The Role of OSAR in moving Towards a Sustainable Transportation Future

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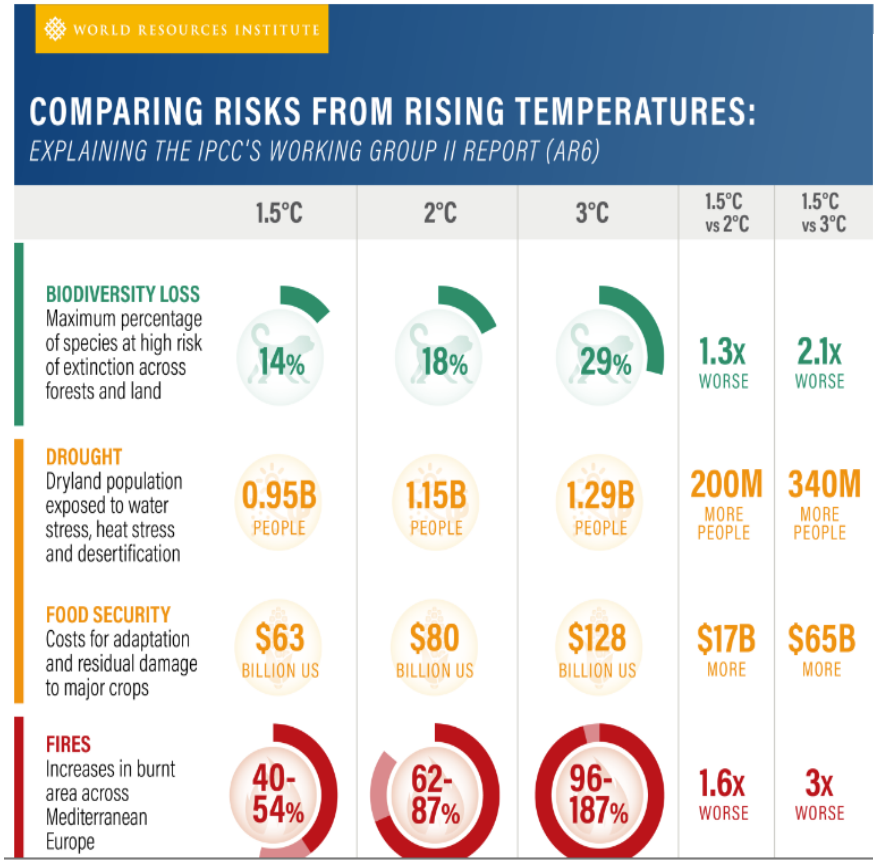
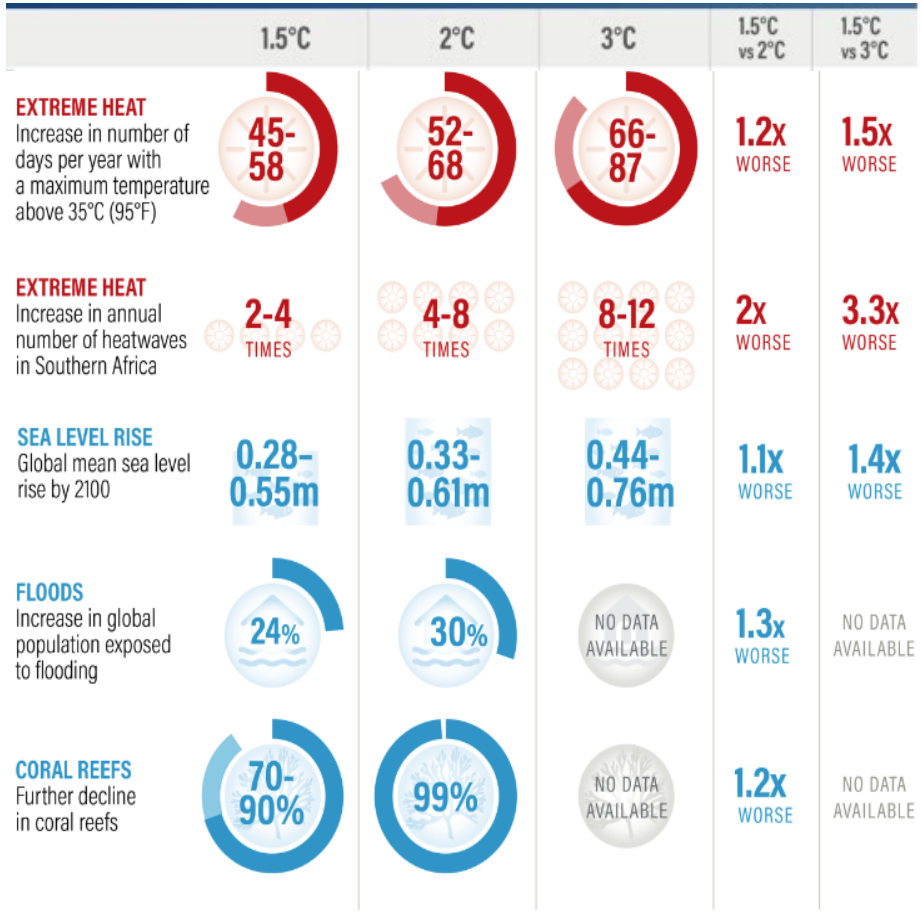
Environmental Impacts of Transportation Emissions

- Mitigating the environmental impacts of transportation emissions is one of the biggest challenges of ours and future generations
- Transportation accounts for approximately 24% of worldwide and 33% of U.S. CO_2 emissions, with about 75% of this from on-road sources.[1]
- World Health Organization (WHO) estimates of air quality impacts include[2]
  - In 2019, 99% of the world's population was living in places where the WHO air quality guidelines levels were not met.
  - Ambient (outdoor) air pollution was estimated to have caused 4.2 million premature deaths worldwide in 2019.
  - The combined effects of ambient air pollution and household air pollution are associated with 6.7 million premature deaths annually.

1 https://ourworldindata.org/co2-emissions-from-transport; https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview
2 https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

Global Warming – Potential Impacts





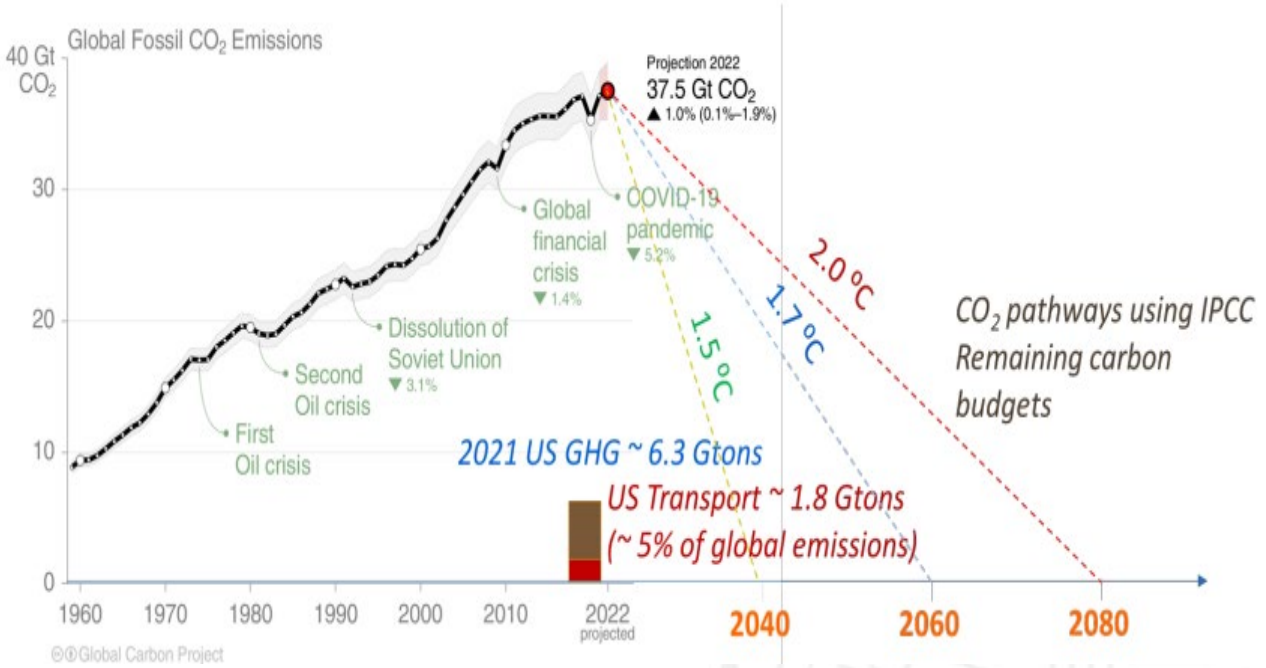
Source: World Resources Institute. https://www.wri.org/insights/2023-ipcc-ar6-synthesis-report-climate-change-findings

