CLEAN FUELS PROGRAM ADVISORY GROUP AGENDA
SEPTEMBER 8, 2022, 9:00 AM – 4:00 PM
South Coast AQMD - Remote Meeting

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https://scaqmd.zoom.us/j/91964955642
Zoom Webinar ID: 919 6495 5642 (applies to all)
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Audience will be allowed to provide public comment through telephone or Zoom connection.

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the South Coast AQMD Clean Fuels Program Advisory Group meeting will only be conducted via video conferencing and by telephone. Please follow the instructions below to join the meeting remotely.
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AGENDA

Members of the public may address this body concerning any agenda item before or during consideration of that item (Gov't. Code Section 54954.3(a)). If you wish to speak, raise your hand on Zoom or press Star 9 if participating by telephone. All agendas for regular meetings are posted at South Coast AQMD Headquarters, 21865 Copley Drive, Diamond Bar, California, at least 72 hours in advance of the regular meeting. Speakers may be limited to two (2) minutes each.

	Welcome & Overview - 9:00 – 10:00 AM	
(a)	Welcome & Introductions	Aaron Katzenstein, Ph.D., Deputy Executive Officer
(b)	Goals for the Day	Patricia Kwon, Acting Technology Demonstration Manager
(c)	South Coast AQMP Update	Sang-Mi Lee, Ph.D., Planning & Rules Manager
(d)	Feedback and Discussion	Advisors and Experts
(e)	Public Comment (2 minutes/person)	
1.	**Areas of South Coast AQMD Focus** **200 Vehicle In-Use Emissions Study – Summary and Lessons Learned** **10:00 AM – 12:30 PM**	
(a)	Background, Summary and Lessons Learned	Sam Cao, Ph.D., Program Supervisor
(b)	In-use Emissions Testing of On-Road Heavy-Duty Vehicles	Thomas Durbin, Ph.D., Research Engineer, UCR/CE-CERT
(c)	Impacts of Deterioration to In-Use Emissions from HD Trucks	Arvind Thiruvengadam, Ph.D. Associate Professor, WVU
(d)	EMFAC Updates using In-Use Data	Mo Chen, Ph.D., Air Pollution Specialist, CARB
(e)	Feedback and Discussion	Advisors and Experts
(f)	Public Comment (2 minutes/person)	
	Lunch 12:30 PM – 1:30 PM	

2.	Infrastructure Priorities and Challenges 1:30 PM – 3:00 PM	
(a)	Overview on Infrastructure Challenges	Watson Collins, EPRI
(b)	Volvo LIGHTS and JETSI Projects	Seungbum Ha, Ph.D., Program Supervisor
(c)	Hydrogen Infrastructure	Maryam Hajbabaei, Ph.D., Program Supervisor
(d)	Electric School Buses/Infrastructure	Joseph Lopat, Program Supervisor
(e)	Feedback and Discussion	Advisors and Experts
(f)	Public Comment (2 minutes/person)	
3.	**Wrap-up – 3:00 PM – 4:00 PM**	
(a)	2023 CF Proposed Plan Update Discussion & Wrap-up	Aaron Katzenstein, Ph.D., Deputy Executive Officer
(b)	Advisor and Expert Comments	All
(c)	Public Comment (2 minutes/person)	

Other Business
Any member of the Advisory Group, or its staff, on his or her own initiative or in response to questions posed by the public, may ask a question for clarification; may make a brief announcement or report on his or her own activities, provide a reference to staff regarding factual information, request staff to report back at a subsequent meeting concerning any matter, or may take action to direct staff to place a matter of business on a future agenda. (Gov't. Code Section 54954.2)

Public Comment Period
At the end of the regular meeting agenda, an opportunity is provided for the public to speak on any subject within the Advisory Group's authority that is not on the agenda. Speakers may be limited to two (2) minutes each.

Document Availability
All documents (1) constituting non-exempt public records; (ii) relating to an item on the agenda for a regular meeting; and (iii) having been distributed to at least a majority of the Advisory Group after the agenda is posted, are available by contacting Donna Vernon at 909-396-3097 from 7:00 a.m. to 5:30 p.m., Tuesday through Friday, or send the request to dvernon@aqmd.gov.

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Instructions for Participating in a Virtual Meeting as an Attendee
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Before joining the call, please silence your other communication devices such as your cell or desk phone. This will prevent any feedback or interruptions during the meeting.

Please note: During the meeting, all participants will be placed on Mute by the host. You will not be able to mute or unmute your lines manually.

After each agenda item, the Chairman will announce public comment.

Speakers will be limited to a total of three (3) minutes for the Consent Calendar and Board Calendar, and three (3) minutes or less for other agenda items.
A countdown timer will be displayed on the screen for each public comment.

If interpretation is needed, more time will be allotted.

Once you raise your hand to provide public comment, your name will be added to the speaker list. Your name will be called when it is your turn to comment. The host will then unmute your line.

Directions for Video ZOOM on a DESKTOP/LAPTOP:

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- This will signal to the host that you would like to provide a public comment and you will be added to the list.

Directions for Video Zoom on a SMARTPHONE:

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- This will signal to the host that you would like to provide a public comment and you will be added to the list.

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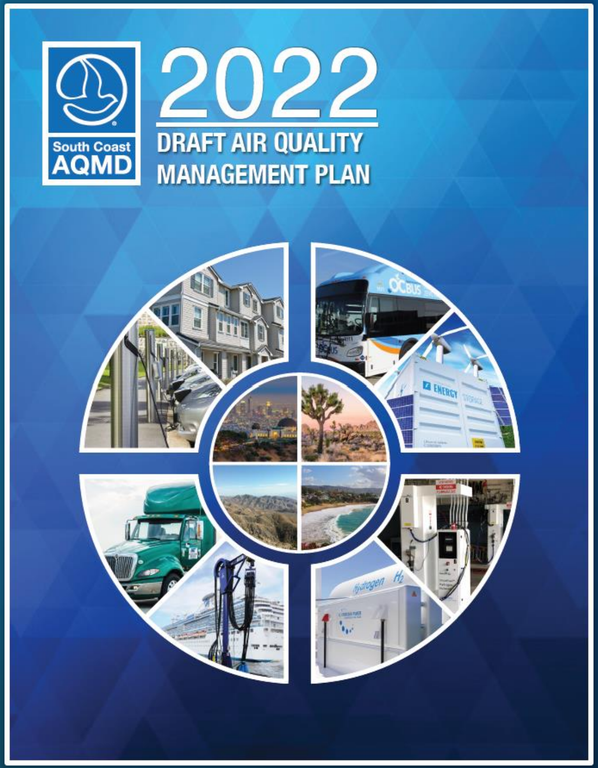
South Coast
AQMD

DRAFT 2022 AIR QUALITY MANAGEMENT PLAN

South Coast Air Quality
Management District

2022 Air Quality Management Plan (AQMP)

- AQMP is a blueprint to improve air quality and achieve federal air quality standards in the South Coast Air Basin and Coachella Valley
- In 2015, the U.S. EPA tightened the ozone air quality standard to 70 parts per billion (ppb), triggering the need to develop an AQMP
- The 2022 AQMP addresses control strategy to meet the ozone standard by 2037
- The Draft 2022 AQMP and all supporting documents are available online at: http://www.aqmd.gov/2022aqmp



Our Challenge

Los Angeles c. 1950

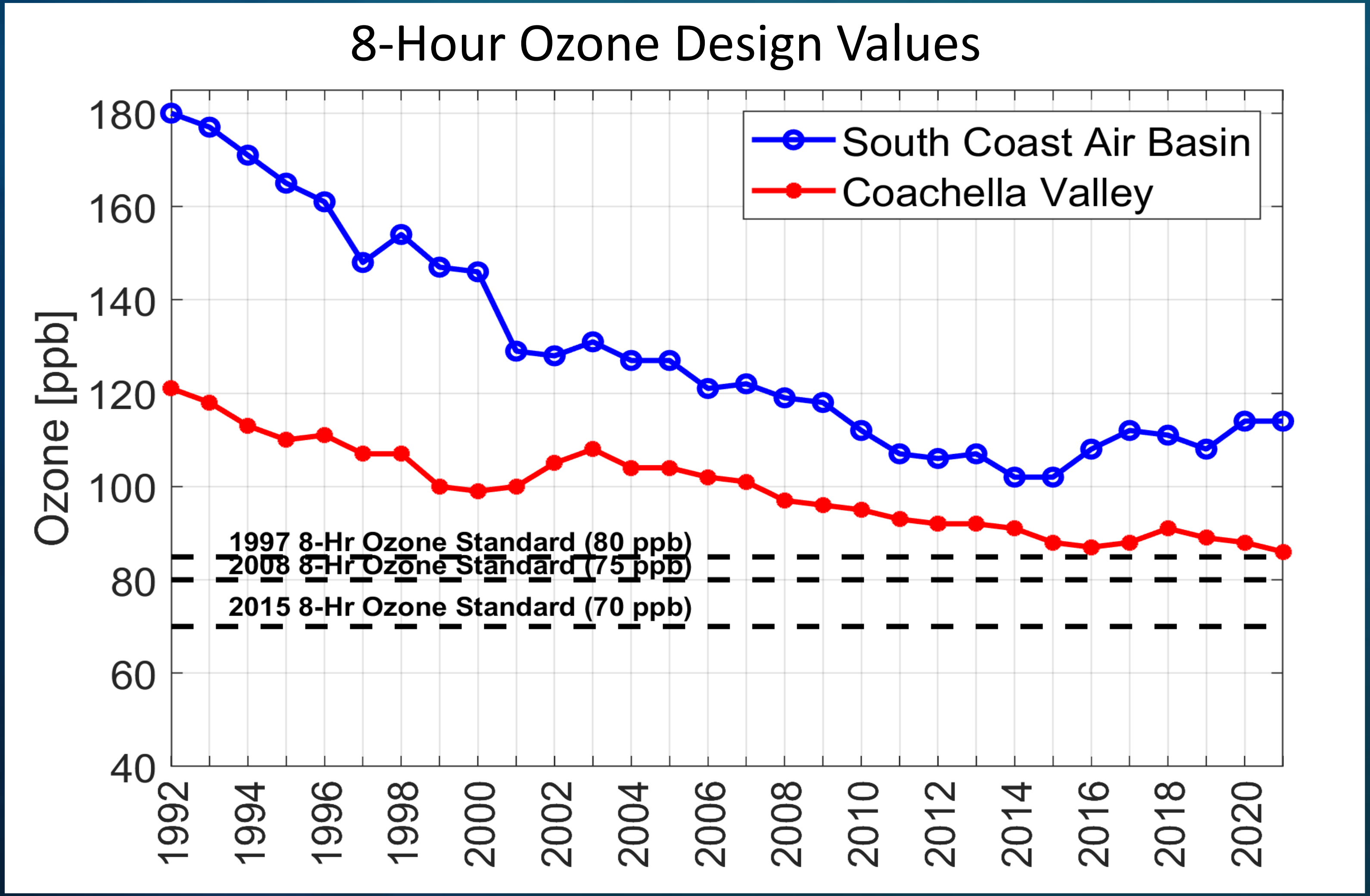
Our region has historically suffered from some of the worst air quality in the United States

We have made significant progress, but still suffer from poor air quality

- Worst ozone (smog) in the nation
- Among the worst fine particulate matter (PM2.5)

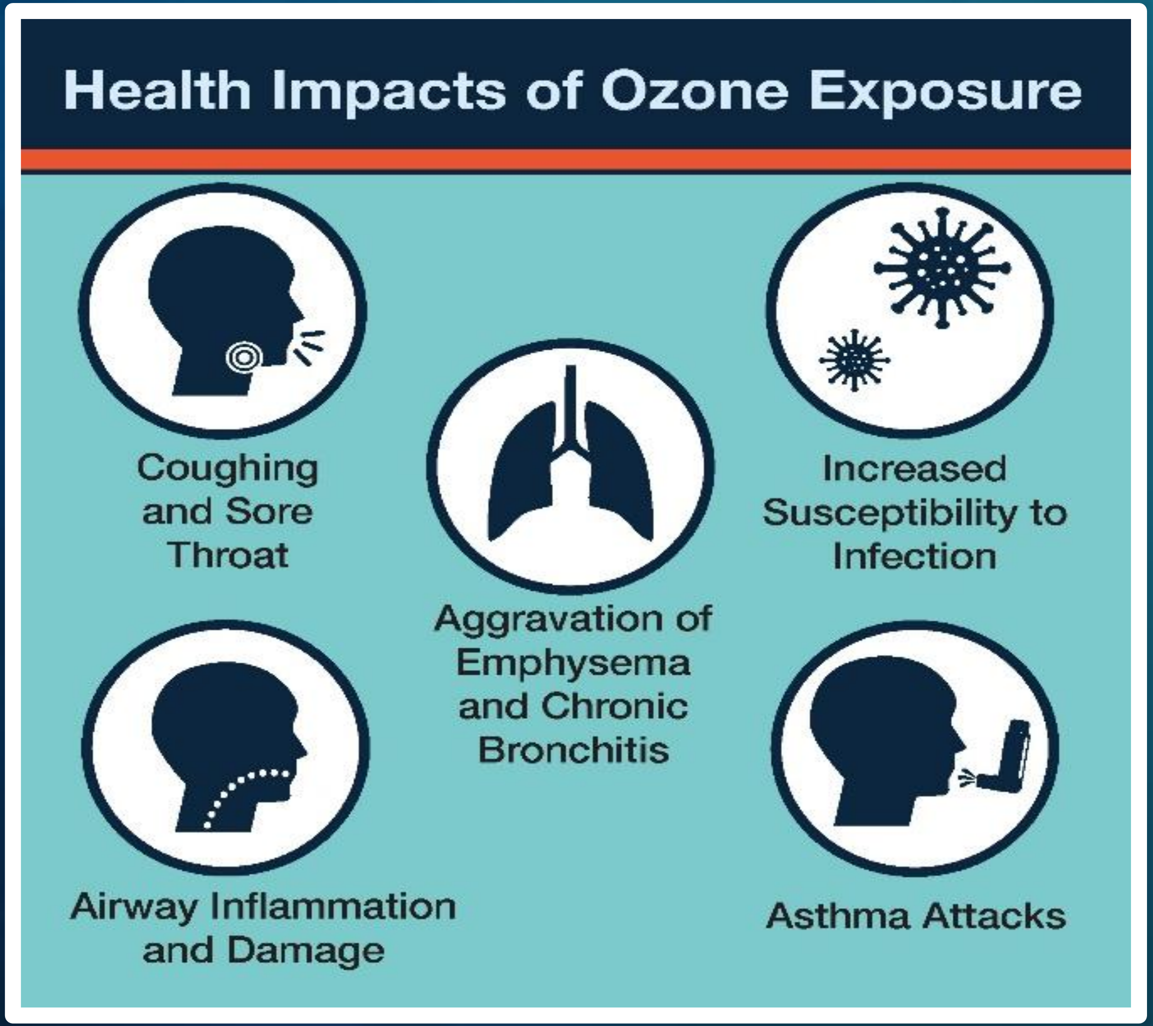
Los Angeles Recent Condition (2018)

Ozone Trends in the South Coast Air Basin



- Overall air quality has dramatically improved
- High ozone in recent years were due to adverse meteorology. Continued emission reductions will improve ozone

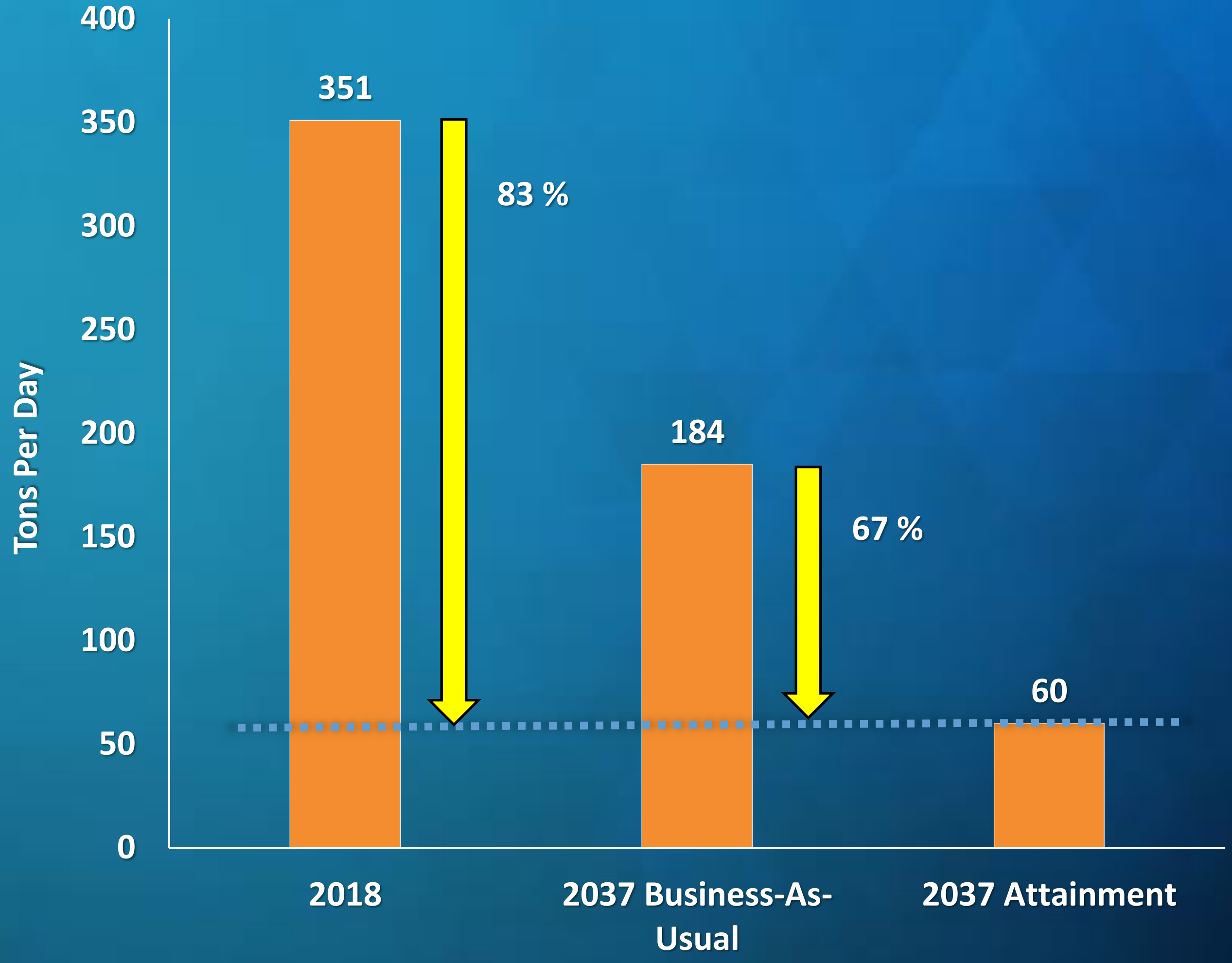
Health Impacts of Ozone



- Ozone precursor pollutants also increase fine particulate (PM2.5) pollution
- PM2.5 can cause premature death in addition to other serious health effects

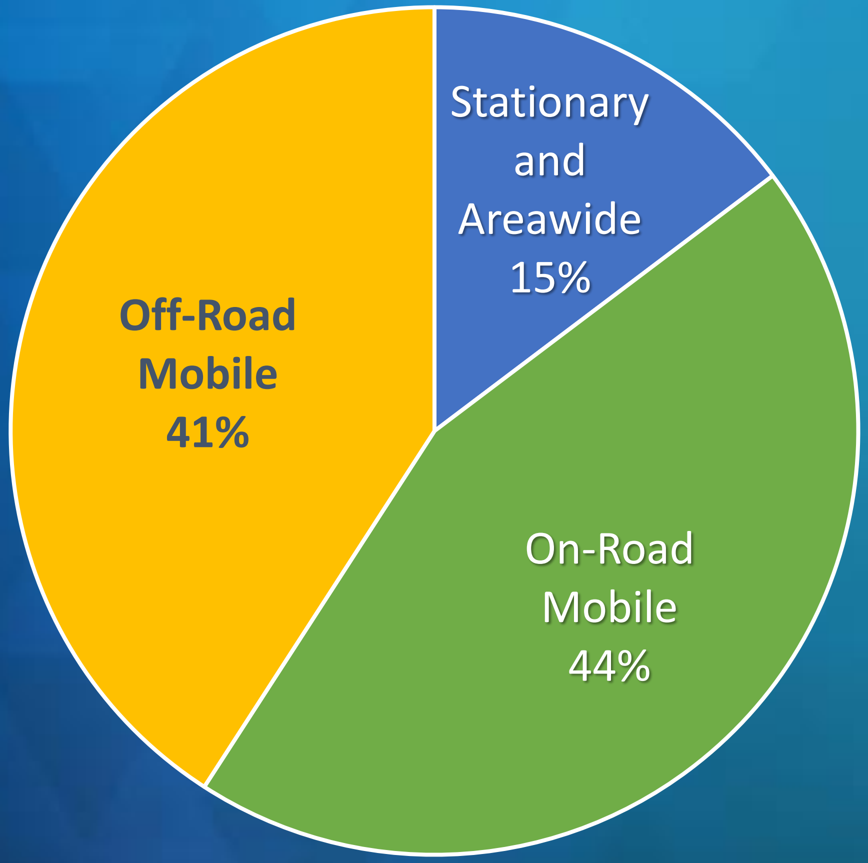
Need to Reduce NOx Emissions

- The primary pollutant that must be controlled to reduce ozone in our region is nitrogen oxides (NOx)
- NOx is formed during processes that burn fuels
- NOx must be reduced to 60 tons per day to meet the ozone standard
  - 83% below current conditions
  - 67% below Business-As-Usual conditions in 2037

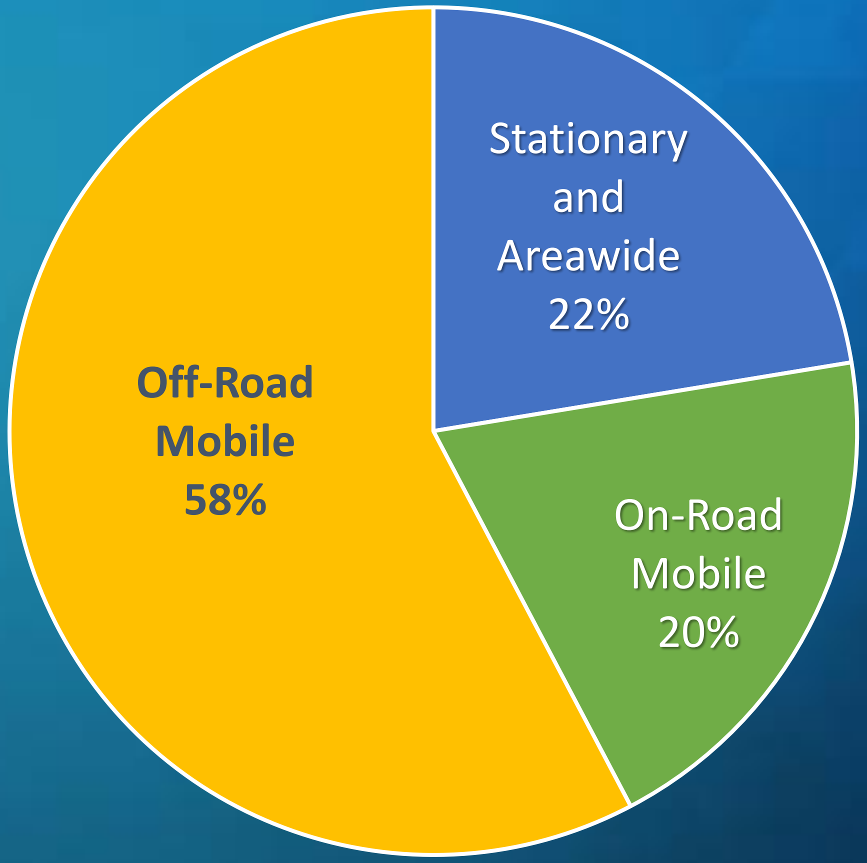


NOx Emission from Different Source Category

2018 NOx Emission
351 tons per day

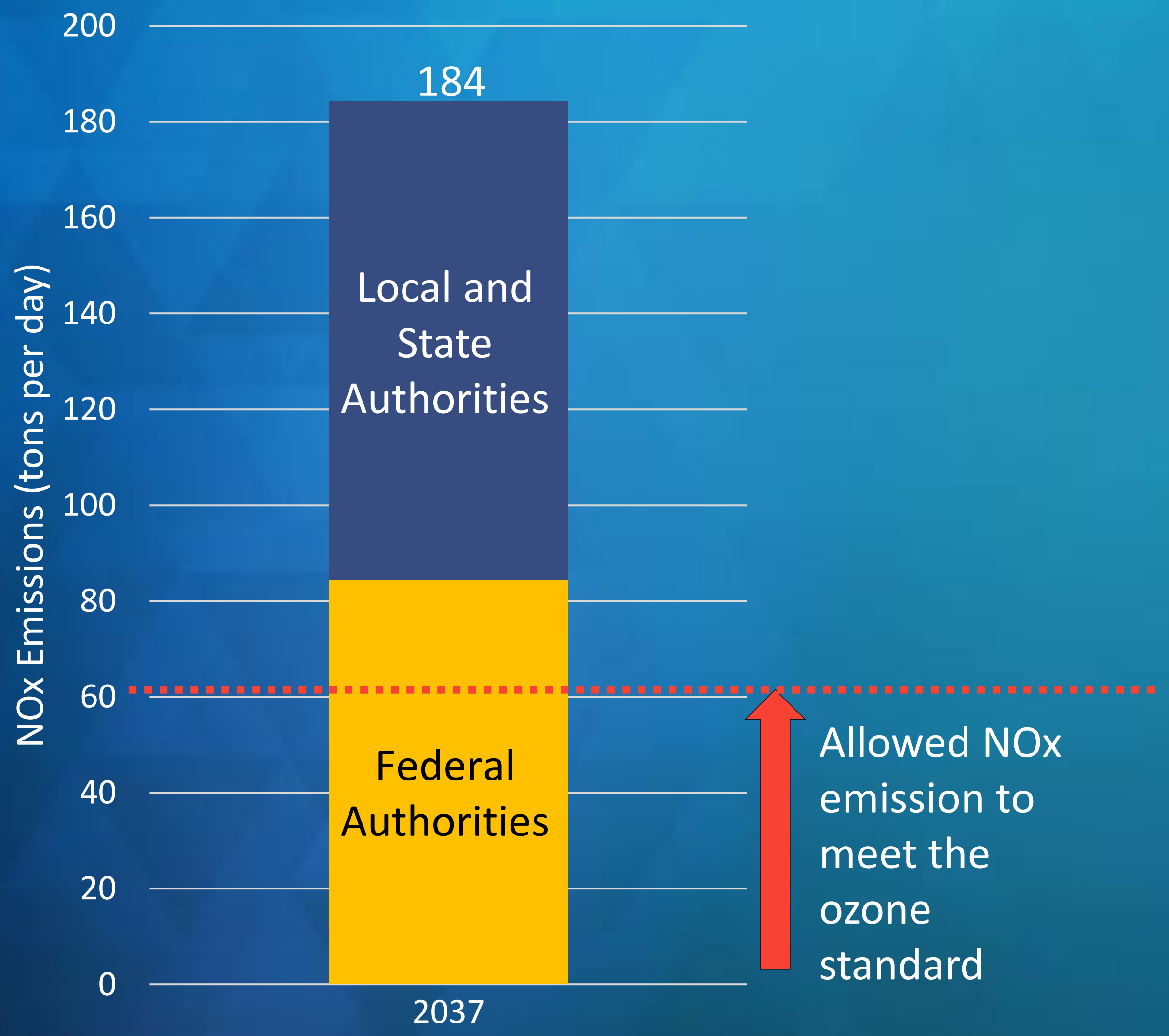


2037 NOx Emission
184 tons per day



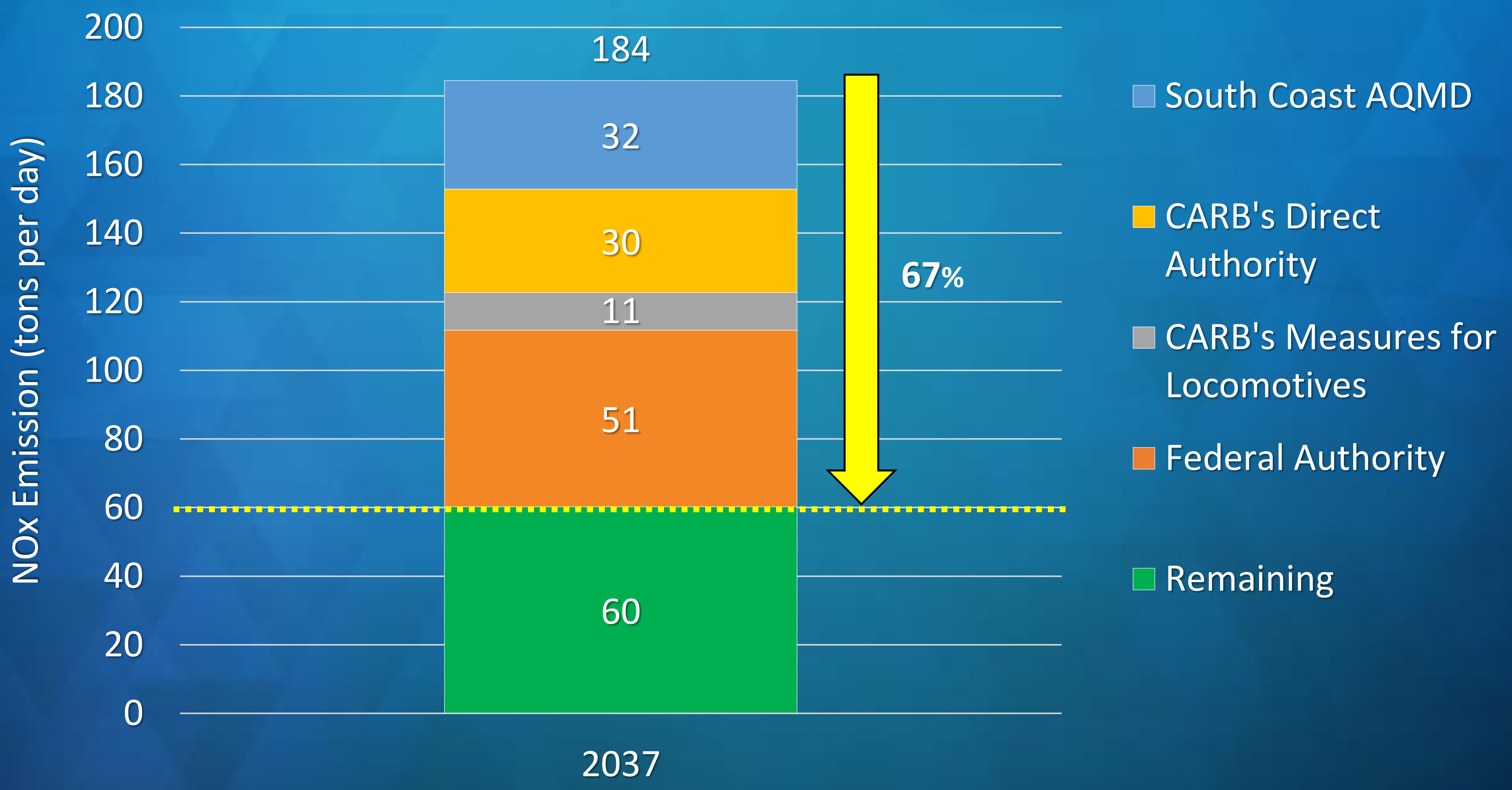
Over 80% of the NOx Emission in 2018 is from mobile sources

Shared Responsibility for Emission Reductions



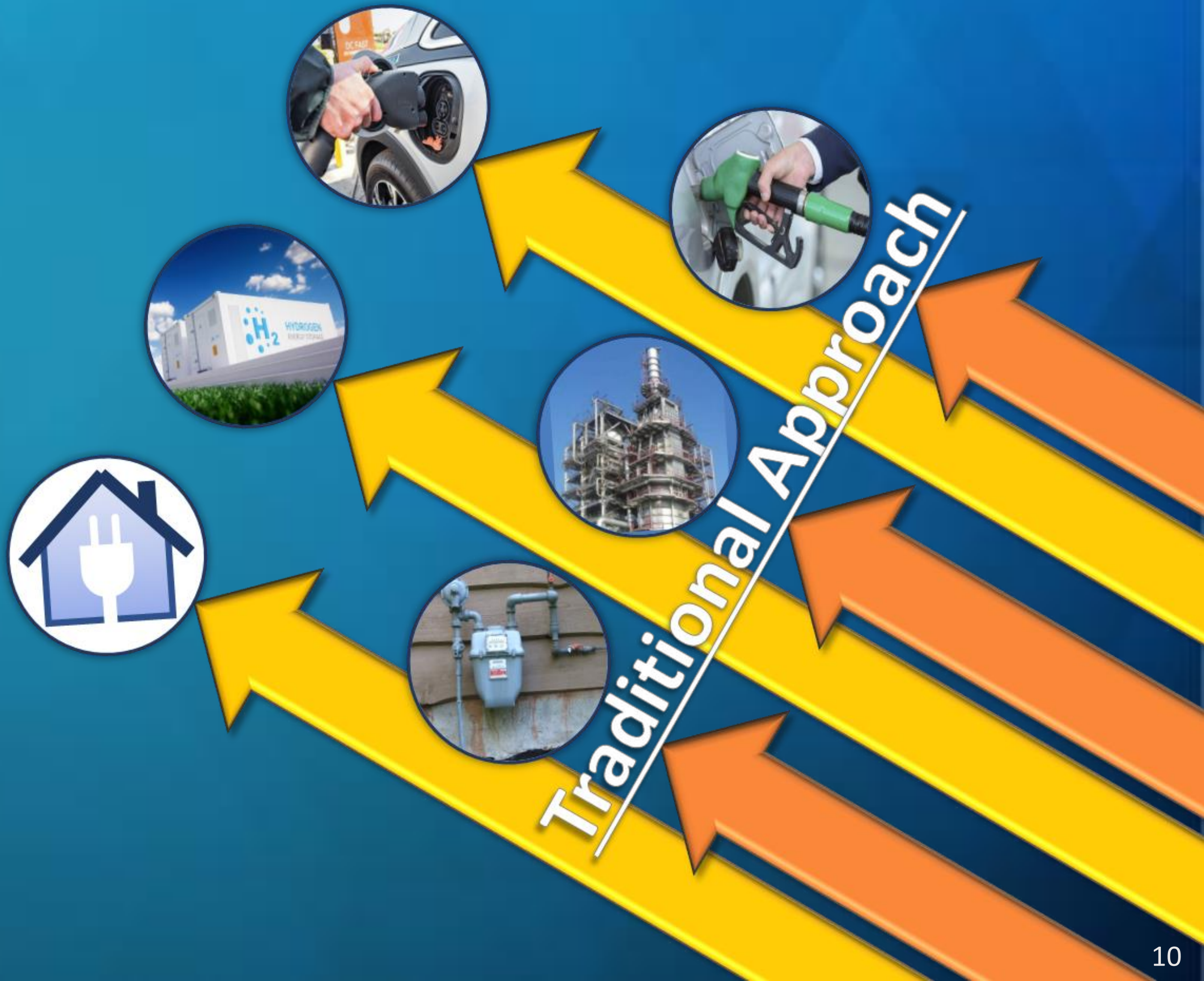
- More than 1/3 of the 2037 baseline emissions inventory is regulated primarily under federal and international jurisdiction, with limited authority for CARB/South Coast AQMD
  - Ships, aircraft, locomotives, etc
- Cannot assign responsibility to federal government to reduce emissions, even from federal sources
- Attainment is not possible without significant reductions from these sources

NOx Reductions Needed for Attainment



Innovative Approaches Needed

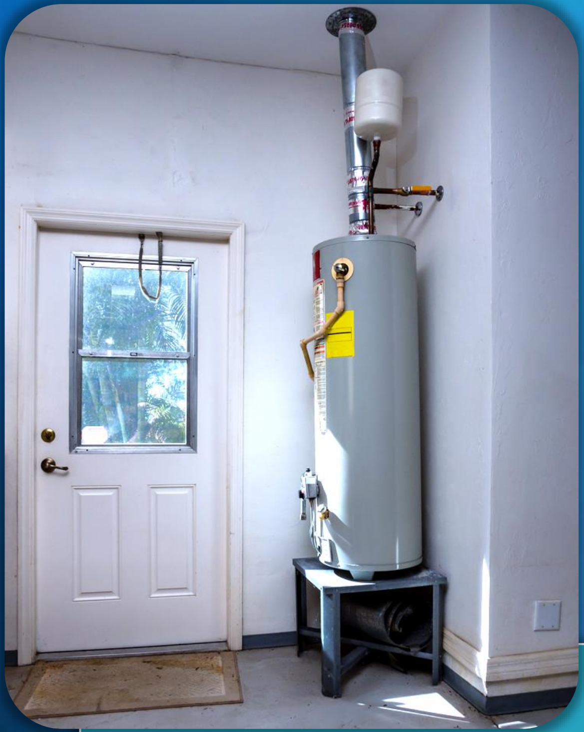
- Traditional approach relies on additional tailpipe/exhaust stack controls, new engines technology, or fuel improvements tailored to individual use cases
- These traditional approaches will not reduce emissions by the amount needed
- We must turn to zero emission and advanced technologies wherever possible



Overview of Draft South Coast AQMD Stationary and Area Source Control Strategy

- NOx Control Measures
- Co-Benefits from Greenhouse Gas Reductions
- Limited Strategic VOC Measures
- Other Measures

Draft Stationary and Area Sources NOx Control Measures



Residential Combustion
Water/Space/Heating/
Cooking/Others

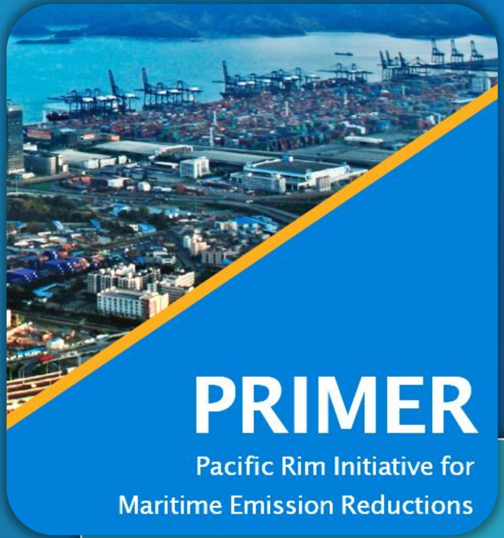
Commercial Combustion
Water/Space/Heating/
Cooking/Others

Industrial Combustion
Boilers/Process Heaters/
Refineries/EGUs/Etc.

