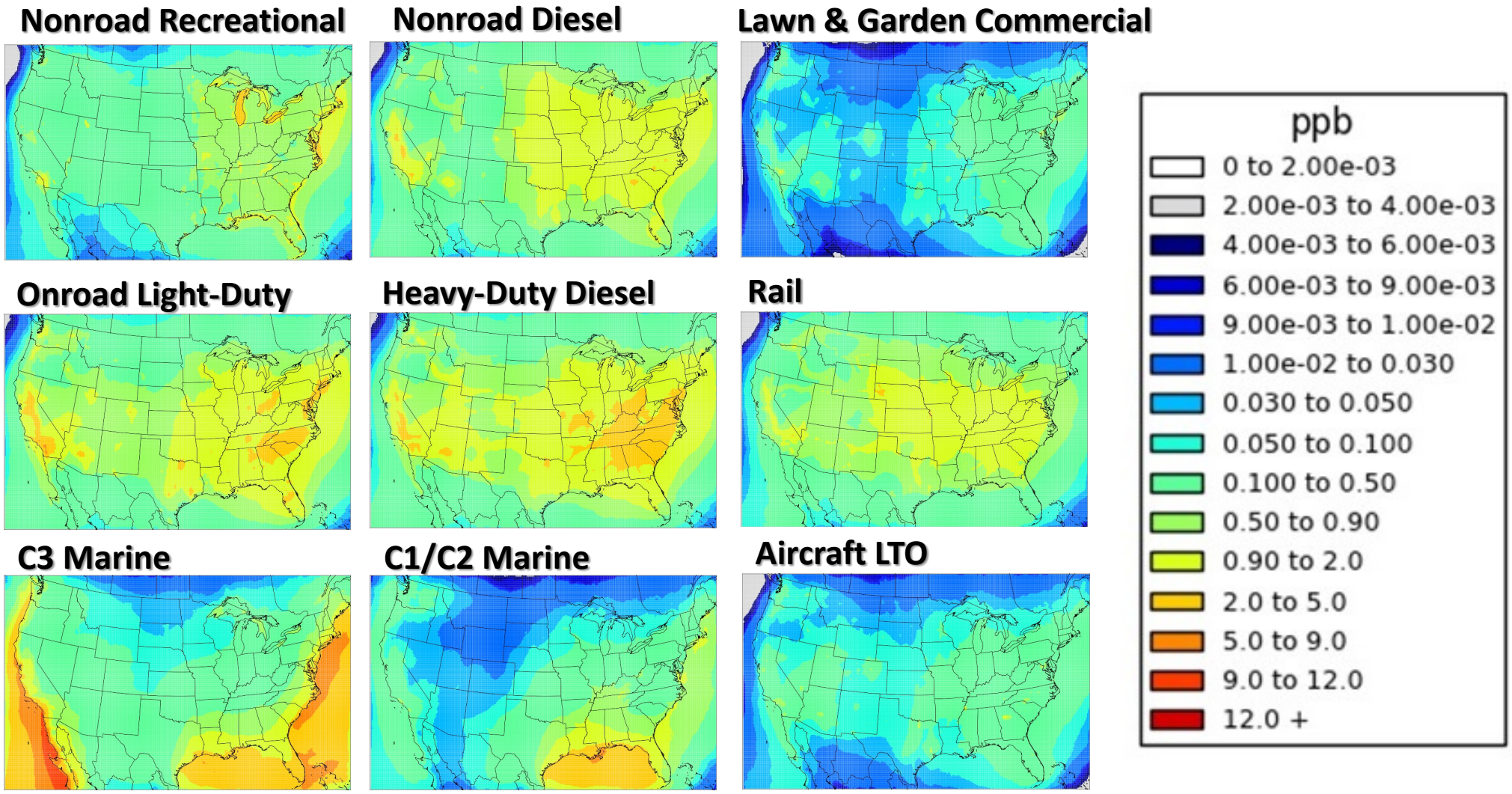
# Historical Trends Tell One Important Part of the Tale