Costs of Global Warming

- **Costs of US$ 143 billion per year attributable to extreme events due to climatic change.[1]**
- **In U.S., 400 weather /climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion (including CPI adjustment to 2024). The total cost of these 400 events >$2.785 trillion.[2]**
- **From 2000 to 2019, extreme weather events globally, like hurricanes, floods and heat waves, have cost an estimated $2.8 trillion. This is around $143 billion/year or $16.3 million/hour.[3]**
- **The global cost of climate change damage is estimated to be between $1.7 trillion and $3.1 trillion per year by 2050. [3]**

1. Newman, R., Noy, I. The global costs of extreme weather that are attributable to climate change. *Nat Commun* **14**, 6103 (2023). https://doi.org/10.1038/s41467-023-41888-1.
2. National Centers for Environmental Information (NCEI) http://www.ncei.noaa.gov/access/billions
3. World Economic Forum. https://www.weforum.org/stories/2023/10/climate-loss-and-damage-cost-16-million-per-hour/

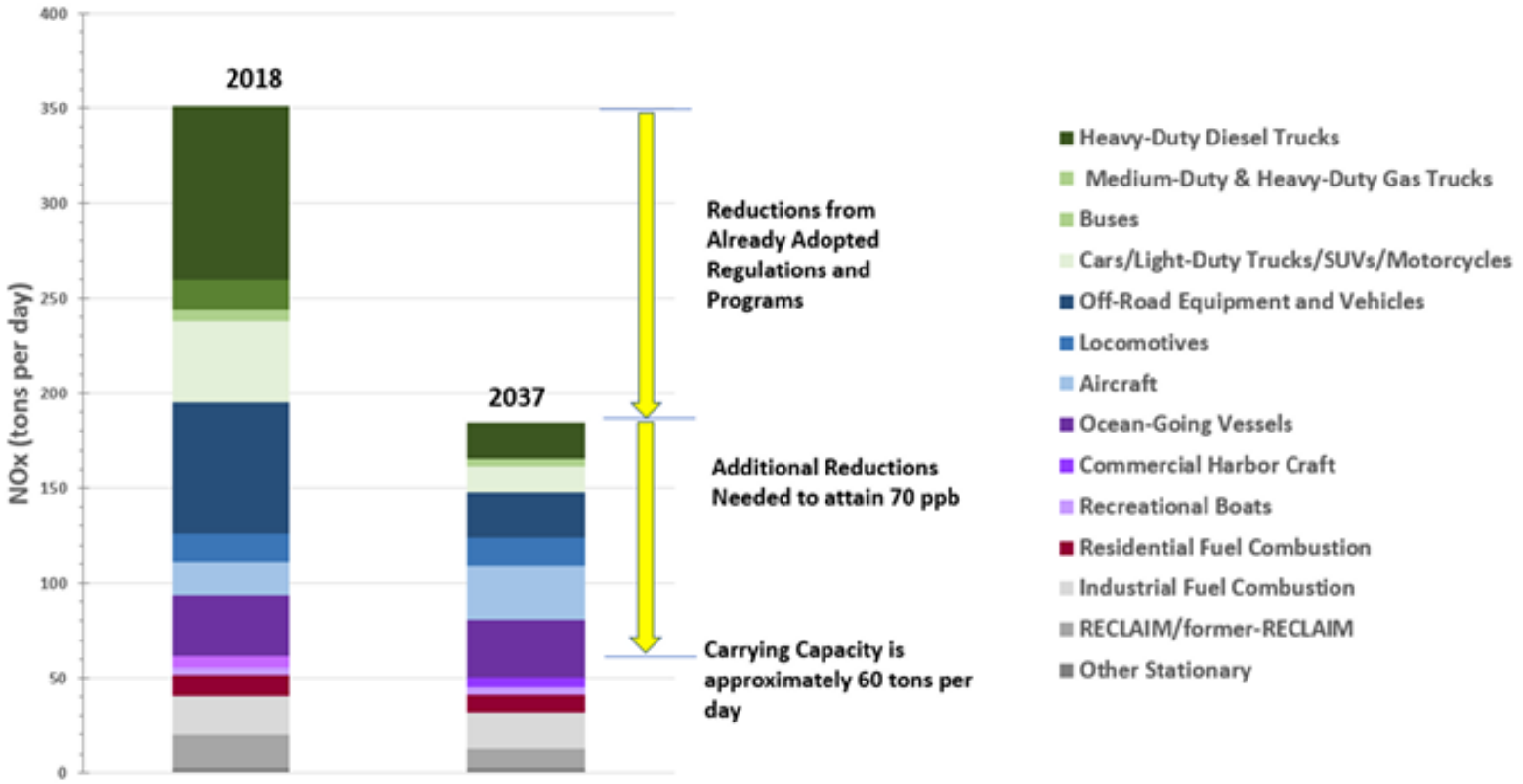
Global Warming – Mitigation Goals



Source: Global Carbon Project 2022 - chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.globalcarbonproject.org/carbonbudget/22/files/GCP_CarbonBudget_2022.pdf

- **But some studies suggest global costs of net zero goal on order of $200 (BloombergNEF)[1] to $275 (McKinsey Global Institute)[2] trillion.**
  - **Global assets: stock market $115T[3] residential real estate $300-500T[4]**

Need for Further Emission Reductions in LA



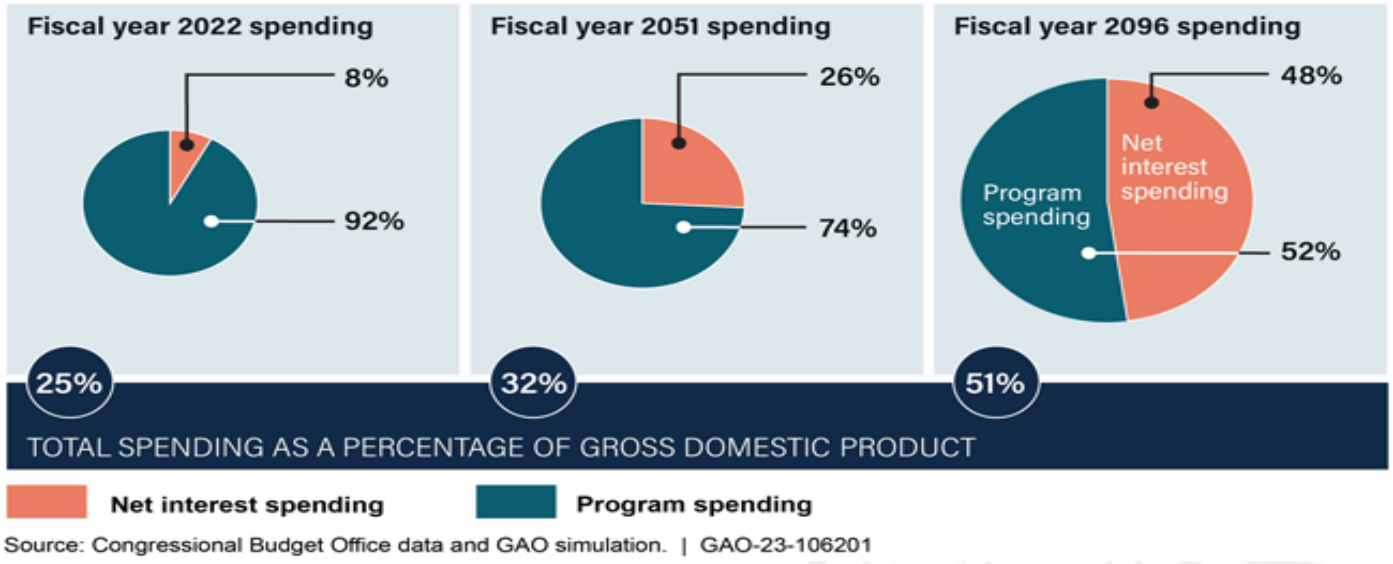
Source: South Coast Air Quality Management District, 2022 Air Quality Management Plan, Adopted December, 2022.