Overview of Draft South Coast AQMD Mobile Source Control Strategy

Facility-Based
- Airports
- Marine Ports
- Railyards
- Warehouses

Emissions Growth
- Clean Construction
- New and Re-development



Incentive and Partnership
- Incentive Funding
- PRIMER

Public Input and Outreach

Development Process

- Release of the Draft 2022 AQMP: May 6, 2022
- Public comments were received during May 6 – July 22, 2022
- Revised 2022 AQMP to be released in late Summer
- Upcoming public meetings and schedule:

Timeline	Milestone
Early September, 2022	Release Revised Draft 2022 AQMP
October 7, 2022	Status update on Draft 2022 AQMP development to South Coast AQMD Governing Board and Set Hearing
October 12-20, 2022	Regional Public Hearings
December 2, 2022	South Coast AQMD Board Consideration of Draft Final AQMP

Regional Public Hearings

2022 AQMP Regional Public Hearings	Date	Time	Location
Regional Public Hearing for Los Angeles County	Wednesday October 12, 2022	2:00 p.m.	https://scaqmd.zoom.us/j/97319116794 Zoom Webinar ID: 973 1911 6794 Teleconference Dial In: +1 669 900 6833
Regional Public Hearing for San Bernardino County	Wednesday October 12, 2022	6:00 p.m.	https://scaqmd.zoom.us/j/91005796281 Zoom Webinar ID: 910 0579 6281 Teleconference Dial In: +1 669 900 6833
Regional Public Hearing for Coachella Valley	Tuesday October 18, 2022	6:00 p.m.	https://scaqmd.zoom.us/j/99950751763 Zoom Webinar ID: 999 5075 1763 Teleconference Dial In: +1 669 900 6833
Regional Public Hearing for Orange County	Wednesday October 19, 2022	1:00 p.m.	https://scaqmd.zoom.us/j/97747622239 Zoom Webinar ID: 977 4762 2239 Teleconference Dial In: +1 669 900 6833
Regional Public Hearing for Riverside County	Thursday October 20, 2022	1:00 p.m.	https://scaqmd.zoom.us/j/94508364659 Zoom Webinar ID: 945 0836 4659 Teleconference Dial In: +1 669 900 6833

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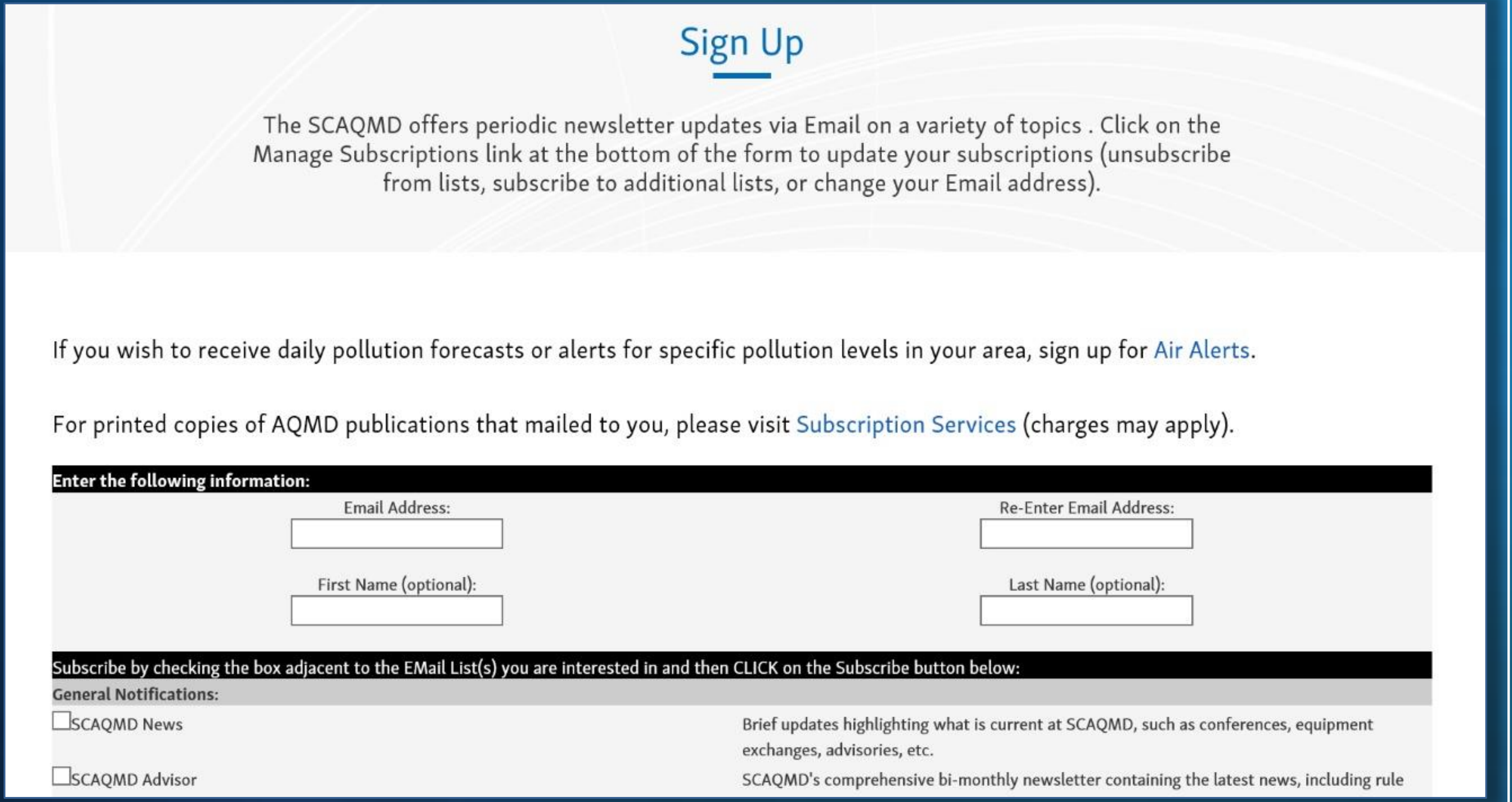

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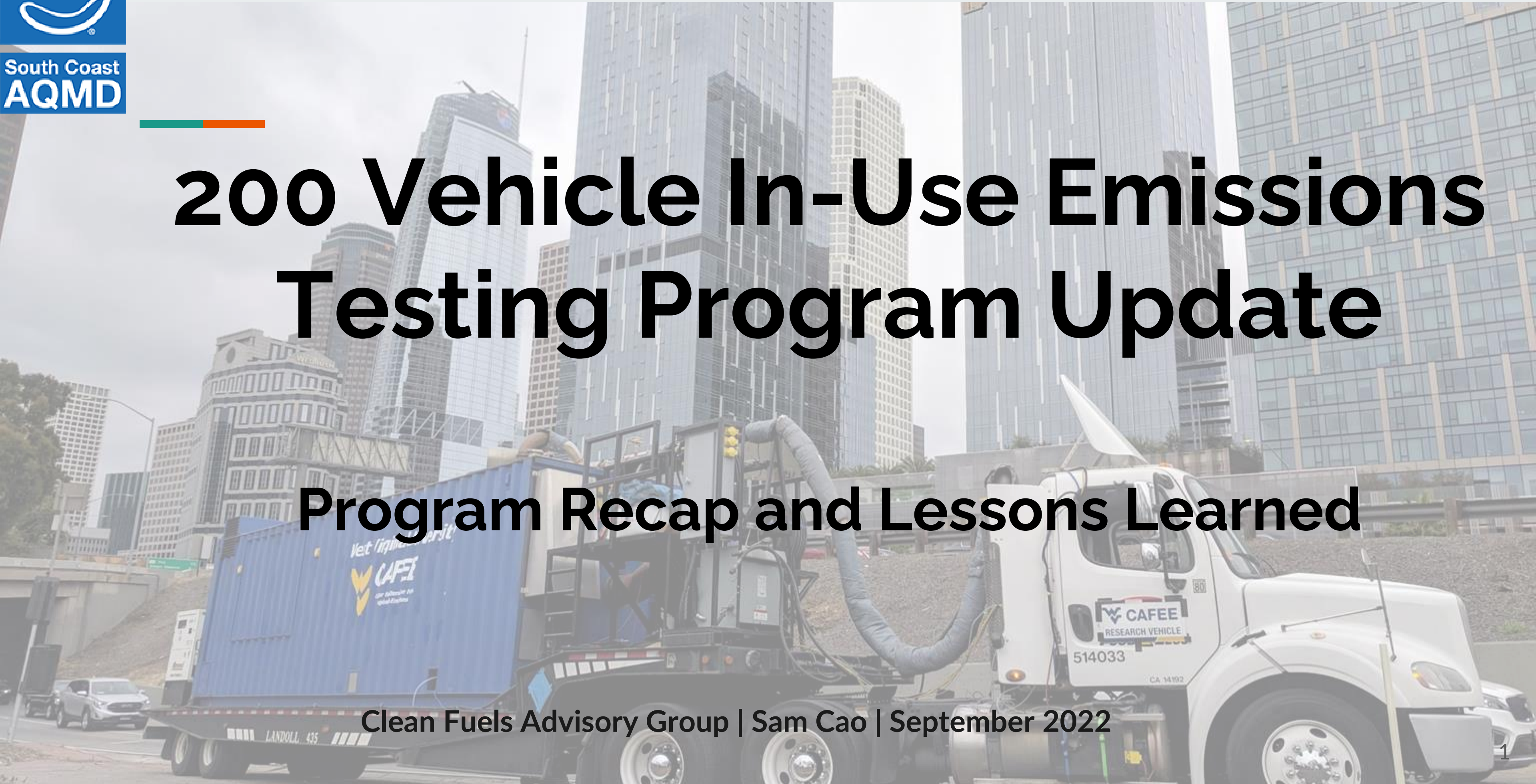
☑ **2022 AQMP Interested Parties**

For comments or questions, please email:
AQMPteam@aqmd.gov

200 Vehicle In-Use Emissions Testing Program Update

Program Recap and Lessons Learned

Clean Fuels Advisory Group | Sam Cao | September 2022



South Coast AQMD

Program Summary & Accomplishments

Identify technology benefits/shortfalls, feed information into future R&D opportunities and regulation development, and improve emissions inventory estimates

Total Vehicles Recruited

236

22 Vehicle OEMs, 9 Engine OEMs, 227 PAMS tests, 100 PEMS tests, 55 Chassis tests, 10 On-Road tests

Vocations Covered

5

39 Fleets: Delivery (52), Goods Movement (99), Transit Bus (26), School Bus (30) and Refuse (32)

Technologies Covered

10

Propane 0.2/0.02 (9), CNG 0.02 (43), CNG 0.2 (83), No SCR Diesel (7), Diesel 0.2 (75), Diesel-Hybrid (6), BEV (10), FCEV (2), HDPI (4)

Testing Elements of This Study

New Chassis Test Cycle

Route Information

PAMS
Activity, Average Speed, VMT, Idle, Starts

PEMS
Real-World Data, NTE/WBW, Start/Running Emissions

Chassis
Lab Grade Data, Real-Word Cycles Start/Running Emissions

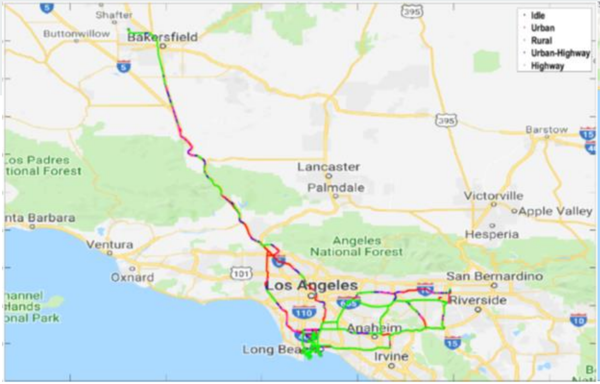
On-Road
Real-World Lab Grade Data, NTE/WBW Start/Running Emissions

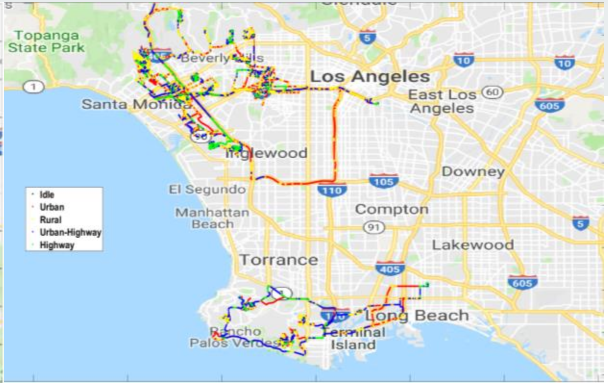
Emission Inventory

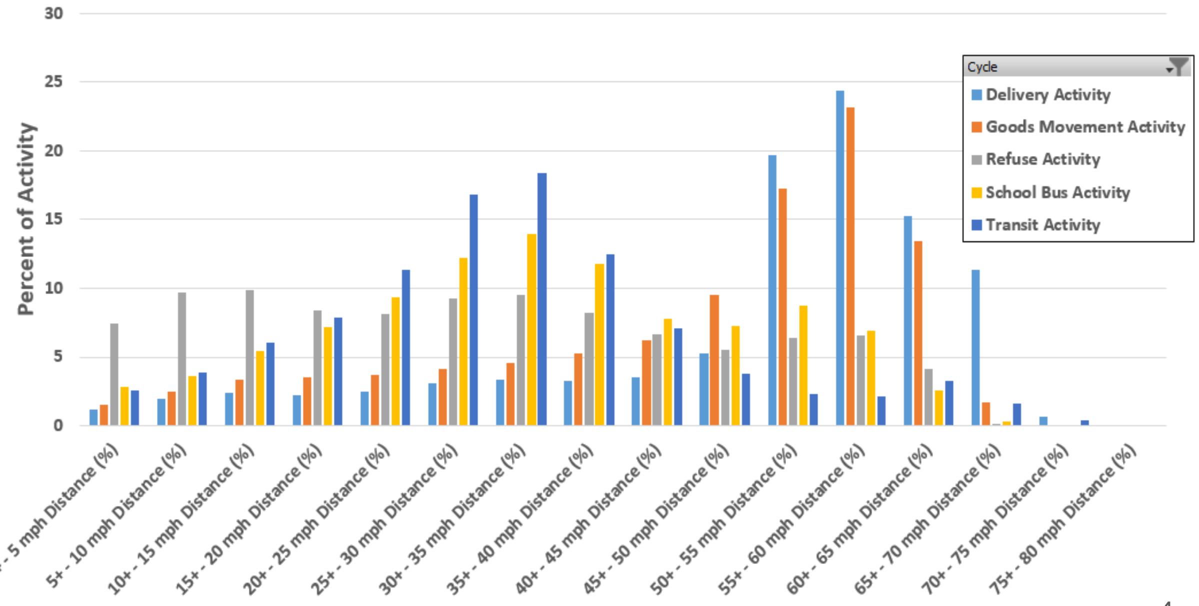
* PAMS: Portable Activity Measurement Systems; PEMS: Portable Emissions Measurement Systems

Key Findings - PAMS

- Idle, low-speed, low power operation dominated activity data set
- Higher vehicle speed for delivery and goods movement, transit and school buses lower, refuse lowest
- 162 PAMS dataset was input into EMFAC 2021
- Three (3) new chassis cycles, four (4) new real world test routes developed from PAMS data
- Data shared/leveraged in other studies
  e.g. CEC HEVI-LOAD





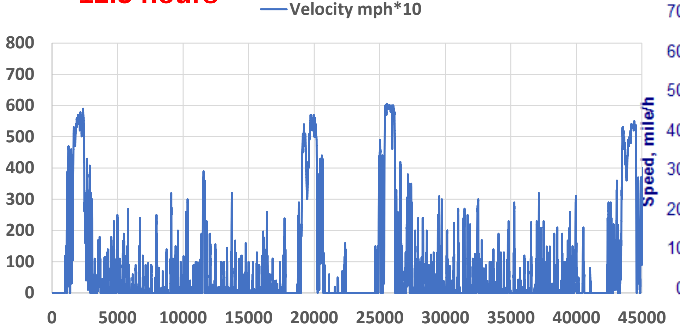


Understand Duty-Cycle and Averaging Method

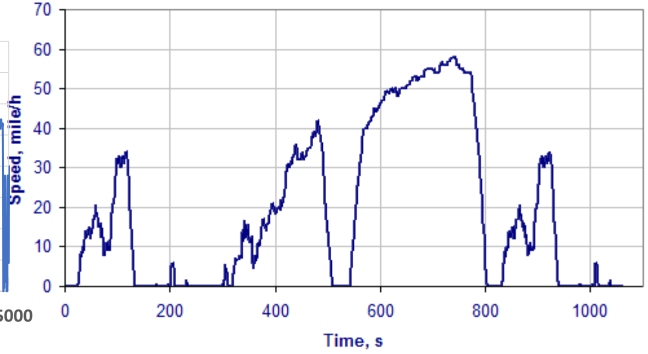
- Duty cycle could have strong impact on results
- *Not the Same*: E.G. Vehicle 101 0.2g NG Goods Movement Trucks, 0.33 g/bhp-hr PEMS, 0.07 – 0.13 g/bhp-hr Chassis, 0.05 to 0.10 g/bhr-hr On-Road, and 0.2 g/bhp-hr engine FTP cycle
- Units and averaging method can impact results
- Real-world variability (other than test article can also impact results
- Relative baseline?

Testing Phase	Averaging Method	Alternative Method
PEMS	"Daily" Averaged	NTE, 3B-MAW, speed bin
Chassis	"Cycle Averaged"	UDDS closest to FTP, vocational are not
On-Road	"Route Averaged"	Segmented, NTE, 3B-MAW, speed bin

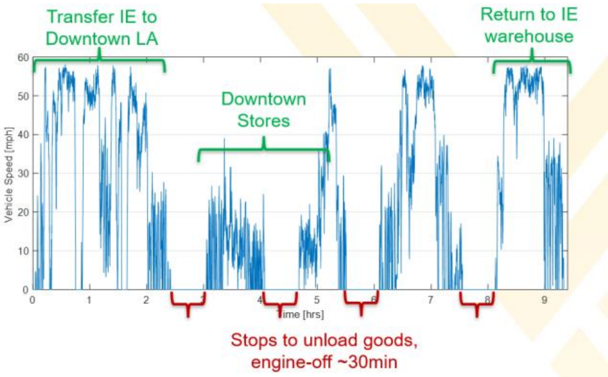
PEMS, a typical refuse truck working day, ~12.5 hours



Chassis, UDDS cycle, ~18 mins (Similar to engine FTP)

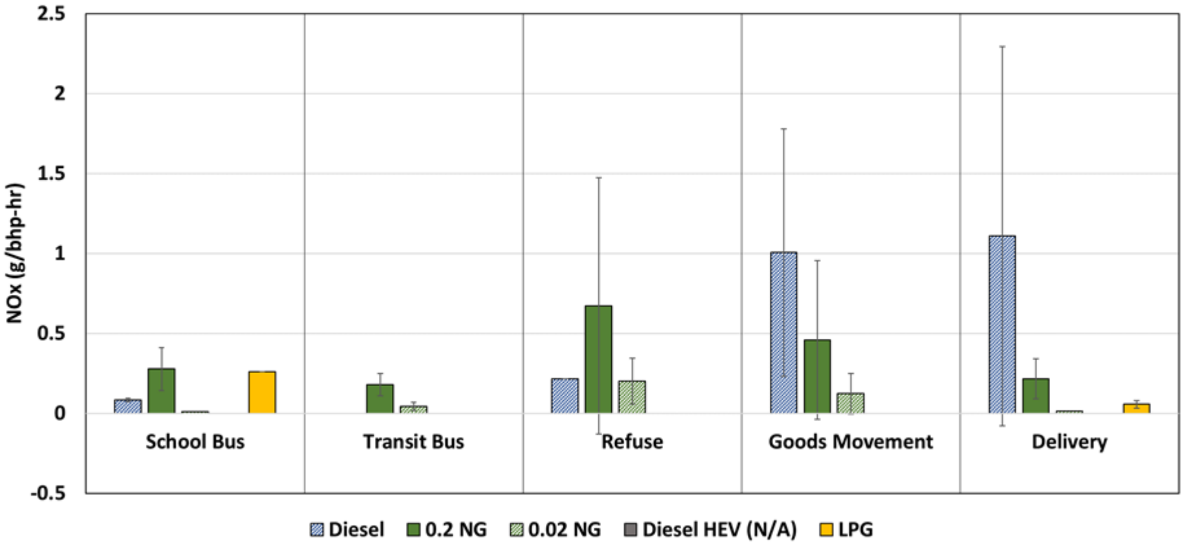


On-Road grocery route, ~9.35 hours



*(see Sept 2021 Clean Fuels update)

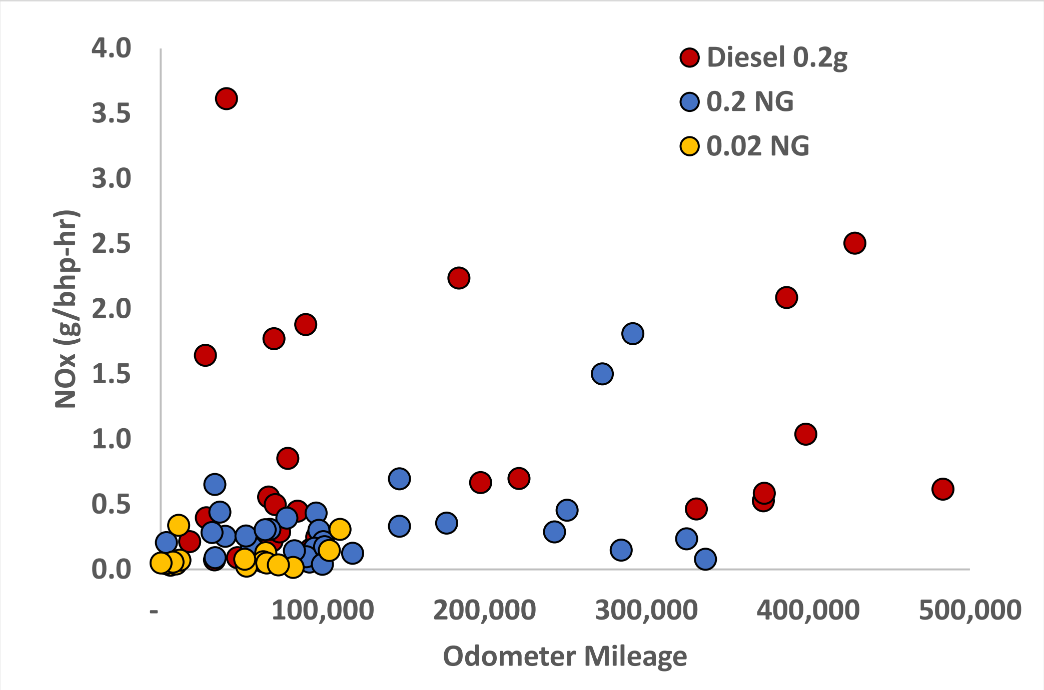
PEMS "Daily" Averaged NOx Emissions show High Variability



- High variability due to diverse set of HDVs, fleet operators and duty cycles
- Technology trends clear (alternative fuel showed significant reductions relative to baseline)
- Very low % data within NTE zone
- (46) 0.2g and 0.02g NG HDV inputted into EMFAC 2021(see CARB presentation later)

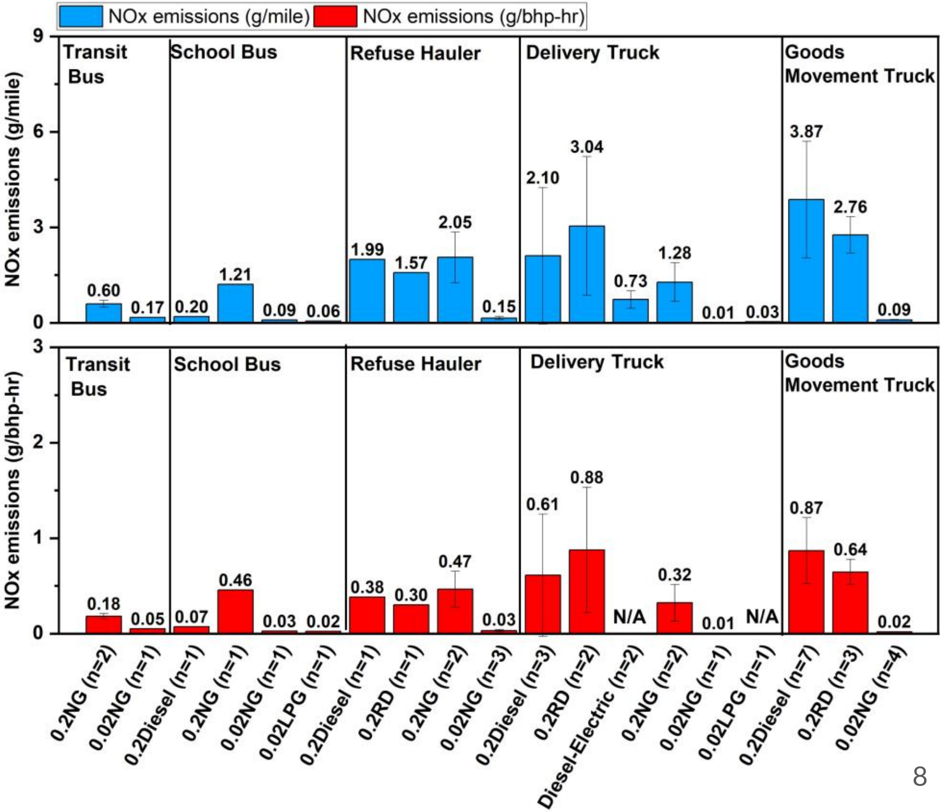
Duty-Cycle Variation Impacts Any Trends

- high variability due to duty cycle (idle, application, traffic
- 0.2g Diesel: 0.076 to 3.616 g/bhp-hr
- 0.009 to 3.616 g/bhp-hr if include NG
- Tighter cluster (emissions reductions) for 0.2g and 0.02g NG compared to 0.2g diesel baseline
- Any other trends (i.e. “daily” average NOx vs. Odometer) not clear on “daily” averaged results
- Additional binning analysis could offer more trends



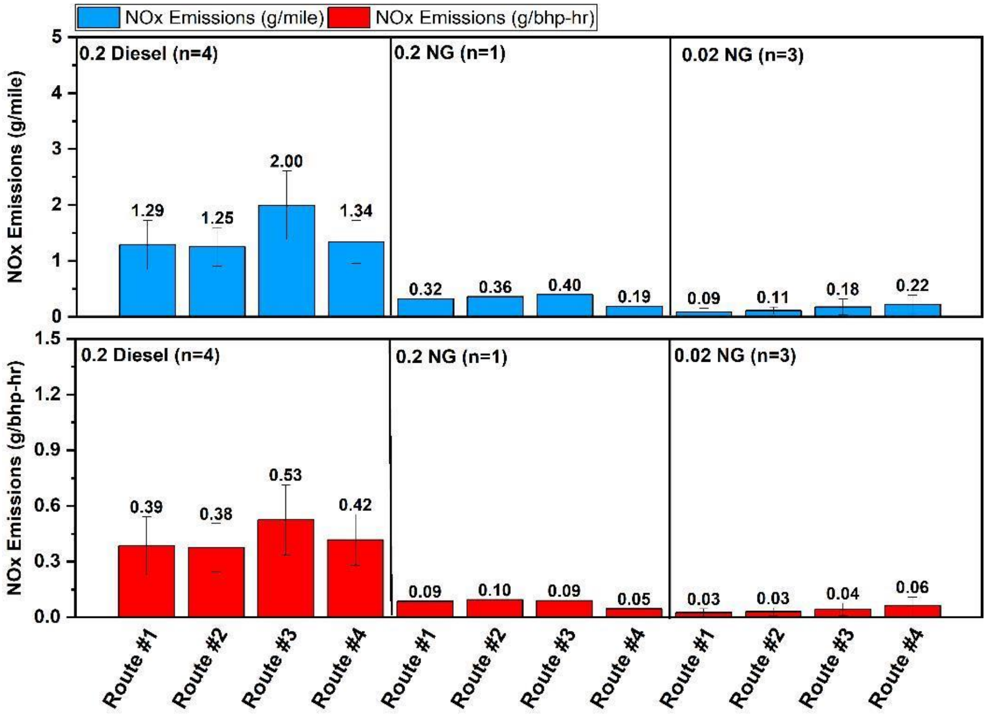
Chassis "Cycle" Averaged Data Show Real NOx Reductions for Alternative Fueled Vehicles

- UDDS results shown, common across all vocation (like FTP)
- Vocational cycles generally lower NOx compared to UDDS but same trend
- NG/LPG significantly lower NOx compared to 0.2g diesel baseline (whenever a baseline is available)
- Results close to FTP standard especially alternative fuel technologies
- Outliers drove up category averages (see report)
- Renewable diesel showed minor NOx benefit on most tests



On-Road Route Averaged NOx Trends as Expected

- Presented in detail at the September 2021 Cleans Fuels Update
- Lower variability due to smaller data set and single vocation, mobile lab also better accuracy compared to PEMS
- Diesel lower compared to chassis but similar to PEMS
- NG similar to chassis but much lower than PEMS
- Segmented/binned analysis shed more light, and have shown previously



Route #1: Grocery Distribution route;
Route #2: Port-Drayage route;
Route #3: Goods Movement with Elevation Change route;
Route #4: Highway Goods Movement route

Lessons Learned: Data Outliers

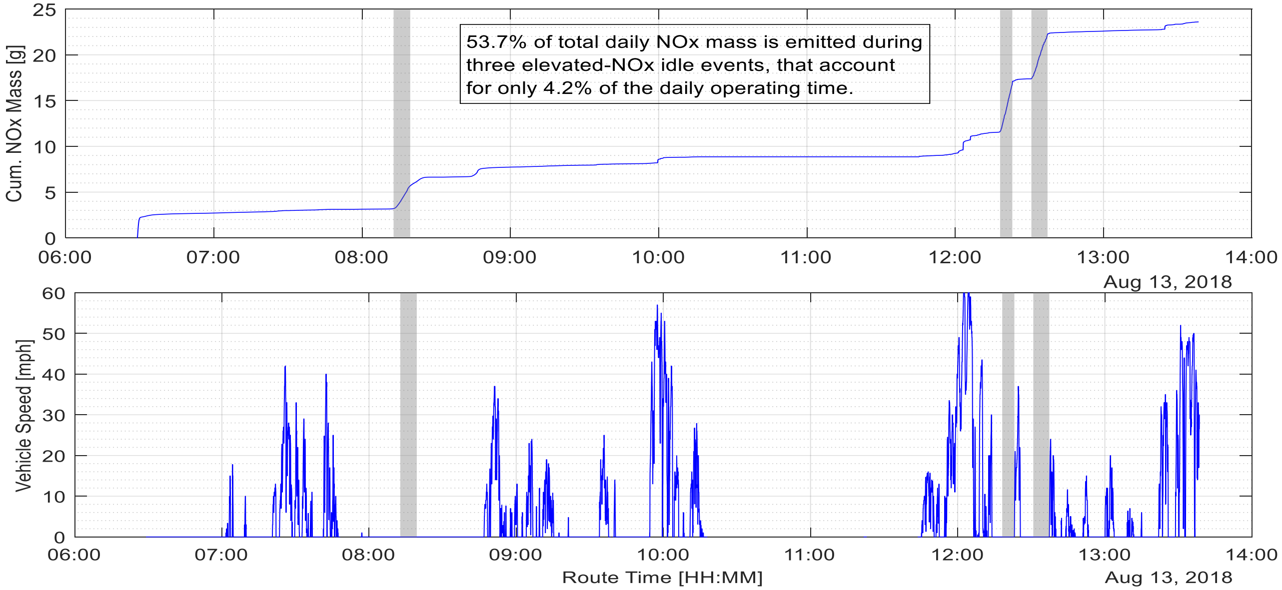
Type of Causes of Outliers	General Description
• **Systemic**: Expected problems/ conditions occur with frequency • These events considered as typical emissions signature	• Increased NOx emission rate events occur consistently if given conditions met (e.g. extended idle) • e.g., 3-way catalyst or SCR failures
• **Rare/Random:** Unexpected/anomalous problems/conditions that occur at low frequency • These events considered NOT representative of typical emissions signature	• Increased NOx emission rate events not representative of typical emissions signature of vehicle operation • Not widely encountered/measured including operator-induced problems from tampering, mal-maintenance or mis-fueling • Unrealistic operating conditions caused by measurement system (i.e. CVS)
• **Duty Cycle Related:** High emission events during off-cycle real-world driving not reflected in certification testing • These events considered as typical real-world activity	• Increased NOx emission rate events occur in certain duty cycle/operational modes • Extended-idle applications or power take-off (PTO) operation where exhaust temperatures are not high enough for proper NOx reduction. Such duty cycles do not occur during engine certification testing.

South Coast AQMD

Data Outlier: Systemic Example

Daily Averaged NOx	Total	W/O Event
g/bhp-hr	0.15	0.07
g/mile	0.73	0.34

PEMS, Vehicle 108, CNG 0.02g, 11.9L, Goods Movement Truck

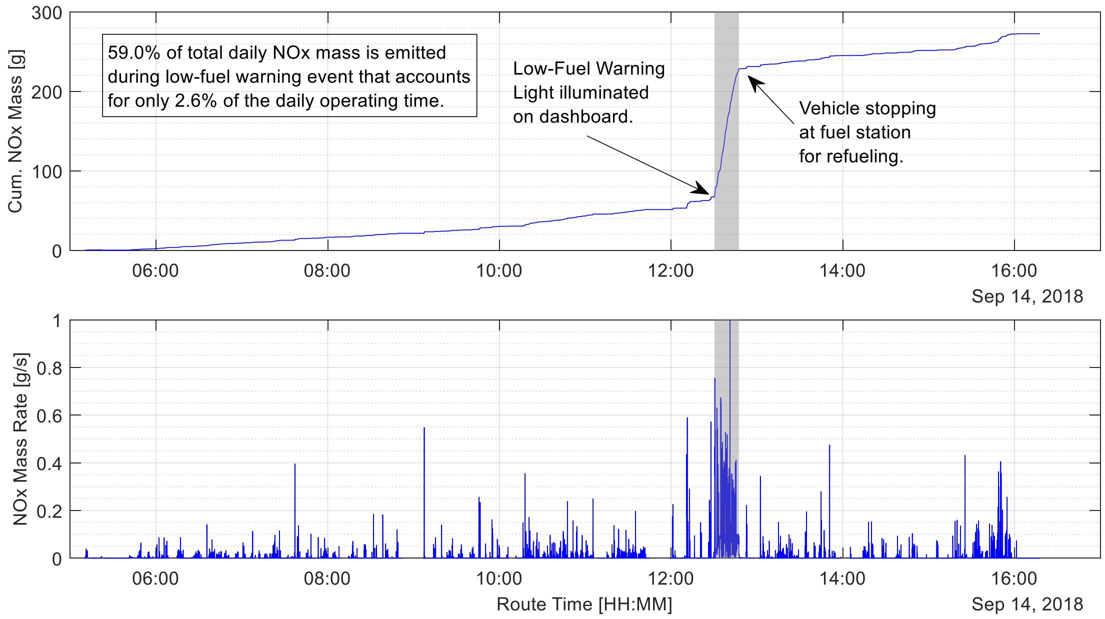


- Higher NOx rate during extended idle operation and while zero torque applied
- About 53.7% of total daily NOx mass emitted during these 3 events, which only accounted for only 4.2% of tim weighted operation throughout the day

Data Outlier: Rare/Random Example

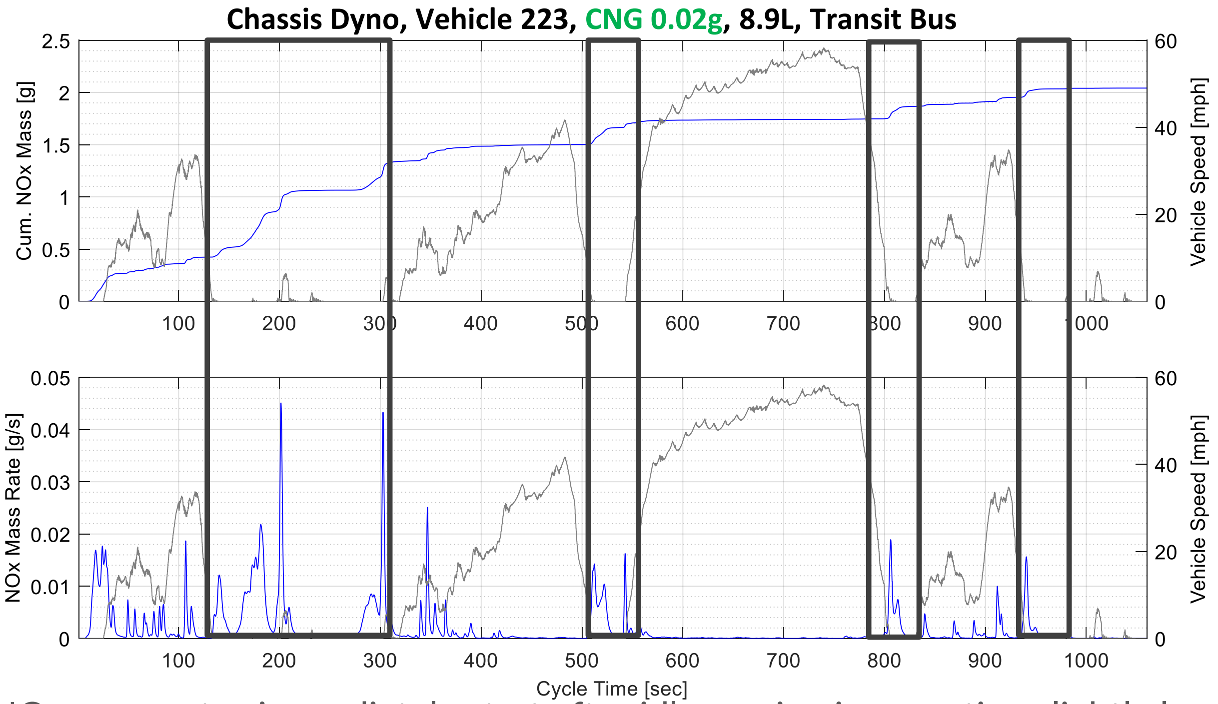
Daily Averaged NOx	Total	W/O Event
g/bhp-hr	0.36	0.15

PEMS, Vehicle 36, CNG 0.02g, 8.9L, Refuse Hauler



- Single low fuel warning event accounted for 59% of daily NOx, 2.6% of time
- Operation back to normal after fueling

Lessons Learned: Measurement System Effect on Emissions



- Increased idle NOx mass rates immediately start after idle, engine is operating slightly lean
- Observed at both UCR and WVU

Lessons Learned: CVS* Effect on Natural Gas Vehicle

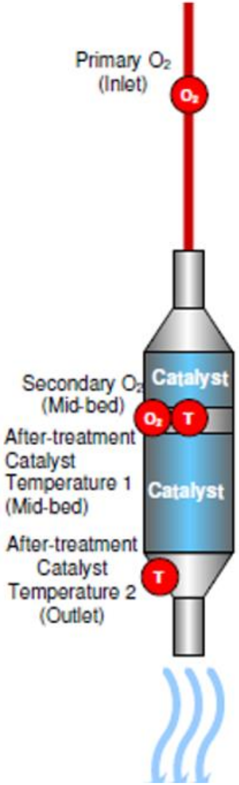
- With OEM support, an 8.9L 0.02g NG bus brought back to retest in August 2022
- High idle NOx condition created with CVS but not found when measured with PEMS**
- O2 sensor between PEMS and CVS suggesting ambient air ingress during idle operations
- Lab and exhaust system leak checks was performed

* CVS: Constant Volume Sampler

** Still on chassis, CVS was pulled away from other testing

Lessons Learned: Unrealistic Condition

- **Lab Check:** CVS can cause suction on engine
- **Unrealistic Condition:** fresh air can enter through loose clamps and unplugged drain holes, interfering with O2 sensor reading and causing high NOx during low flow conditions such as low load idle
  - Condition will not exist under real-world /PEMS where exhaust is open to atmospheric
  - Flow dependent (e.g. low flow condition when 8.9L idling and high CVS flow rate)
- **Lessons learned:** tighter leak check, certain CVS type might not be suitable for measuring NG vehicles



Take Aways

- Truck activity patterns highly associated with functions of HDVs and varied by vocation
- Important to understand duty-cycle and averaging method, e.g. “daily”/”cycle”/”route” averaged results
- Natural gas/alternative fueled HDVs may have higher NOx emissions under different conditions, although generally significantly lower emitting than corresponding diesel baselines
- Study provided regulators, researchers as well as OEMs with valuable lessons learned
- Additional data analysis warranted to dig deeper beyond the “averages”

Thank you!