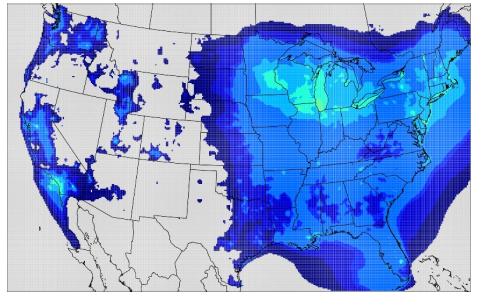
# Mobile Source NOx & VOC Contributions to Ozone in 2025



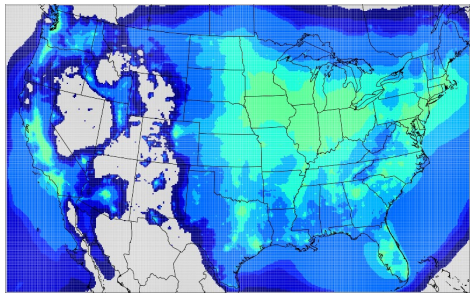

*Zawacki et al, 2018* https://doi.org/10.1016/j.atmosenv.2018.04.057

# Mobile Source Contributions to $PM_{2.5}$ in 2025 *

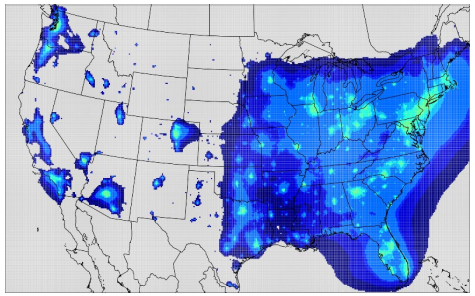
Nonroad Recreational



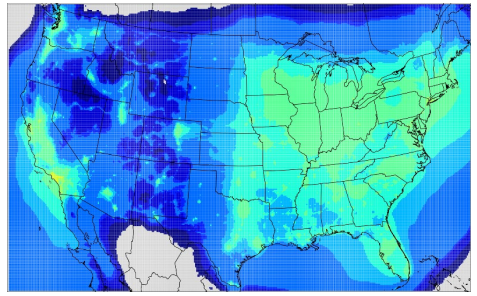
Nonroad Diesel



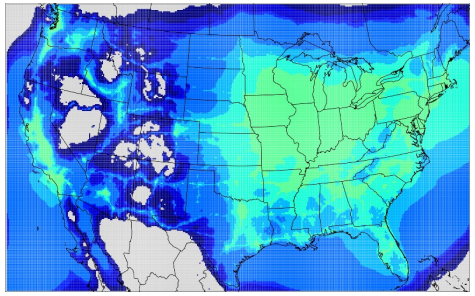
Lawn & Garden Commercial



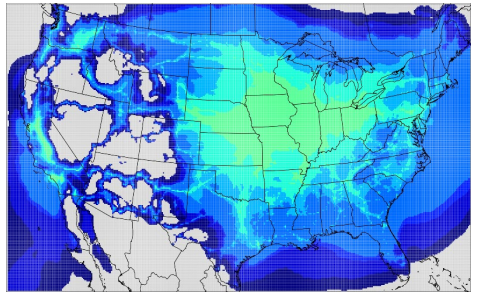
Onroad Light-Duty



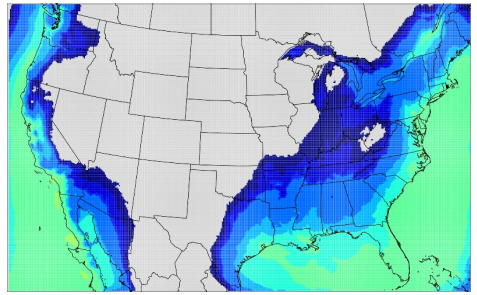
Heavy-Duty Diesel



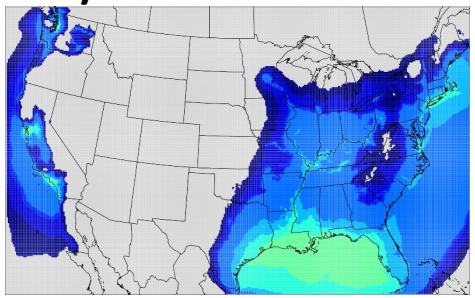
Rail



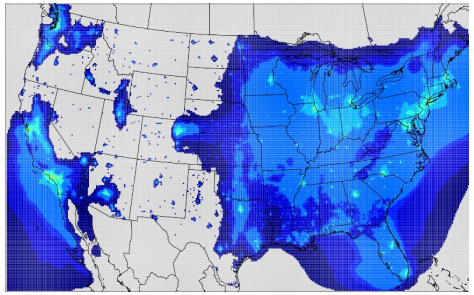
C3 Marine

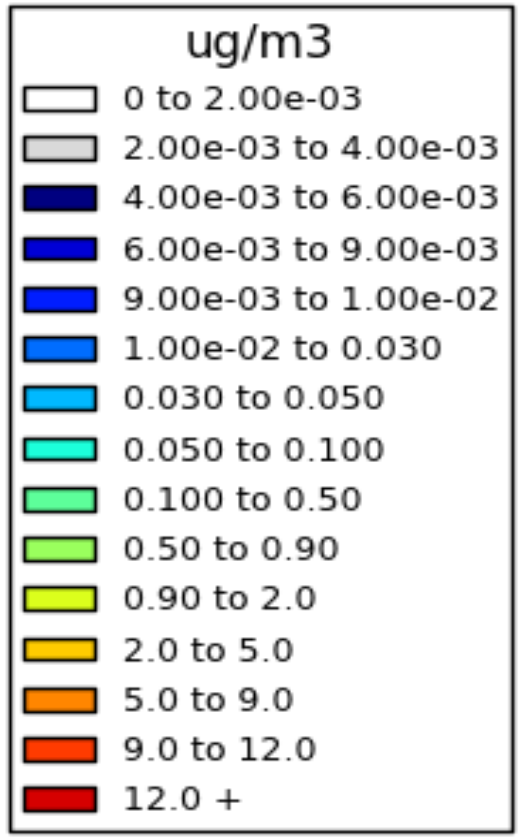


C1/C2 Marine



Aircraft LTO





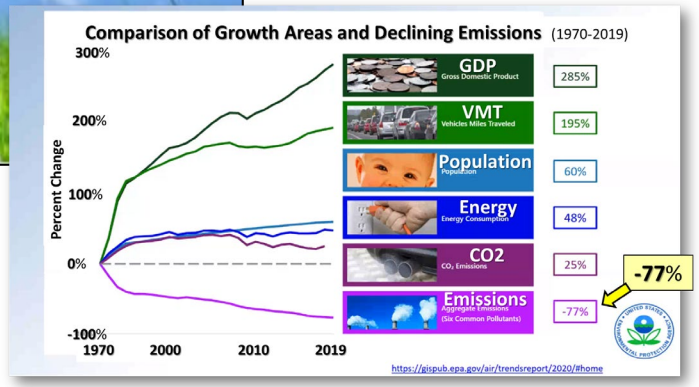

*Includes both primary and secondarily formed PM

*Zawacki et al, 2018* https://doi.org/10.1016/j.atmosenv.2018.04.057