Economic Challenges going into 2030s - I

- **Government debt is increasingly becoming a problem**
  - CFOs, bankers (Jamie Diamond), the Fed and others see government debt as looming crisis[1]
  - Overall debt $36.7 trillion[2] 1/10/24, U.S. stock market $52.0 T,[3] U.S. residential real estate - $49.7T[4]
- **Federal Government Spending is very high and continuing to grow**
  - $6.75 Trillion for 2024[5] ($52,656 per household), 51.8% higher than pre-COVID levels
  - Social Security/Medicare/Medicaid + Interest $2.51 Tril. ($19,640/house) in 2019 to $3.89 Tril. ($30,307/house) in 2024
  - ~ All private real estate in 12 mid-west states (IL, IM, IA, KS, NE, MN, MI, MO, OH, WS, ND,SD)[6]
  - ~ Market cap Autos, Oil, Telecom/TV, Retail (Major+specialty), + many Food Companies combined[7]
  - ~ U.S. Retail sales revenue minus motor vehicles, auto parts & gas stations[8]
- **Federal government deficit is growing at historic levels**
  - $1.83 Tril. in 2024[5] ($14,275/house) (~$3,000/house Aug 2024[9]), 86% higher than pre-COVID levels
  - Equivalent to the value of all residential real estate in Colorado and Oregon combined
  - All profits 220 most profitable U.S. companies in 2022[10]

Economic Challenges going into 2030s - II

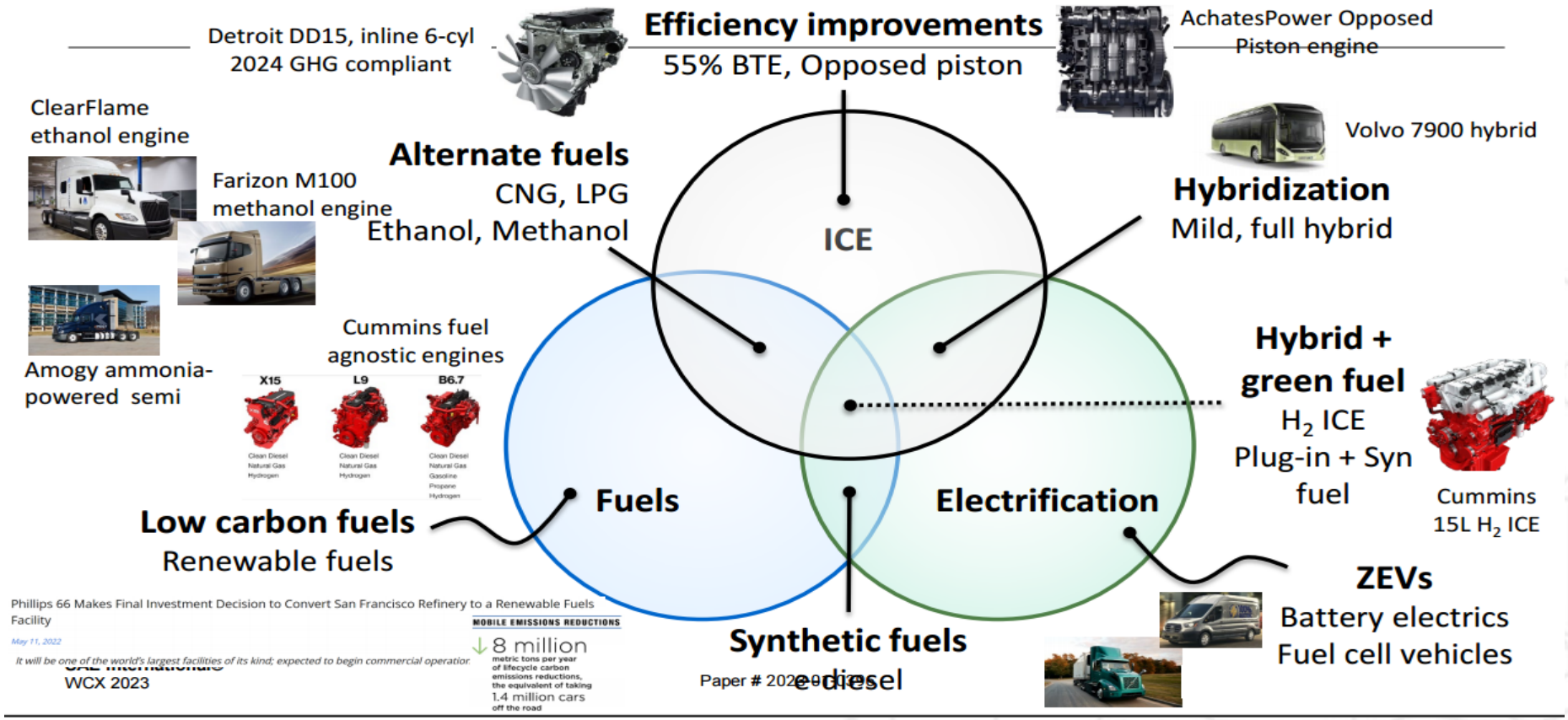
- **Solutions will be problematic - higher taxes / slower economy, increase money supply /inflation, probably in combination with less services**
  - Interest payments
    - $892 B in 2024 - $6,958 per household[1]
    - 2051 - 8% of GDP - $16,486/household[2]



- **Economic constraints / cost effectiveness will continue to play an important role in environmental policy for the foreseeable future**

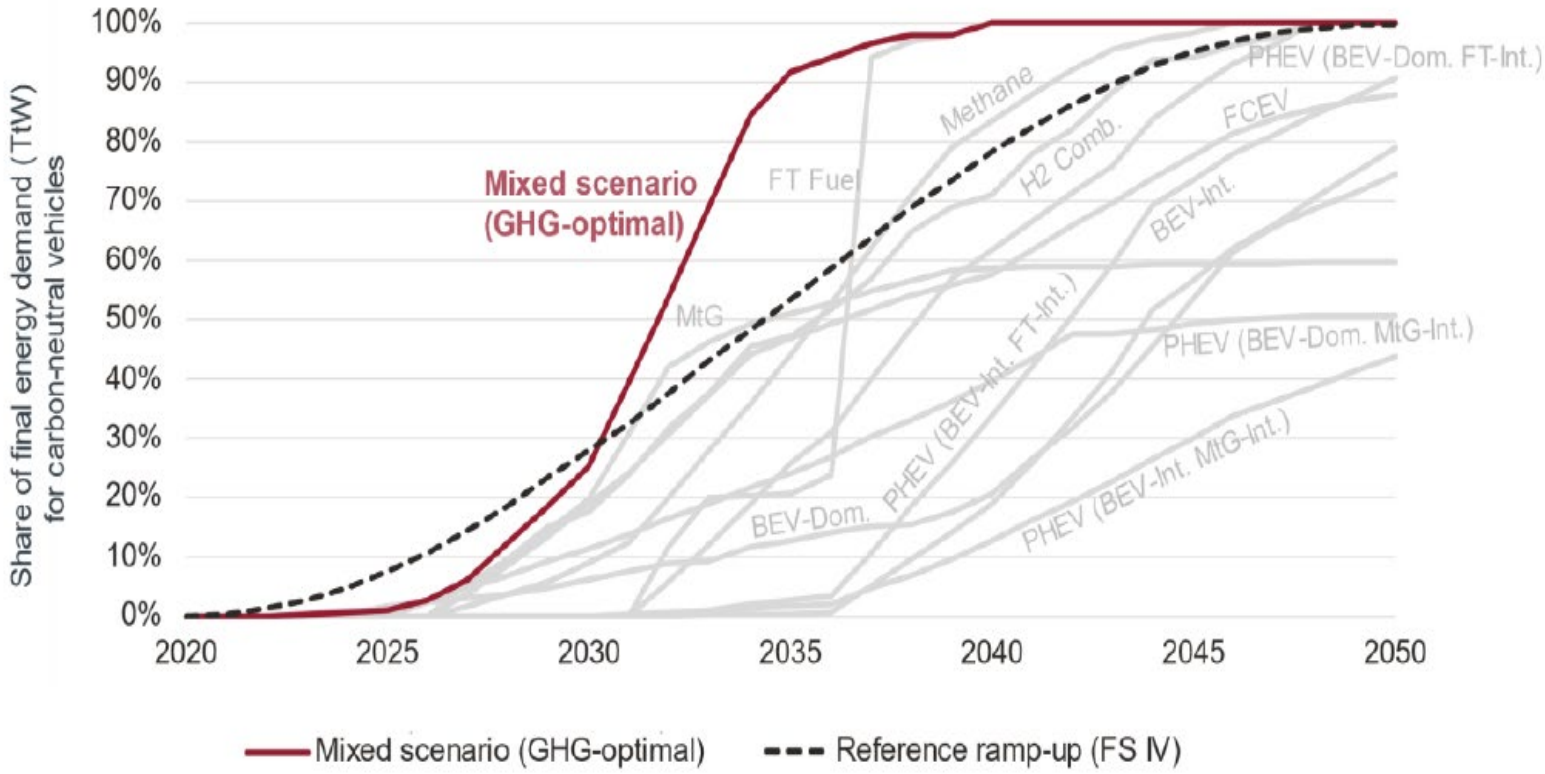
1 /https://www.cbo.gov/system/files/2024-11/60843-MBR.pdf
2. U.S. Government Accountability Office, 2023, https://www.gao.gov/assets/gao-23-106201.pdf

In a challenging environment, various pathways will likely needed to be pursued for transport decarbonization



Source: Joshi, A., 2023, "Year in review – Progress towards decarbonizing transportation and zero emissions," presentation at Society of Automotive Engineers, WCX conference, Detroit, MI, April.