Contractors: WVU, UCR/CE-CERT

Funding Partners: CEC, CARB, SoCalGas and South Coast AQMD

Other Supporting Contractors: GNA, AEE Solutions, Wale Associates, University of Denver and more

In-use Emissions Testing of On-Road Heavy-Duty Vehicles

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Project Overview

- **One of the most extensive studies of HDVs in the country**
  - PAMS, PEMS, Chassis, and On-road Testing
  - Provides a robust empirical source of information on new technology
- **200 vehicles were tested in total in conjunction with WVU**
- **Vehicles from five vocations were tested**
  - Transit buses, school buses, refuse haulers, delivery trucks, goods movement trucks
- **Alternative fuels, conventional diesel fuel, and Hybrid Technology**
- **This presentation will provide a summary of results of the PEMS, Chassis, and real-world/on-road testing portions of the study**

Test Vehicles

Allocation of PEMS tests

Vocation	Transit	School Bus	Refuse	Delivery	Goods Movement
Number of PEMS Vehicles	6	7	7	10	20
CNG 0.20g	3	4	5	2	3
CNG 0.02g	3	0	2	0	7
Diesel 0.20g	0	1	0	4	9
Diesel (No SCR)	0	1	0	0	1
Other Alt Fuels					
Diesel-Electric Hybrid	0	0	0	2	0
Propane (0.2g)	0	1	0	1	0
Propane (0.02g)	0	0	0	1	0
RD 0.20g	0	0	0	0	0

Allocation of Chassis Dynamometer tests

Vocation	Transit	School Bus	Refuse	Delivery	Goods Movement
Number of Chassis Dyno Vehicles	5	3	4	7	11
CNG 0.20g	2	1	3	1	1
CNG 0.02g	3	0	1	0	2
Diesel 0.20g	0	0	0	2	3
Diesel (No SCR)	0	1	0	0	1
Other Alt Fuels					
Diesel-Electric Hybrid	0	0	0	1	0
Electric	0	0	0	0	1
Propane (0.02g)	0	0	0	1	0
RD 0.20g	0	0	0	2	2
RD (No SCR)	0	1	0	0	1

Allocation of on-road tests

Vocation	Transit	School Bus	Refuse	Delivery	Goods Movement
Number of On-road Vehicles	0	0	0	0	5
CNG 0.02g	0	0	0	0	2
Diesel 0.20g	0	0	0	0	2
Diesel (No SCR)	0	0	0	0	1

PEMS Test Setup

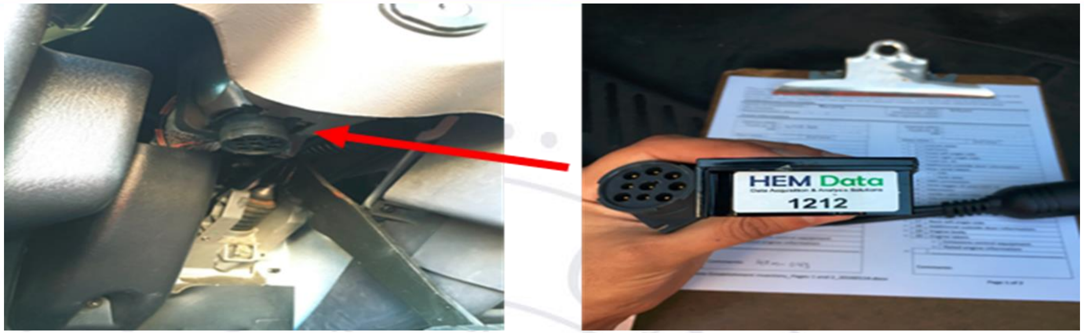


Figure 1 J1939 ECM port (left) and HEM logger (right)

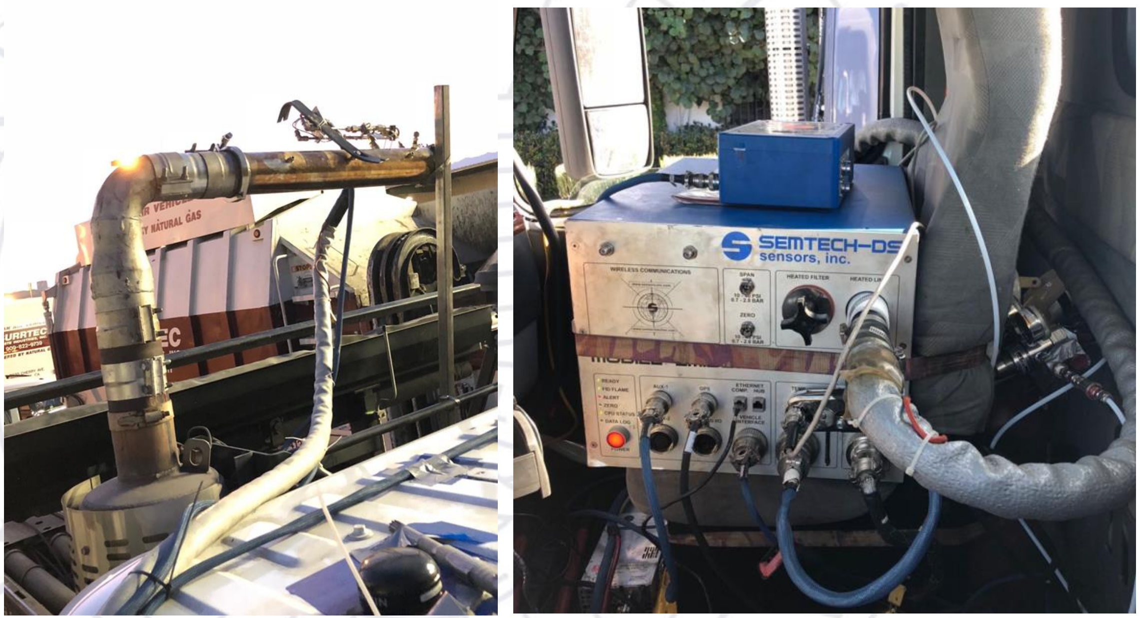
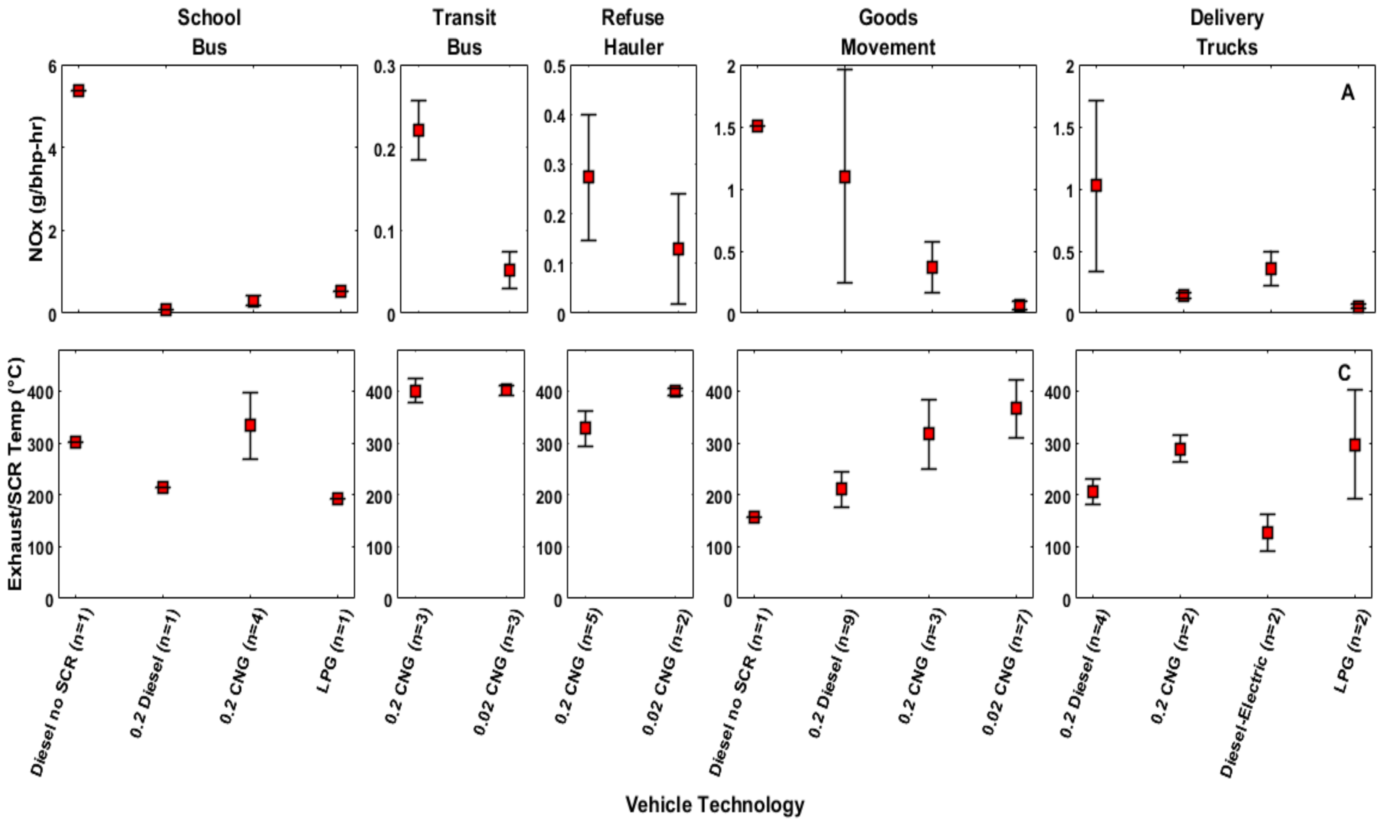


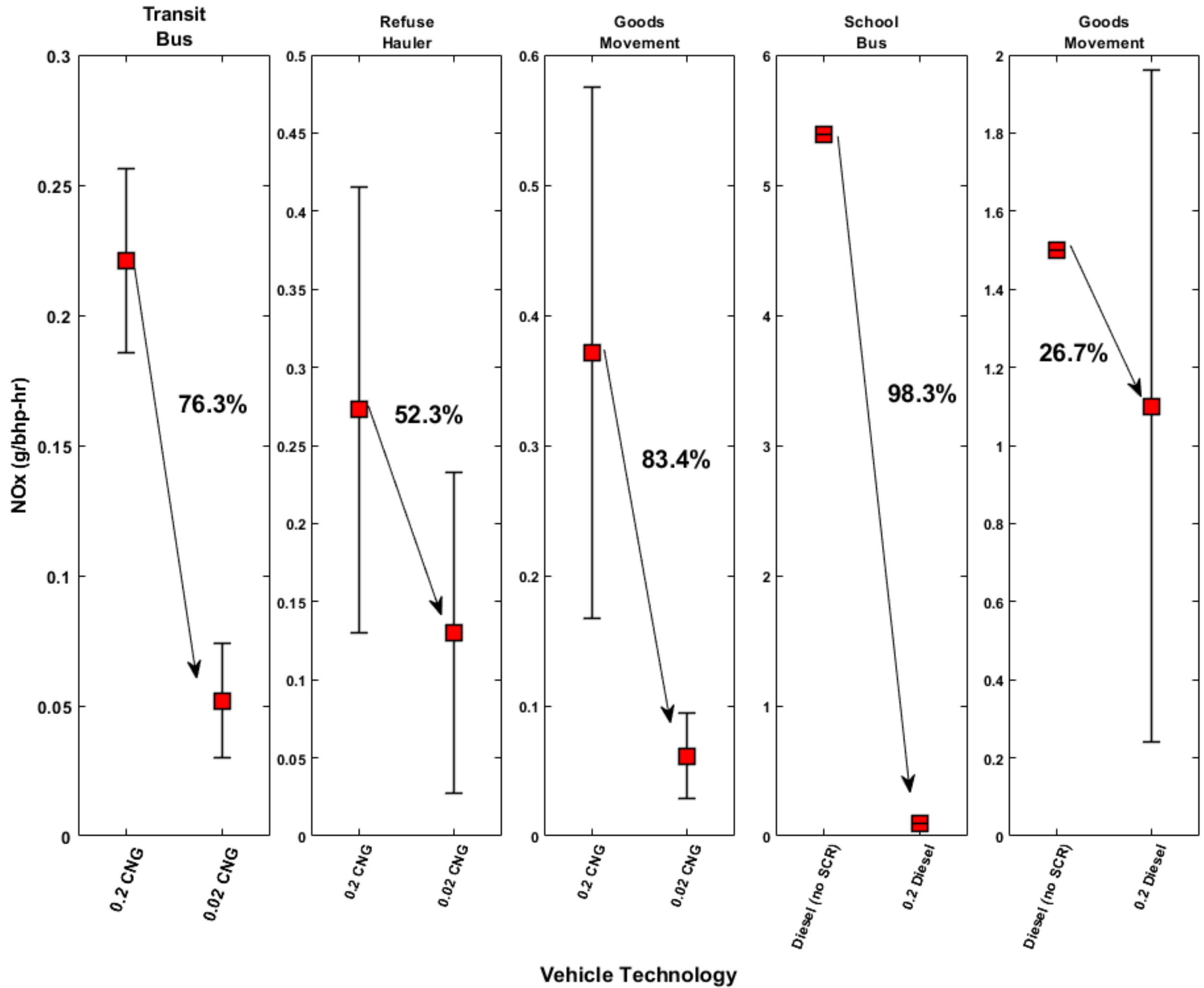
Figure 2. Exhaust Flow Meter (left) and SEMTECH-DS unit (right)

PEMS NOx Results



- **Diesel vehicles with SCR (0.2 g) showed highest NOx emissions, other than the diesel vehicles with no SCR**
- **Goods Movement and Delivery 0.2 g diesel vehicles showed SCR temperatures near or below 200°C greatly effecting total NOx emission rates, with high NOx emissions also found even for SCR temperatures > 250°C for some vehicles**
- **CNG vehicles NOx were generally lower than diesel vehicles, particularly 0.02 g CNG, although emission rates were generally higher than certification levels.**

PEMS NOx Reductions



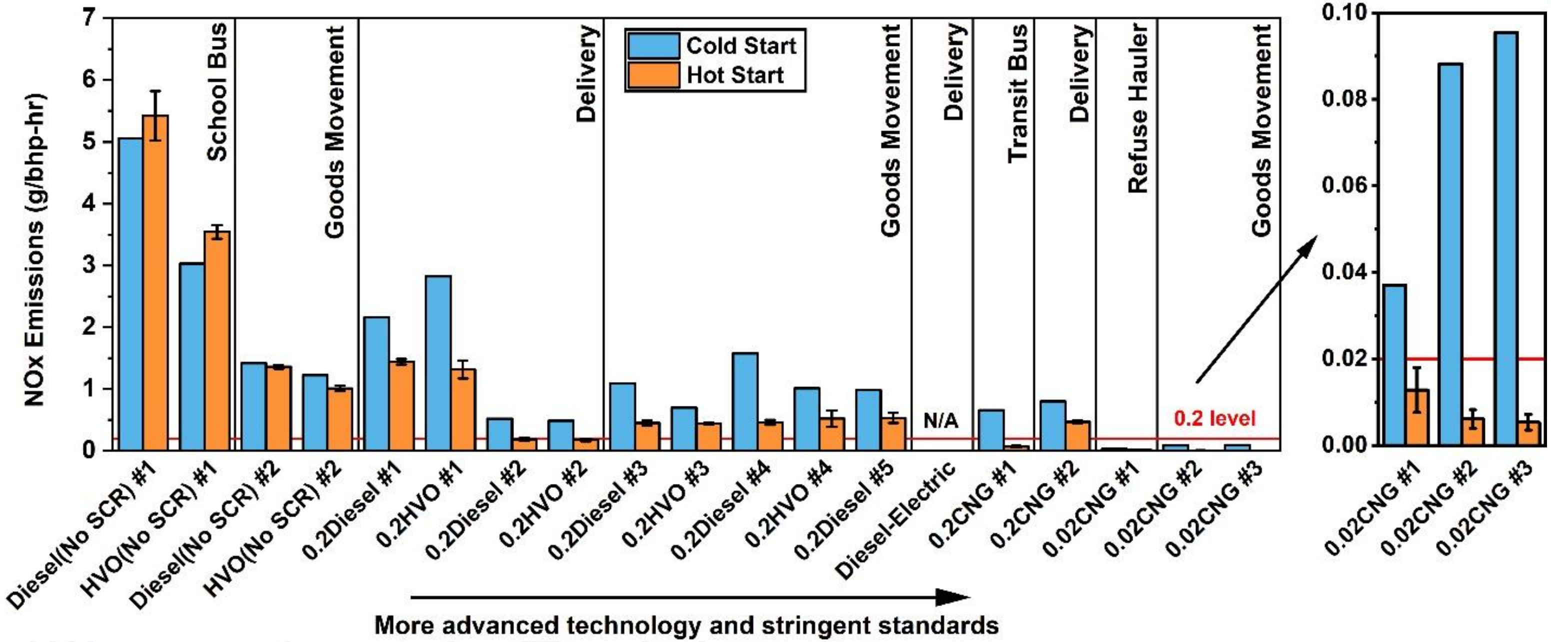
- **0.02 CNG technology provided 76.3%-83.4% reduction efficiencies compared to 0.2g CNG**
- **Diesel with SCR showed 26.7 to 98.3% reductions in NOx relative to the Diesel no SCR vehicles**
  - 3 Goods Movement vehicles showed NOx emissions higher than 2 g/bhp-hr

Chassis Test Cycles

Test ID	Vocation	Technology Group	UDDS (CS+3xHS)	Markov Cycle	3rd cycle tested	Test weight
0.2CNG #1	Transit Bus	0.2g NG	x	OCTA	-	32500
Diesel(No SCR) #1	School Bus	0.2g Diesel (no SCR)	x	School Bus Cycle	-	32500
0.02CNG #1	Refuse	0.02g NG	x	Refuse Cycle (w grade)	-	32500
0.2Diesel #1	Delivery	0.2g Diesel	x	Delivery Cycle	HHDDT Cruise	56000
0.2Diesel #2	Delivery	0.2g Diesel	x	Delivery Cycle	HHDDT Cruise	56000
Diesel-Electric	Delivery	Diesel-Electric	x	Delivery Cycle	HHDDT Cruise	56000
0.2CNG #2	Delivery	0.2g NG	x	Delivery Cycle	HHDDT Cruise	56000
Diesel(No SCR) #2	Goods Movement	Diesel (no SCR)	x	Goods Movement Cycle	HHDDT Cruise	56000
0.2Diesel #3	Goods Movement	0.2g Diesel	x	Goods Movement Cycle	HHDDT Cruise	16000
0.2Diesel #4	Goods Movement	0.2g Diesel	x	Goods Movement Cycle	HHDDT Cruise	56000
0.2Diesel #5	Goods Movement	0.2g Diesel	x	Goods Movement Cycle	HHDDT Cruise	69500
0.02CNG #2	Goods Movement	0.02g NG	x	Goods Movement Cycle	HHDDT Cruise	69500
0.02CNG #3	Goods Movement	0.02g NG	x	Goods Movement Cycle	HHDDT Cruise	69500

Figure 3 test vehicles

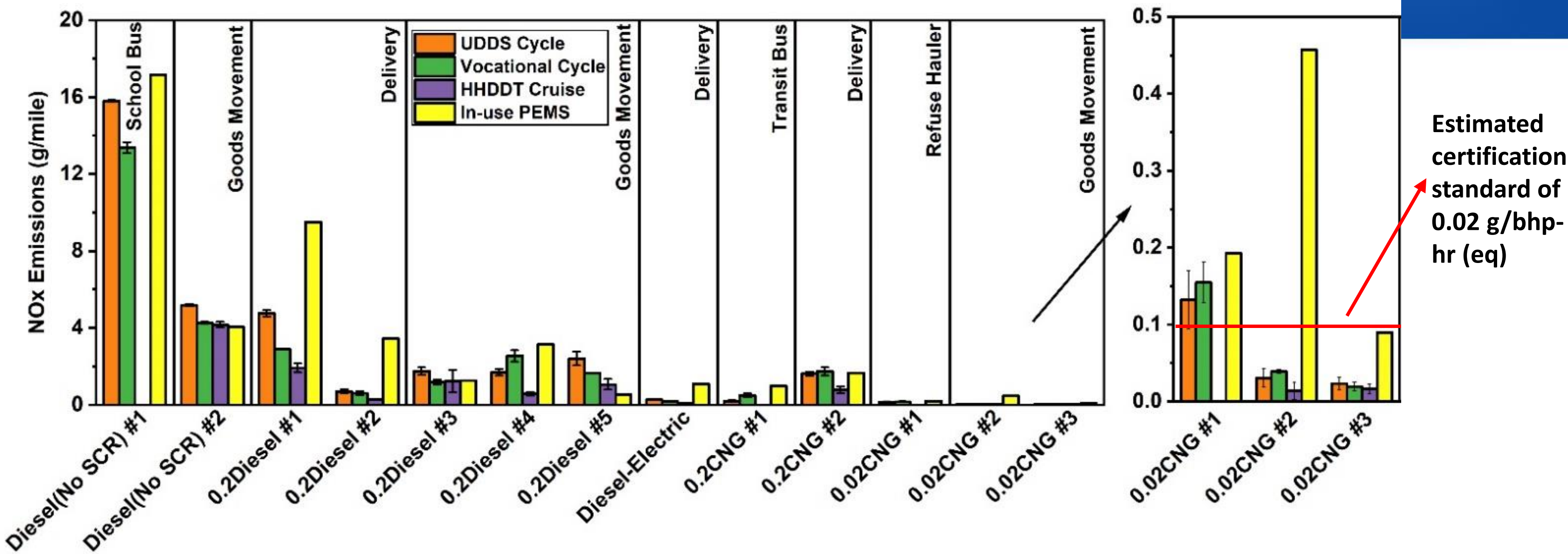
Chassis NOx emissions



Chassis NOx emissions for UDDS cycle (g/bhp-hr)

- For 0.2 g diesel vehicles, the NOx emissions were generally above the certification levels, with SCR NOx reduction efficiencies around 80% for most of the vehicles for the hot start UDDS.
- NOx emission for the two 0.2 g CNG vehicles varied between vehicles and for both cold and hot start UDDS.
  - Note one high emitting 0.2 CNG transit but with a deteriorated catalyst is not shown
- The 0.02 g CNG vehicles generally showed emissions that were considerably lower than those for the other vehicle technologies, and within the certification limits, except for during cold starts.

Chassis NOx emissions



Chassis NOx emissions for UDDS cycles, Vocational cycles, HHDDT cruise cycles and in-use PEMS (g/mile)

- **For the 0.2 g diesel vehicles, the in-use PEMS NOx emissions were higher than those over the vocational and UDDS cycles, except for goods movement vehicles 0.2 Diesel #3 and #5**
- **NOx emissions for the HHDDT cruise cycles showed similar or lower NOx emissions comparing to those for the UDDS cycles, the vocational cycles, and the in-use PEMS testing for all the vehicles in delivery and goods movement categories**

Investigation on elevated emissions during idle period

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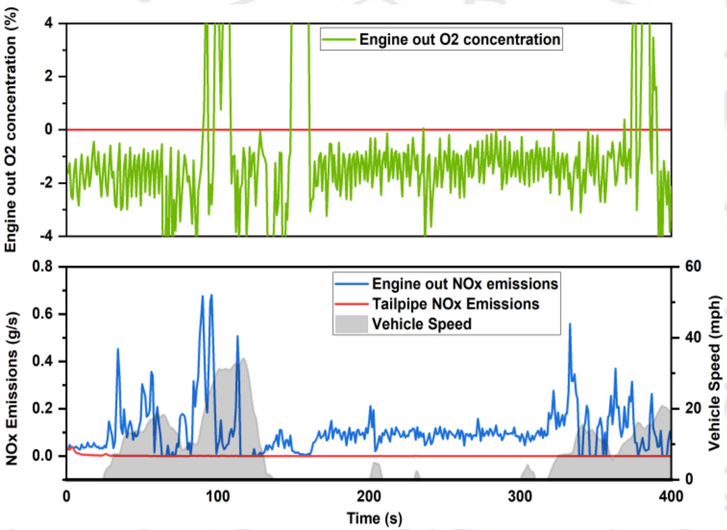
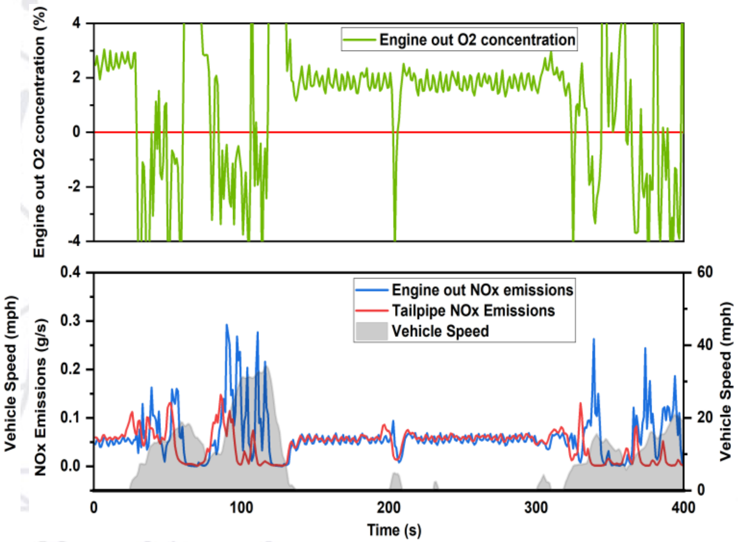
Technology	#	Vocation	Engine M/Y
0.2CNG	18002	School Bus	2013 ISL G 280
0.02CNG	18025	Refuse	2017 ISL G 320

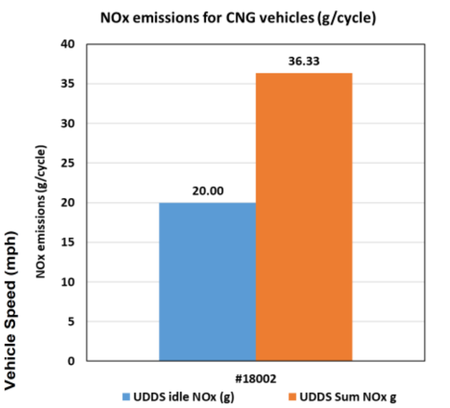


18025 w/o idle issue



18002 w idle issue

Measured engine out O_2 concentrations from sensor were above 0 for the idle period, excessive O_2 into the catalyst reduced NOx reduction efficiency



NOx emissions for CNG bus 18002 (w issue)

55% of total NOx emission from idle period

On-road Test Routes

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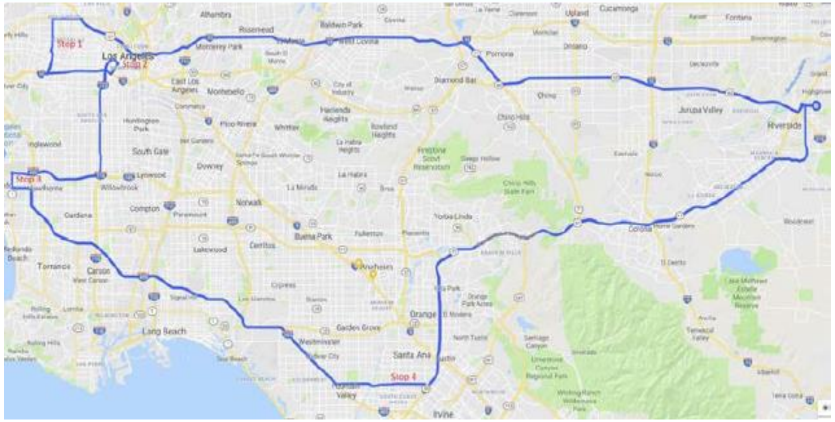
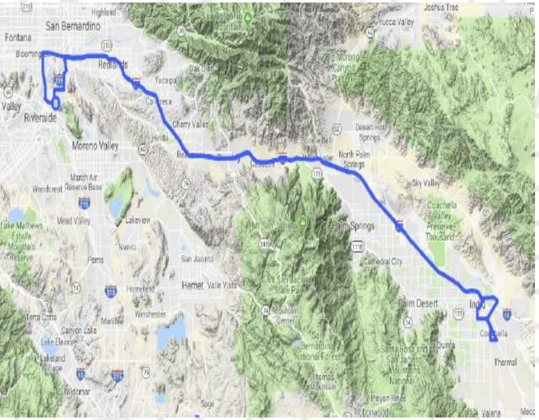
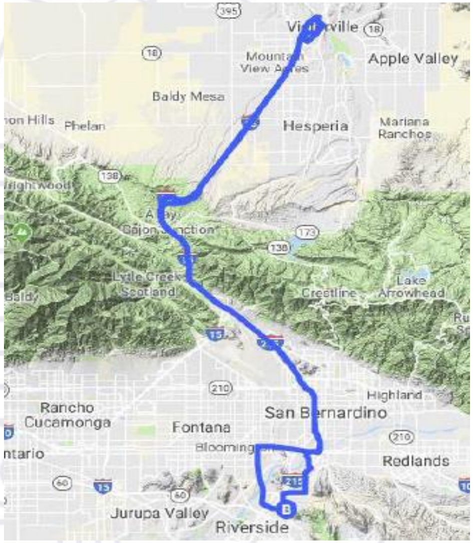


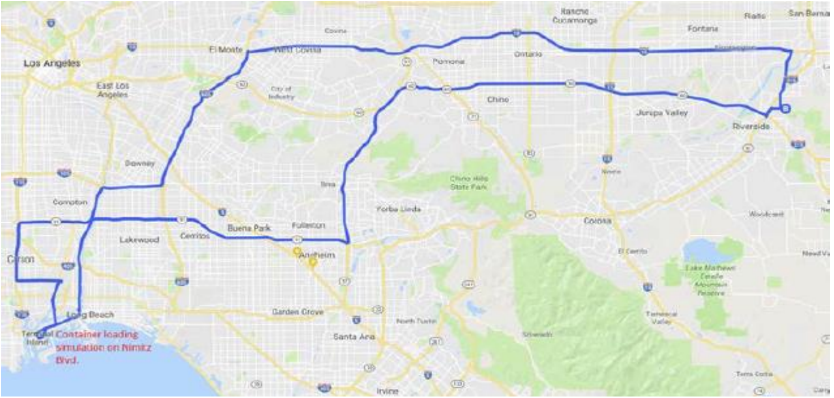
(a) The Grocery Distribution route



(b) The Highway Goods Movement route

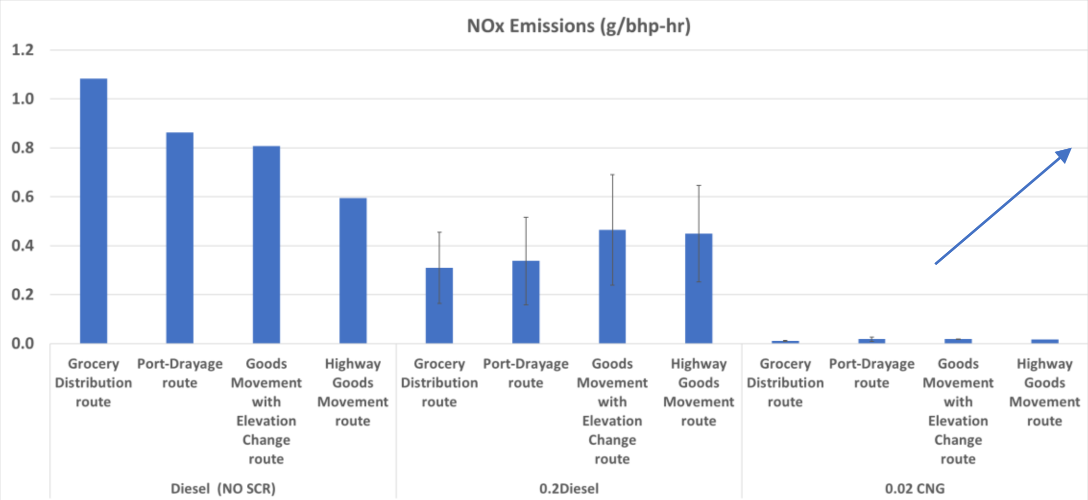


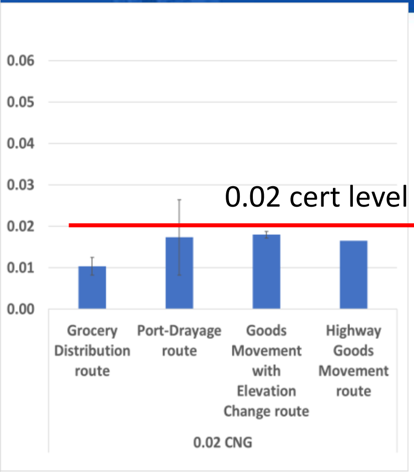
(c) The goods movement with elevation change

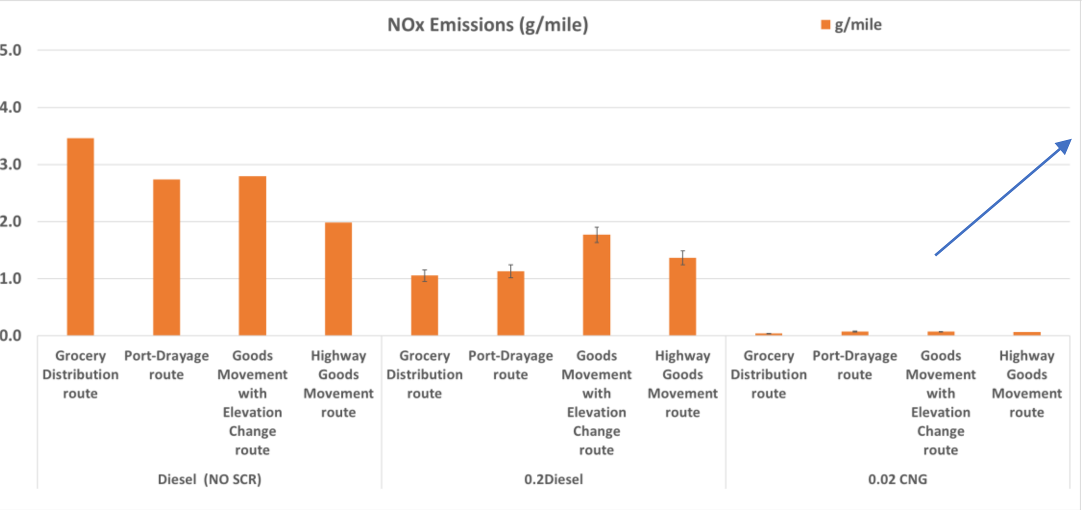


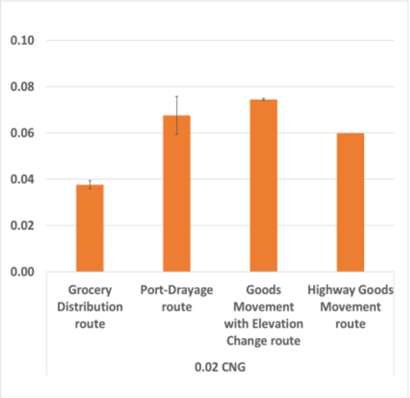
(d) The port-drayage route

On-road NOx Emissions Results



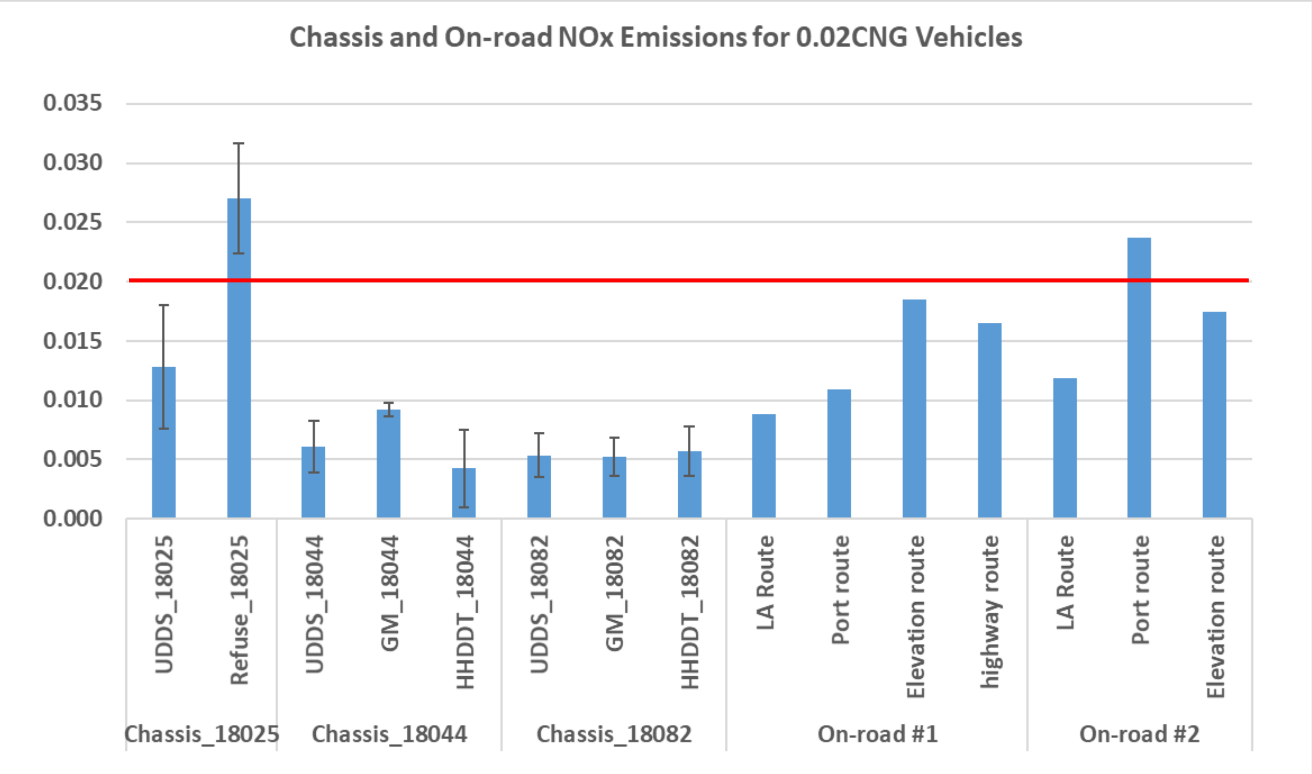






- **Diesel NO SCR showed the highest, followed by 0.2 Diesel and 0.02CNG**
- **0.02 CNG showed average emissions well below 0.02 certification standard for all vehicles over all of the routes**

0.02 CNG NOx Emissions Results



The 0.02 CNG vehicles showed emissions rates generally below or comparable to the 0.02 limit for the different cycles and routes for the chassis dynamometer and on-road testing.