# Tale of Two ~~Cities~~ Communities



**Historical Trends in Emission Reduction**



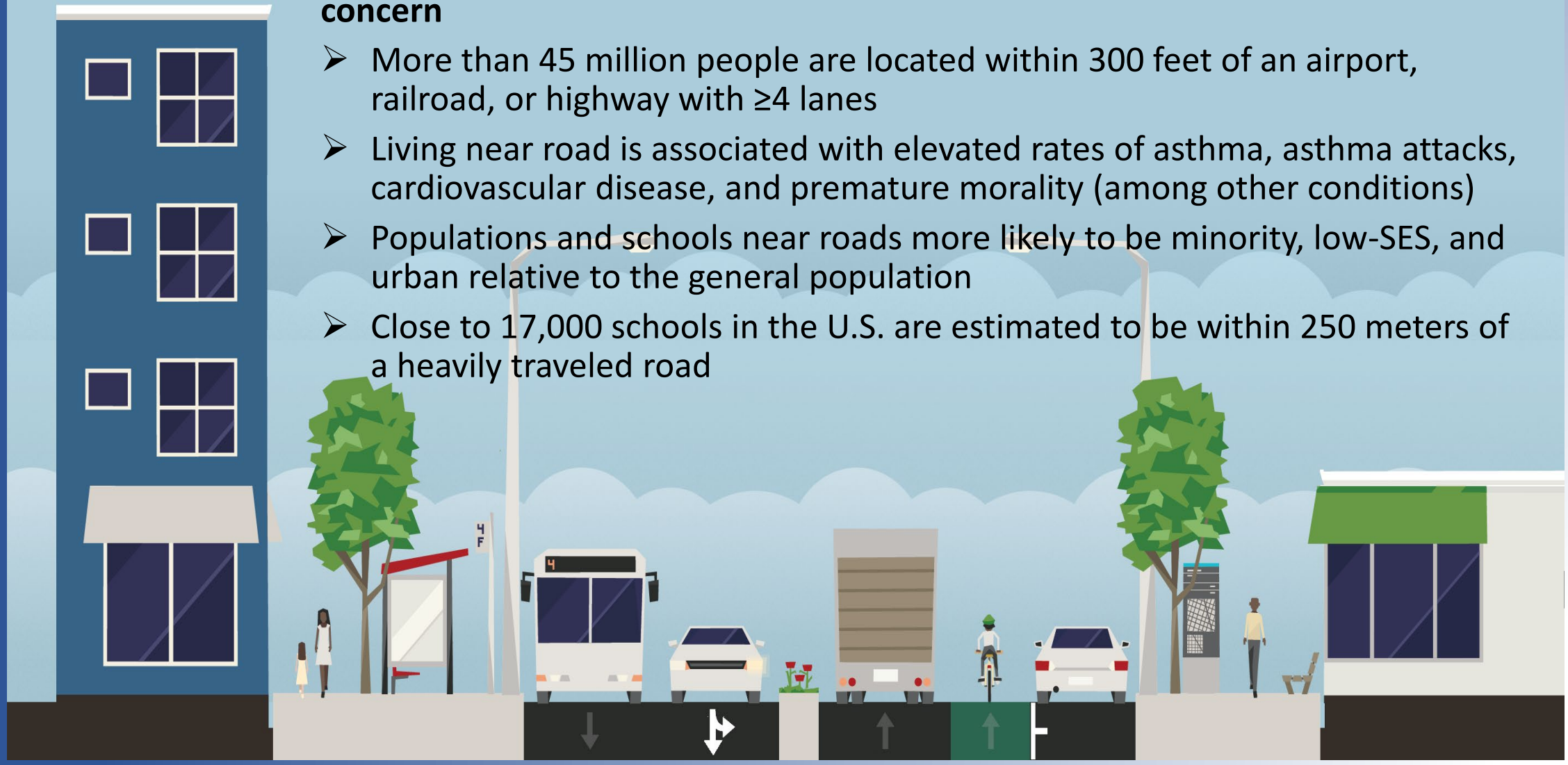

***in aggregate emissions**
(nation-wide , 6 common pollutants)

**However, some communities and areas are still disproportionately affected by air pollution issues.**

# Continued Community Exposure Tells Another Important Tale

**Air quality near roads, ports, airports and rail yards is a major public health concern**

- More than 45 million people are located within 300 feet of an airport, railroad, or highway with ≥4 lanes
- Living near road is associated with elevated rates of asthma, asthma attacks, cardiovascular disease, and premature morality (among other conditions)
- Populations and schools near roads more likely to be minority, low-SES, and urban relative to the general population
- Close to 17,000 schools in the U.S. are estimated to be within 250 meters of a heavily traveled road



# A Government-Wide Approach to Environmental Justice

**Addressing disproportionate health and environmental impacts on disadvantaged communities is at the center of Biden's Climate Plan**

**Recent Executive Orders emphasize EJ as a top priority:**

- Establishment of White House EJ Interagency and Advisory Councils to develop a government-wide strategy to address current and historic environmental injustice.
- Creation of the Justice40 Initiative – 40% of relevant federal benefits would flow to disadvantaged communities, focusing on clean energy, transit, sustainable housing, training, remediation and reduction of legacy pollution, and clean infrastructure.
- Development of a Climate and Economic Justice Screening Tool to publish interactive maps highlighting disadvantaged communities that will inform equitable decision making across the federal government.