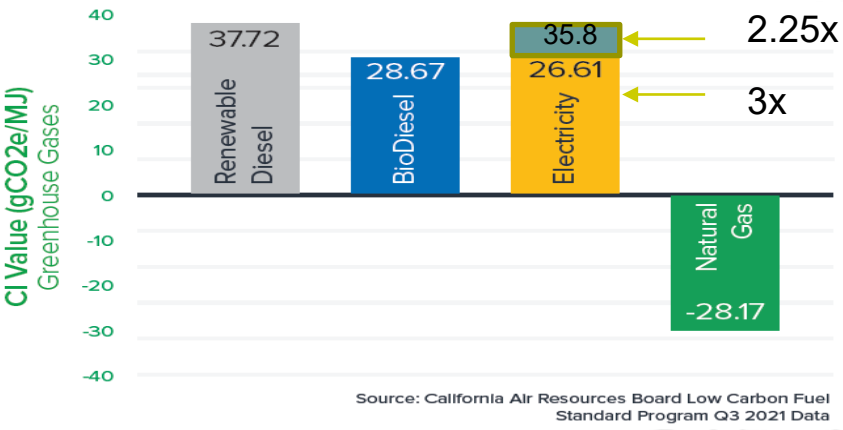
Various pathways will need to be pursued for transport decarbonization

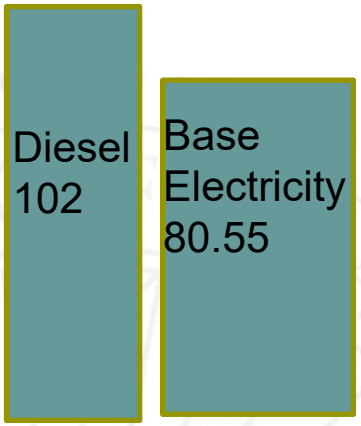


Source: Krammer, U. Bothe, D., Gatzen, C, et al., 2022, FVV eV // Science for a moving society (FVV), Future Fuels: FVV Fuel Study IVb Follow-up study: Transformation of Mobility to the GHG-neutral Post-fossil Age, Project. No. 1452.

Renewable Fuels

- In California, over 50% of diesel fuel is comprised of renewable fuels [Q1 2023][1], with diesel fuel for off-road equipment required to be renewable
- Renewable Diesel (RD) has ~70% (100%?) carbon intensive benefit of electricity (basis CA current grid)
- Biofuels provide carbon intensity benefits equivalent to electrifying
  - 35%-50% of the Heavy-duty vehicles (HDVs) + off-road engines (OREs) in CA
  - 70%-100% of off-road equipment (since RD required for off-road in CA)

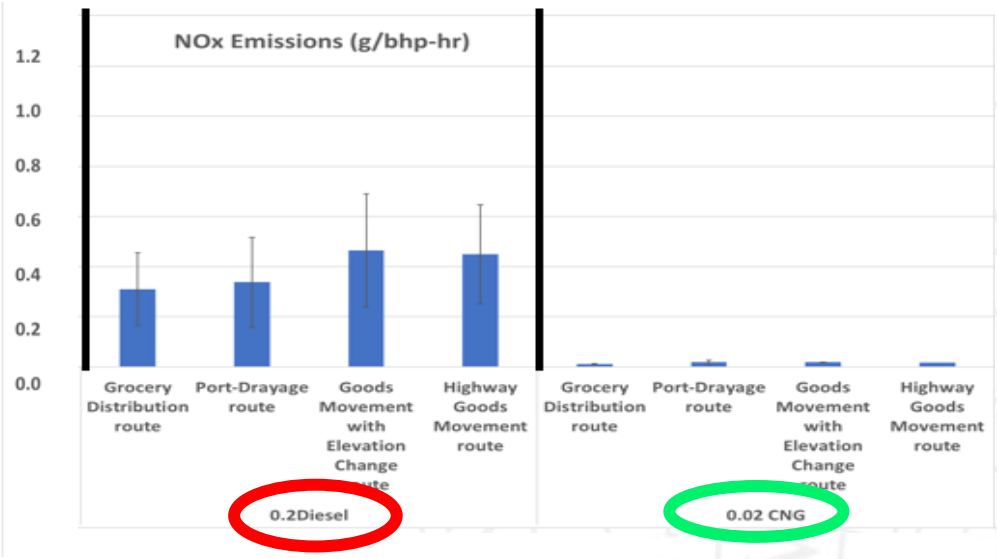




--- [1]https://ww2.arb.ca.gov/news/first-time-50-california-diesel-fuel-replaced-clean-fuels
--- Diesel fuel = 102 gCO2e/MJ
--- Electricity value from electrical grid value of 80.55 gCO2e/MJ w/ BEVs being 3x more efficient. Probably overstated as diesel engines are getting towards 40% efficient now
--- Note negative carbon intensity for RNG is due to avoided methane emissions into the atmosphere

Biofuels + Ultraclean engines

- When biofuels are combined with ultralow NOx HDVs there is a potential for significant near and intermediate term benefits in both GHGs and exhaust pollutants, as the market transitions towards BEVs
- This could include both 2027+ diesel vehicles and current technology 0.02 g NOx CNG vehicles

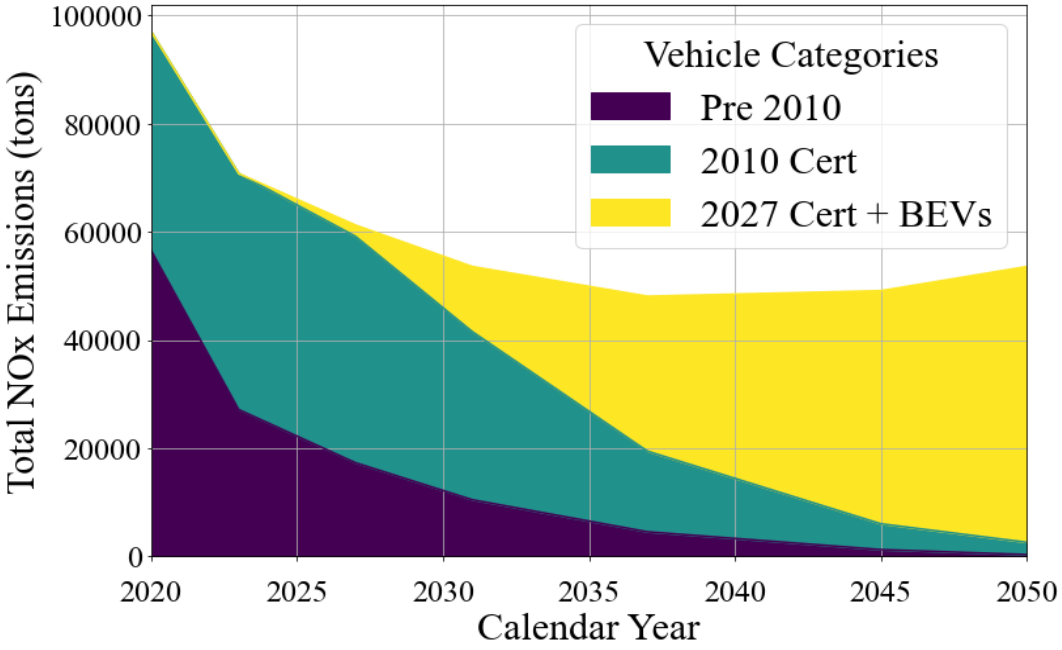


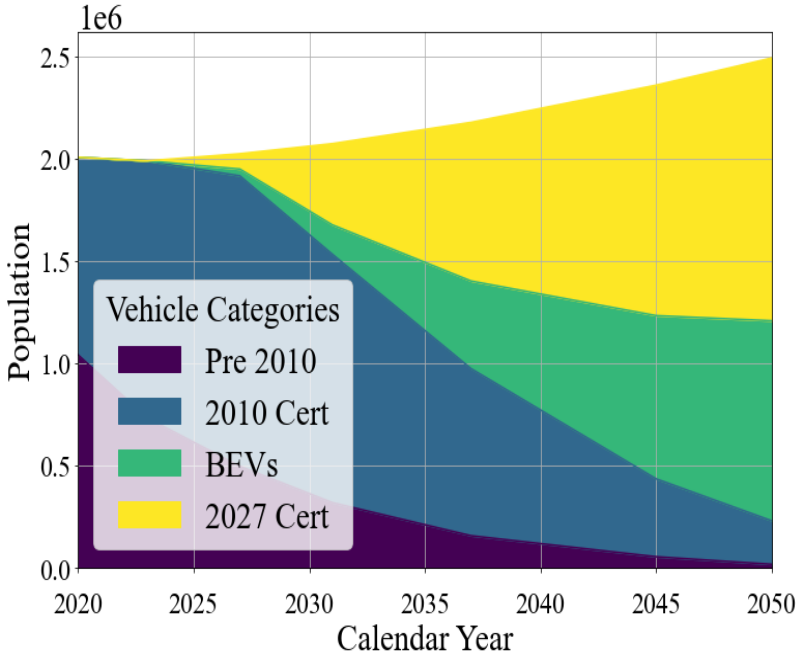
2010 SCR-equipped Diesels

2027+ Diesels + 0.02 CNG

Understanding In Use Emissions and Emissions Inventories

- Base case EMFAC emissions inventory modeling (without ultralow NOx diesel engines) shows increases in vehicle population could be an important contributing factor to emissions inventories