Results Summary

- **Diesel Vehicles showed highest NOx emissions, specifically in the Delivery and Goods Movements vocations, as well as diesel no-SCR vehicles**
- **CNG vehicles generally showed lower NOx emissions compared to SCR diesel vehicles**
  - Emission rates higher than certification levels for PEMS testing, but closer to or below certification standards for the chassis and on-road testing.
  - One 0.2 g CNG high emitter was observed during the chassis dynamometer testing.
- **0.02 g CNG vehicles showed solid near-term potential for reducing NOx emissions**
  - Significantly lower NOx emissions for 0.02 g CNG compared to 0.2g CNG and 0.2 g diesel vehicles.
  - 0.02 g CNG vehicle for Chassis and On-road testing show emission rates comparable to or solidly below the 0.02 certification standard, with the exception of cold starts.

Acknowledgement

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- We acknowledge funding from the California Energy Commission, the South Coast Air Quality Management District, the California Air Resources Board, and Southern California Gas Company.
- We thank participating fleets

CALIFORNIA AIR RESOURCES BOARD

FUNDING PROVIDED BY THE CALIFORNIA ENERGY COMMISSION

South Coast AQMD

SoCalGas

A Sempra Energy utility®

IMPACTS OF DETERIORATION ON IN-USE EMISSIONS FROM HD TRUCKS

FILIZ KAZAN
MARC BESCH
ARVIND THIRUVENGADAM

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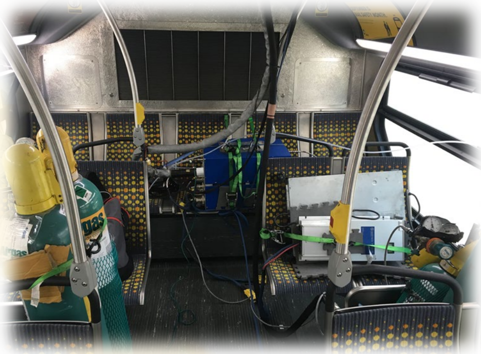
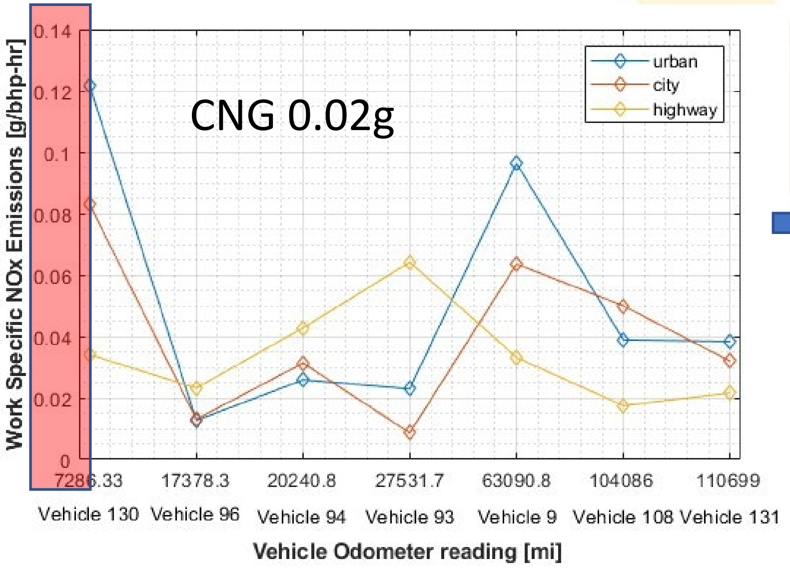
South Coast Air quality management district



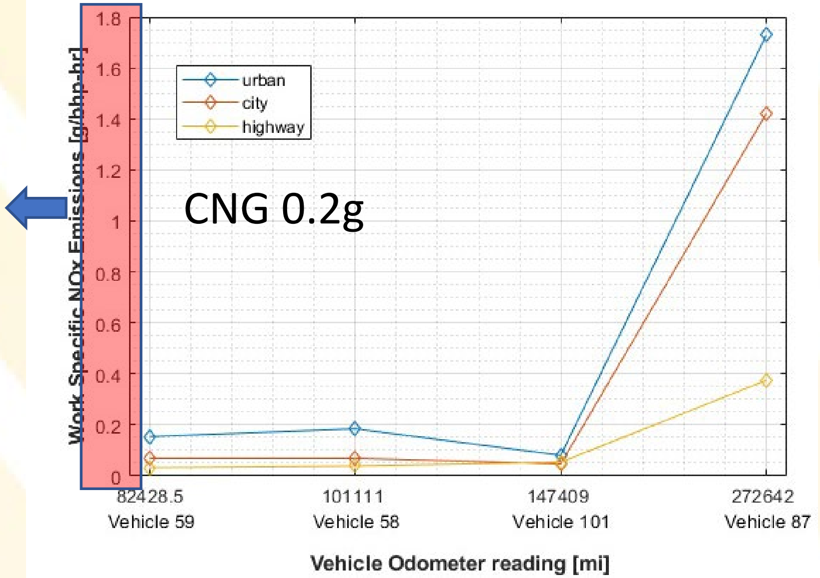
Introduction

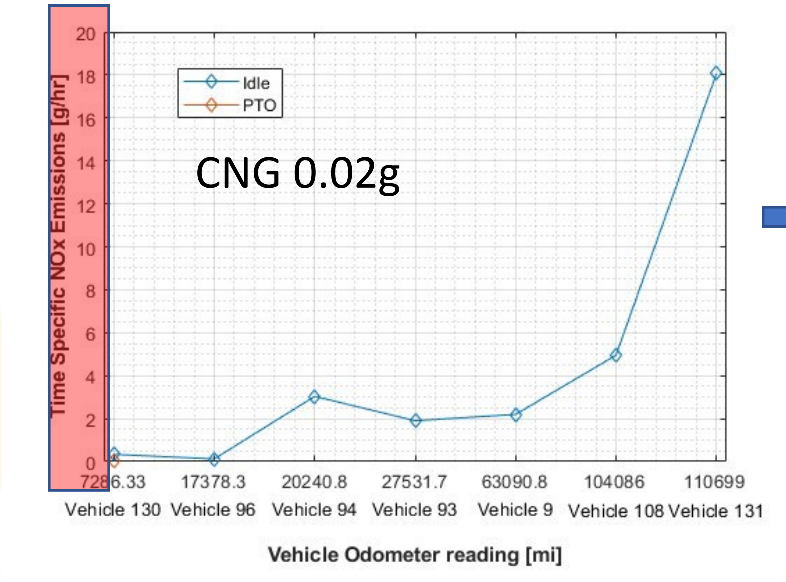
- Project sponsored by SCAQMD, CEC and CARB aimed at characterizing HD duty cycles, in-use emissions rate as well as chassis dynamometer emissions rate of various vocations
- Study included comparison between diesel and alternative fuels operating under various vocations
- Study conducted in joint partnership with UC-Riverside Ce-CERT

COMPARISON OF CNG VEHICLE NOX EMISSIONS WITH AGE-GOODS MOVEMENT

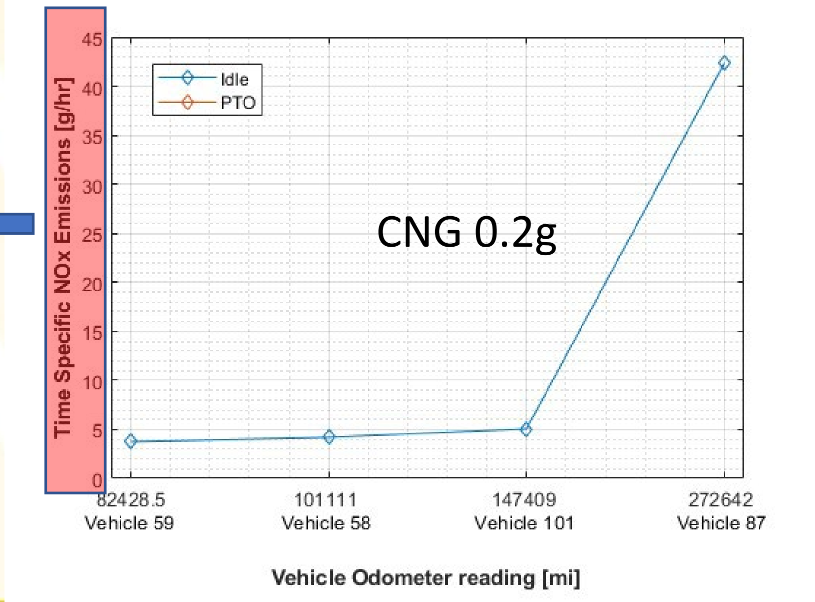


- Order of magnitude difference in bs-NOx emissions between the newer 0.02 g and the older 0.2 g CNG engines
- The 0.02 g goods movement vehicles do not show any NOx deterioration with vehicle age during non-idle operation
- The 0.2 g engines show an order of magnitude increase in NOx emissions after 150K miles

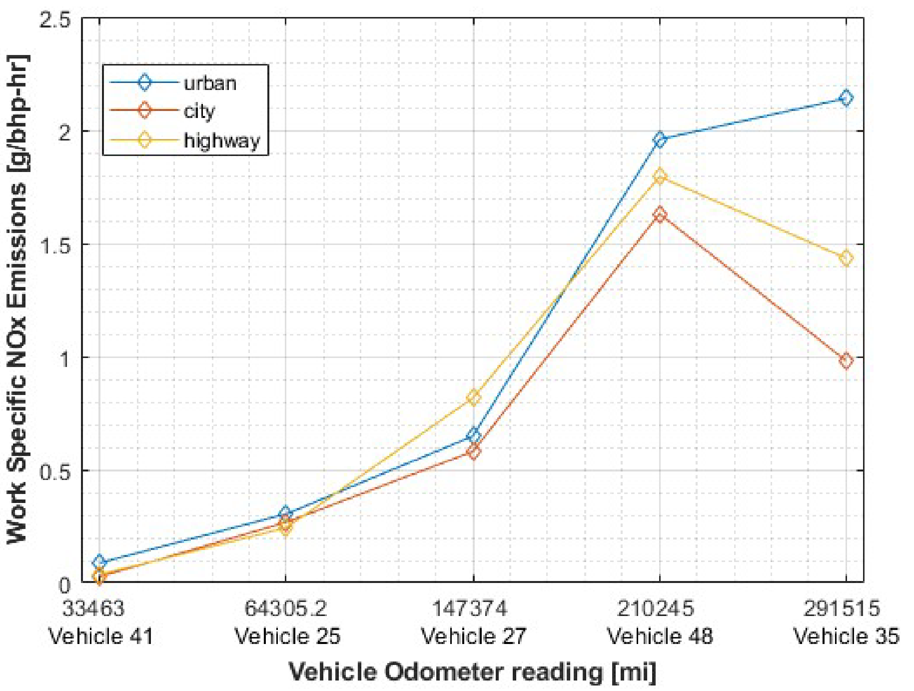


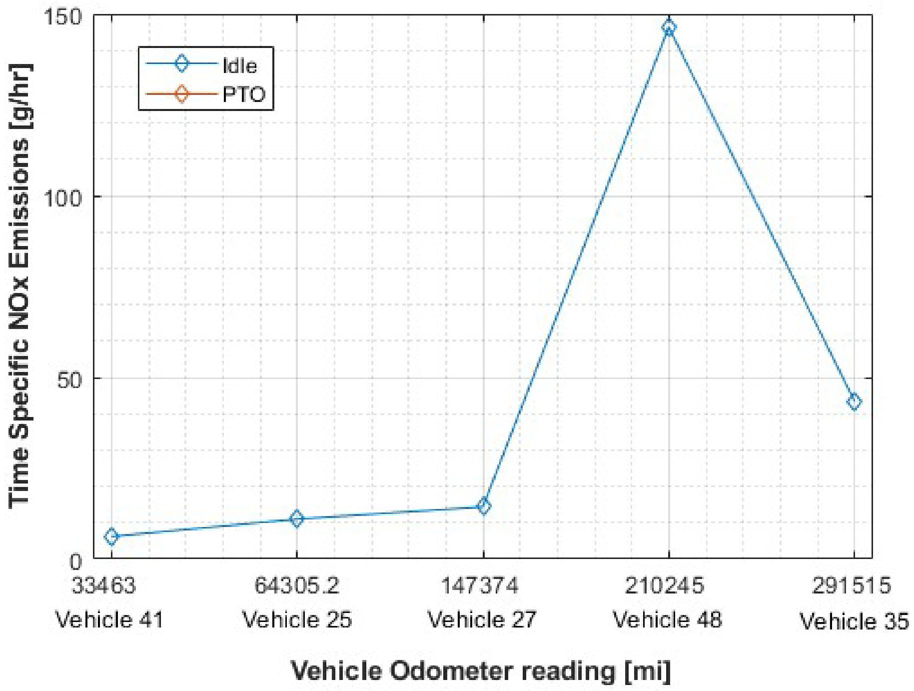


- An increase in NOx emissions is observed during idle emissions for the 0.02 g vehicles with age.
- Emissions from Vehicle 131 is being reevaluated to address the excessive idle NOX emission



0.2g CNG VEHICLE NOX EMISSIONS WITH AGE-REFUSE TRUCKS

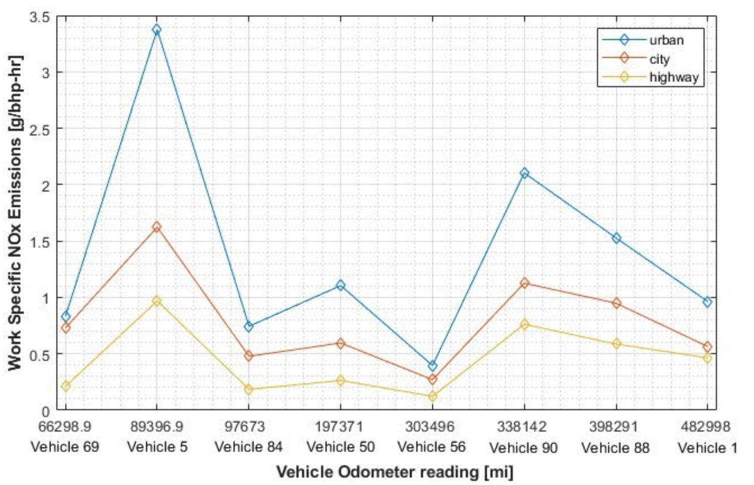


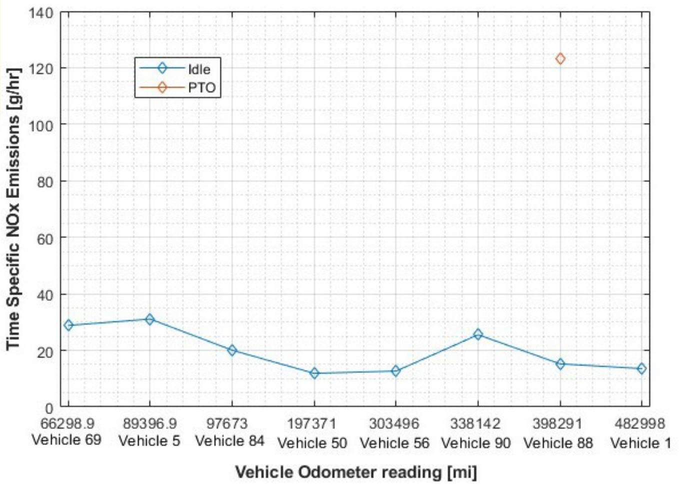


- Refuse trucks are characterized by aggressive duty cycles
- Catalyst aging maybe accelerated in a refuse truck duty cycle compared to a good movement application
- In comparison to goods movement application, we observed increase in NOx emissions even during transient operation
- Order of magnitude increase in emissions are observed as early as 140K miles (engine operating hours would be more than miles for refuse truck vocations)
- Idle NOx emissions from Vehicle 48 maybe associated with maintenance issues

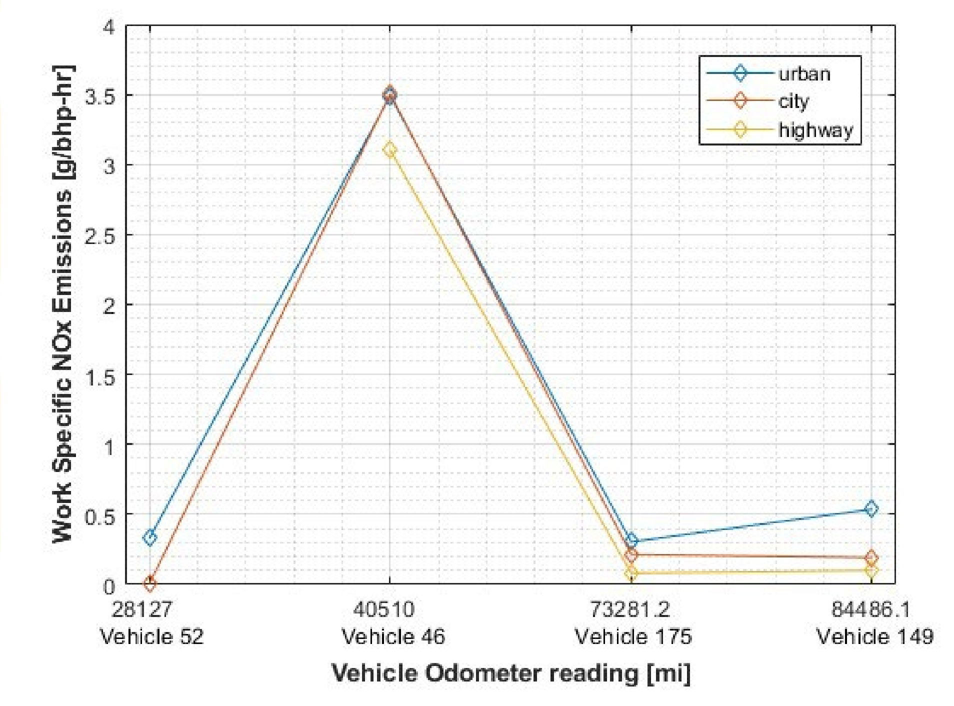
0.2g DIESEL VEHICLE NOX EMISSIONS WITH AG- GOODS MOVEMENT AND DELVERY

Goods Movement



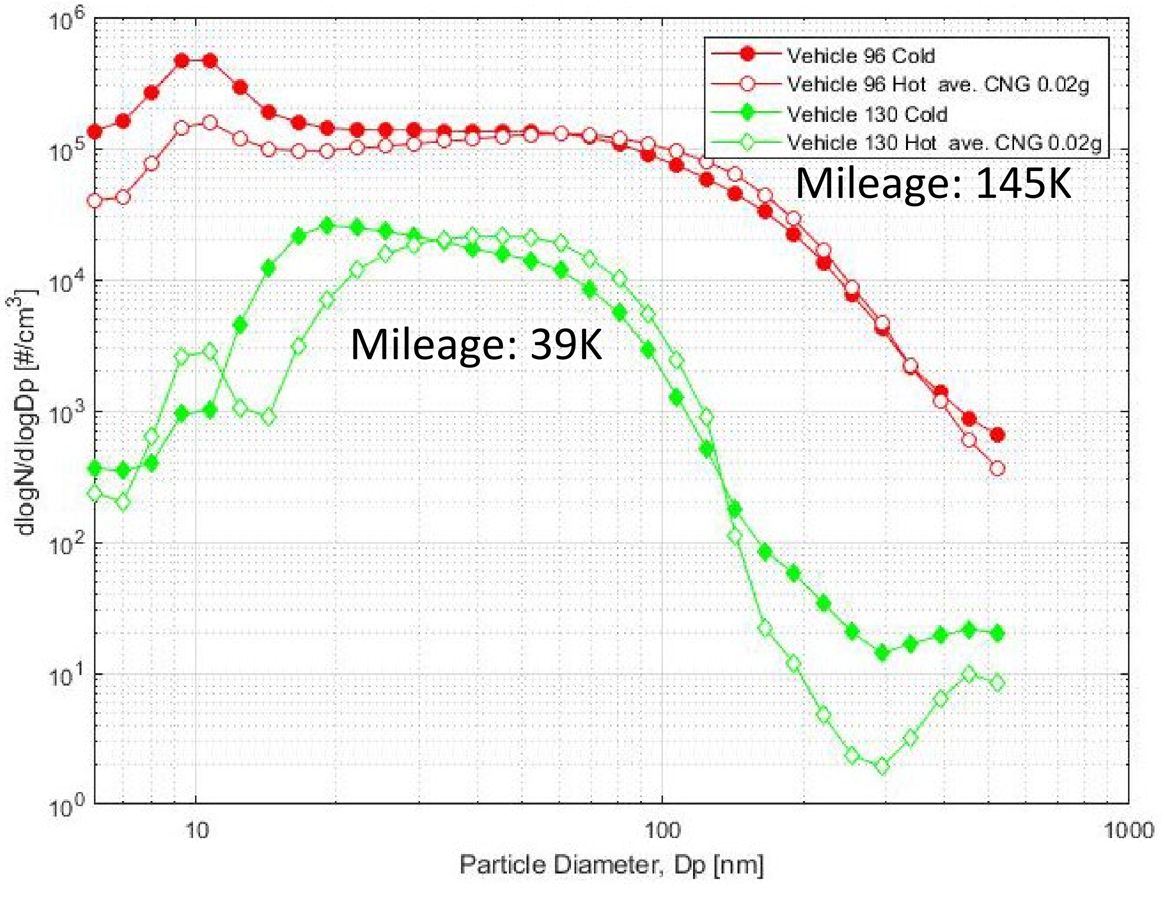


Delivery



- 0.2 g diesel vehicles do not exhibit any increase in NOx emissions with age
- NOx emissions from highway operation would be indicative of any deterioration of SCR on older vehicles
- Higher NOx emissions during urban and city driving could indicate deterioration in engine-out emissions.
- Results do not indicate SCR deterioration or engine-out emissions deterioration
- Diesel delivery trucks were relatively newer in vehicle mileage
- Vehicle 46 was an exception in exhibiting 6 times higher NOx emissions than other older vehicles.

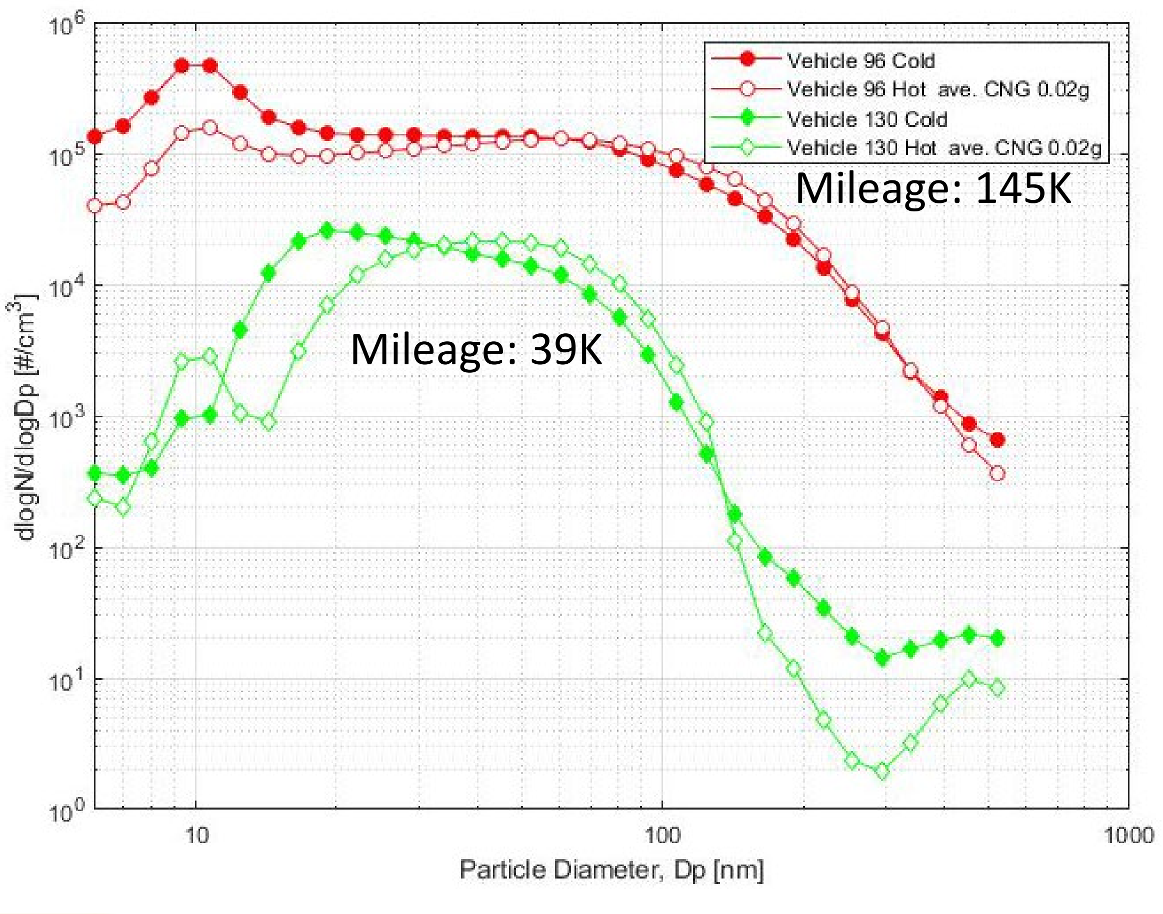
Deterioration from a PM Perspective



- Deterioration of CNG vehicles are more observable from the PM results
- Previously it has been shown that lubrication oil contributes to majority of the PM emissions from CNG vehicles
- Lubrication oil combustion can be linked to signs of engine aging.

- Both vehicles shown here are 0.02 g engines operating in a goods movement application
- A clear trend in PM emissions between an aging vehicle and a relatively newer vehicle is observed
- The expected size distribution peak in the 10 nm size range is observed for both vehicles
- The aging vehicle shows a larger concentration of accumulation mode particles

Deterioration from a PM Perspective



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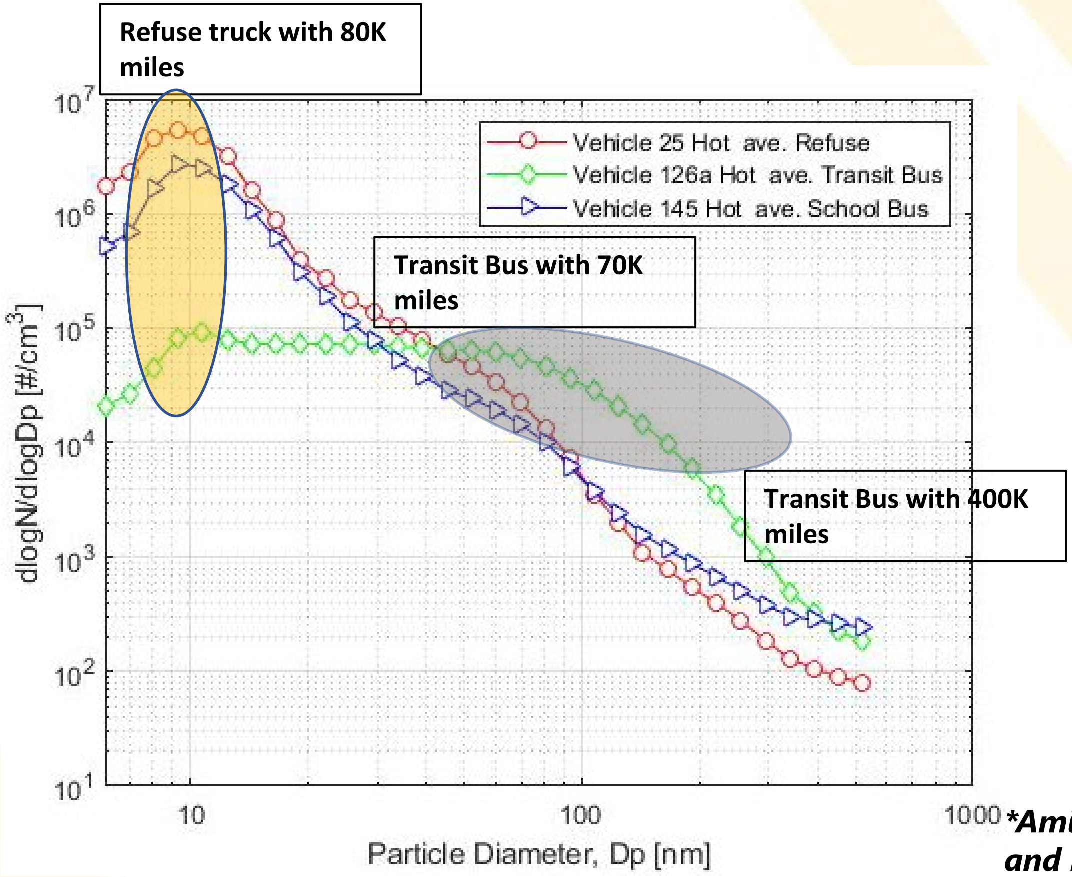
PM Emissions- Vocation Based Aging

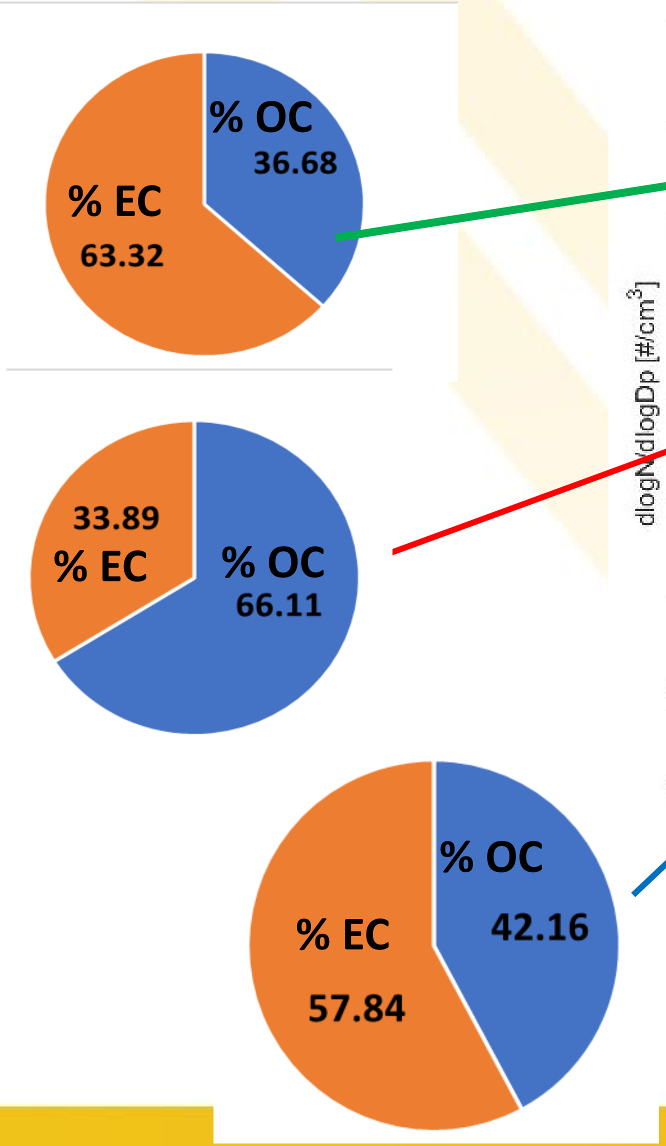


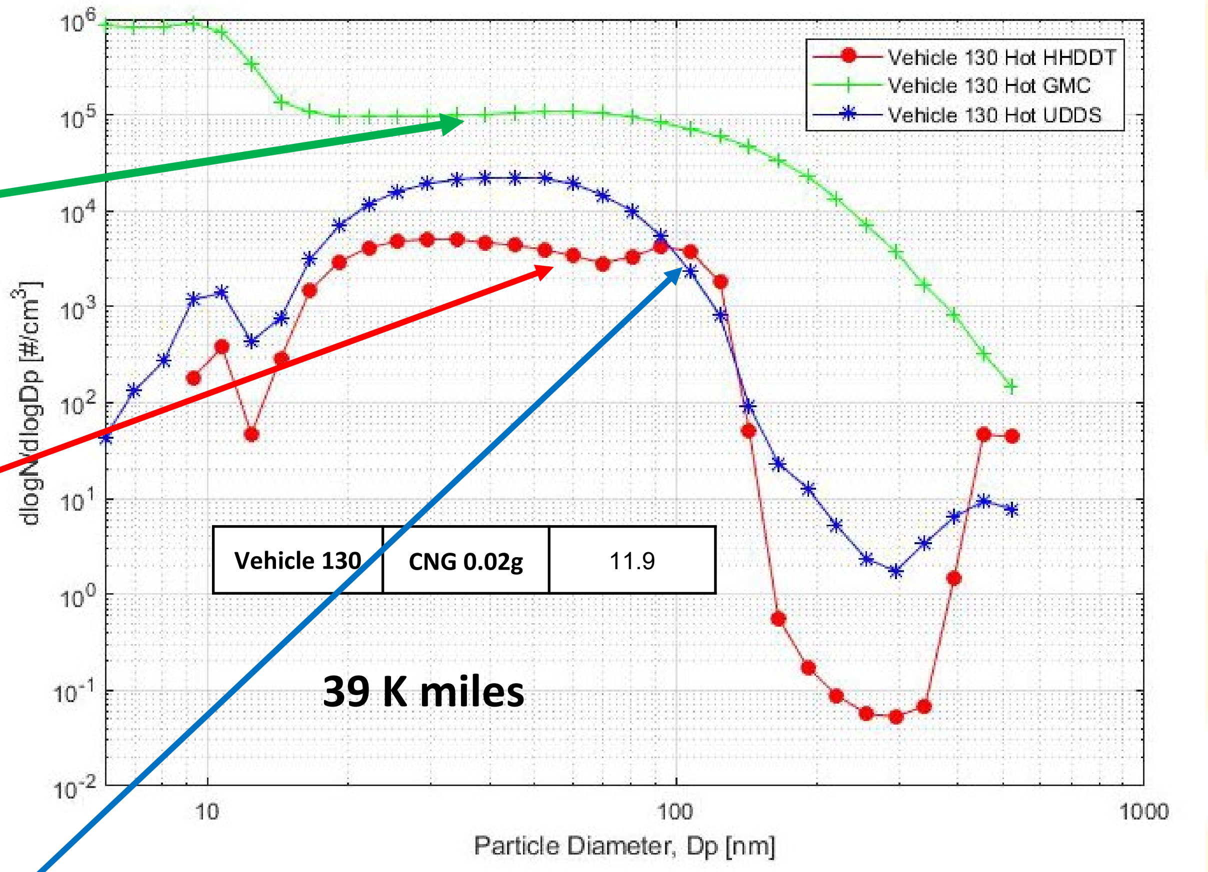
- Research* has shown that nucleation mode (10-30 nm) particles are linked to lubrication oil entering through intake manifold
  - Crankcase ventilation
  - Turbocharger oil leak
- Accumulation mode particles are linked to entry of lubrication oil directly into combustion chamber
  - Piston rings
  - Valve seals
- Transit bus with 400K miles shows higher 100 nm particles than refuse and school bus with lower miles

**Amirante, R., E. Distaso, M. Napolitano, P. Tamburrano, S. D. Iorio, P. Sementa, B. M. Vaglieco and R. D. Reitz (2017). "Effects of lubricant oil on particulate emissions from port-fuel and direct-injection spark-ignition engines." International Journal of Engine Research 18(5-6): 606-620.*

PM Emissions- Duty Cycle Based Aging

- GMC duty-cycle with greater percentage of idle and low load operation
  - Two orders of magnitude higher nucleation mode particles compared to freeway type operation (HHDDT)
  - An order of magnitude higher accumulation mode particles compared to freeway type operation (HHDDT)
- We expect oil consumption to be higher during idle and low load operation due to lower piston ring sealing

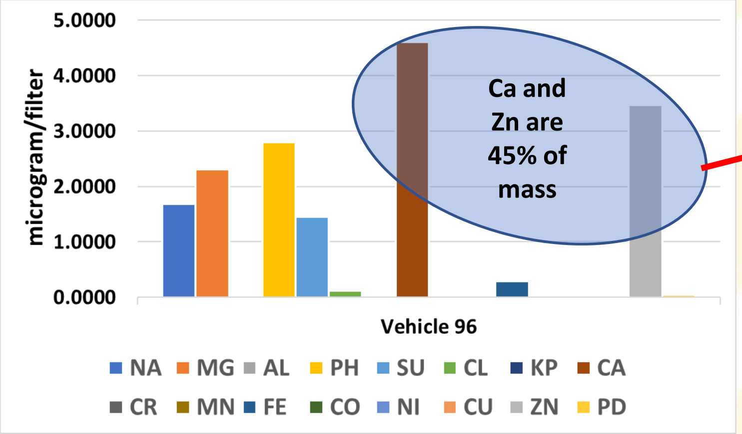


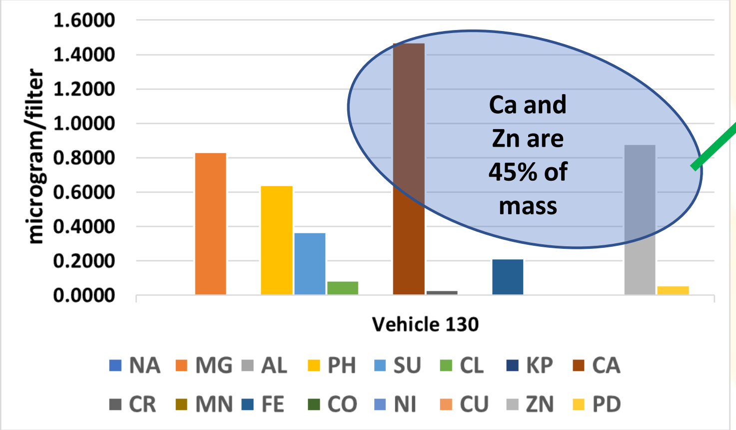


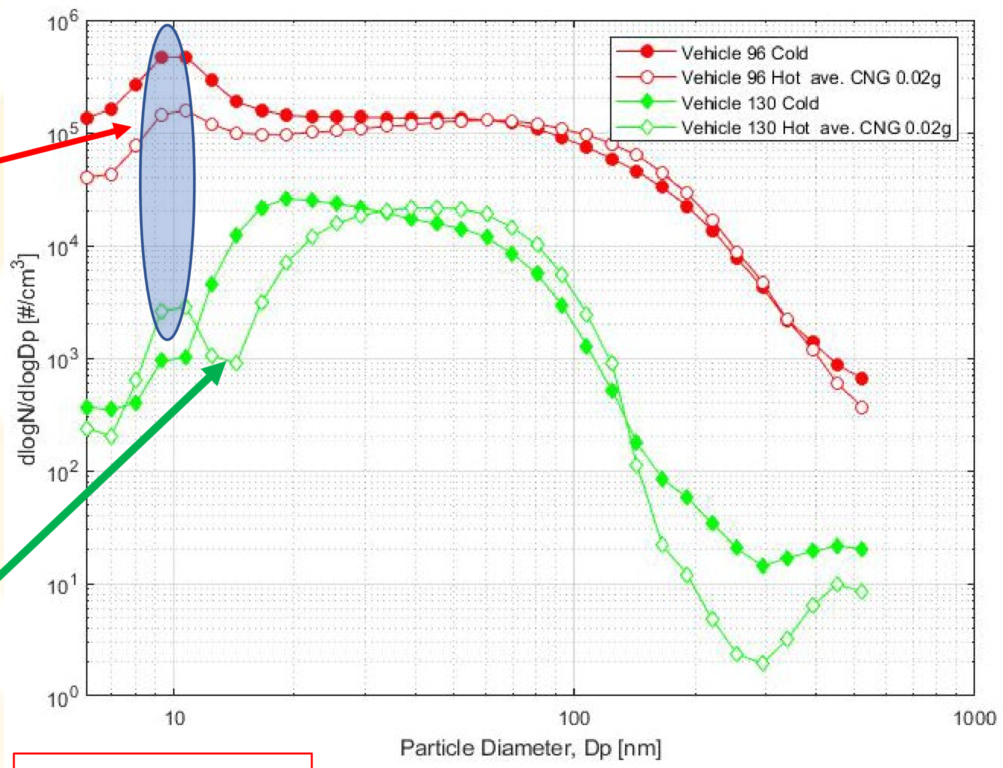
The GMC cycle was developed from the TTSI drayage truck routes

PM Emissions- Evidence of Lubrication Oil Consumption

- Metals/ions analysis shows primarily lubrication oil-based emissions
  - Calcium, Zinc, Phosphorous, Magnesium are common lubrication oil additives
  - Zn and Ca are excellent tracers to identify lubrication oil derived elemental emissions
- Difference in nucleation mode concentration is reflected in mass emissions of lube-oil derived elements







ZDTP (Zn & Ph): Is a common additive to reduce engine wear

Ca is a detergent in oil

Conclusions

- From a NOx perspective, the TWC aging appears to be more significant than SCR aging.
- The high temperatures of the stoichiometric engine with higher exhaust moisture content from natural gas combustion could potentially contribute to accelerated aging
- Oxygen sensor feedback could also be a potential area of concern for an aged vehicle to maintain stoichiometry low-NOx emissions
- Proper maintenance of natural gas and other spark-ignited engine platforms is highly critical compared to diesel vehicles
  - Need for robust diagnostics in alternative fuel vehicles
  - A large-scale maintenance cost data collection effort is underway as part of a DOE project
  - Preliminary findings: **LOW OIL LEVEL** **(Single most commonly found maintenance issue)**
  - Maintenance of closed crankcase ventilation systems
- OEM requirements: Low ash lubrication oil for natural gas
  - **Do all fleets follow OEM requirements?**

CARB's Use of Data From the "200 Vehicle Program" in EMFAC2021

Presentation to the South Coast Air Quality Management District
Clean Fuels Program Advisory Group

September 8, 2022

Background

- The goal of the 200 vehicle in-use study, or “200 Vehicle Project”, is to better understand real-world (or in-use) emissions and activity of modern medium and heavy heavy-duty diesel and natural gas vehicles.
- The California Air Resources Board (CARB), along with several other agencies, funded and participated in the project.
- Data from the project are valuable for understanding the in-use performance of newer technologies under real-world conditions, and therefore informing inventory modeling in EMFAC.