Photo source: Angelo Logan, East Yards Communities for Environmental Justice presentation on 1/14/14 EPA webinar: "A National Conversation on the State of US Ports"

**EPA's Environmental Justice Definition:**

**Fair Treatment** + **Meaningful Involvement**

*of all people, regardless of race, color, national origin or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies*

# Promoting Environmental Justice through OTAQ Programs


## The EPA Ports Initiative

- Supports efforts to reduce diesel emissions at ports, which can pose health risks to nearby communities often comprised of low-income populations and people of color.
- Promotes community-port collaboration and effective engagement between the port industry and communities to address air quality concerns.

**Ports Initiative Community-Port Collaboration Resources:**

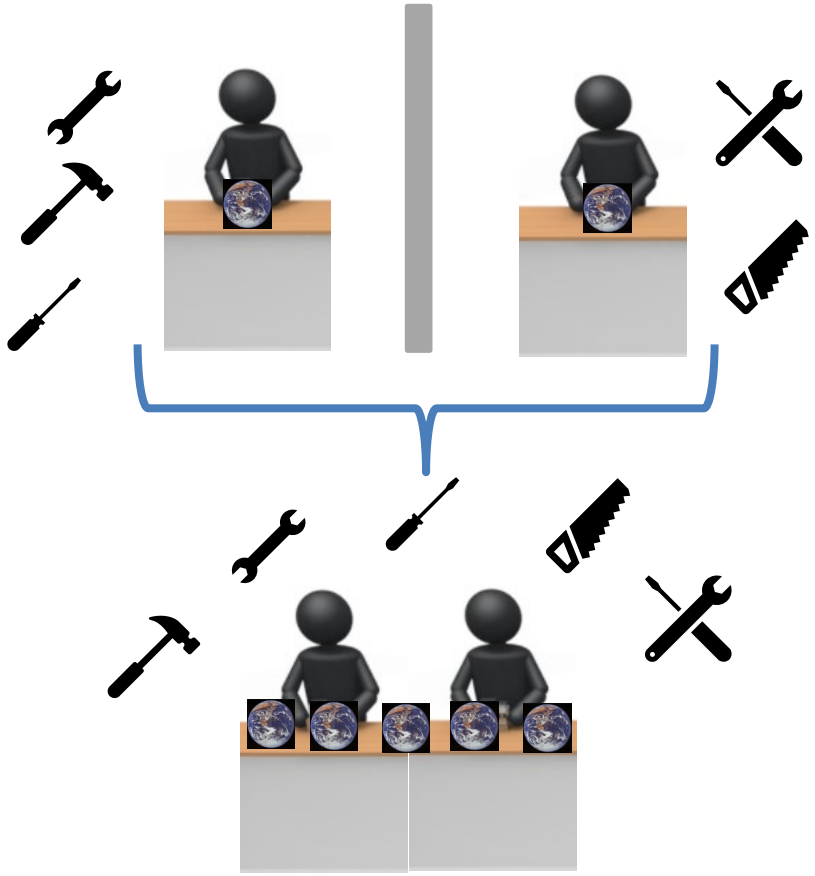
- Toolkit and Training Modules
  - *Ports Primer for Communities*
  - *Community Action Roadmap*
  - *EJ Primer for Ports*
- Case studies with lessons learned from Pilot Projects

## Diesel Emissions Reduction Act (DERA) Program

- Funds grants and rebates that protect human health and improve air quality by reducing harmful emissions from diesel engines.
- Incentivizes fleet owners to purchase new, cleaner vehicles and engines and removes the old, polluting engines from service.
- Prioritizes projects that engage affected communities or take place in nonattainment areas, places with air toxic concerns, and goods movement areas that receive a disproportionate quantity of air pollution from diesel fleets.

# Invitation to explore ways to work together…

- Data being generated in laboratories and in-use monitoring operations today is needed to solve community-based problems
- Let's find ways to collaborate, working with your existing partners, creating new projects with EPA, and energizing citizen science.
- The more we can pull in the same direction, the greater the environmental and societal benefit!



# Questions?

# References for Graphics …



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