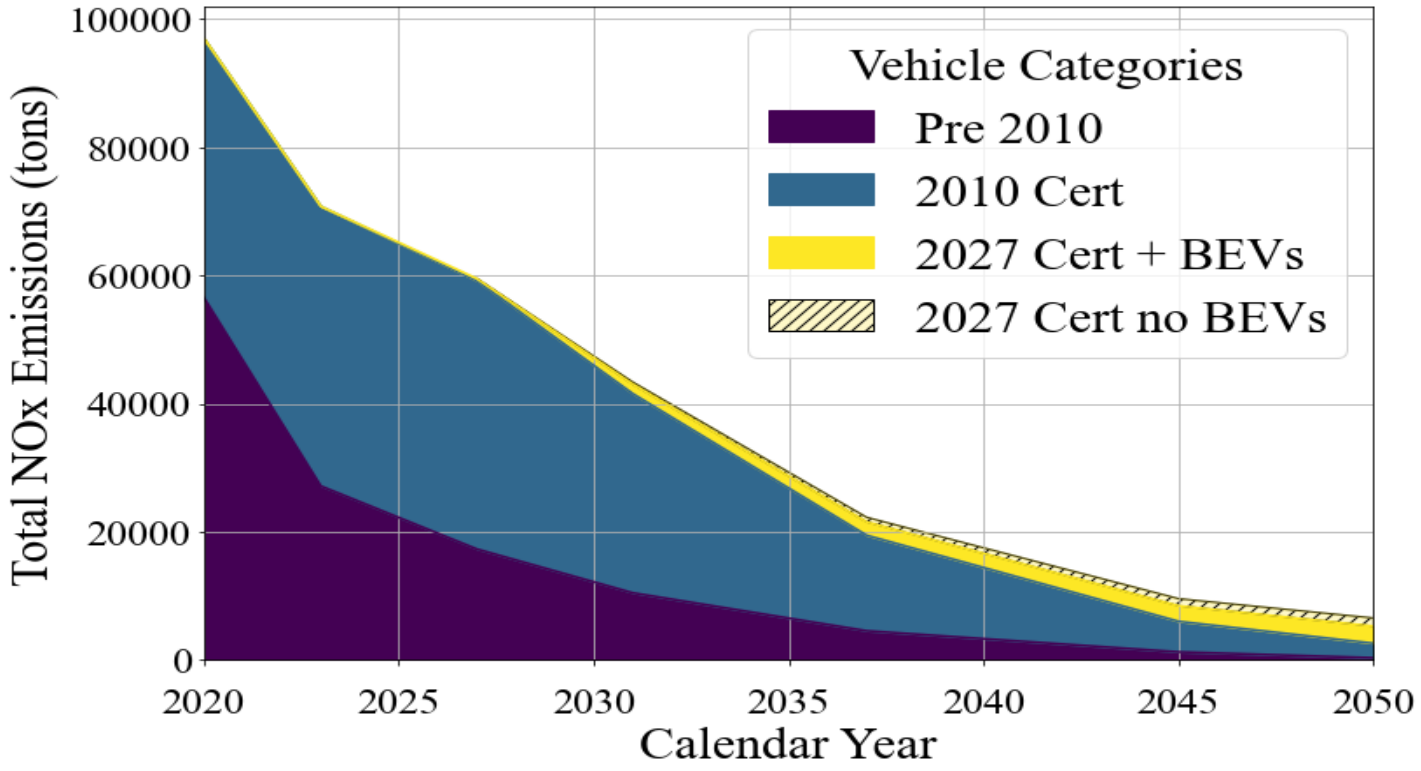




Potential Importance of Ultralow NOx Engines

- Incorporating ultralow NOx diesel engines could have a dramatic impact on emissions inventories.
- 95% of the NOx emissions reductions between 2025 and 2040 for heavy-duty vehicles could come from fleet turn over with ultralow NOx diesel vehicles……