Heavy-Duty (HD) Vehicle Emissions Updates: Overview

EMFAC 2017

Heavy HD (HHD) Diesel

- Running emissions from **20** MY* 2013+ trucks (chassis dyno)
- Start and idle emissions from **4** MY 2010+ trucks (PEMS**)

Medium HD (MHD) Diesel

- Emission rates by scaling HHD trucks

Natural Gas (NG)

- Emission rates from **five** 0.2 g/bhp-hr transit buses (chassis dyno)

EMFAC 2021

HHD Diesel (MY 2013+)

- Running emissions from **26** trucks (chassis dyno)
- Start emissions from **11** trucks (PEMS)
- Activity profile updated using **200-vehicle project**

MHD Diesel (MY 2013+)

- Running emissions from **8** trucks (chassis dyno)
- Activity updated using **200-vehicle project**

Natural Gas

- Running emissions from **47** vehicles of **200-vehicle project** (PEMS)

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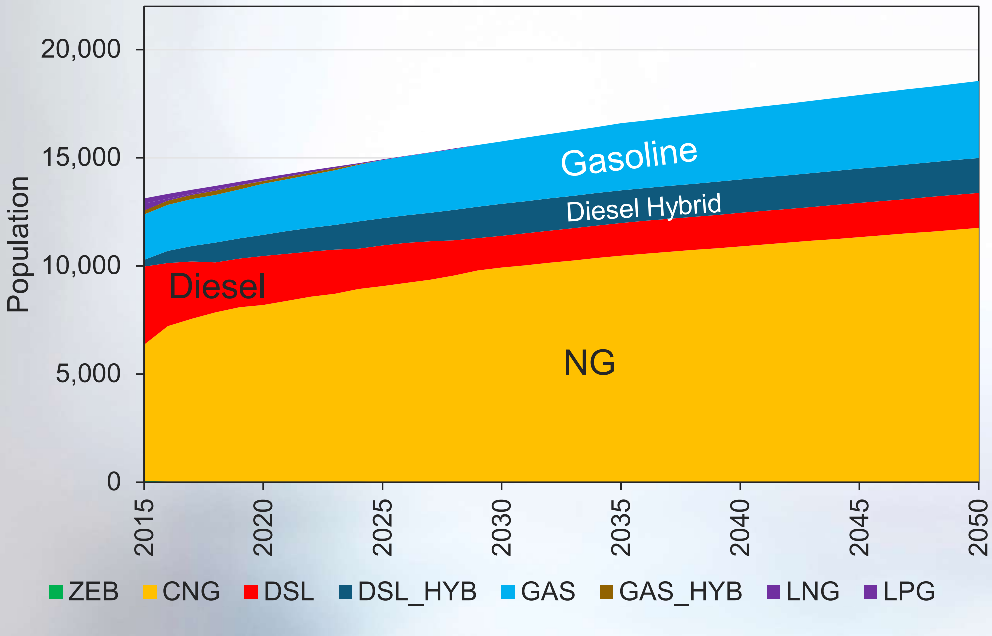
*MY = Model Year

**PEMS = Portable Emissions Measurement Systems

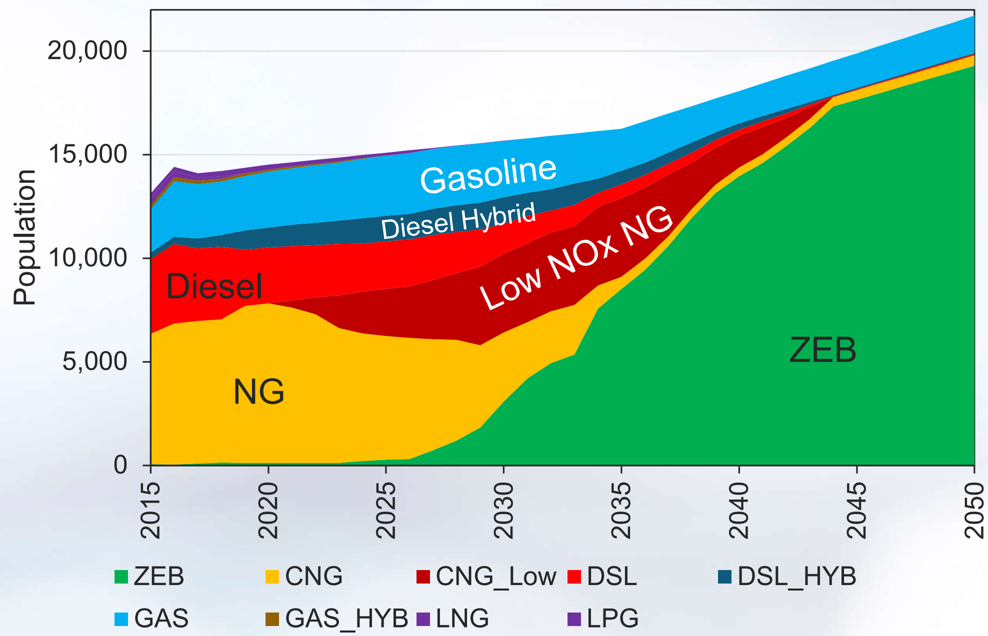
HD population in EMFAC2021

Bus Population by Fuel and Technology

EMFAC2017



EMFAC2021



- Future fleet mix in EMFAC2021 reflects benefits of Innovative Clean Transit (ICT) Regulation

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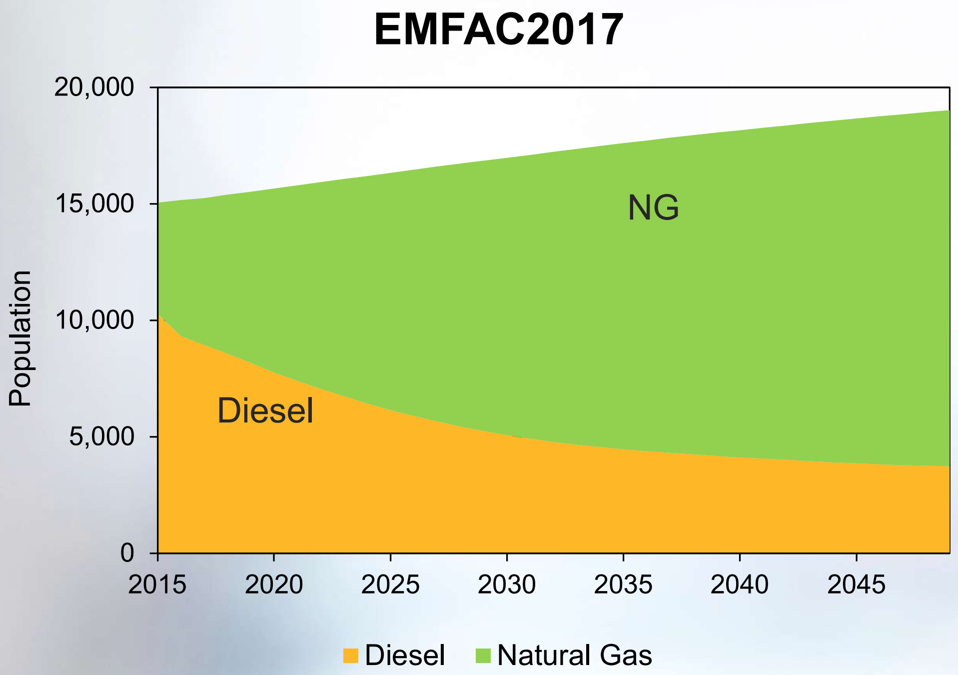
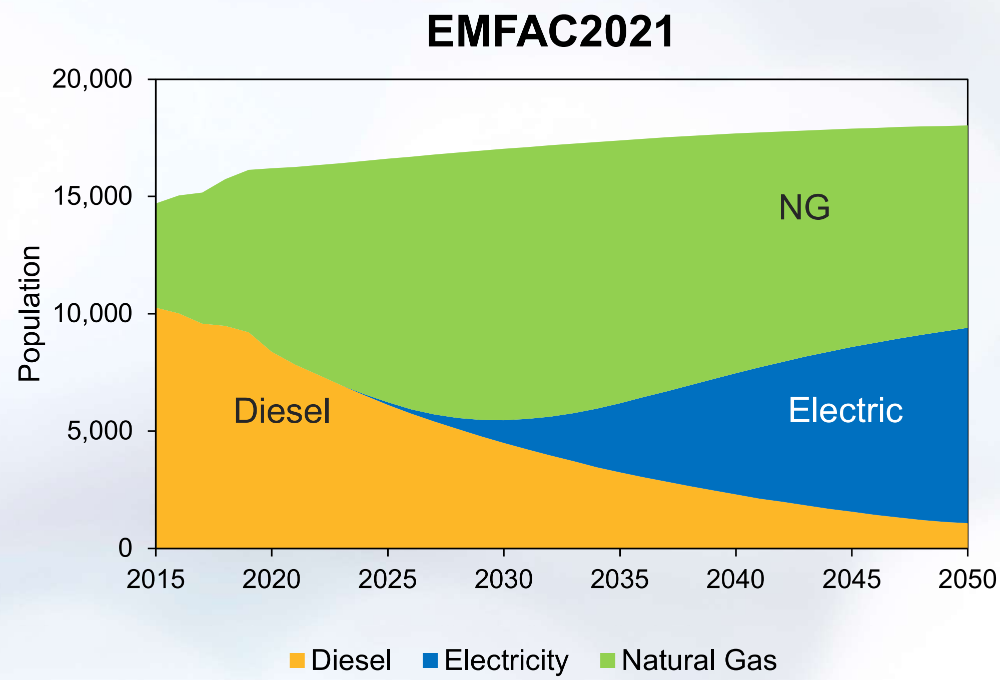
HD population in EMFAC2021

Solid Waste Collection Vehicles (SWCV*) Population by Fuel





*SWCV, T7, Class 8 Trucks (33,000+ lbs)

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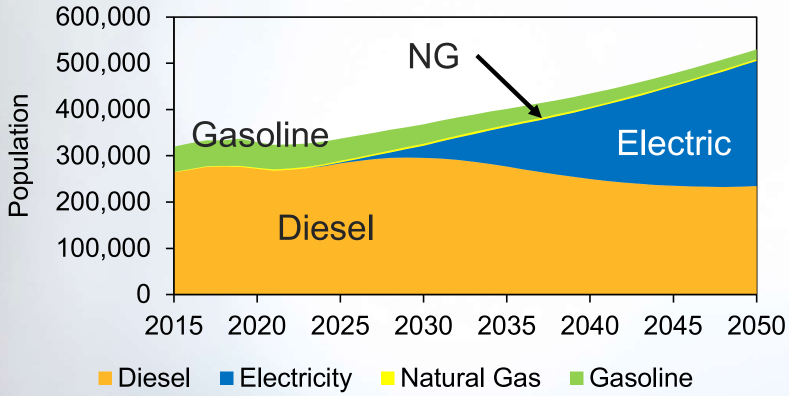
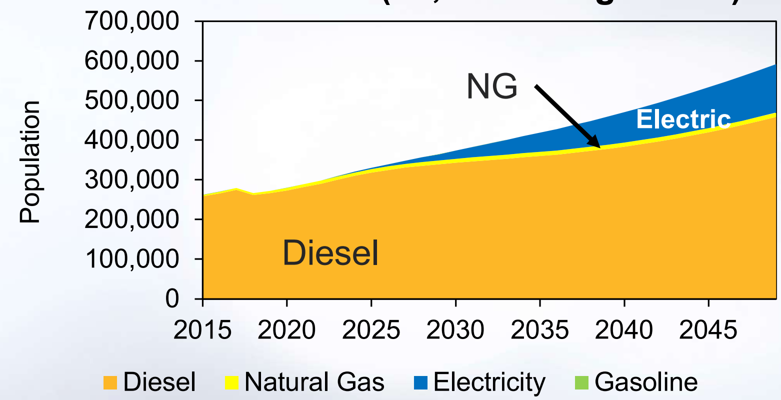
HD population in EMFAC2021

Three Newly Created Categories of Natural Gas Vehicles in EMFAC2021

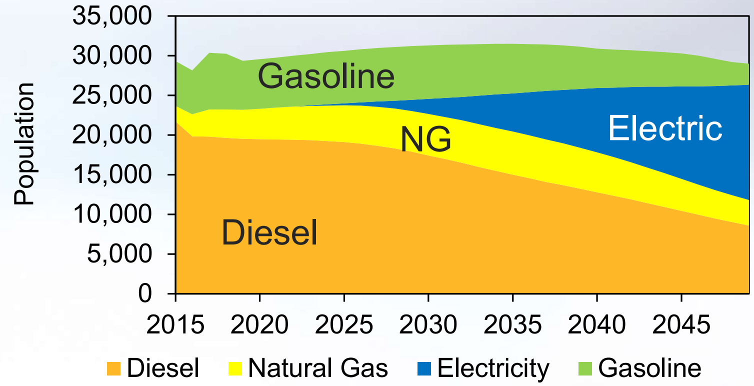
Class 4-7 Vehicles (T6)



Class 8 (T7, excluding SWCV)



School Buses



*T6: Class 4-7 (14,000-33,000 lbs)
T7: Class 8 (33,000+ lbs)

Test Matrix of 200-Vehicle Project

Fuel Type	Delivery Truck	Refuse Hauler	Transit Bus	Goods Movement Truck	School Bus	PEMS / dyno* / PAMS**
Diesel (NO SCR)	2	-	-	5	2	**5 / 4 / 9**
Diesel 0.2g	19	3	-	44	6	**29 / 12 / 72**
NG 0.2g	15	20	9	22	21	**31 / 13 / 87**
NG 0.02g	-	9	6	18	-	**26 / 15 / 33**
Dual Fuel (HPDI)	-	-	-	4	-	**0 / 0 / 4**
Propane 0.2g	4	-	-	-	1	**0 / 0 / 5**
Propane 0.02g	1	-	-	-	1	**5 / 2 / 2**
Diesel Electric	6	-	-	-	-	**4 / 2 / 6**
Battery Electric	-	-	4	4	-	**0 / 3 / 8**
H2 Fuel Cell Electric	-	-	1	-	-	**0 / 1 / 1**
Total	47	32	20	97	31	**100 / 52 / 227**

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*dyno: chassis dynamometer, **PAMS: Portable Activity Monitoring System

HD Activity Profiles in EMFAC

- Activity profiles include:
  - Vehicle Miles Traveled (VMT) distribution by speed bin and time of day
  - Frequency of daily engine starts and soak time distributions
  - Fraction of engine idling time
- In EMFAC2017, activity profiles were informed by Portable Activity Measurement Systems (PAMS) data from 90-vehicle study*
- In EMFAC2021, PAMS data of **170** vehicles from the "200-vehicle project" were analyzed and pooled with **45** vehicle samples from EMFAC2017

*University of California, Riverside (UCR). College of Engineering (CE) – Center for Environmental Research and Technology (CERT). Boriboonsomsin, K., Johnson, K., Scora, G., Sandez, D., Vu, A., Durbin, T., & Jiang, Y. (2017) Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles. Available at https://www.arb.ca.gov/research/apr/past/13-301.pdf

Activity Profile Sample Sizes

Vehicle category	Count in 200-vehicle study (new in EMFAC2021)	Count in 90-vehicle study (used in EMFAC2017)	Total in EMFAC2021
Out of State (OOS)	18	5	**23**
School Bus	27	0	**27**
T6 Instate Delivery	2	2	**4**
T6 Instate Tractor	5	4	**9**
T7 Port of LA (POLA)	36	4	**40**
T7 Single Other	5	11 (construction)	**16**
T7 Solid Waste Collection Vehicle (SWCV)	26	6	**32**
T7 Tractor	40	8	**48**
Transit Bus (UBUS)	11	5 (not used in EMFAC2017)	**16**
Grand Total	170	45*	**215**

* Public, Utility, Ag, POAK trucks are not used for this analysis

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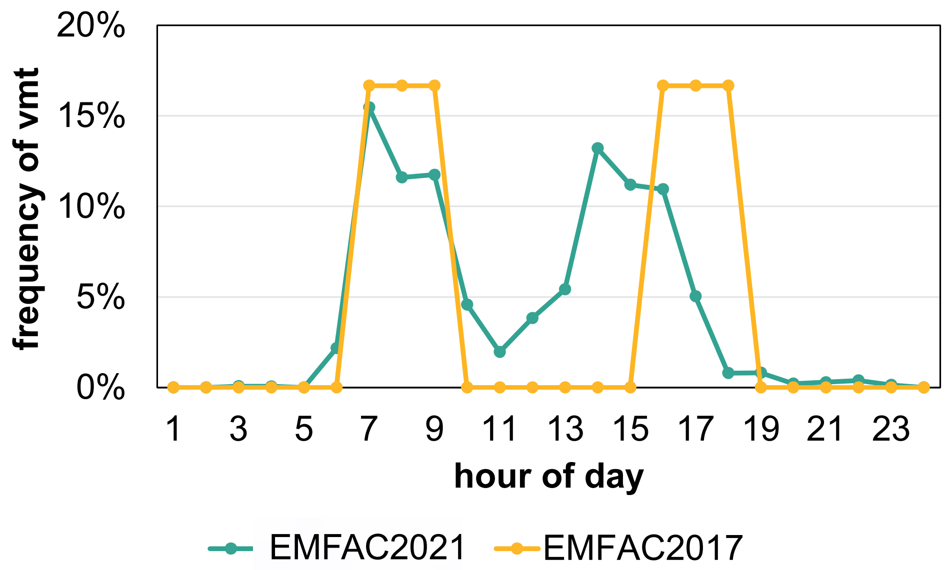
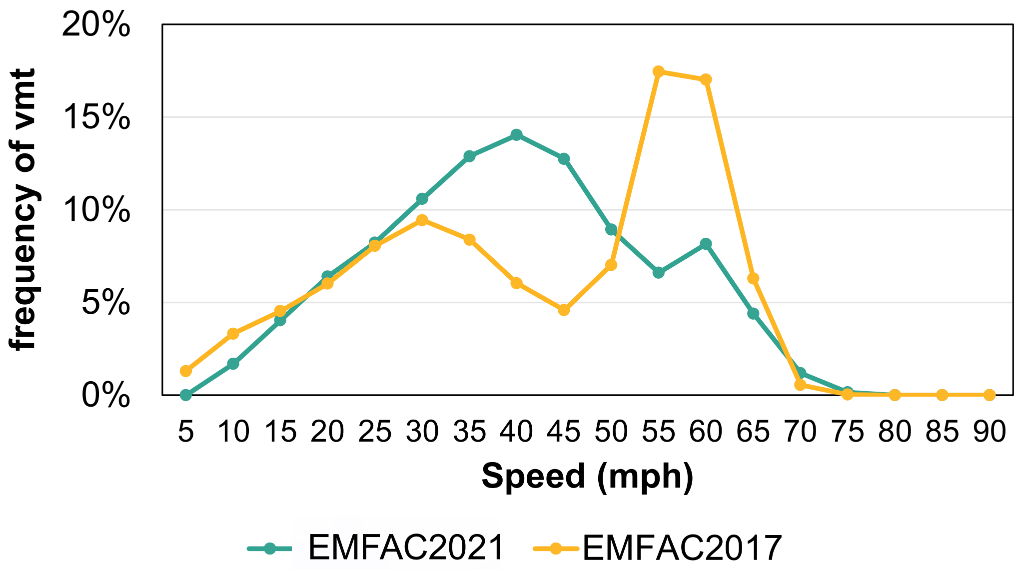
HD activity in EMFAC2021

Example of VMT Distribution Update: School Bus (SBUS)





Vehicle category	Count in 200 vehicle	Count in 90 vehicle	Total
SBUS	27	0	27

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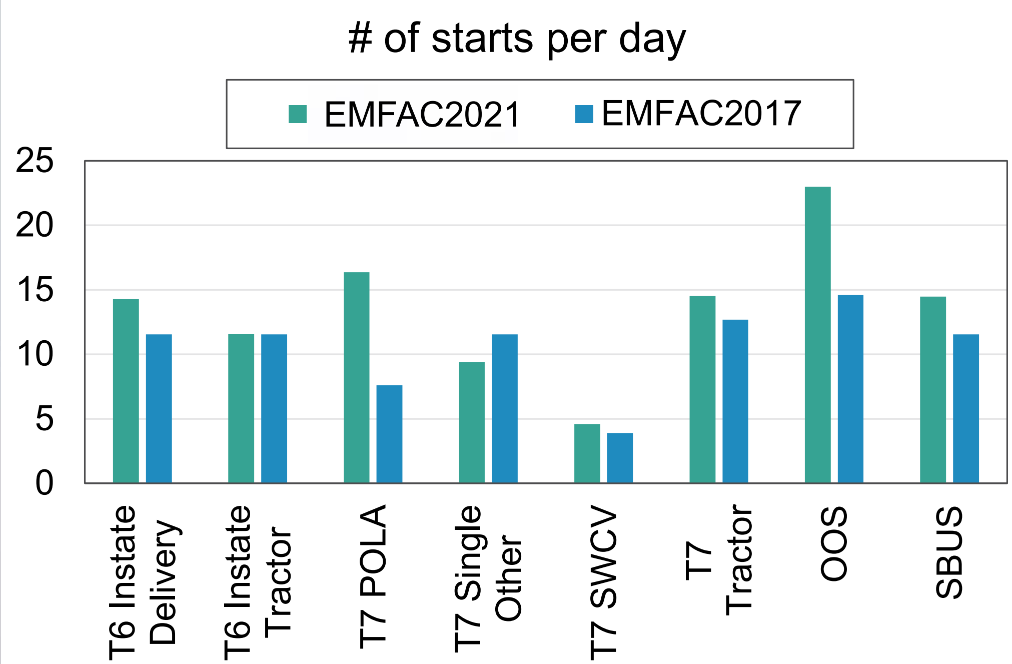
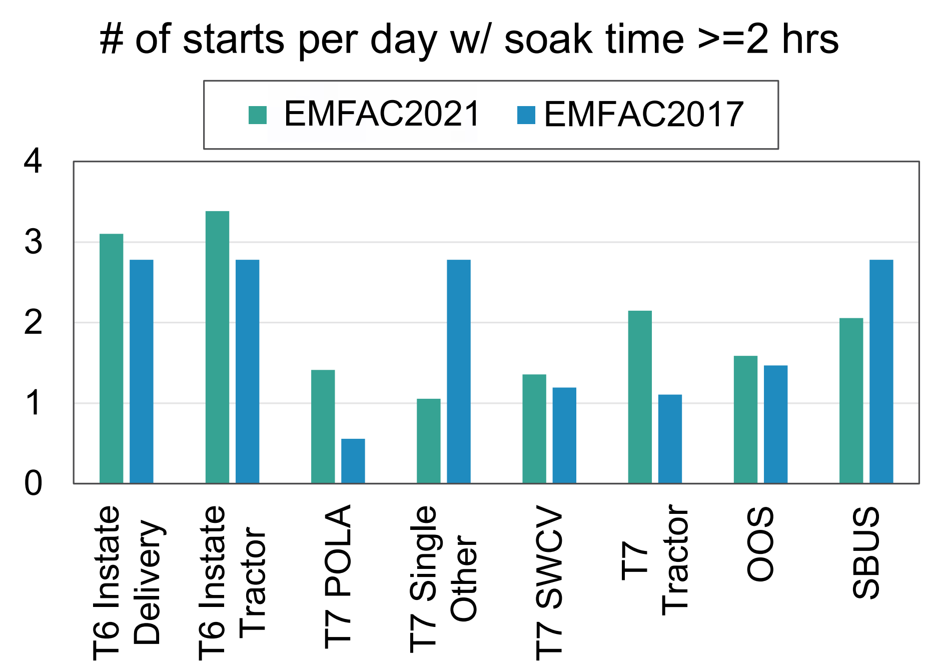
EMFAC2021 Reflects More Starts Per Day and Longer Soak Times Between Starts





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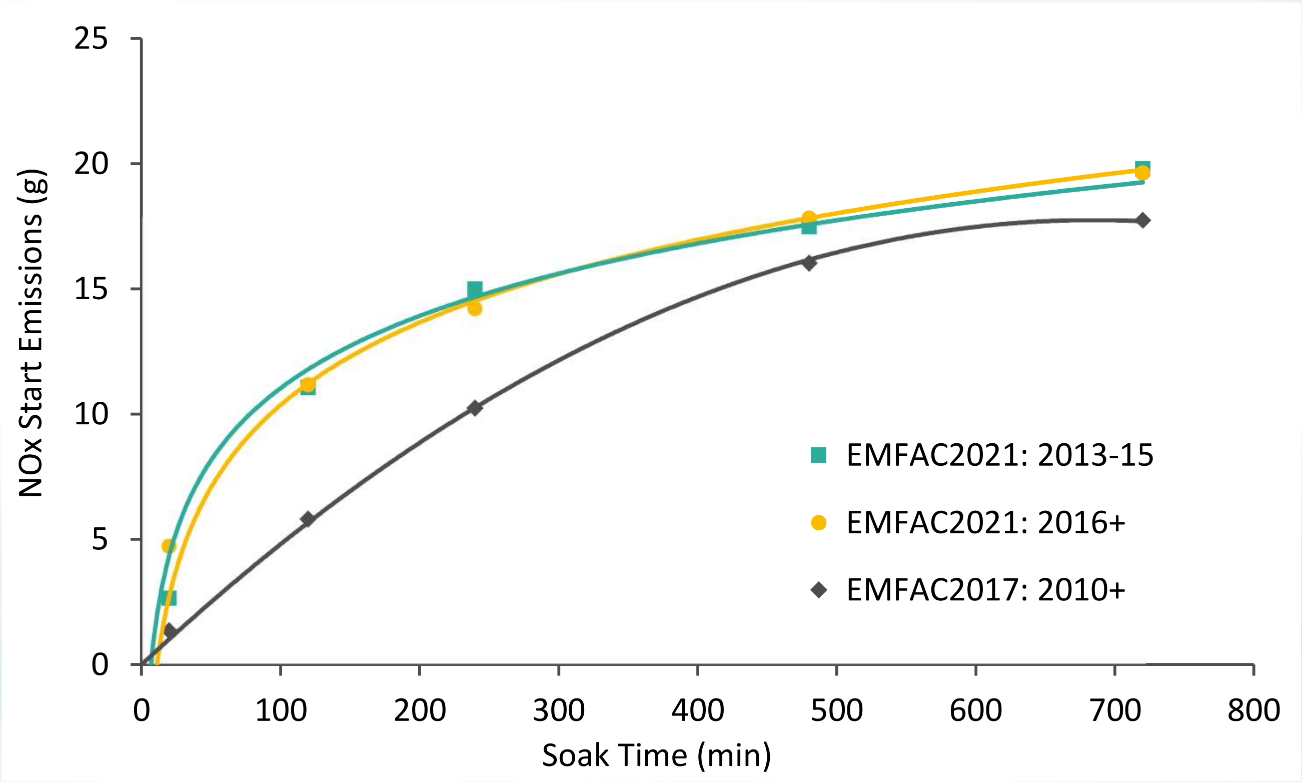
Emissions per Start as a Function of Soak Time



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Emission Factors for Natural Gas Vehicles

- PEMS data from 47 NG HD vehicles were used in EMFAC2021
  - Three newly introduced NG categories: School Bus, Class 4-6 (T6) and Class 8 (T7)

Technology	Transit Bus	School Bus	Refuse Truck	Goods Movement Truck	Delivery Truck	Total
TWC* (0.2 g/bhp-hr)	5	5	11	8	3	32
TWC (0.02 g/bhp-hr)	5	--	1	9	--	15
Total	10	5	12	17	3	47

*TWC: Three-Way Catalyst

- CARB staff assumptions for 0.2 vs. 0.02 g/bhp-hr split for NG engines:

Model Year	0.02g Engines Fraction in EMFAC2021
Pre-2017	0%
2017	50%
2018+	100%

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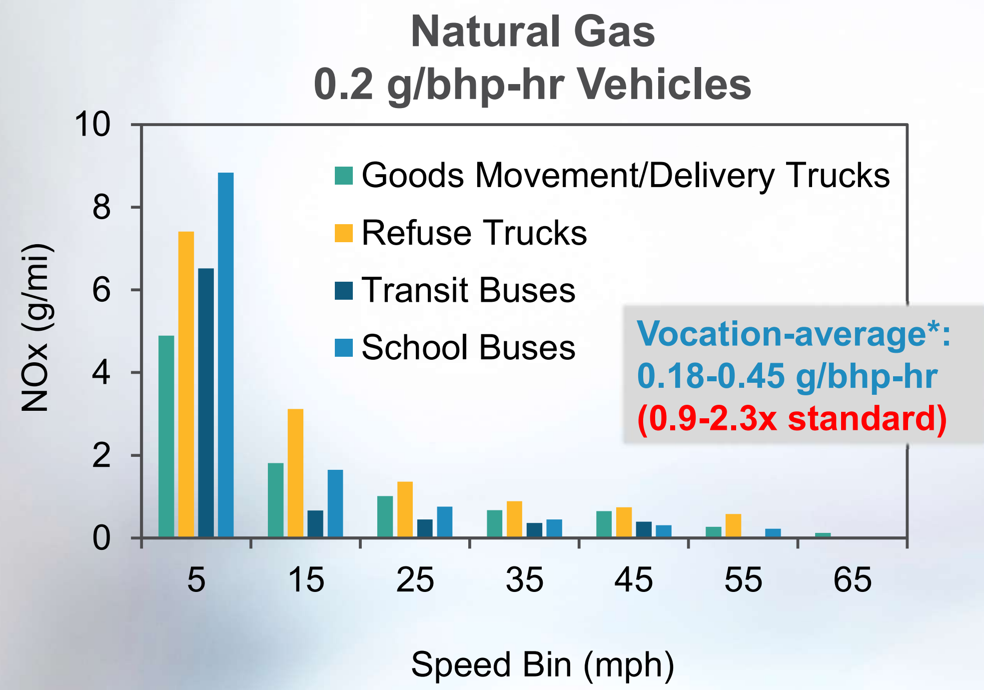
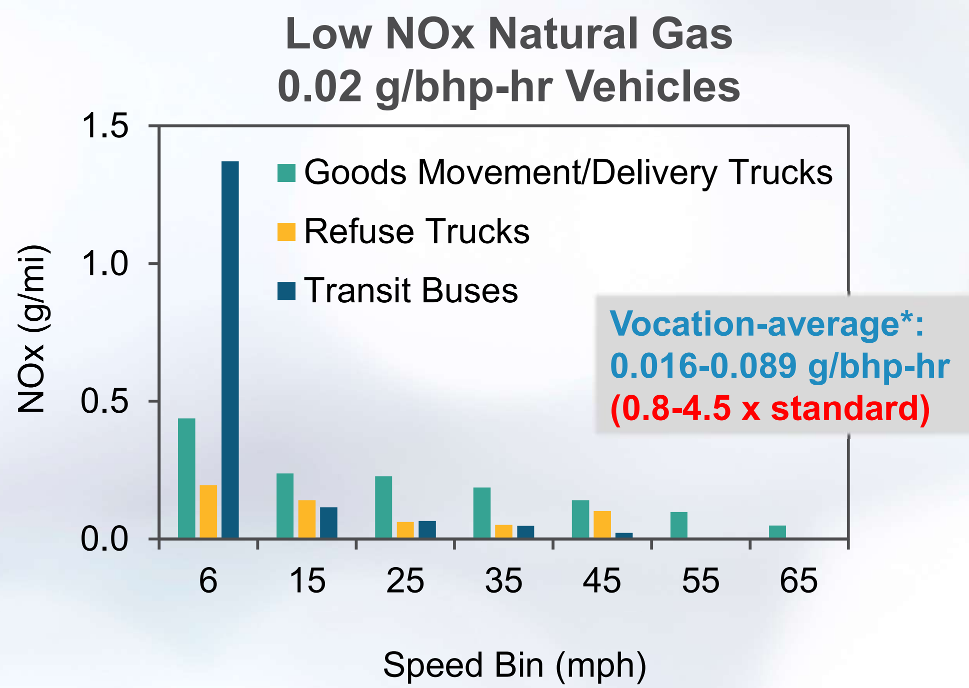
In-Use NOx Emissions Rates by Vocation Used in EMFAC2021





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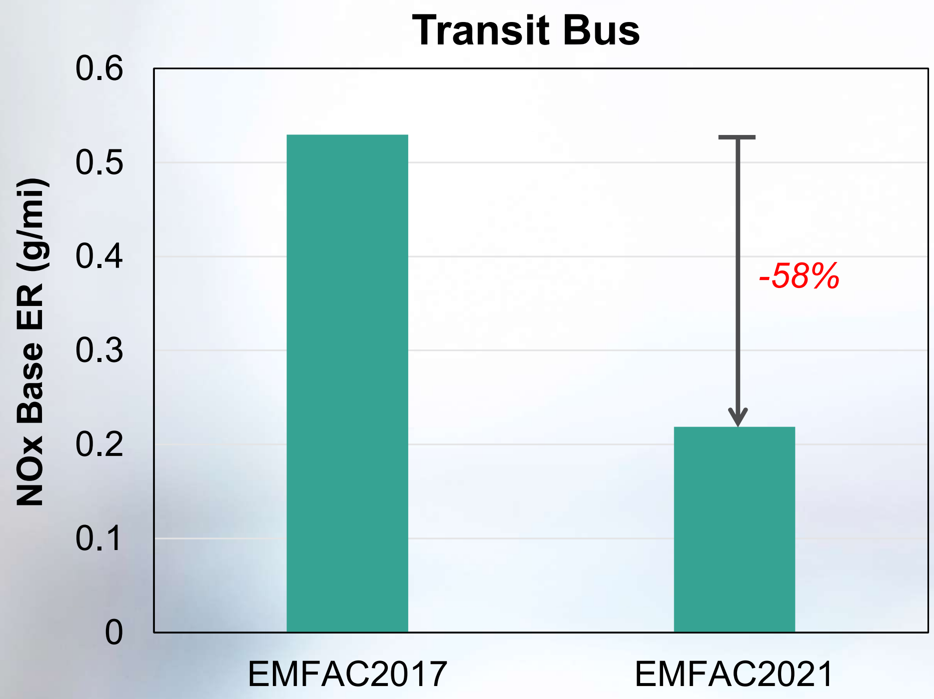
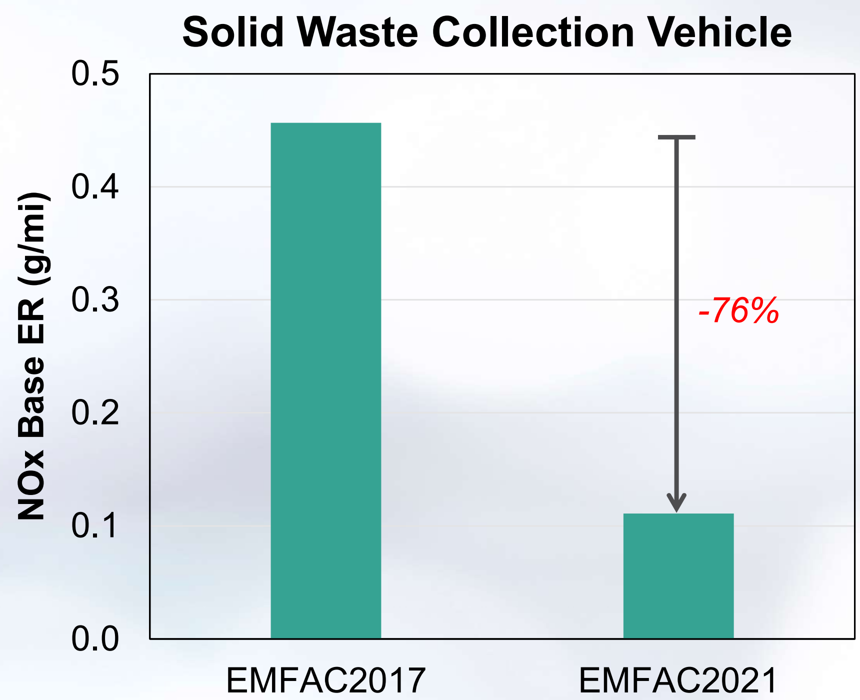
* PEMS daily averages

Model Results for MY 2022 Natural Gas Engines: EMFAC2017 vs. EMFAC2021



Speed=15 mph, Temp=70 degrees F, Relative Humidity=50%



Speed=20 mph, Temp=70 degrees F, Relative Humidity=50%

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Contributors to NG Reductions Between EMFAC2017 and EMFAC2021

1. Fleet mix
   - EMFAC2017 assumes 100% “0.2 g” for MY2008+
   - EMFAC2021 assumes 100% “0.02 g” for MY2018+
2. Emission rates (using Transit Bus as an example):

Engine NOx Standard	EMFAC2017 (g/mile)	EMFAC2021 (g/mile)
0.2 g/bhp-hr	0.61 (MY2008+)	1.44 (MY2007-2017)
0.02 g/bhp-hr	No Data	0.23 (MY2018+)

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Conclusions

- Data from “200 Vehicle Project” were used in EMFAC2021:
  - Activity profiles from 170 vehicles (PAMS data)
  - Emission rates using 47 NG vehicles (PEMS data)
- EMFAC2021 includes additional natural gas vehicle categories with updated emission rates about 75 percent lower NOx than predicted by EMFAC2017
- Optional Low NOx technology still had up to 4.5 times the 0.02 g/bhp-hr standard during in-use operation

Next Steps

- The “200 Vehicle Project” data will continue to inform future model releases (i.e. EMFAC202Y)
  - Only 47 out of 120 NG vehicles were used in EMFAC2021, the rest will be considered for EMFAC202Y (PEMS and dyno)
  - All 81 diesel trucks data will be analyzed for EMFAC202Y (PEMS and dyno)
- EMFAC202Y development in progress
  - First workshop anticipated in October 2022

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Infrastructure Priorities and Challenges

Overview of Infrastructure Challenges

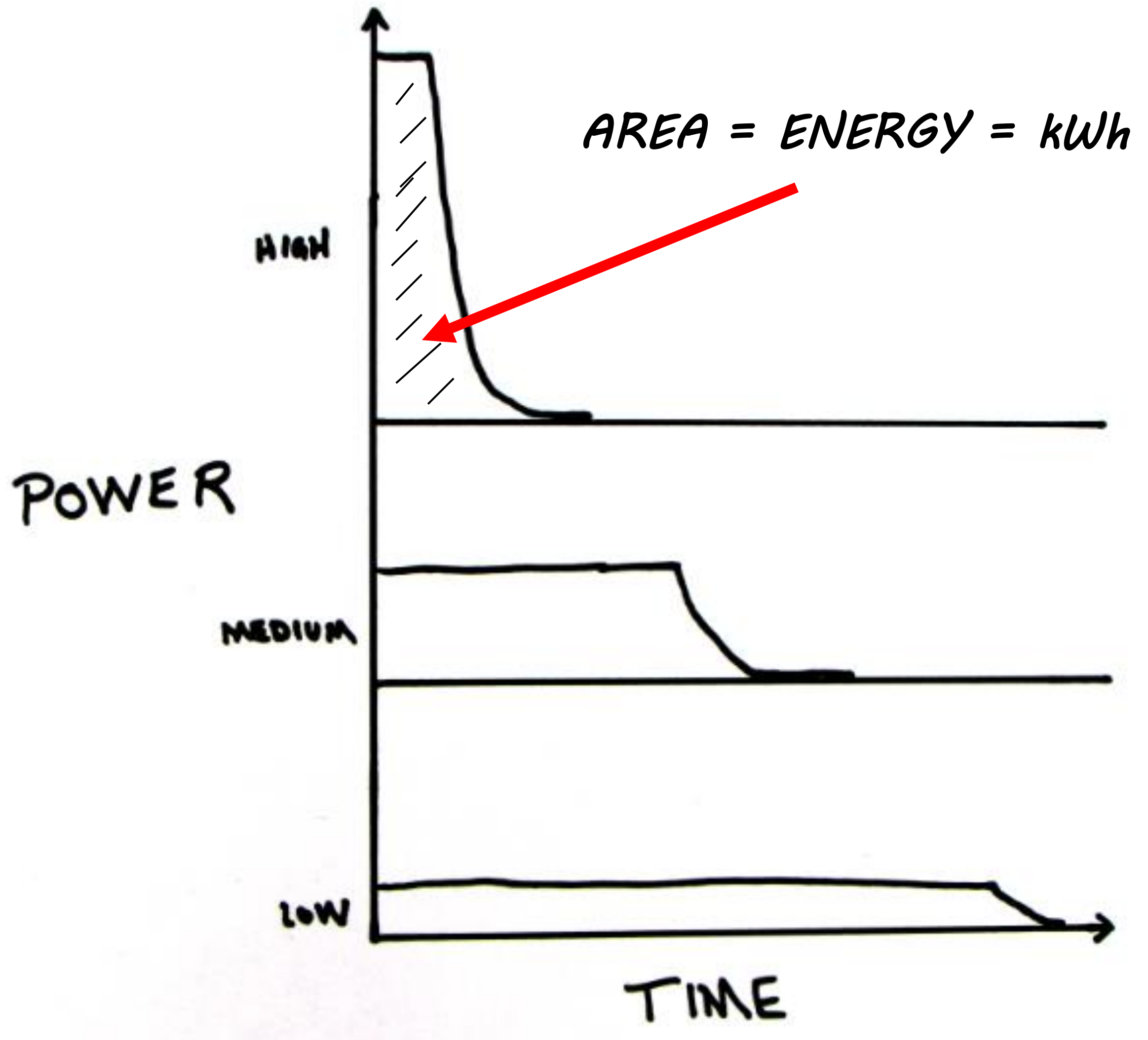
Watson Collins
Senior Technical Executive
wcollins@epri.com

Clean Fuels Program Advisory Group
September 8, 2022

FAQs

- Can what we've learned from Light-Duty EV infrastructure inform us about Medium- / Heavy-Duty EV?
- What are the best strategies to charge EVs?
- What power levels will the forthcoming MCS / CHARIN address?
- Is the grid ready to serve EVs at Scale?
- What are the high impact things EPRI has underway to enable EV infrastructure for Medium- / Heavy-Duty EVs?

What Are the Best Strategies to Charge an EVs?



"The general rule for EVs: the slower you charge, the cheaper it is, the less expensive the infrastructure, and the better for the batteries."

… But the specific application determines the dwell time potential

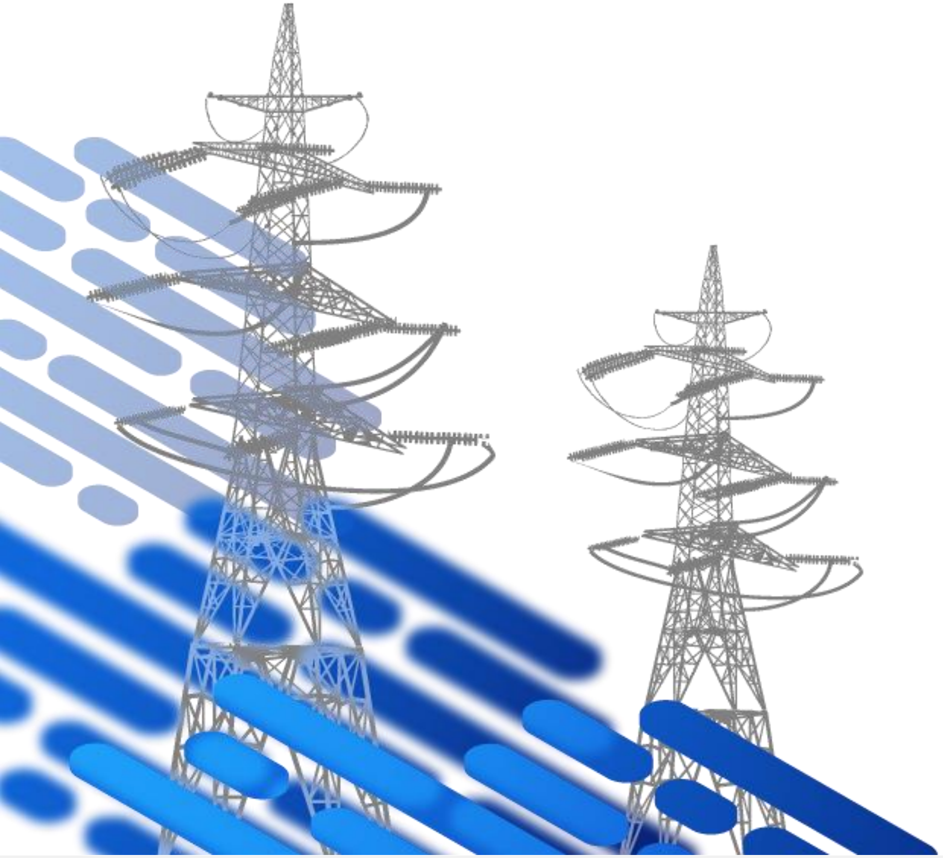
Power Levels are Significantly Different for MD- / HD Vehicles

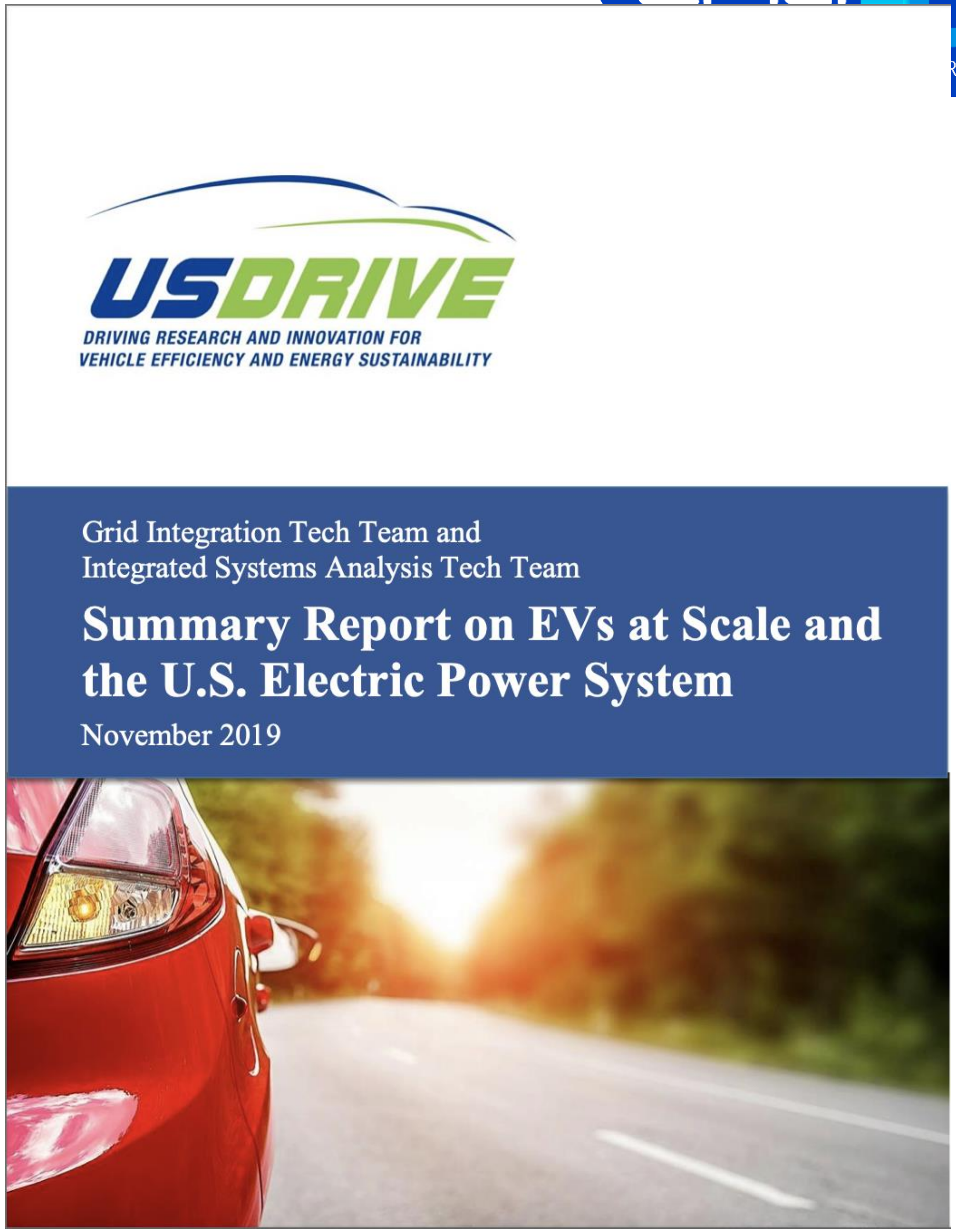
Megawatt Charging System – Power Class Levels

MCS Level	Description	*Max Current (A)	Power (kW) @ Nominal Battery Voltage			Power (kW) @ Max Voltage
			400 Vdc	800 Vdc	1200 Vdc	1500 Vdc
1	no liquid cooling	300	120	240	360	450
2	infrastructure (plug and cable) liquid cooled	1000	400	800	1200	1500
3	both infrastructure (plug and cable) and EV port liquid cooled	3000	1200	2400	3600	4500

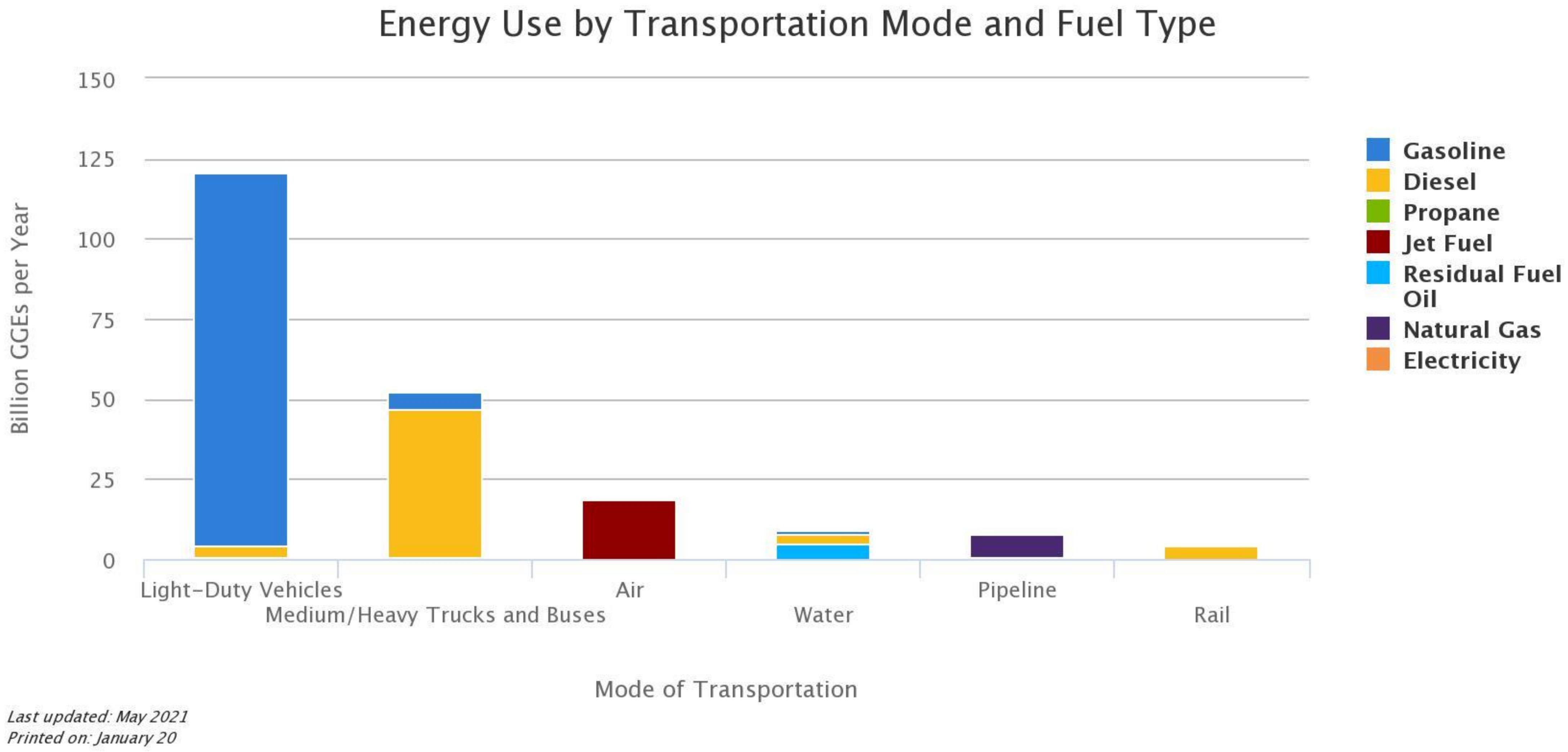
* The current limits are approximate and subject to change

Is the Grid Ready to Serve EVs at Scale?





Light-Duty Transportation Accounts for ~50% of Transportation Sector Energy Usage



Can a Simplified Approach Help to Answer the Question of the Grid Readiness for EVs at Scale?

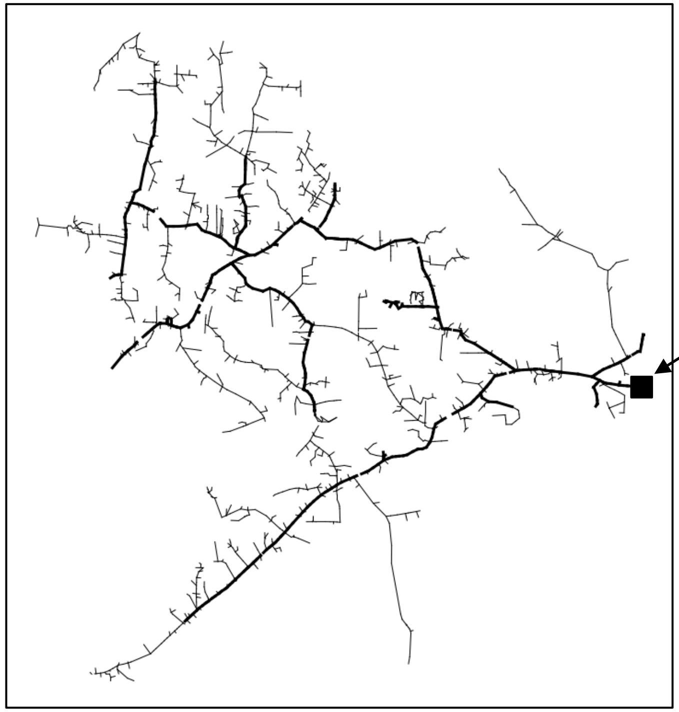
A simplified calculation indicates that Total US electrical energy consumption would increase by about 25% if every passenger vehicle was electrified.

… But the simplified approach doesn't help identify what issues/ areas need attention. It comes down to when and where.

Assumptions For the Simplified Calculation

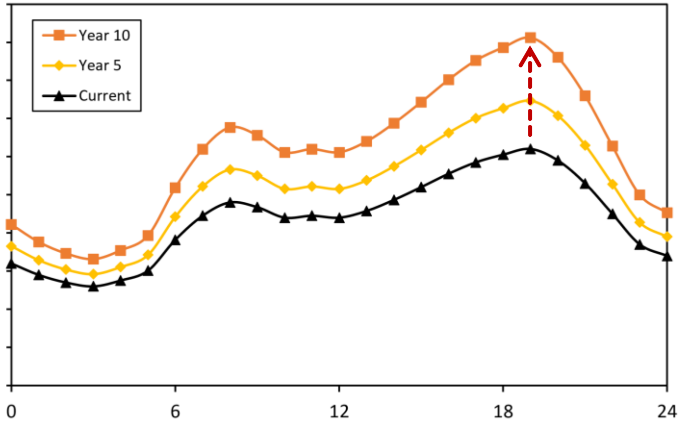
- Annual US Electricity Consumption in US 3,800,000 GWh
- https://www.eia.gov/energyexplained/electricity/use-of-electricity.php
- Approximately 270 M passenger vehicles in the US
- Approximately 3,500 kWh per year Annual kWh per passenger EV
- Implied 945,000 GWh Annual GWh for 100% passenger EV (GWh equals million kWh)

Are EVs just like another load on the system?

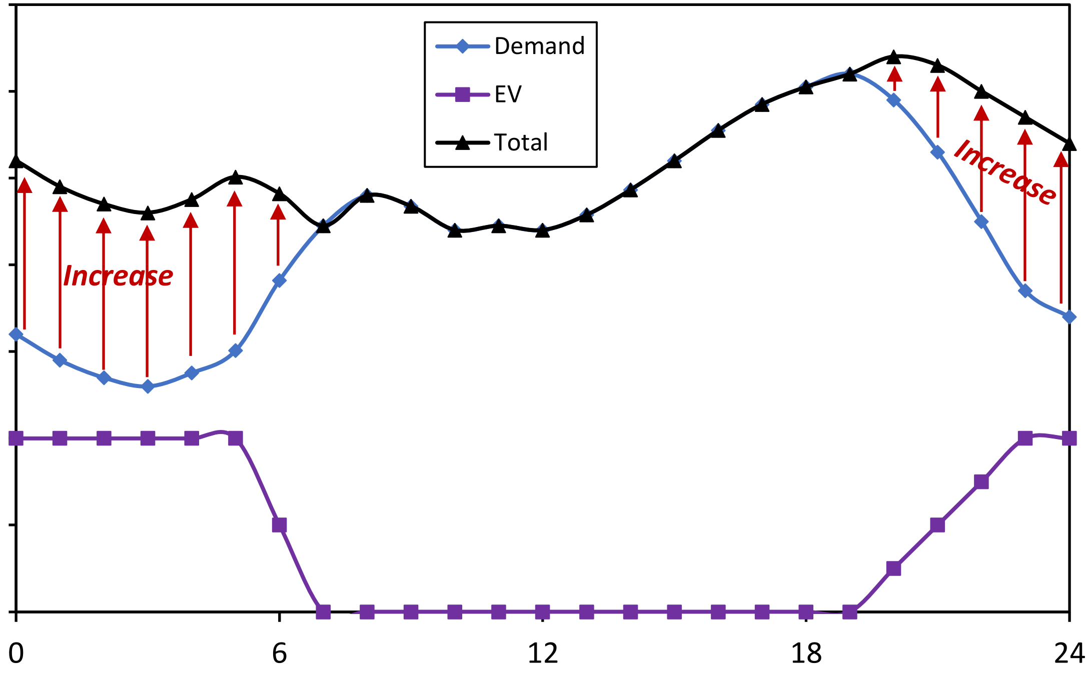


Impact at the substation

Conventional Load Growth



Fleet Electrification



Data needed for both grids and fleets to understand when and where issues

- <u>Fleet Electrification Characterization</u>
  - *Fleet Travel Patterns and Needs Assessment*
  - *Technology Maturity Assessment*
  - *Charging Strategies and Applications*

- <u>Grid Planning for Fleet Electrification</u>
  - *Assess system-wide grid electrification opportunity*
  - *Future fleet electrification assessment*
  - *Grid readiness and integration assessment*

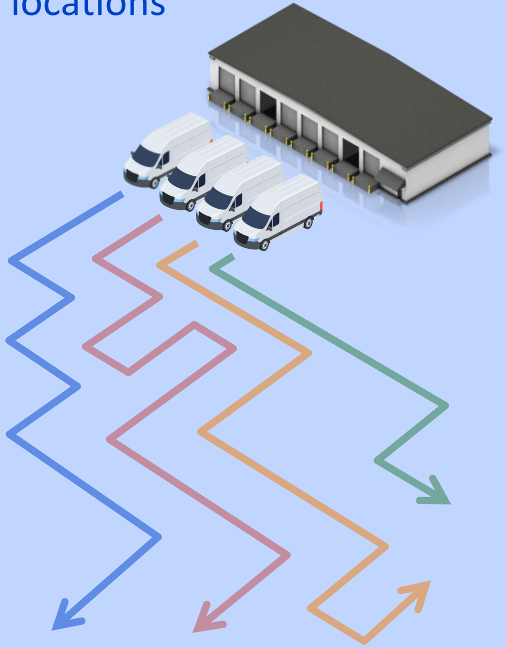
Fleet Electrification Characterization

Project-wide

Utilities need a better understanding of fleet customer needs by segmenting fleet customer to assess their characteristics, operations, and charging strategies.

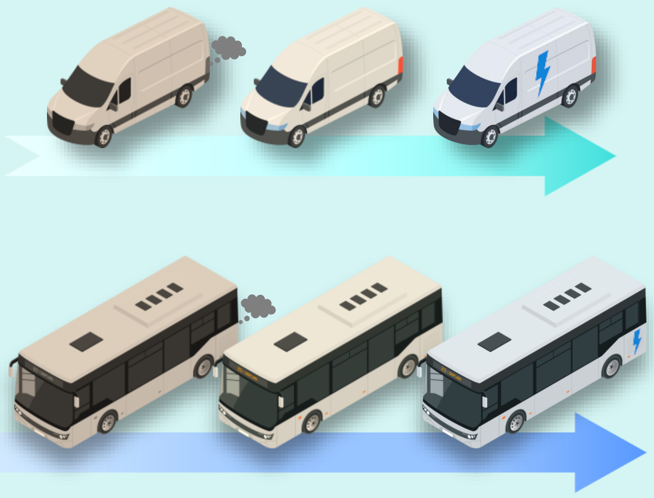
Fleet Operation and Needs Assessment (WHERE)

- Travel Patterns (miles and dwell)
- Vehicle types
- Dwell locations



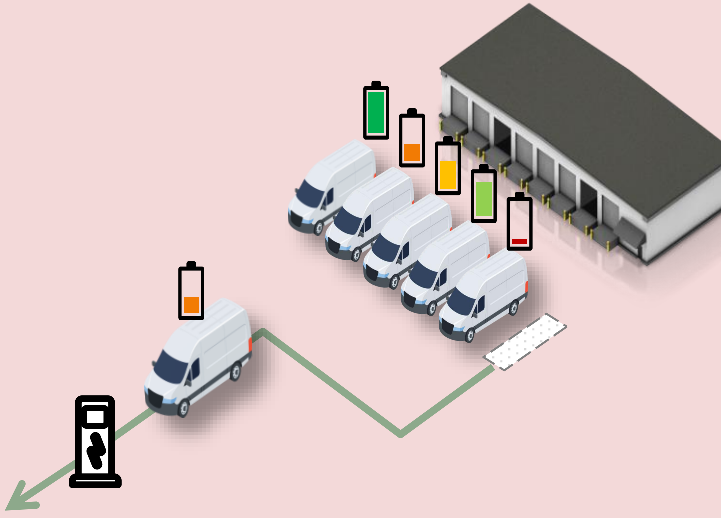
Technology Maturity Assessment (WHEN)

- Electric vehicle technology
- High-power charging equipment
- Required supporting infrastructure

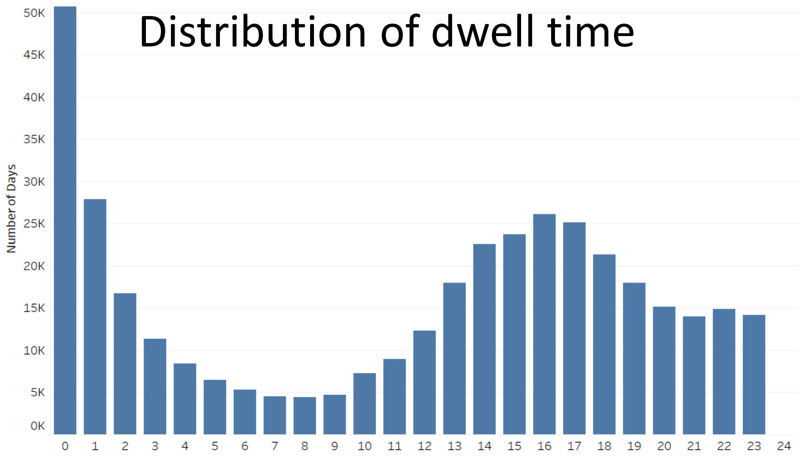


Charging Strategies and Applications (FLEXIBILITY)

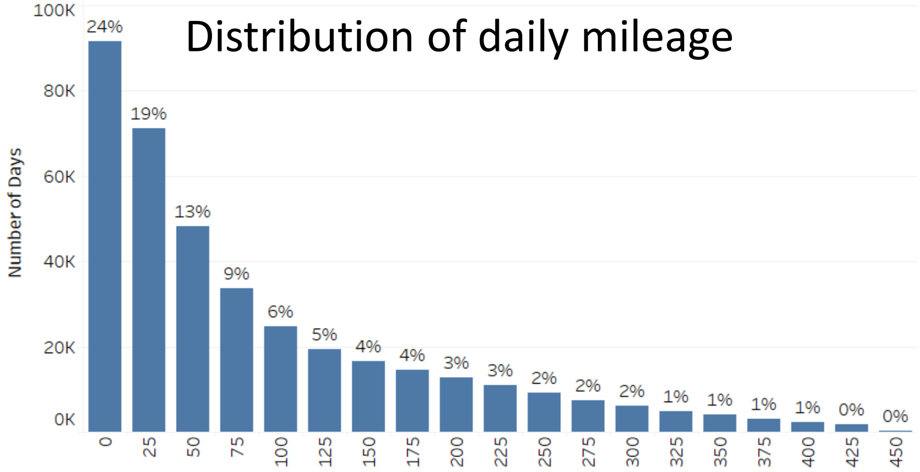
- En-route vs depot-based charging
- Charge management strategies
- Market-based vs. incentive-based operations



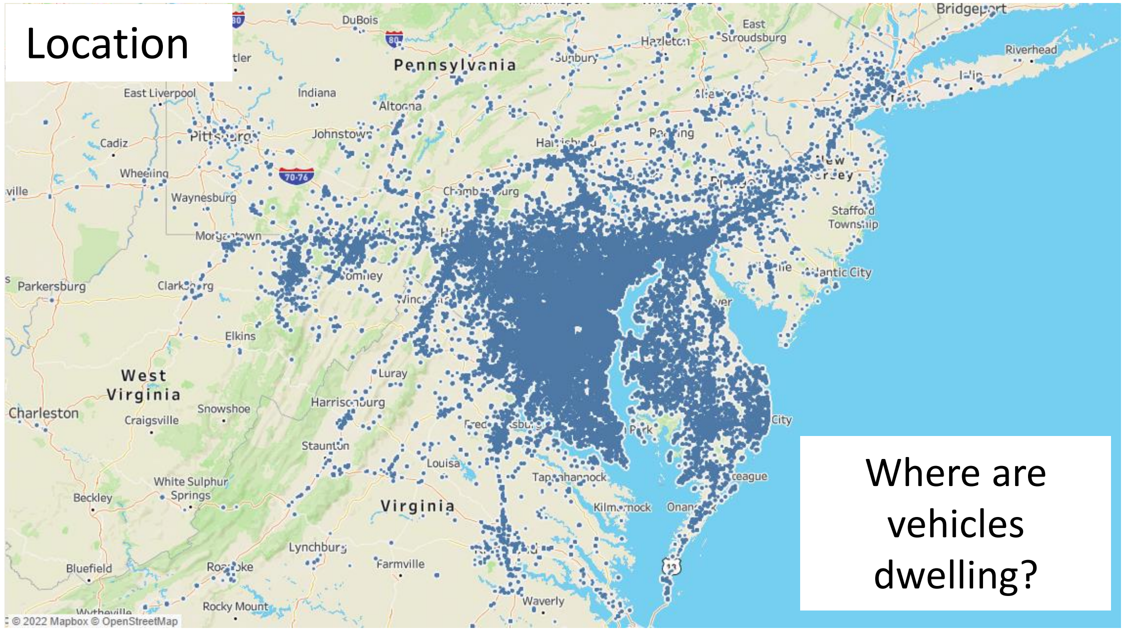
Fleet Characterization: Dwell, miles and location



Dwell Time Bins →



Daily Miles Bins →



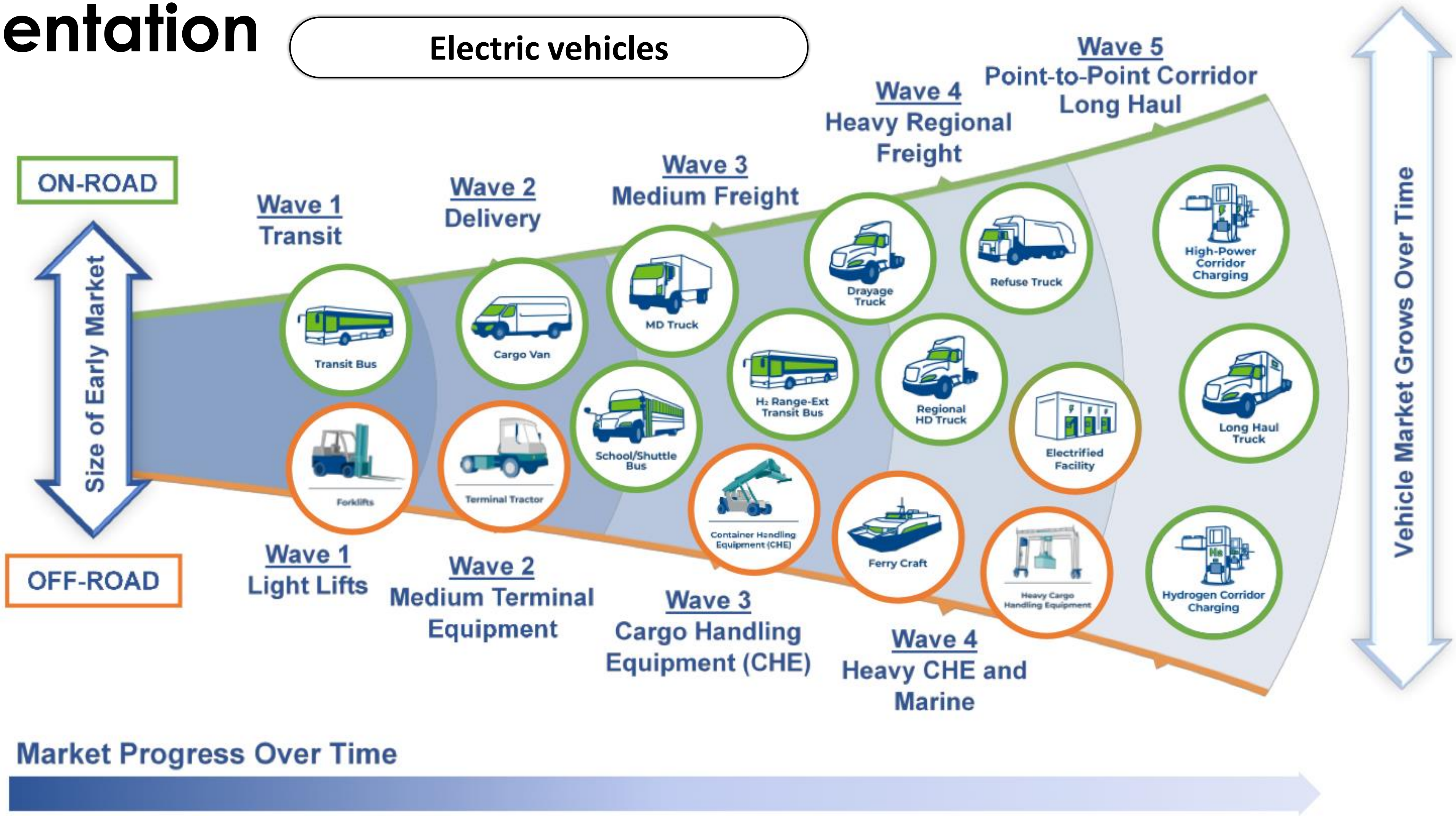
Miles Driven + Dwell Time +
Vehicle Efficiency + Battery Capacity

=

Unique Charging Needs

Fleet Characterization: Adoption and vehicle segmentation

Electric vehicles



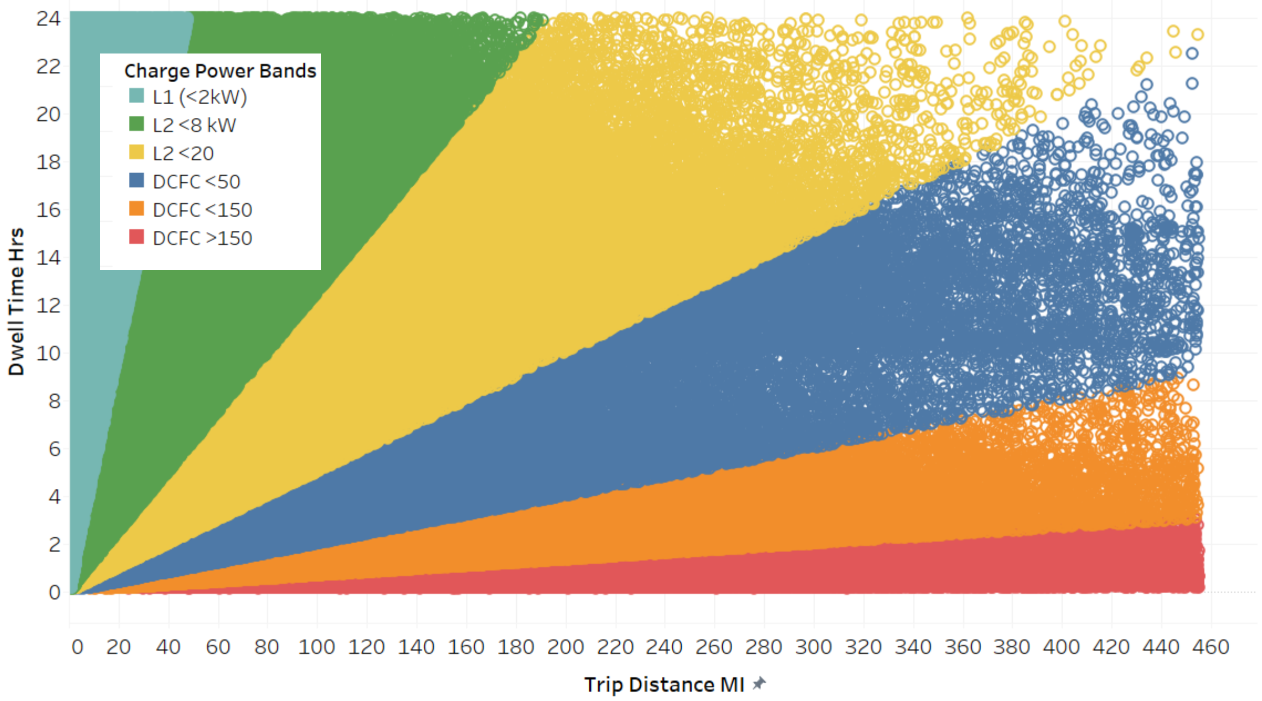
Charging Equipment **Supporting infrastructure**

Note: The off-road applications show above are not being considered for selection

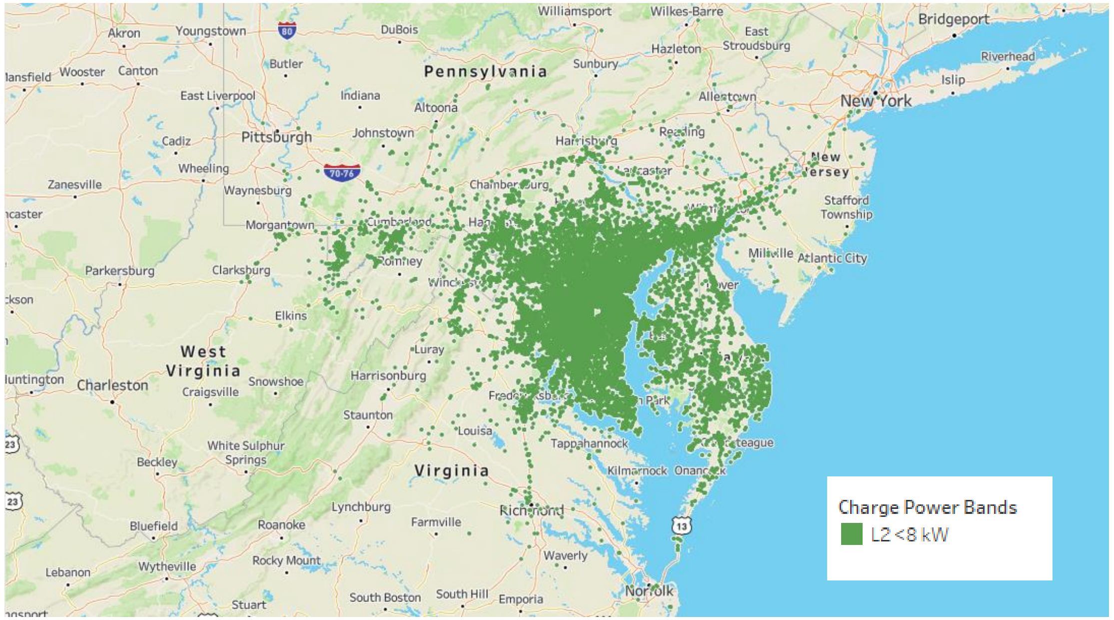
Source: CALSTART, The Beachhead Model, Catalyzing Mass-Market Opportunities for Zero-Emission Commercial Vehicles

Fleet Characterization: Vehicle Segmentation by Charging Solutions

Charging solutions



Location based charging solutions



What tools do we need?