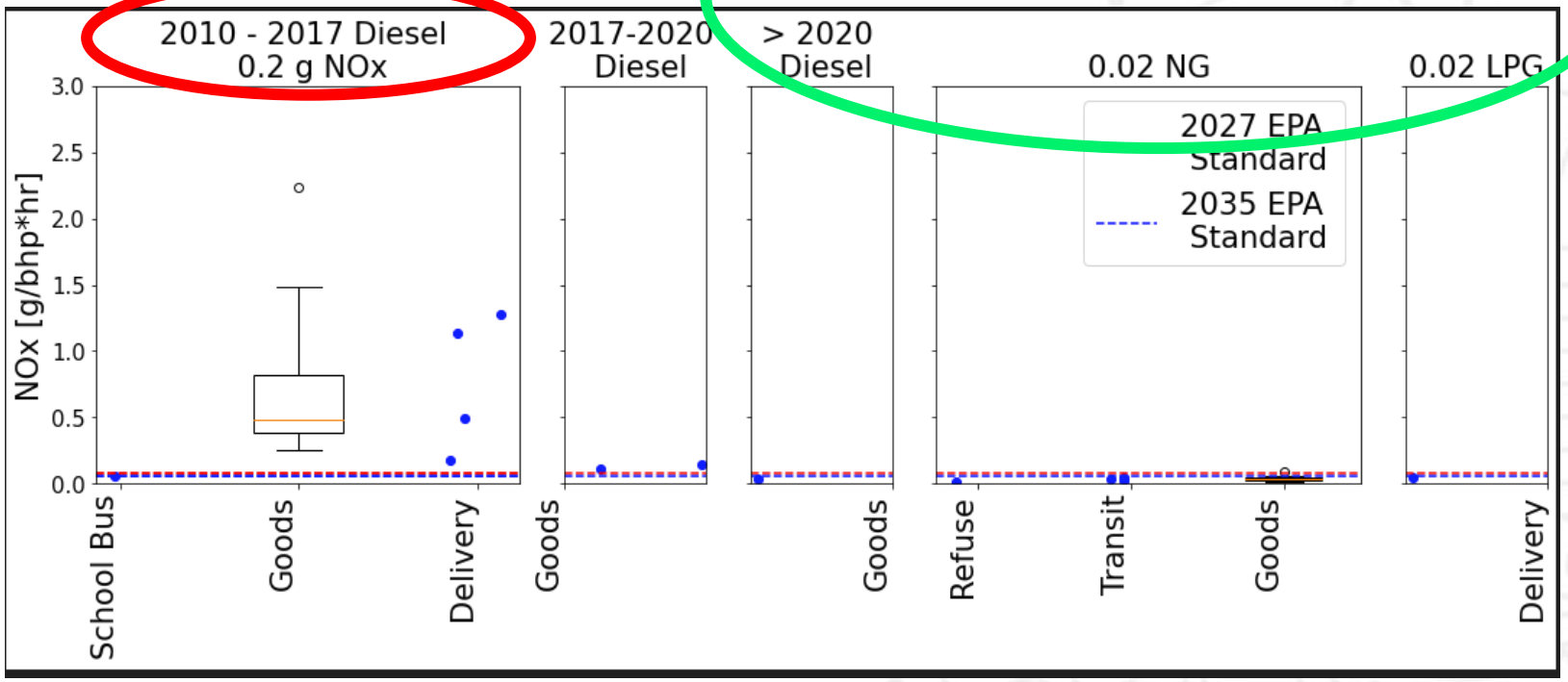
If we can keep the vehicles clean



Trends CE-CERT is examining in heavy-duty vehicle emissions

Regulations

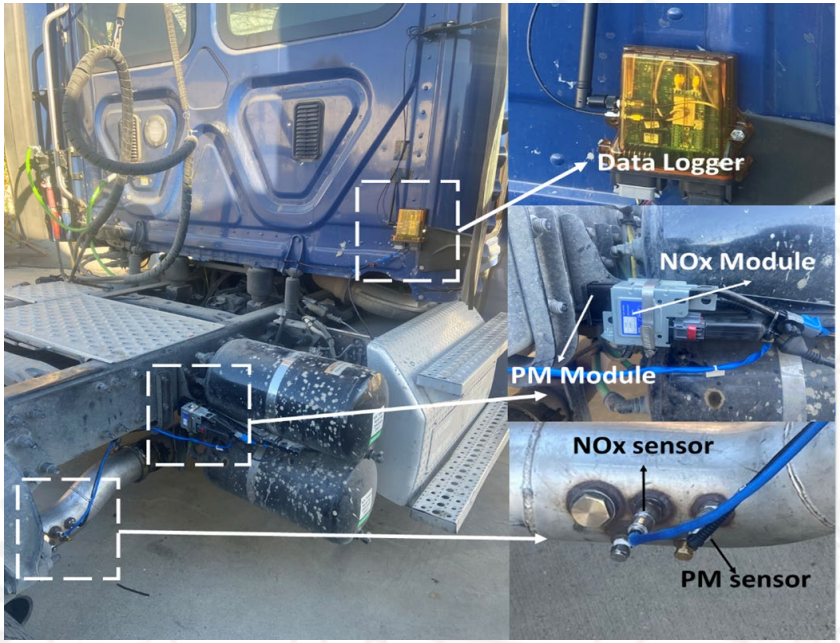
Available Now



CE-CERT Methodology is On Board Sensing and Reporting (OSAR)

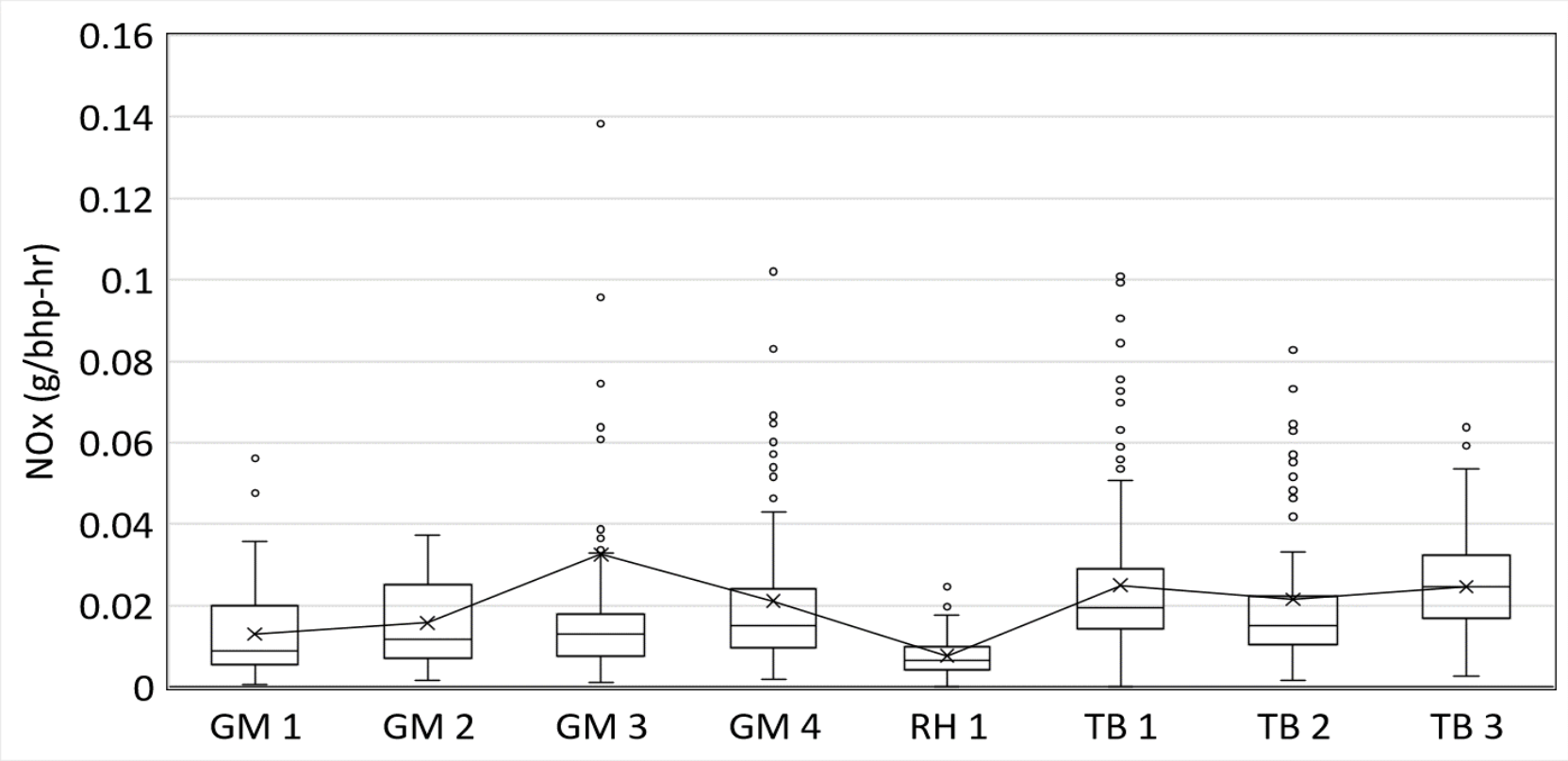
- Onboard Sensing Analysis and Reporting (OSAR) was developed for continuous monitoring of diesel technologies annually
- OSAR started out as a consortium lead research initiative, but has now grown to over nine funded programs
- OSAR includes
  - NOx, PM, GPS, CAN, and other sensors
  - Auto starting and shutdown to capture cold starts and all truck operation

NOx/O2 Module | PM Module | Data Logger (CAN, GPS, LTE) | GPS & LTE Antennas



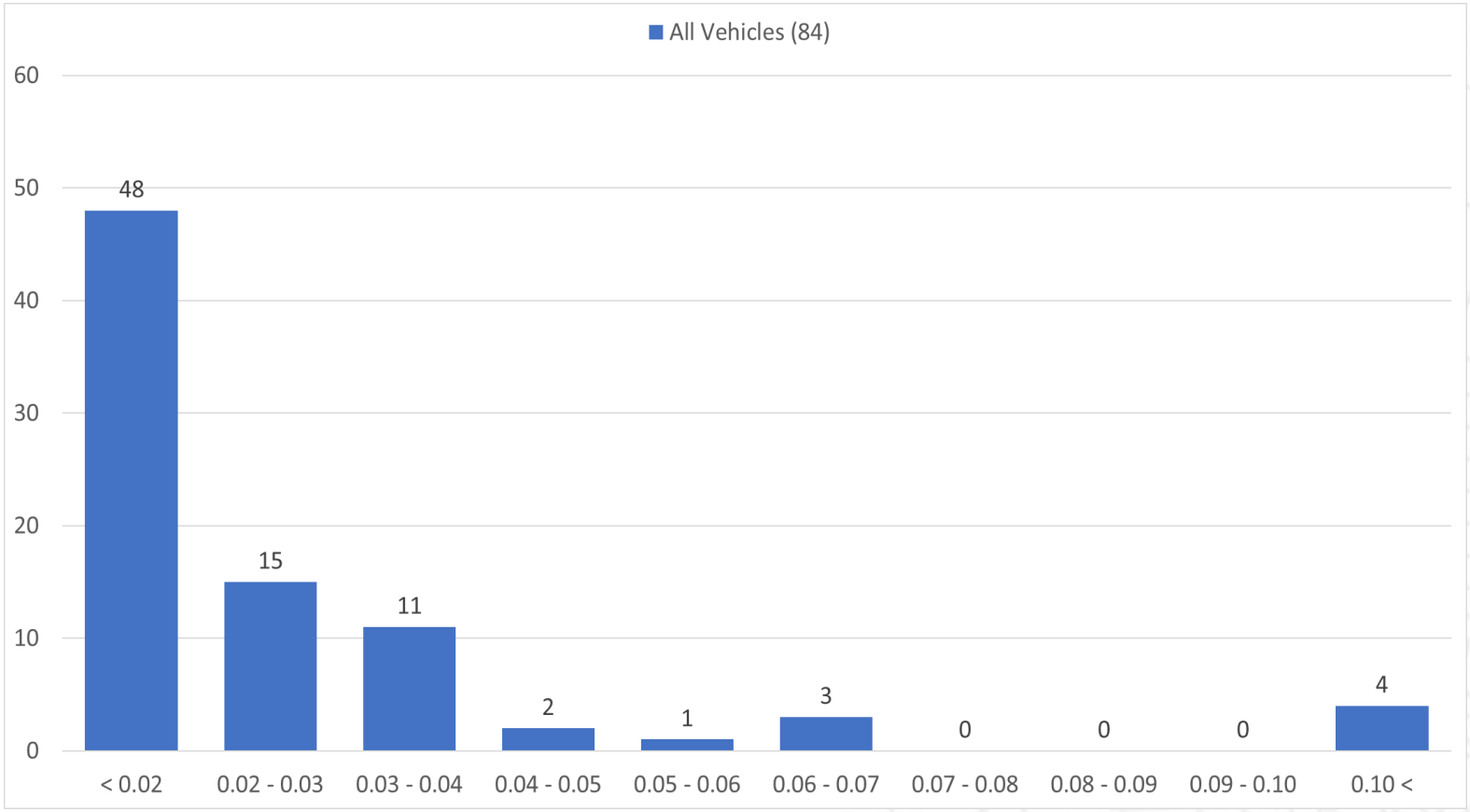
OSAR Monitoring of CNG Vehicles - I

- The average trip emissions for most fleets are on the order of the 0.02 g/bhp-hr level
- But there are outliers that have higher emissions