DRIVE

Hosting Capacity Analysis

- ***Grid Capacity (utilities + fleet managers) <- Drive tool***
- ***Fleet Intel (utilities) – a layered approach***
  – Conventional fleet behavior
  – Warehouse location
  – Conventional vehicle registrations
  – Pollution impacts

[Explore the map - Climate & Economic Justice Screening Tool (geoplatform.gov)]

What tools do we need?

Fleet Tools (*Fleet managers+ utilities)*

Inputs:

- *Vehicle type and schedule*
- *Location (rates + utility)*
- *Option to send info to utility*

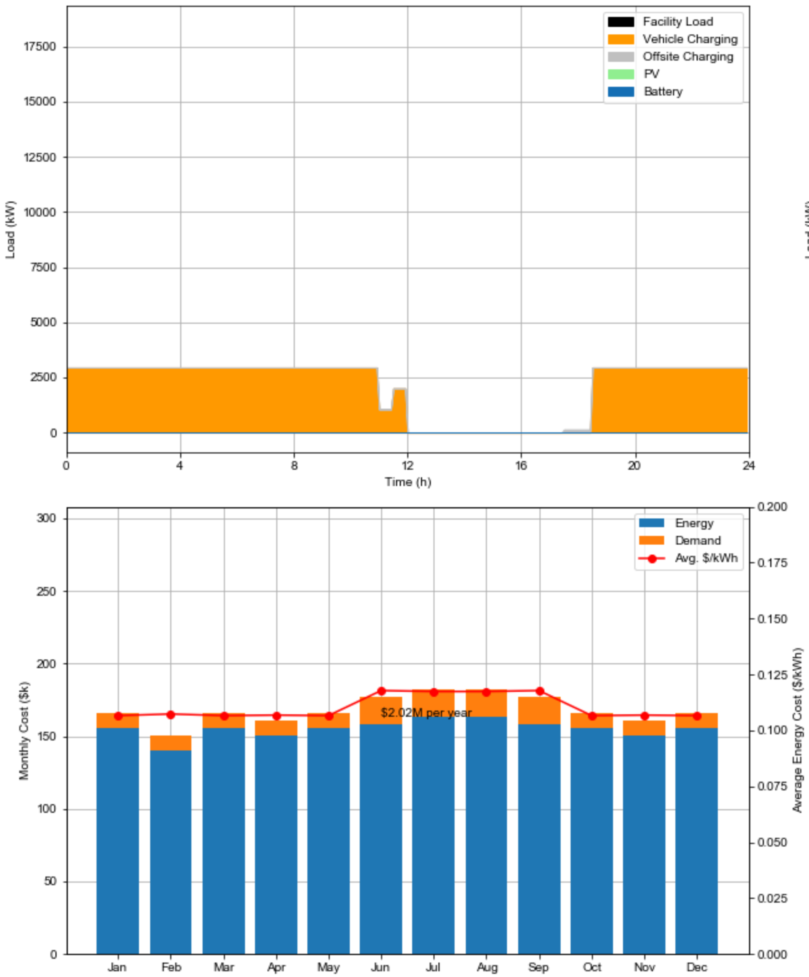
Outputs:

- *OpEx*
- *Charging solutions*
- *Charging optimization*
- *DER integration*

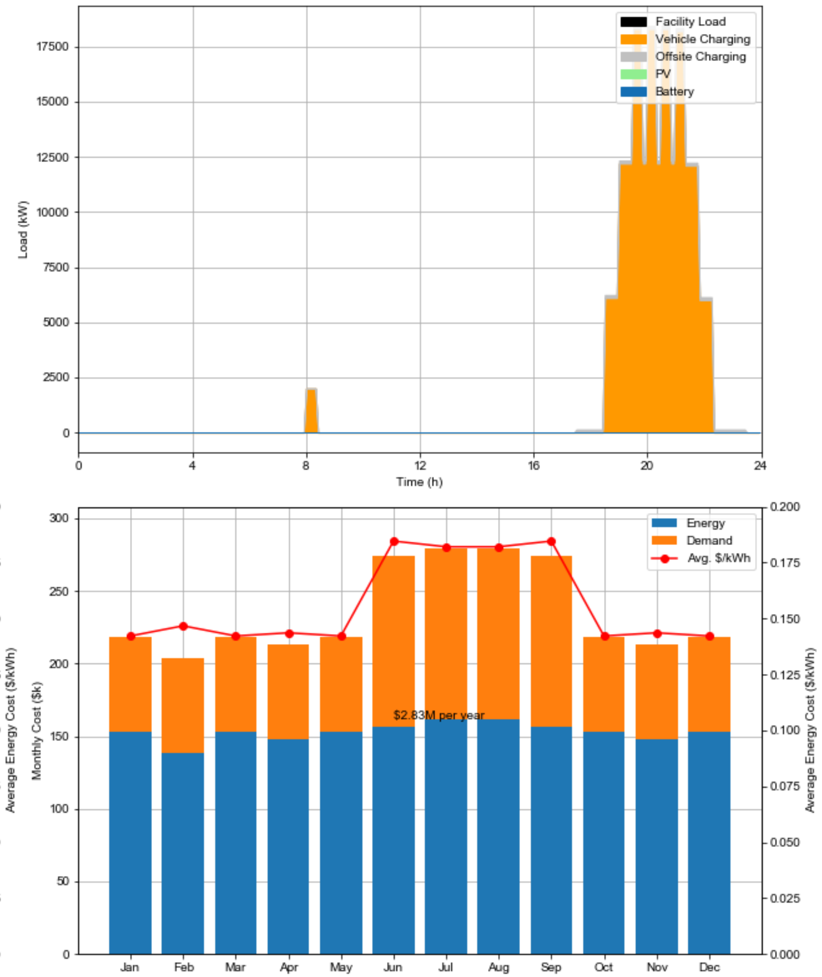
Not Included:

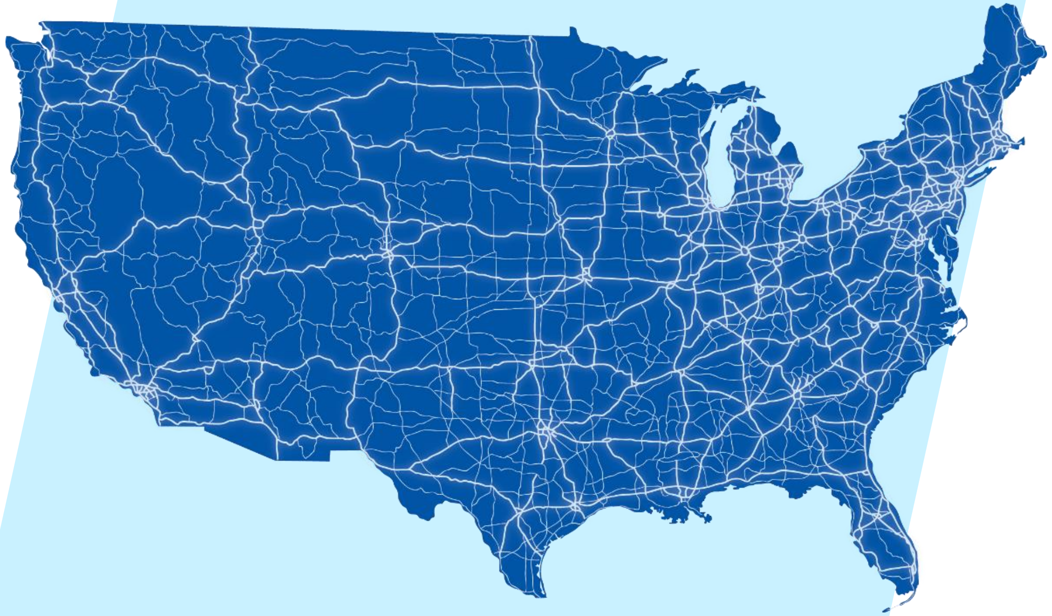
Line extension costs

Basic Load Management



No Load Management





EPRI with Co-lead CALSTART Receiving CEC Funding for Research Hub for Electric Technologies in Truck Applications (RHETTA)

Focused on development, advancement, and deployment of innovative medium- and heavy-duty (MDHD) high-power charging infrastructure along key freight corridors that promote adoption of Class 7 and 8 battery electric zero-emission (ZE) trucks

- **CEC Funding:** $23M ($13M Phase 1, $10M Phase 2)
- **Timing:** Phase 1 – Through Q1 2025, Phase 2 – Through Q2 2028

Southern California Edison · SCAG · gna · Berkeley Lab · EPRI Electric Power Research Institute · CALSTART · ORBCOMM · MHX · Cambridge Systematics · TA · Oberon Insights · GRID Alternatives · NREL · CharIn · UC Riverside · Burns McDonnell · RISE Research Institutes of Sweden

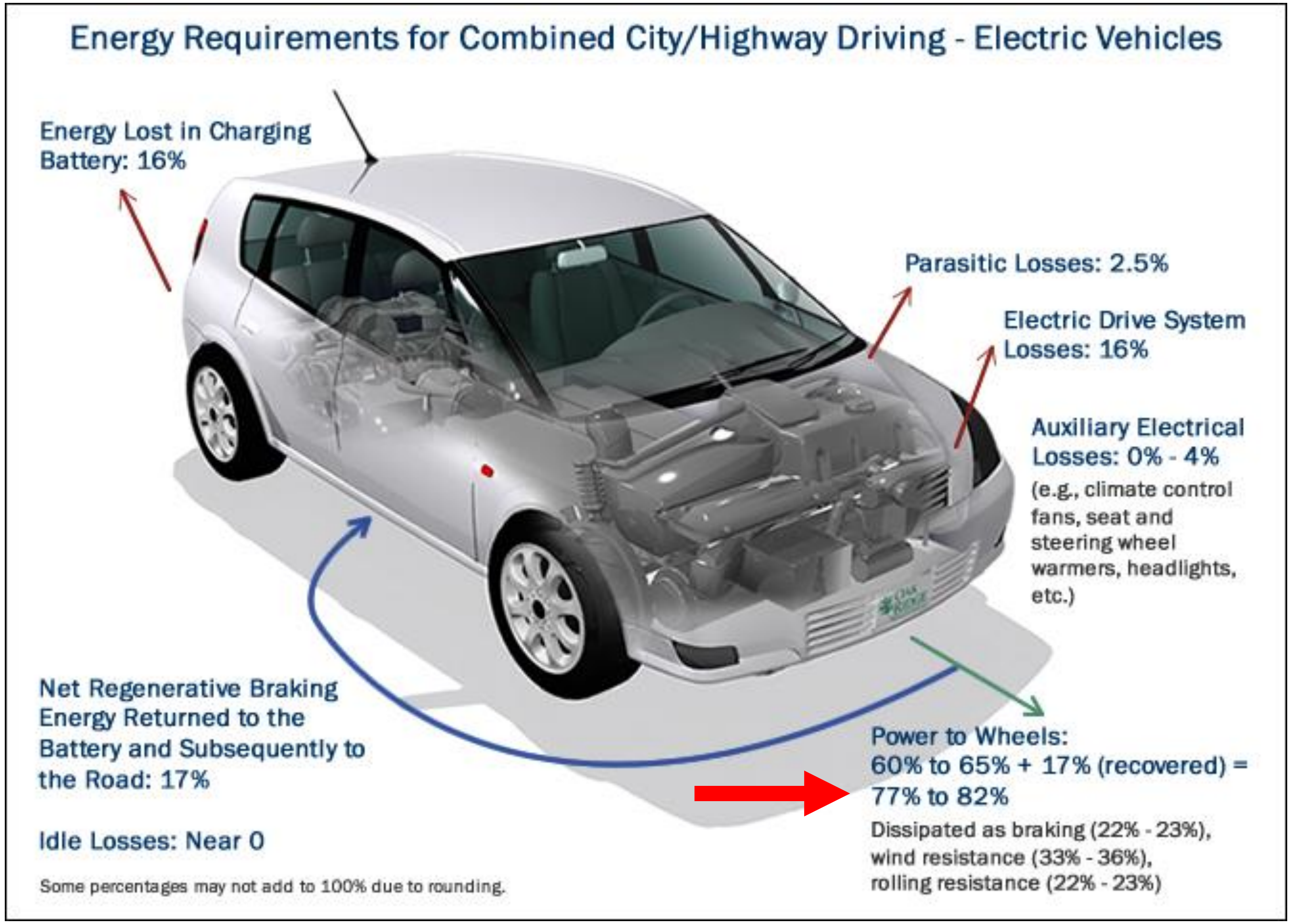
eTRUC Partnership

Key Activities

- Community Engagement and Workforce Development
- Fleet Needs and Technology Maturity Assessment
- Advanced High-Powered Charger System R&D
- Phase 1 Pilot Deployment
- Plan for Phase 2 Public Corridor Network
- Phase 2 Implementation
- Technology/Knowledge Transfer Activities

Together...Shaping the Future of Energy®

Efficiency Advantage is Fundamental to EVs

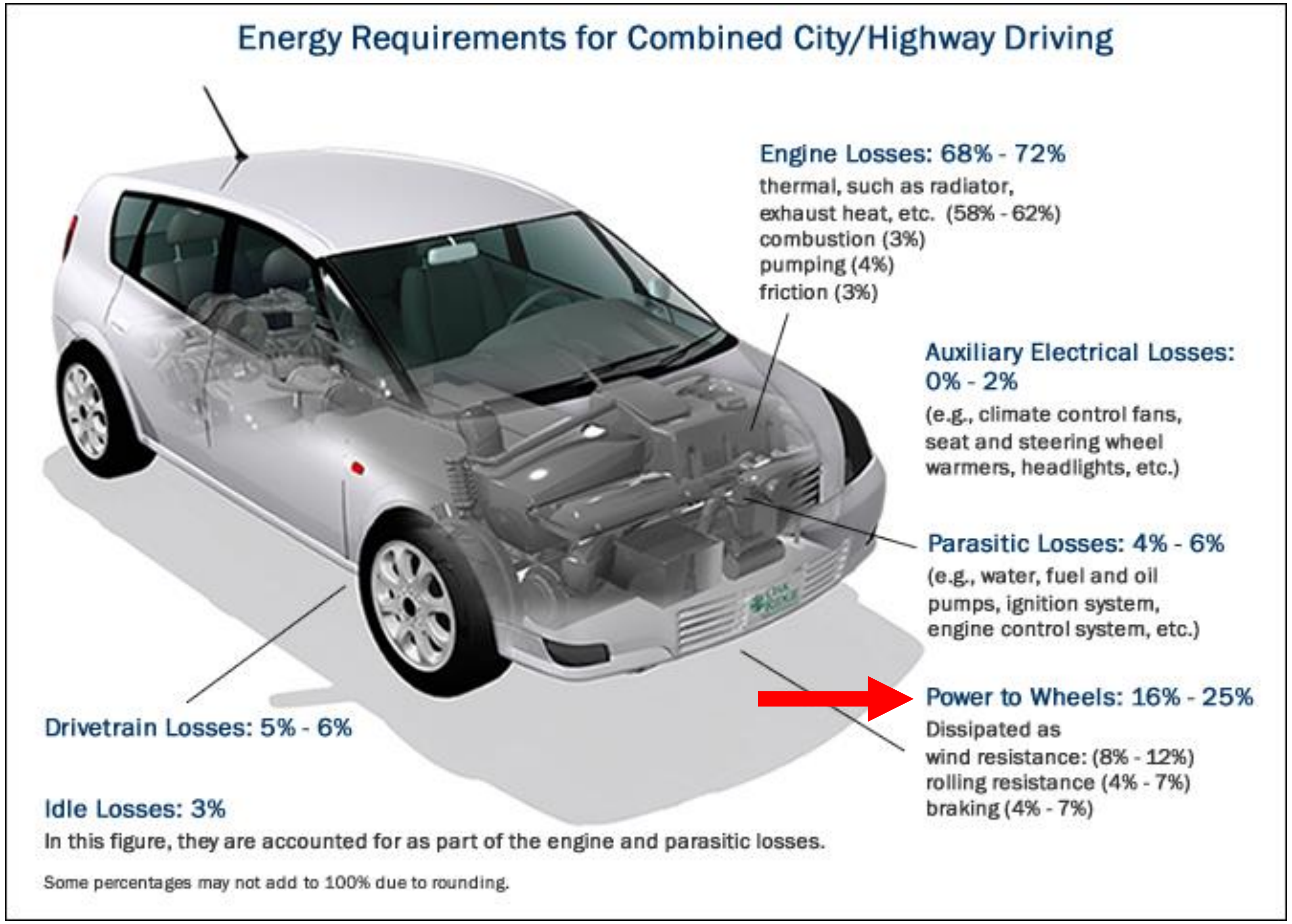


Source: U.S. Department of Energy, Fact of the Week

https://www.energy.gov/eere/vehicles/articles/fotw-1045-september-3-2018-77-82-energy-put-electric-car-used-move-car-down

About 80% of energy delivered to the plug is used to move the vehicle down the road.

Internal Combustion Vehicle Have an Efficiency Disadvantage



Source: U.S. Department of Energy, Fact of the Week

https://www.energy.gov/eere/vehicles/articles/fotw-1044-august-27-2018-12-30-energy-put-conventional-car-used-move-car-down

Only 16-25% of energy put into a conventional car is used to move the vehicle down the road

South Coast AQMD

Volvo LIGHTS and Beyond

Technology Advancement Office
Program Supervisor

Seungbum Ha

Clean Fuels Fund Advisory Retreat
September 8, 2022

Volvo LIGHTS
- Heavy-Duty Battery Electric Trucks & Infrastructure

- Volvo LIGHTS (Low Impact Green Heavy Transport Solutions)
- 23 battery electric trucks, 29 off-road equipment, solar for zero emission freight handling
- Funding: $44.8M CARB/CCI, $4M South Coast AQMD, $41.6M Volvo & Partners – Total: $90.4M
- Battery electric forklifts, yard tractors at fleets

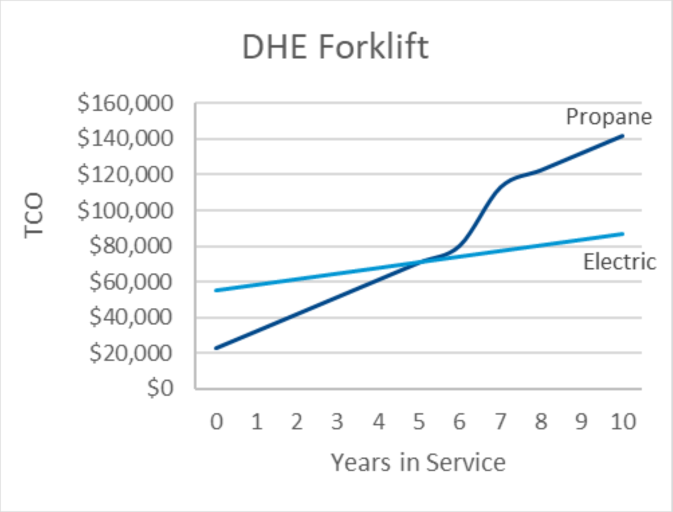
Project Partners

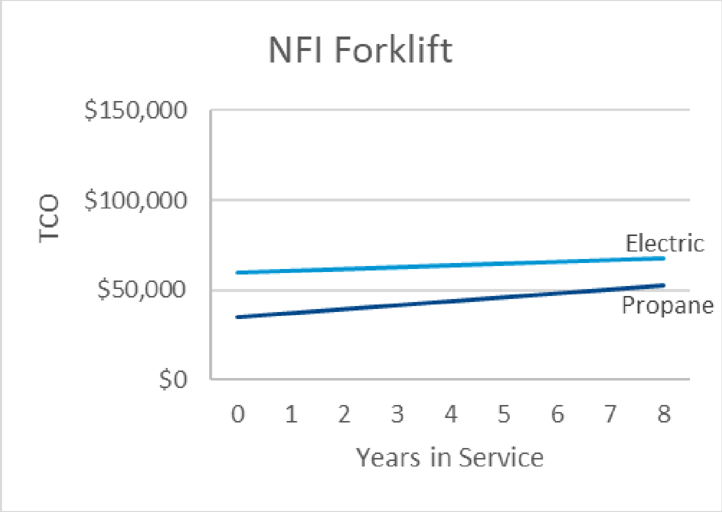
- OEM
- Government
- Utilities
- Fleets
- Education/Training
- Ports
- Dealership
- Outreach
- Charging Infrastructure

ZE Equipment Deployed at DHE & NFI

	DHE		NFI	
	Count	Original Equipment Manufacturer (OEM)	Count	OEM
Forklift	14	Yale	8	Crown
Yard Tractor	2	Orange EV	2	Kalmar Ottawa
Class 7 Box Truck	1	Volvo	-	-
Class 8 Tractor	3	Volvo	1	Volvo
Workplace Charging	3	EvoCharge	3	EvoCharge
Solar	1	Solar Optimum	1	Hanwha
Battery Energy Storage	1	CPS Energy	-	-

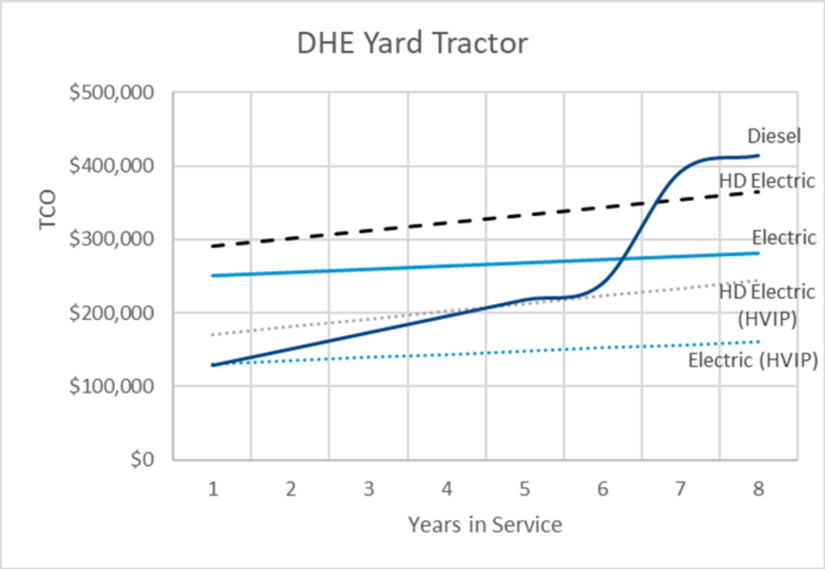
DHE and NFI Propane and Electric Forklift Total Cost of Ownership

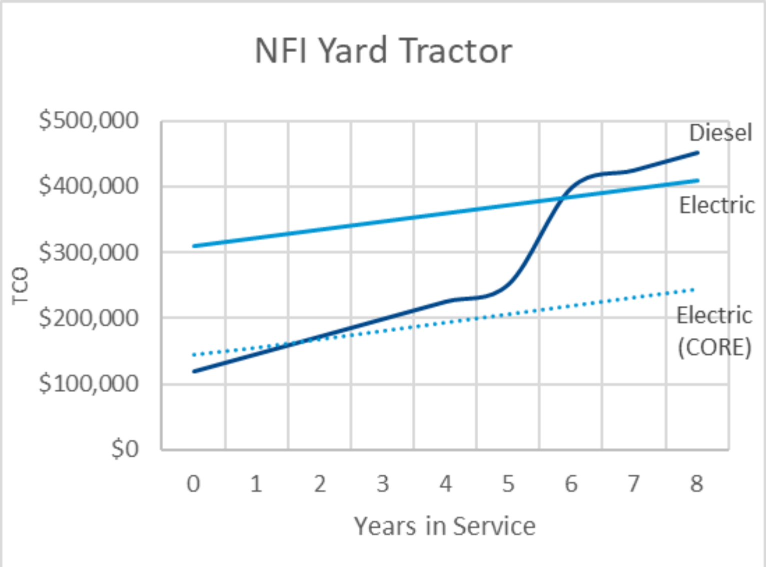




Performance Metric	DHE Electric	DHE Propane	NFI Electric	NFI Propane
Daily Operating Time (hours)	9	9	1.4	1.4
Daily Energy Charged (kWh)	28	-	7	-
Operating Cost ($/hour)	2.25	4.79	3.63	6.80
Annual Fuel or Electricity Cost with LCFS ($)	72	2,149	-82	364
Annual Emissions (kg CO2)	-	11,265	-	2,416

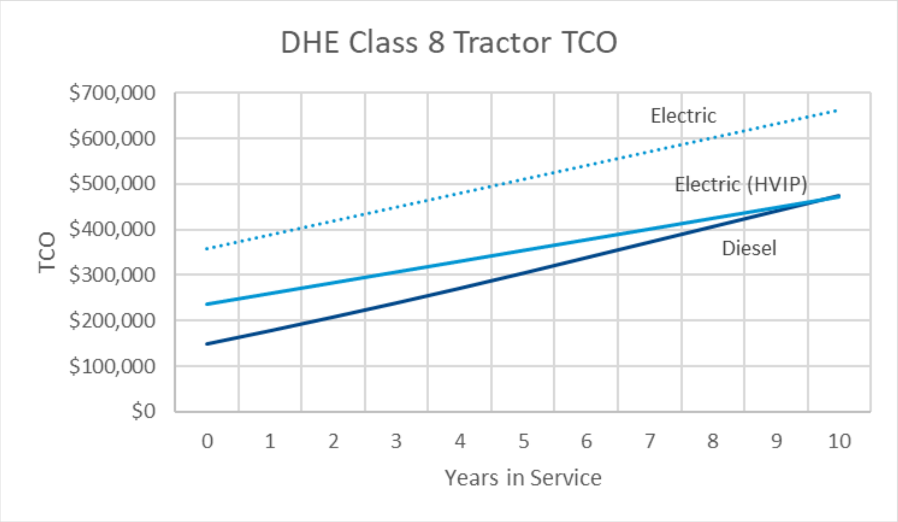
DHE and NFI Diesel and Electric Yard Tractor TCO

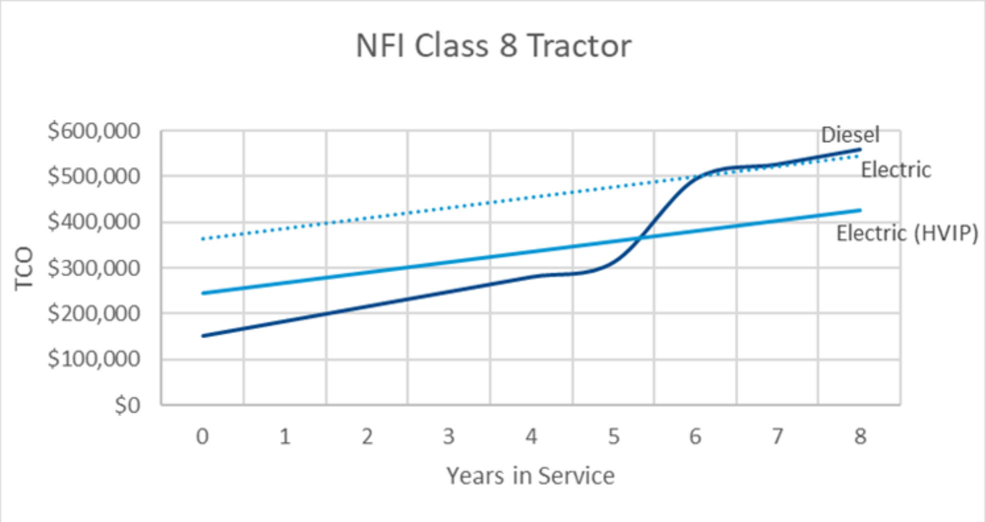




Performance Metric	DHE Electric	DHE Diesel	NFI Electric	NFI Diesel
Daily Operating Time (hours)	12	12	8	14
Daily Energy Charged (kWh)	73	-	89	-
Operating Cost ($/hour)	2.30	7.42	3.54	8.83
Annual Fuel or Electricity Cost with LCFS ($)	-11	10,233	1,204	11,571
Annual Emissions (kg CO2)	-	33,669	-	21,661

Diesel and Electric Class 8 Tractor TCO



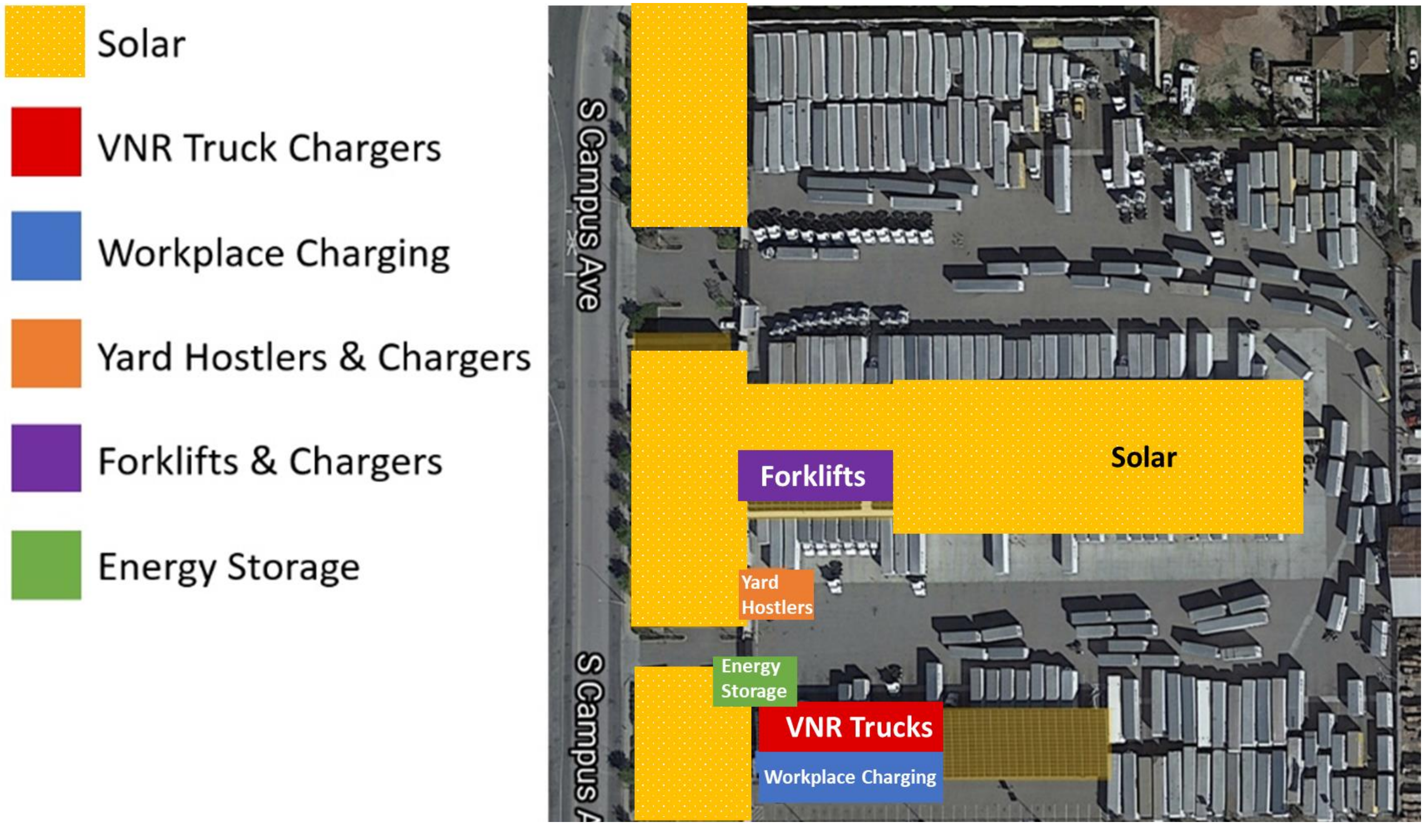


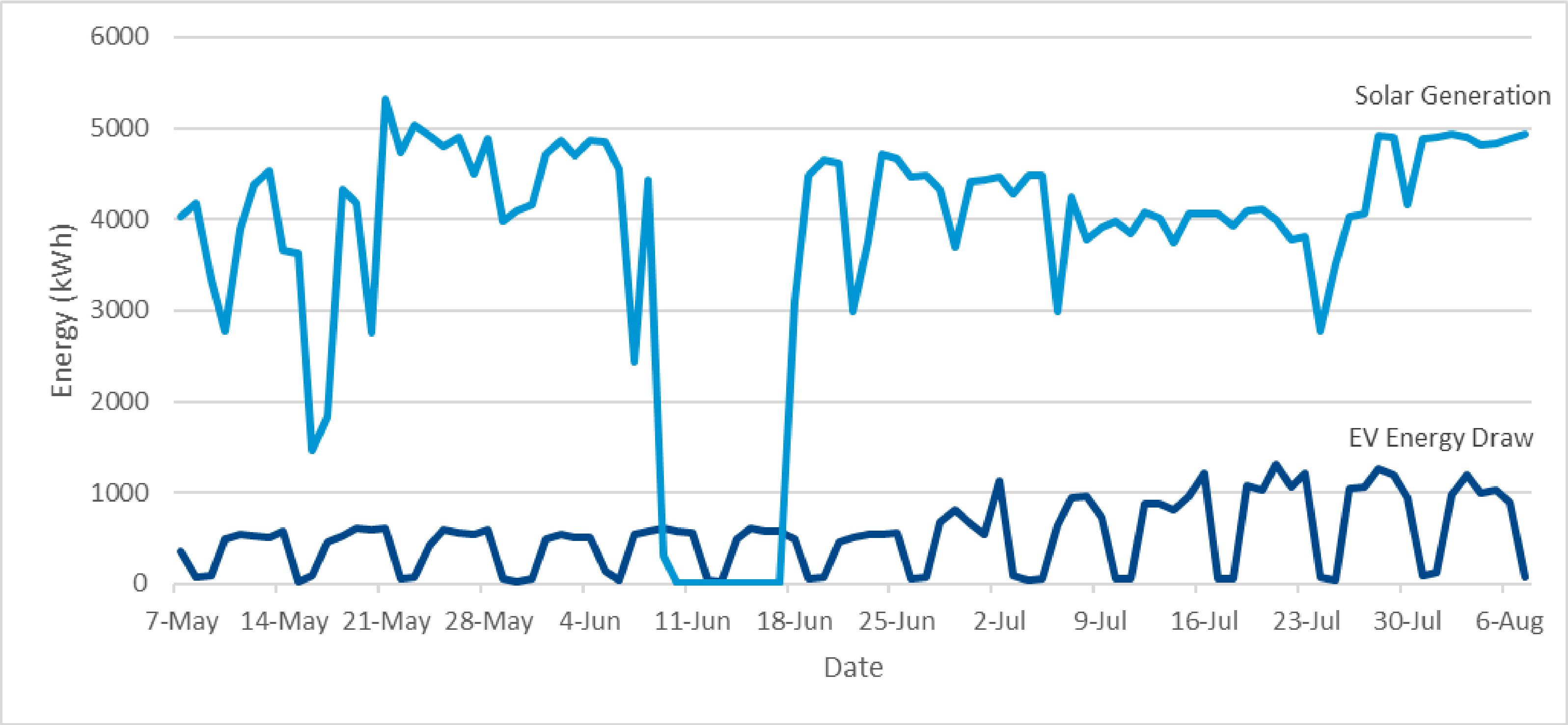
Performance Metric	DHE e-Box Truck	DHE Diesel Box Truck	DHE e-Tractor	DHE Diesel Tractor	NFI e-Tractor	NFI Diesel Tractor
Daily Distance Driven (miles)	60	60	86	150	108	152
Daily Energy Charged (kWh)	111	n/a	189	n/a	144	n/a
Fuel and Maintenance Cost ($/mile)	0.52	0.79	0.65	1.06	0.70	1.06
Annual Fuel Cost ($)	2,469	9,643	4,211	12,857	3,300	12,857
Annual Emissions (kg CO2)	n/a	23,242	n/a	36,776	n/a	34,111

IX. Lessons Learned - Vehicles

- EVs may have different load capacities
- Low profile battery pack caused limited vehicle accessibility
- Benefits of regenerative braking
- Considerations for range
- Optimizing operations using vehicle data
- Driving EVs have performance benefits compared to baseline vehicles
- Range still significant limitation for electric HD on-road trucks

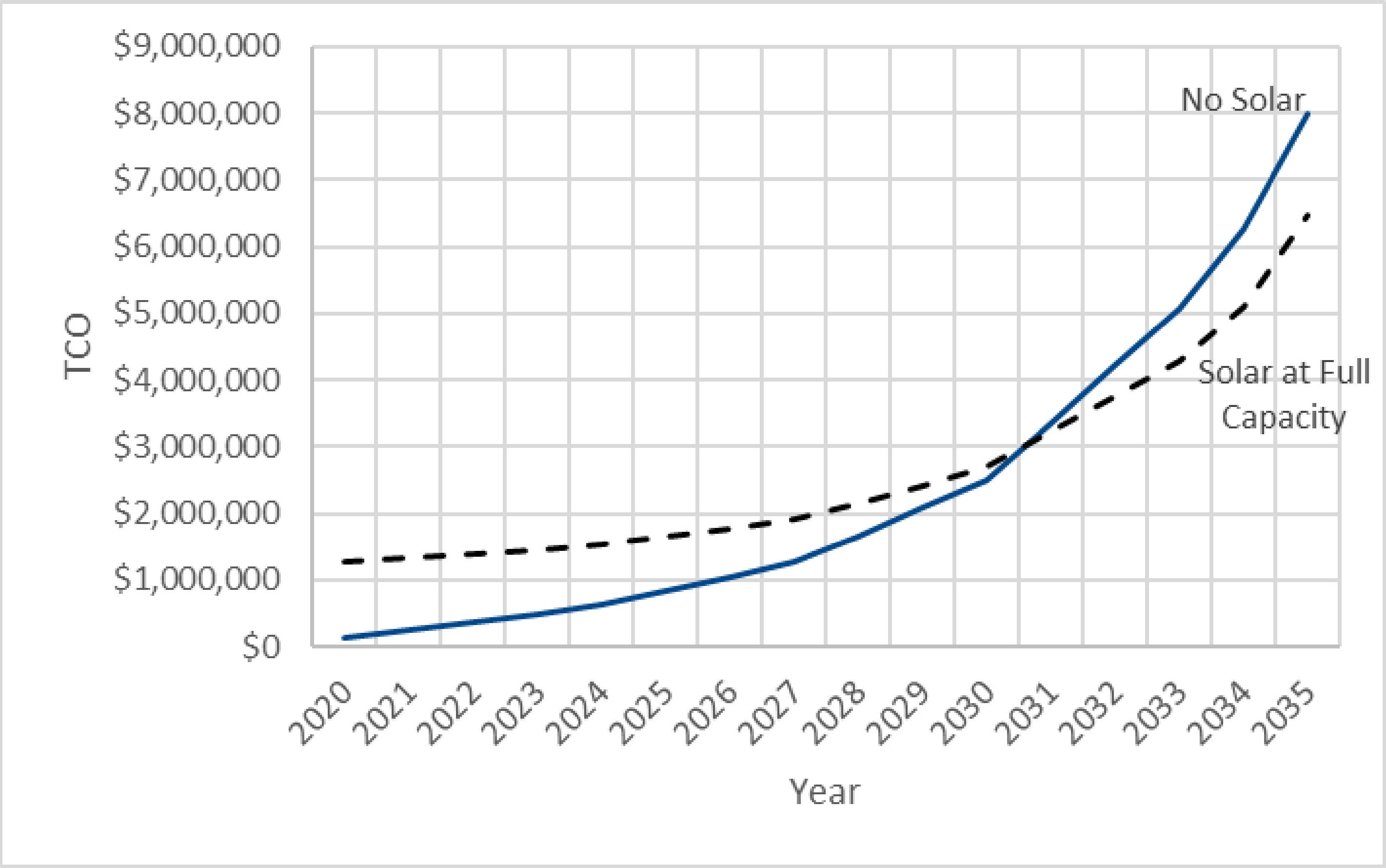
DHE Infrastructure





Solar and Energy Storage @DHE

DHE Solar and Storage System TCO



Lessons Learned – Charging & Maintenance

- Opportunity charging allowed for more seamless EV integration
- Managed charging can decrease operating costs
- Importance of mitigating demand charges
- Charging connector matters
- Adequate training for maintenance staff essential for smooth rollout
- Close proximity to OEM service shop invaluable
- Less maintenance can lead to significant cost savings

Lessons Learned - Infrastructure

- Clear expectations and communication with contractors can help avoid unnecessary delays
- Not all chargers created equal
- Designing and permitting multiple infrastructure solutions may mitigate potential delays
- Operational resilience
- Data collection platforms

Next phase of Volvo LIGHTS: CARB-CEC JETSI

- CARB and CEC awarded South Coast AQMD $16M and $11M respectively to deploy 100 Daimler and Volvo Class 8 BETs and infrastructure at two fleets

DAIMLER

Daimler eCascadia

- Daimler and Volvo will manufacture trucks certified by U.S. EPA and CARB

Daimler	Volvo
200 – 250-mile electric range	195 – 220-mile electric range
475 kWh lithium-ion battery pack	564 kWh lithium-ion battery pack
CCS1 connector for fast charging	CCS1 connector for fast charging

- Data Collection
  - Ricardo—BET data collection/analysis
  - CALSTART—charger pricing analysis, fleet case studies
  - EPRI—charger performance analysis, fleet reliability uptime dashboard

VOLVO

Volvo VNR Electric

Hydrogen Infrastructure

MARYAM HAJBABAEI

CLEAN FUEL PROGRAM ADVISORY GROUP – SEPTEMBER 2022

Heavy-Duty Hydrogen Infrastructure Projects at the Ports

H2Freight Project at Port of LB

- $8M CEC award to Shell to build renewable HD hydrogen station at POLB
- 1,000 kg/day truck refueling with multiple fueling positions at 700 bar
- Evaluate fueling protocols, dispenser design, station throughput/reliability, etc.
- Shell continues station soft opening, and data collection and analysis

Zero Emission Freight "Shore to Store" at Port of LA

- $82.5M CARB, POLA, SCAQMD)
- Develop and demonstrate ten fuel cell trucks (Class 8 Kenworth T680 with Toyota fuel cells) – In Service in 2021
- Develop and operate hydrogen stations in Ontario & Wilmington – Shell
- Station soft openings - July 21, 22

Hydrogen Infrastructure Research Studies

California Heavy-Duty Hydrogen Infrastructure Research

- U.S. DOE H2@Scale program with national labs, GO-Biz, CEC, CARB, and South Coast AQMD
- Joint agreement led by NREL to continue hydrogen infrastructure research

California High Flow Bus Fueling Protocol

- U.S. DOE H2@Scale program
- Apply MC fueling protocol for LD to HD vehicles (H35HF)
-Bus fueling protocol modeling & simulation
- NREL Protocol test/validation
- Demonstration at Sunline

UC Davis - Hydrogen Systems Analysis

- Co-Sponsors: Aramco, CEC, GM, Honda, Hyundai, Leighty, Shell, SoCalGas, and Toyota
- Analyze and model hydrogen's role through 2050
- Identify gaps in next 5-10 years
- Role of h2 for FCVs & BEVs

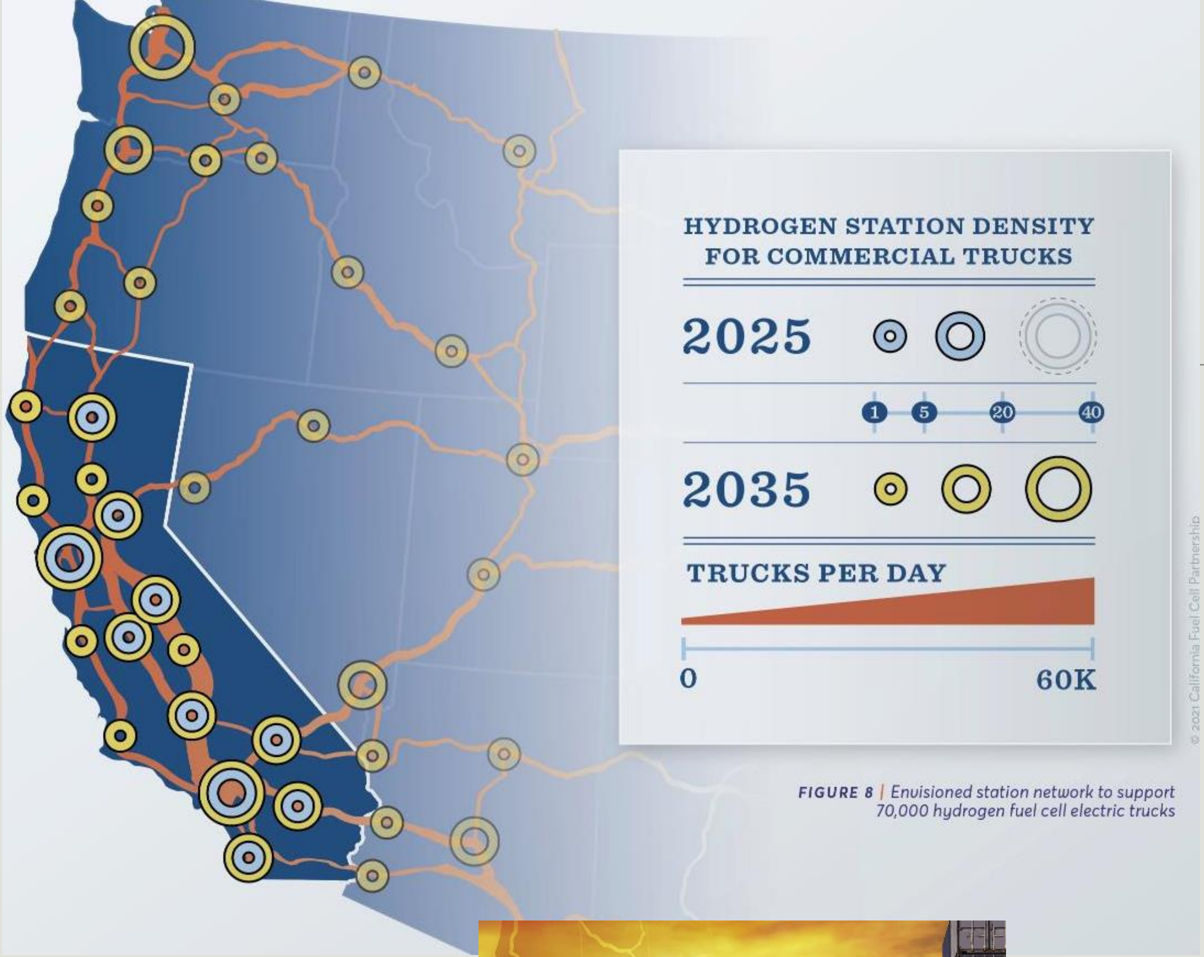
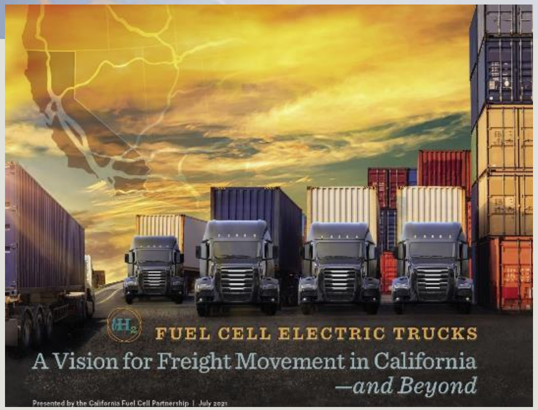


FIGURE 8 | Envisioned station network to support 70,000 hydrogen fuel cell electric trucks

HYDROGEN + FUEL CELL PARTNERSHIP



Numbers as of July 31, 2022	Total
FCEVs—Fuel cell cars sold and leased in US*	14,198
FCEBs—Fuel cell buses in operation in California	**66**
Fuel cell buses in development in California	>103
Hydrogen stations available in California**	**56**
Retail hydrogen stations in *construction* in California***	8
Retail hydrogen stations in *permitting* in California***	28
Retail hydrogen stations *proposed* in California***	11
Retail hydrogen stations *funded*, but not in development in California***	70
Total retail hydrogen stations in development in California***	**117**
Truck hydrogen stations in operation in California	3
Truck hydrogen stations funded in California****	9

A Vision for Freight Movement in California – *and Beyond*

Efforts to Standardize Heavy-Duty Hydrogen Stations

Existing hydrogen fueling stations are mostly for light-duty vehicles and buses

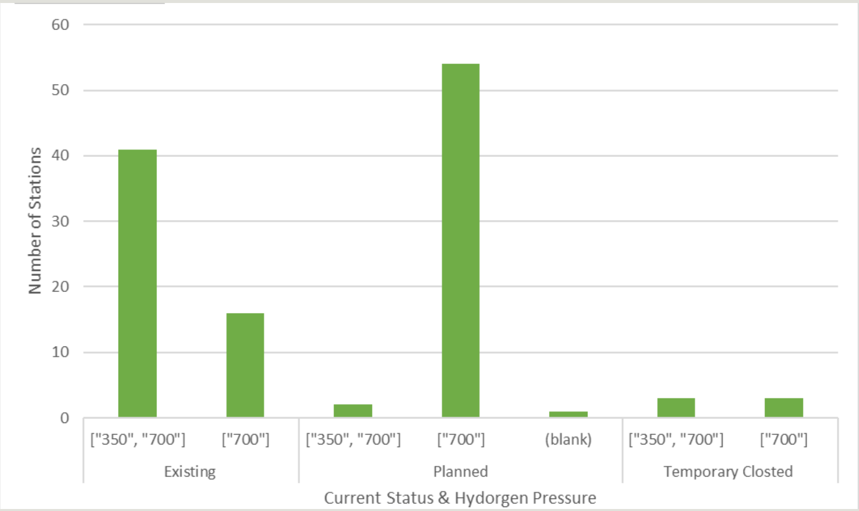
- Several demonstrations for medium and heavy-duty sectors

How to expand Hydrogen fueling stations beyond light-duty applications?

Develop high flow nozzle and fueling protocols to meet higher flow refueling targets for heavy-duty vehicles (~ 10 kg/min)

Current timeline for standards development is 2023, aligned with commercialization of Class 8 Fuel Cell Trucks

While high flow nozzle/fueling protocols are being developed, ongoing optimization of existing technologies is used for demonstrations



Source: US DOE Alternative Fuel Data Center

U.S. DOE Energy Earth shots – Hydrogen Shot

Goal of 1$/kg of hydrogen by 2030 “1.1.1”

- Multiple pathways to produce hydrogen from domestic energy uses
- Addresses carbon emissions for hydrogen production from non-renewable sources
- Engagement from multiple stakeholders with diverse perspectives, expertise, and experience
- Career development – DOE Hydrogen Shot Fellowships

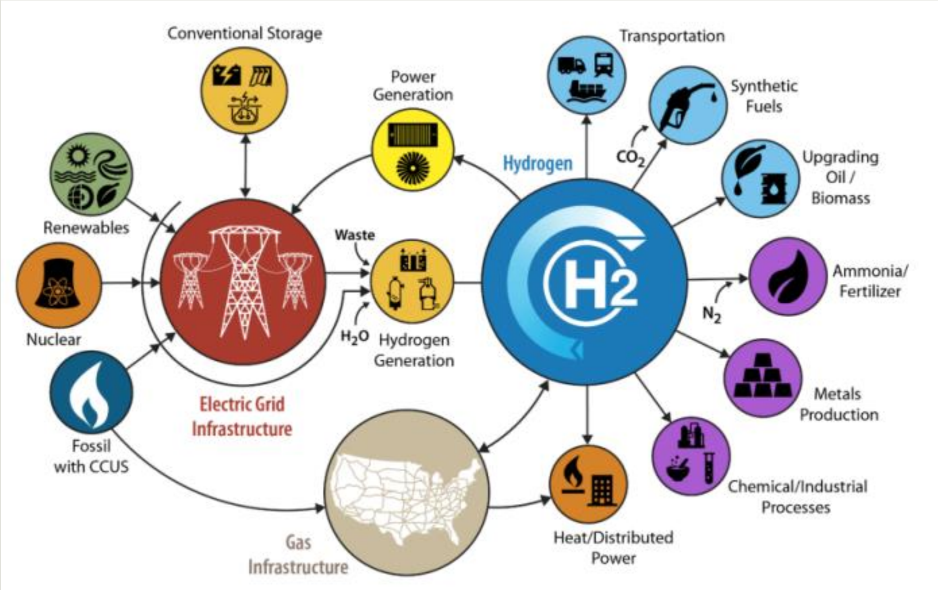
U.S. DOE Regional Hydrogen Hubs

Infrastructure Investment and Jobs Act (IIJA) or Bipartisan Infrastructure Law (BIL) – *2021*

$8B – Develop 4 Regional Hydrogen Hubs

Network of clean hydrogen producers, potential clean hydrogen consumers, and connected hydrogen infrastructure located in close proximity

U.S. DOE Hydrogen Hubs Implementation Strategy - *Request for Information (RFI) announced February 2022*



California Formally Announces Intention to Create a Renewable Hydrogen Hub – *May 2022*

https://business.ca.gov/california-formally-announces-intention-to-create-a-renewable-hydrogen-hub/

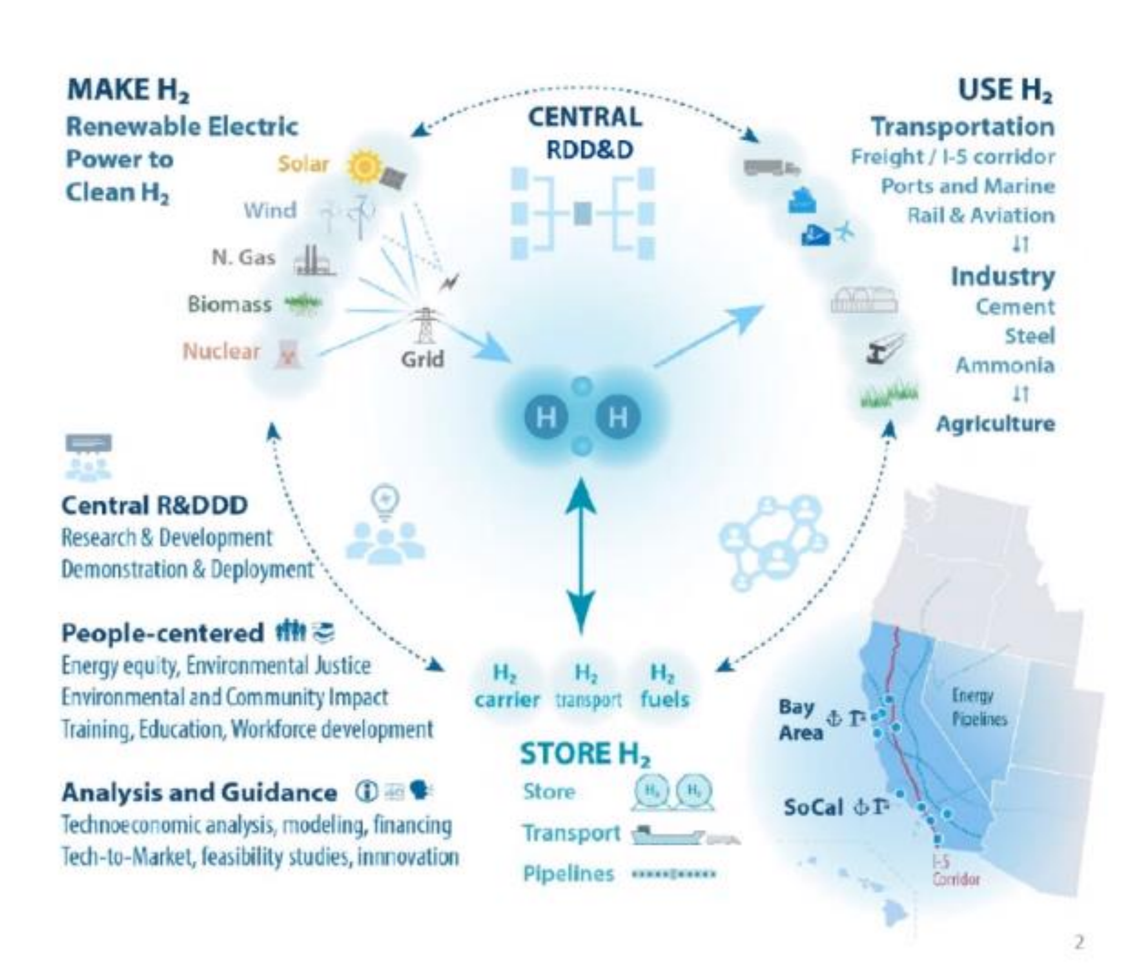
U.S. DOE Regional Hydrogen Hubs – cont'd

Go-Biz is lead agency in California

- Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES LLC) established
  - Public – Private Partnership

DOE releases requirements for concept paper in Sept/Oct 2022

- Applicants must be single entities



Infrastructure Challenges & Opportunities

Policy & funding predictability

Supply chain: Hydrogen production, distribution, parts, and materials

Skilled labor and workforce training

CEQA and Permits

Safety: Robust codes & standards

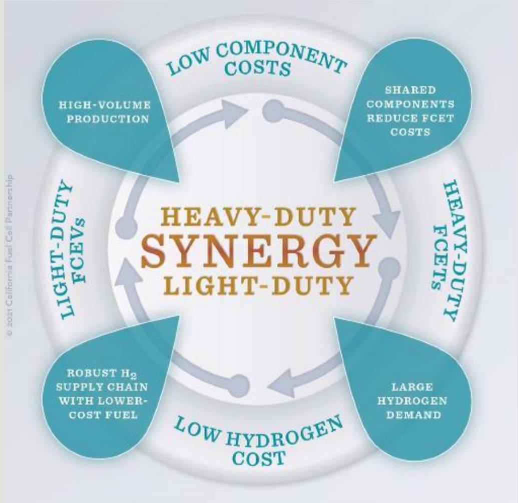
Address short-term hydrogen network fragility

Increasing capacity stations to reduce hydrogen dispensed cost

Refined HD fueling protocols to become “Recommended Practice”

Site specific development & operational issues

Increase renewable hydrogen production dedicated to transportation



CaFCP: 2021 HD Vision

2022 Clean Fuels Retreat

Joseph Lopat

ADVANCEMENTS IN EV SCHOOL BUS PROGRAMS AND INFRASTRUCTURE

Improving Air Quality for Children

Since 2001, South Coast AQMD has spent $325 million replacing over 1,800 school buses through the Low Emission School Bus program

- Replaced over 50 additional school buses with battery electric buses though EPA grant programs

Advancements in Technology and Infrastructure

Electric school buses currently have no wait time for orders

Continue to replace diesel school buses with zero emission buses based on available funding

Infrastructure advancements and coordination improvements between schools and utilities

Zero emission fleets in AB 617 communities where air quality is primary concern

Charging Infrastructure

- Two types of fleet chargers
  - Level 2 AC charger (32-80 amps)
    - Smaller, less expansive, longer charge times
    - 315 KW bus takes about <u>19 hrs</u> to fully charge
    - Wall or pedestal mounted
  - DC fast chargers (30KW-420KW)
    - Larger, more infrastructure, faster chargers
    - 315 KW bus takes about <u>5 hrs</u> to charge (60kw)
    - Pedestal or floor mounted
  - IC Bus
    - Maximum 125KW charger
    - Needs 600 volt charger

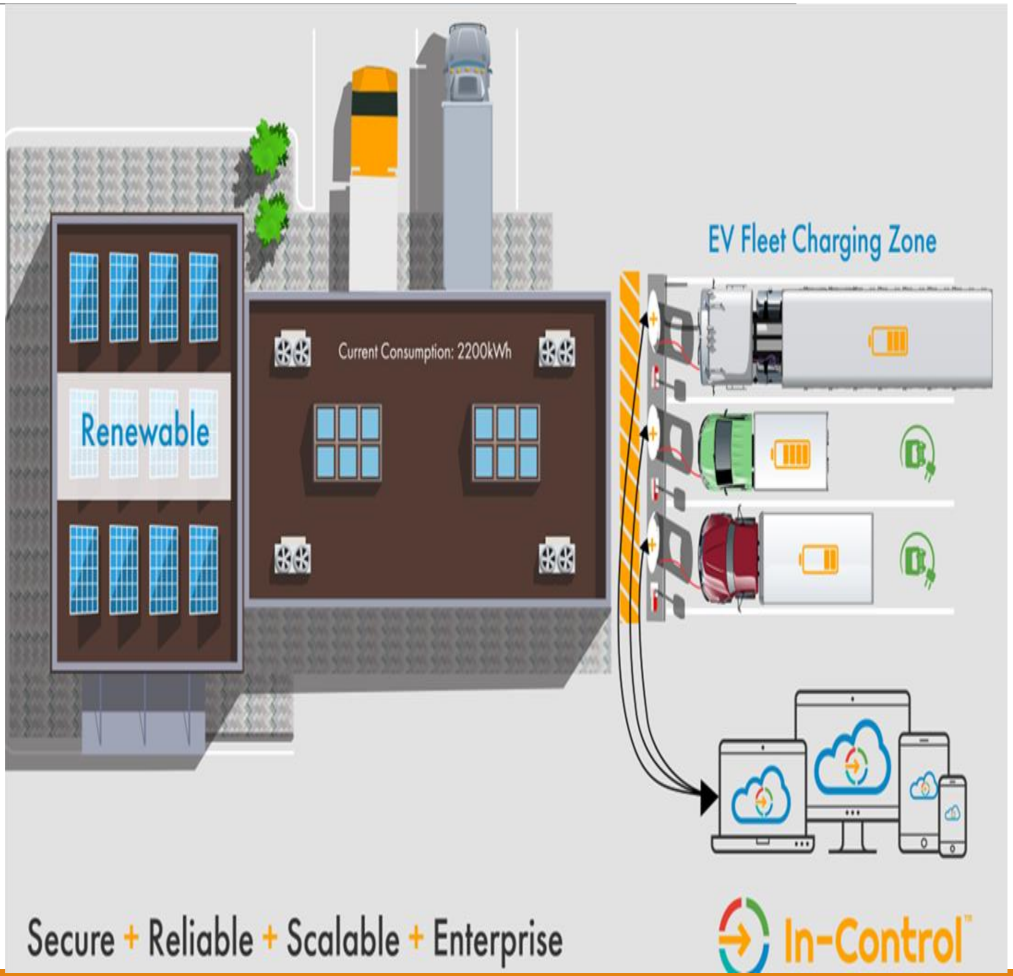
Determining Needs for EV Infrastructure

- Miles driven per day
- Size of battery in bus
- Amount of time to charge bus
    - Route schedule
    - Utility pricing
    - Weather, hills, etc
- Current utility infrastructure
- Space available
- Future proofing

- Solar energy
- Battery storage
- Certified charger with bus manufacturer, standard connector

Software for Chargers and Buses

- Remotely manage chargers
- Flexible, customizable reporting
- Live charging & energy consumption data
- Reduce operating costs and save time with remote service and over-the-air updates
- Track service, warranty, & preventative maintenance



Impact of One Day of Unmanaged Charging

Unmanaged demand increases costs dramatically

	Unmanaged load	Managed Load
Cost per KWh	$ 17.34	$ 16.02
Demand charges	$ 403.70	$ -
Other	$ 54.12	$ 3.54
Total Cost	$ 475.16	$ 19.56
Daily impact	$ 475.16	$ 19.56
Monthly Impact	$ 919.94	$ 430.41
Yearly Impact	$ 11,039.33	$ 5,164.91

Data courtesy of InCharge

Vehicle To Grid (V2G)

- V2G is using energy in bus battery to create saving or revenue to school districts
  - Reduce building demand charges
    - Peak demand charges
    - 4CP events
  - Utility will pay for energy
    - Demand Response
    - Computer memory requirements
    - Ancillary services
  - Not available in all markets

Improvements Needed

kWh demand

Transformer and utility upgrades

Uniformity in manufacturing battery charging requirements and duty cycles

High power and dynamic wireless charging

V2G capacity

Clean Fuels Program Advisory Group Meeting

September 8, 2022

Patricia Kwon
Acting Technology Demonstration Manager

2022 Annual Report & 2023 Plan Update

2022 Key Funding Partners

Total = $11M

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

CALIFORNIA AIR RESOURCES BOARD

CALIFORNIA CLIMATE INVESTMENTS

STATE OF CALIFORNIA ENERGY COMMISSION

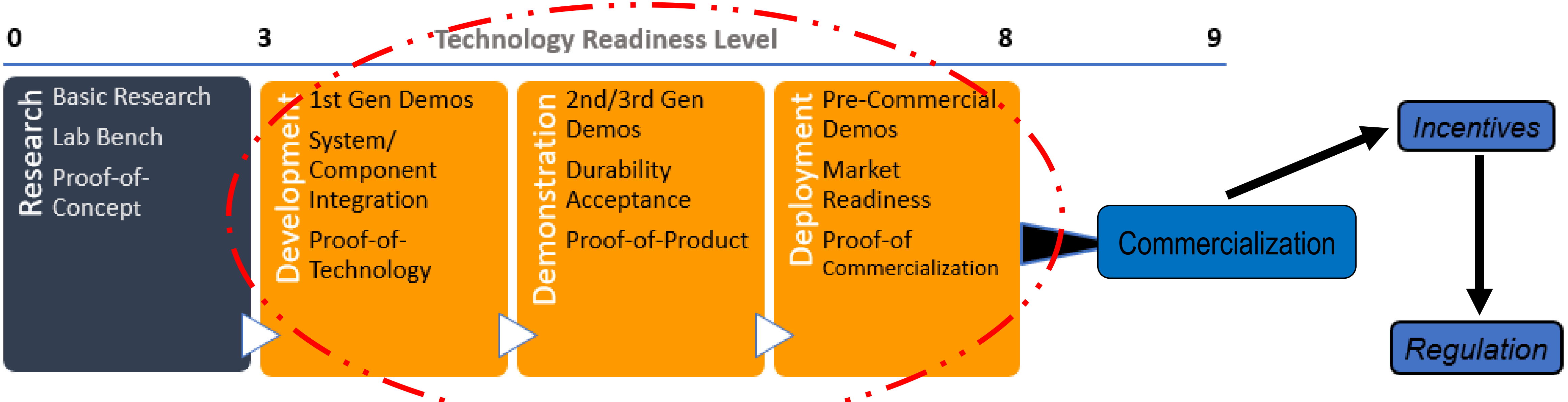
Port of LONG BEACH The Green Port

THE PORT OF LOS ANGELES

SoCalGas A Sempra Energy utility

Clean Fuels Fund Program

- Established in 1988
- $1 fee on DMV registrations ($~12M/yr)
- Stationary source fee (~$400k/yr)
- Research, develop, demonstrate, and deploy clean technologies



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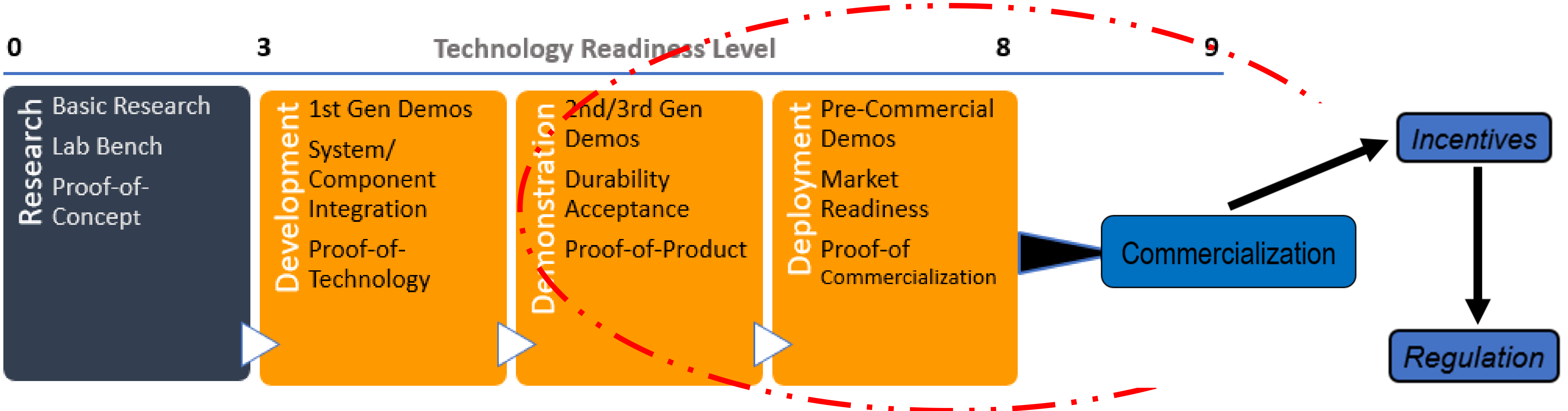


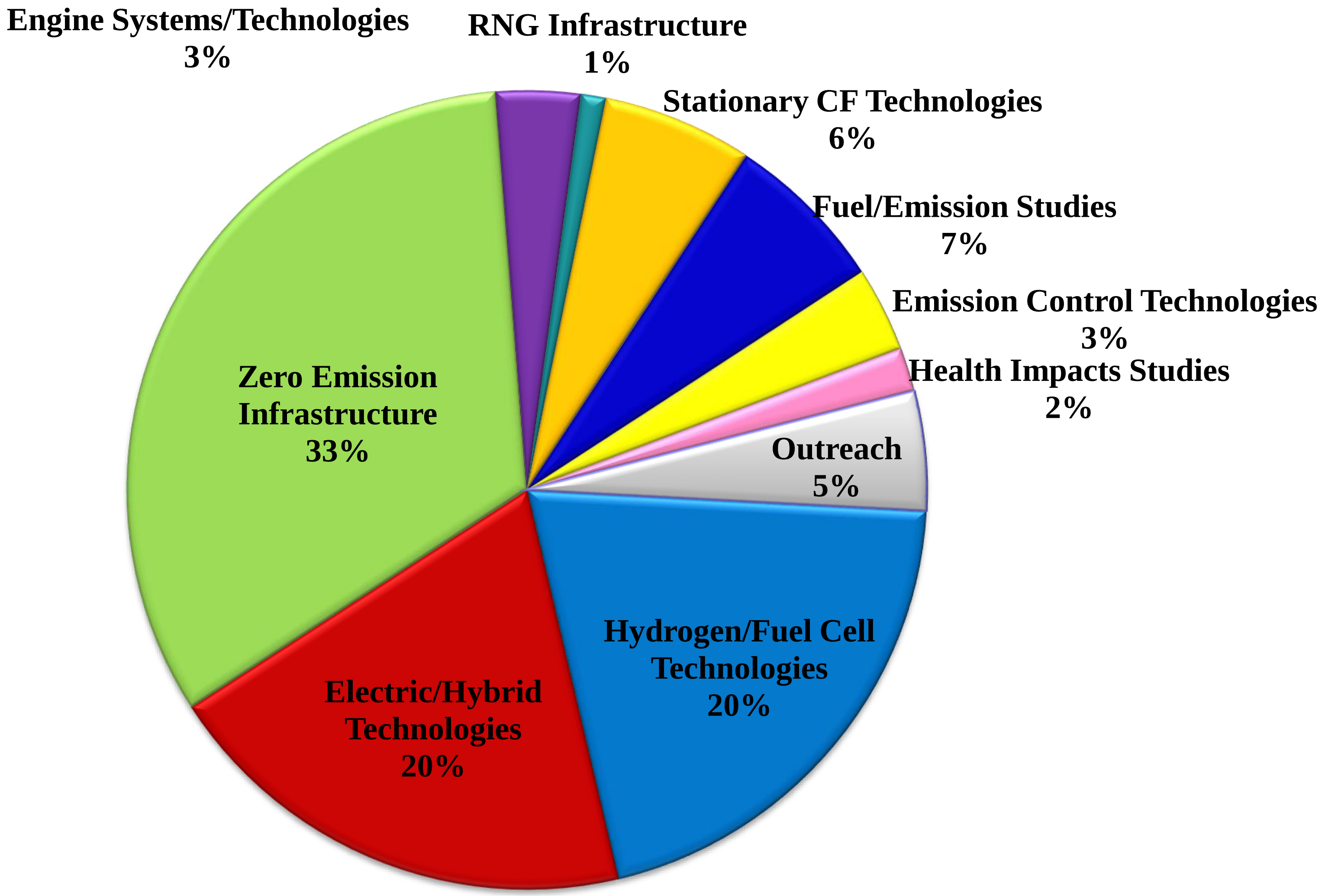
Draft 2023 Plan Update
(Key Technical Areas)

- Zero emission medium and heavy-duty trucks and equipment
- Challenges and solutions to deploy zero emission infrastructure
- Zero emission microgrids
- Ultra-low NOx and HD zero emission engine technologies
- Emission studies on renewable fuels and other sources
- Maintain other areas of emphasis

Draft 2023 Plan Update
Proposed Projects

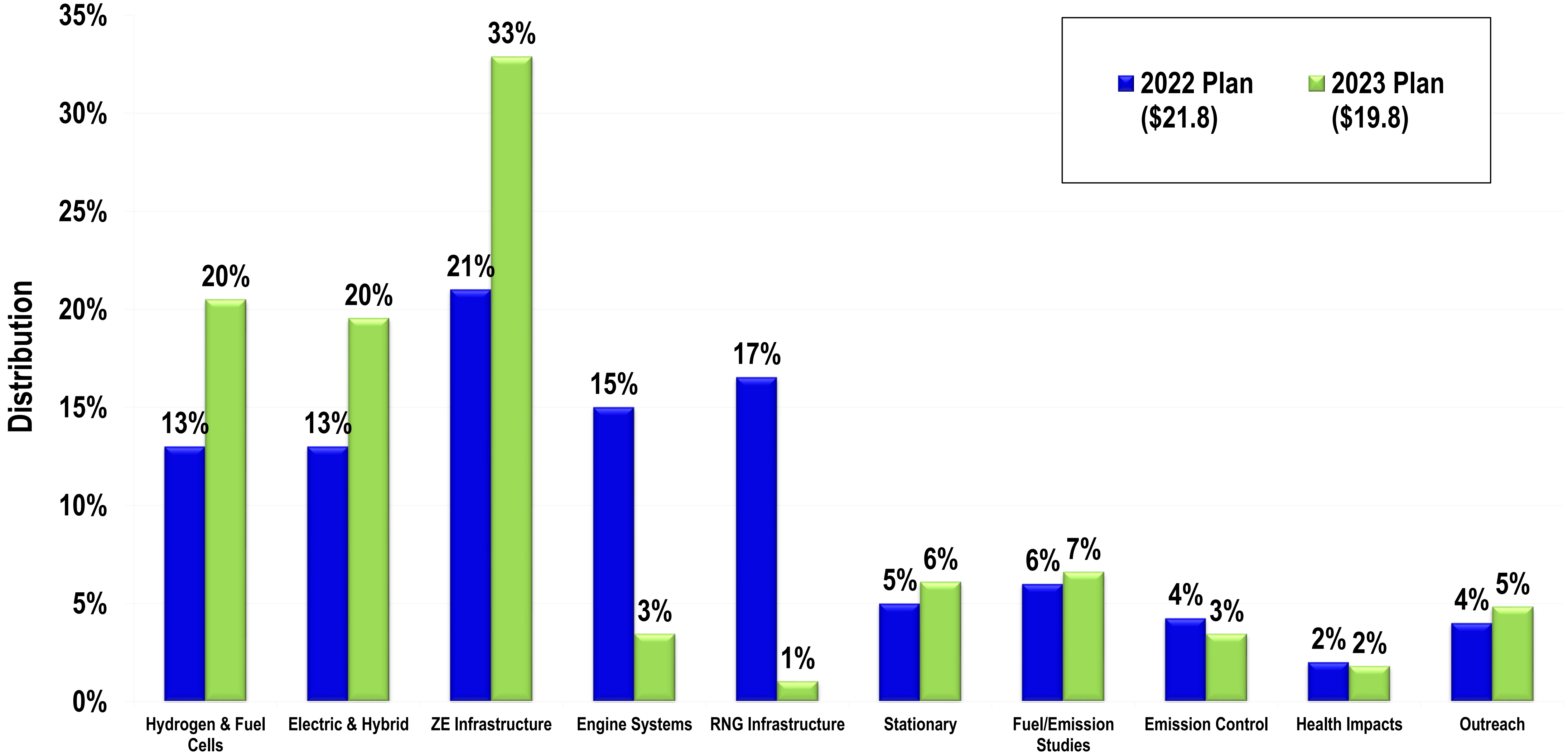
- Large deployments of medium and heavy zero emission trucks and infrastructure
- Microgrid demonstrations to support HD truck charging and hydrogen fueling
- High-power charging to increase range of battery electric trucks
- Develop and demonstrate long range Class 8 fuel cell electric trucks and equipment
- Develop and demonstrate green hydrogen production pathways

Proposed 2023 Plan Distribution



$19.8M

Plan Update Comparison



Proposed Distribution

	2022 Plan	Draft 2023 Plan
Hydrogen & Fuel Cell Technologies	13%	20%
Electric/Hybrid Technologies	13%	20%
Zero Emission Infrastructure	21%	33%
Engine Systems/Technologies	15%	3%
RNG Infrastructure	17%	1%
Stationary Technologies	5%	6%
Fuel/Emission Studies	6%	7%
Emission Control Technologies	4%	3%
Health Impacts Studies	2%	2%
Outreach	4%	5%
	100%	100%

Feedback

Email

Patricia Kwon
pkwon@aqmd.gov

or

Aaron Katzenstein
akatzenstein@aqmd.gov