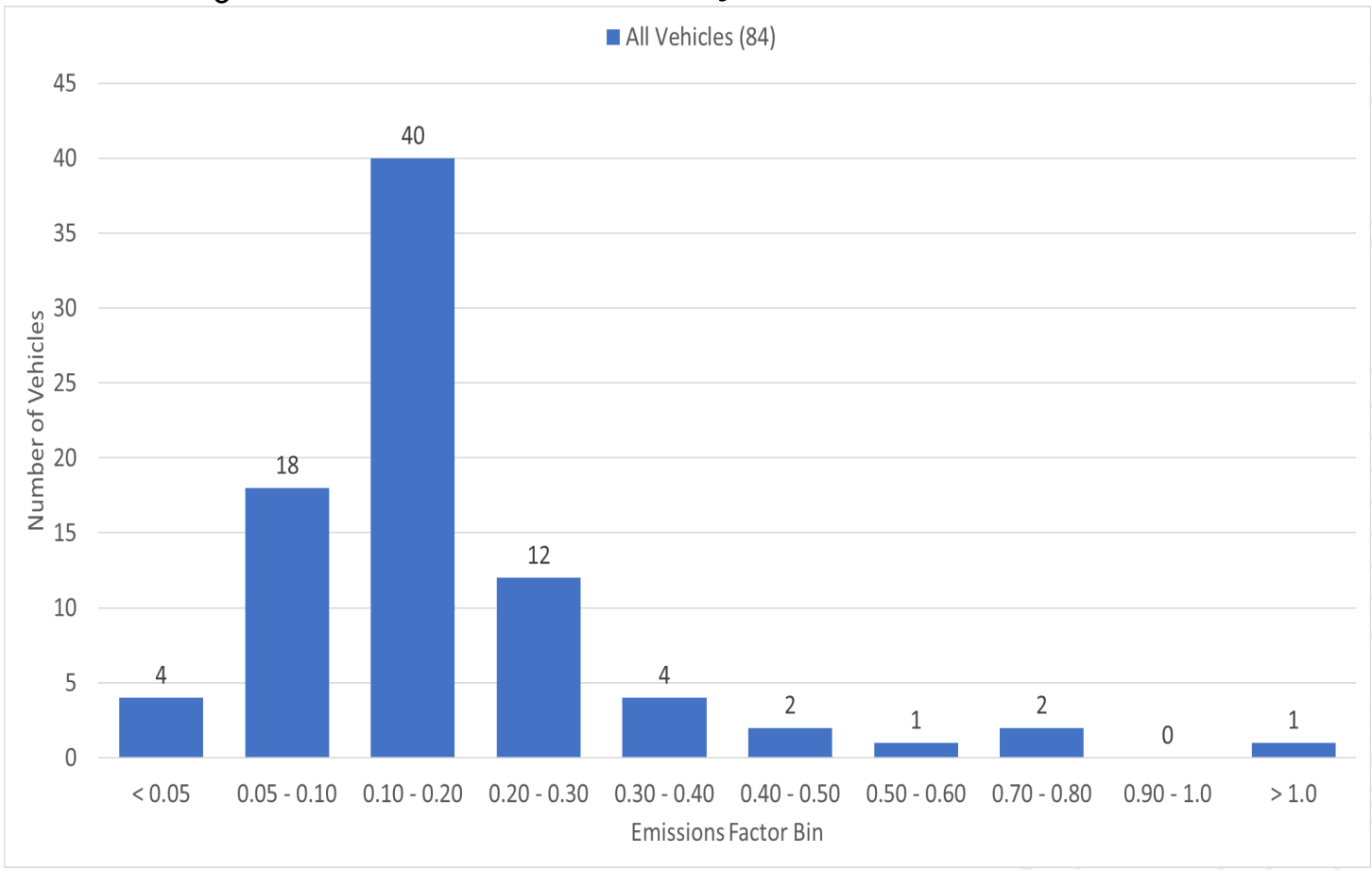
OSAR Monitoring of CNG Vehicles - II

- Based on sum of all NOx emissions over all work for each vehicle
- Most vehicles are operating within 2x of the 0.02 g/bh-hr limit
- But more investigation is needed for vehicles with > 0.1 NOx g/bhp-hr



CNG Vehicle Histogram
NH_3 Emissions

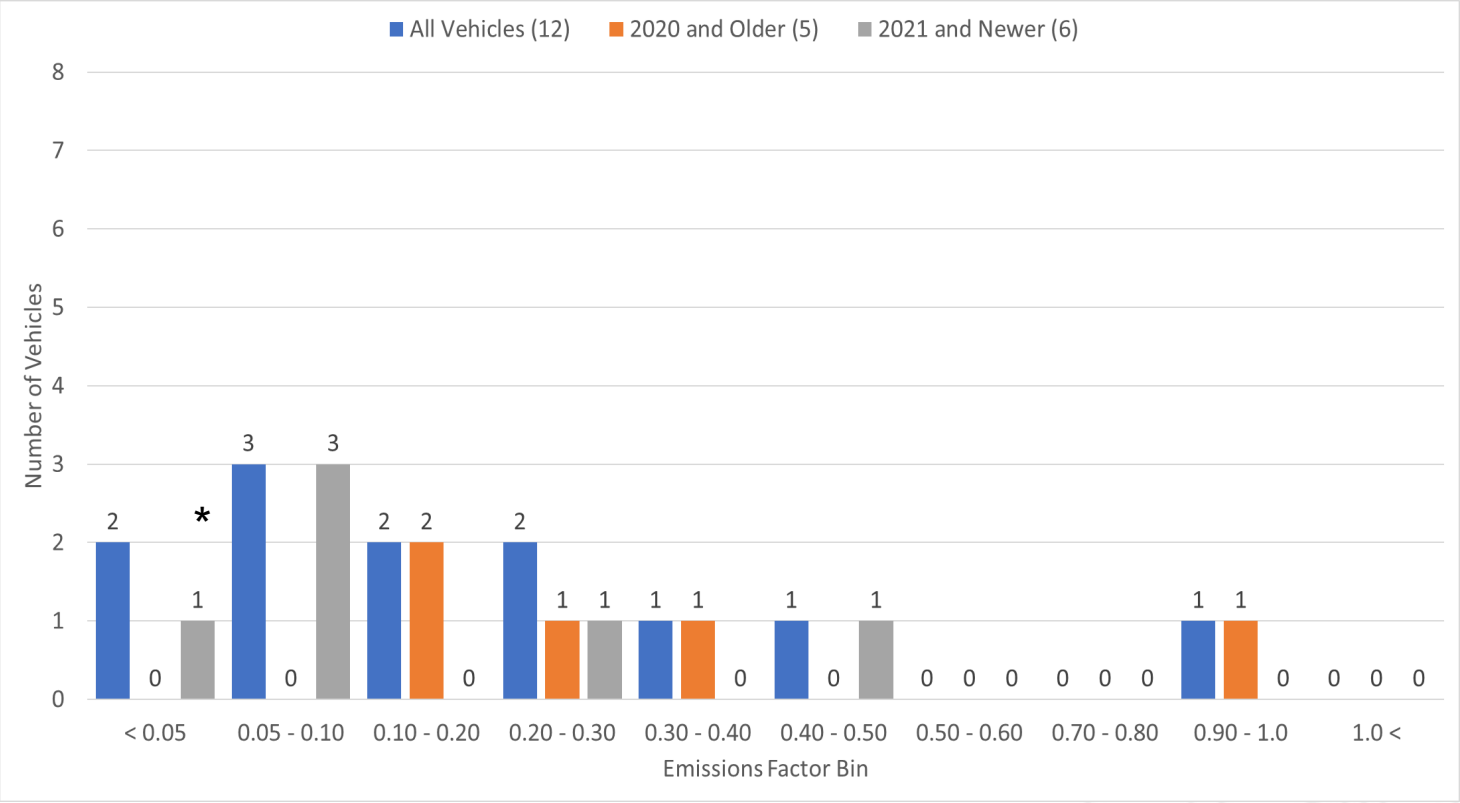
- To the extent that ultralow NOx CNG vehicles expand into the fleet, control of NH_3 emissions would likely need to be addressed more aggressively



Sum NOx g all trips
Sum Work all trips

Preliminary Diesel Vehicle Emissions Histogram

- Initial data is suggesting lower emission rates than found in “200 vehicle study, with some vehicles showing higher emissions than others.

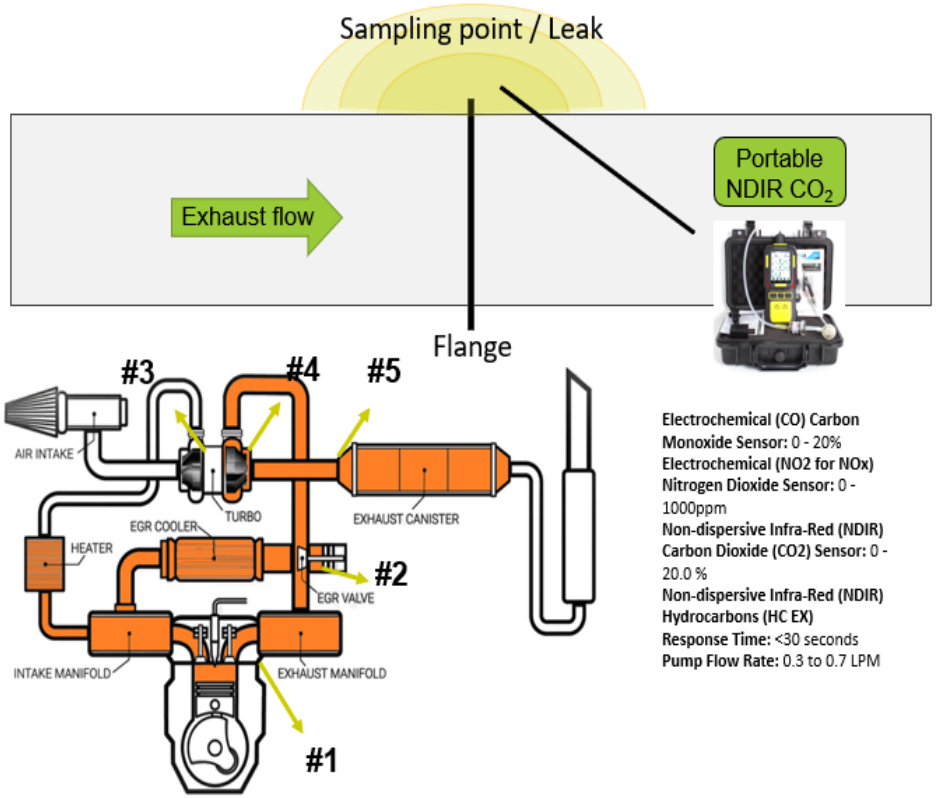


Sum NOx g all trips
Sum Work all trips

*The vehicle missing from this section is from the OEM fleet. We have not been given this information

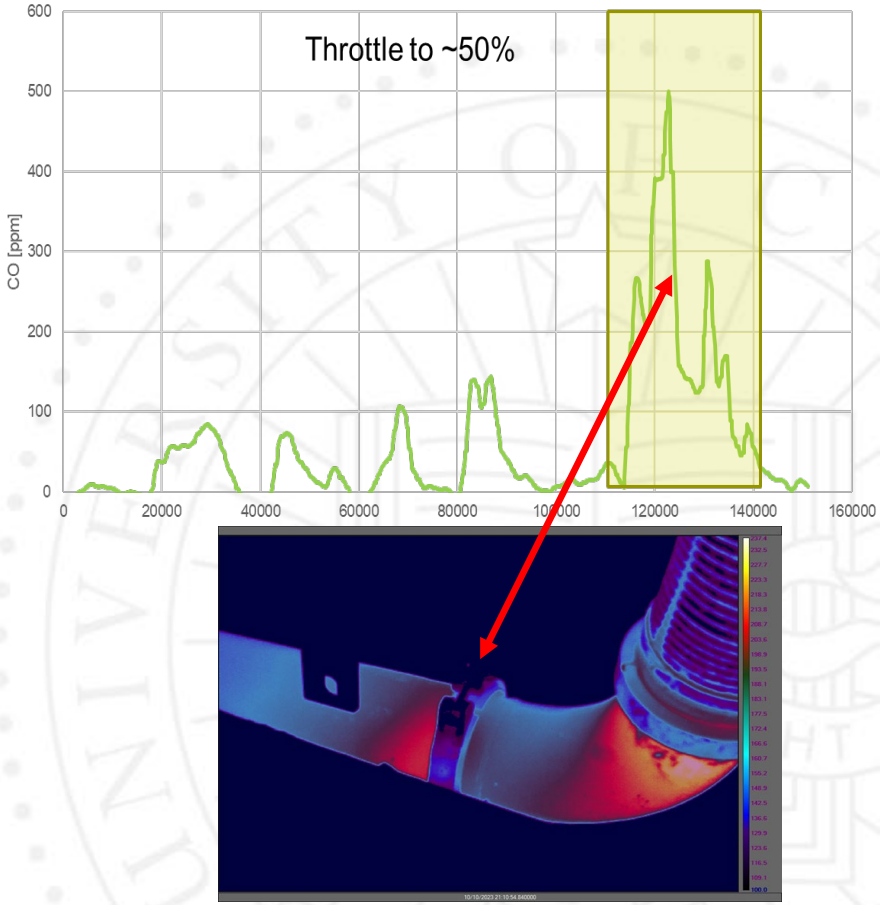
Monitoring for Leaks

- The potential for exhaust leaks prior to the aftertreatment system could add significantly to in-use emission rates
- CE-CERT is currently working on a CARB-funded project to evaluate the potential extent on more than 300 heavy-duty vehicles



Electrochemical (CO) Carbon Monoxide Sensor: 0 - 20%
Electrochemical (NO2 for NOx) Nitrogen Dioxide Sensor: 0 - 1000ppm
Non-dispersive Infra-Red (NDIR) Carbon Dioxide (CO2) Sensor: 0 - 20.0 %
Non-dispersive Infra-Red (NDIR) Hydrocarbons (HC EX)
Response Time: <30 seconds
Pump Flow Rate: 0.3 to 0.7 LPM

Figure 1 Illustration of sampling system methodology



Inspection and Maintenance Programs can play a big role in keeping emissions low

- **High emitters in-use will remain a key consideration for ICEs**
- **The CARB Clean Truck Check program is expected to be one of the most impactful programs approved in decades.**
- **Projected emissions reductions include:**
  - Reductions of 8.6 tons per day (tpd) NO_x and 0.09 tpd PM emissions in San Joaquin Valley (SJV) in 2024.
  - Reductions of statewide NO_x emissions by 81.3 tpd and PM emissions by 0.7 tpd in 2037.
- **Benefits of these PM and NO_x emissions reductions include**
  - Roughly 7,500 avoided premature deaths
  - 6,000 avoided hospitalizations statewide
  - Equivalent monetized health benefits of $75.8 billion for 2023-2050 period.
- **Clean Truck Check would reduce NOx from HDVs >14,000 lbs.**
  - Reductions of 50% in 2031, increasing to a 56% reduction by 2037 compared to baseline.

Inspection and Maintenance Programs can play a big role in keeping emissions low

- Trucks “caught” having high emissions will have to be brought to inspection locations to be evaluated
- UC Riverside CE-CERT involved in the CARBTest “referee” part of this of the program to CE-CERT in part because of our reputation as being an honest broker

Takeaways

- Climate change will likely remain one of the most significant challenges facing the world for the foreseeable future.
- An "All hands on deck" will be needed in the drive to a sustainable transportation future.
- Conventionally-fueled technology vehicles will play a important part in the intermediate term in achieving environmental metrics.
  - Some early data show trends towards lower in-use emissions with later generation vehicles, with some vehicles still having higher emissions.
  - If the vehicles can maintain ultralow emissions during operation, fleet turnover could provide 95% of emissions reductions from 2025 to 2040.
  - This could be coupled with greater renewable fuels use for reducing GHGs.
- Ensuring conventionally fueled vehicles can maintain low or ultralow emissions levels will likely be the key to ensuring continued progress towards achieving future air quality goals.
- Emissions monitoring and inspection will continue to play an important role as we continue our journey to a fully sustainable transportation sector.