CLEAN FUELS PROGRAM ADVISORY GROUP AGENDA
FEBRUARY 2, 9:00 AM – 4:00 PM
South Coast AQMD - Remote Meeting

INSTRUCTIONS FOR ELECTRONIC PARTICIPATION
Join Zoom Webinar Meeting - from PC or Laptop
https://scaqmd.zoom.us/j/91964955642
Zoom Webinar ID: 919 6495 5642 (applies to all)
Teleconference Dial In +1 669 900 6833
One tap mobile +16699006833, 91964955642#

Audience will be allowed to provide public comment through telephone or Zoom connection.

Pursuant to Governor Newsom's Executive Orders N-25-20 (March 12, 2020) and N-29-20 (March 17, 2020), 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.
INSTRUCTIONS FOR ELECTRONIC PARTICIPATION AT BOTTOM OF AGENDA

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 three (3) minutes each.

	Welcome & Overview - 9:00 – 10:00 AM	
(a)	Welcome & Introductions	Matt Miyasato/Naveen Berry, Deputy/Assistant Deputy Executive Officer
(b)	Zero & Near Zero Emission Vehicle Incentive Programs	Vicki White, Technology Implementation Manager
(c)	Mobile Source Strategy	Zorik Pirveysian, Planning and Rules Manager
(d)	Goals for the day	Joseph Impullitti, Technology Demonstration Manager
(e)	Feedback and Discussion	All
1.	**Areas of South Coast AQMD Focus** **Commercialization of Zero and Near-zero Emission Heavy Duty Trucks** **10:00 AM – 12:00 PM**	
(a)	200 Vehicle In-Use Emission Study	Sam Cao, PhD, Air Quality Specialist
(b)	Ultra-Low Emission Heavy Duty Engines	Joseph Lopat, Program Supervisor
(c)	ZECT 1 & 2	Phil Barroca, Program Supervisor
(d)	Progression of Zero Emission Truck Development	Seungbum Ha, PhD, Program Supervisor
(e)	Feedback and Discussion	All
	Lunch 12:00 PM – 1:30 PM	
2.	**Projects of Interest Outside of Clean Fuels Program** **1:30 PM – 3:30 PM**	
(a)	Ocean Going Vessels & Locomotives	Mei Wang, Program Supervisor
(b)	Off-road ZE Equipment	Sam Cao, PhD, Air Quality Specialist
(c)	Lithium Battery Recycling	Ajay Kochhar, Co-Founder, President & CEO, Executive Director Li-Cycle

3.	Wrap-up – 3:30 PM – 4:00 PM	
(a)	2021 CF Proposed Plan Update Discussion & Wrap-up	Joseph Impullitti
(b)	Advisor and Expert Comments	All

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 three (3) 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.

Americans with Disabilities Act
Disability and language-related accommodations can be requested to allow participation in the Clean Fuels Program Advisory Group meeting. The agenda will be made available, upon request, in appropriate alternative formats to assist persons with a disability (Gov't Code Section 54954.2(a)). In addition, other documents may be requested in alternative formats and languages. Any disability or language-related accommodation must be requested as soon as practicable. Requests will be accommodated unless providing the accommodation would result in a fundamental alteration or undue burden to South Coast AQMD. Please contact 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.

INSTRUCTIONS FOR ELECTRONIC PARTICIPATION

Instructions for Participating in a Virtual Meeting as an Attendee
As an attendee, you will have the opportunity to virtually raise your hand and provide public comment.

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:

- If you would like to make a public comment, please click on the **"Raise Hand"** button on the bottom of the screen.
- 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:

- If you would like to make a public comment, please click on the **"Raise Hand"** button on the bottom of your screen.
- 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 TELEPHONE line only:

- If you would like to make public comment, please **dial *9** on your keypad to signal that you would like to comment.

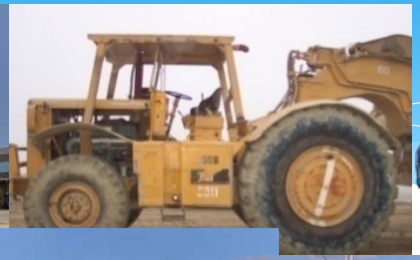
South Coast AQMD Incentives Update

Vicki White
Technology Implementation Manager

Role of Incentives

- Accelerate deployment of new, cleaner technologies that have become commercialized
- Designed to offset the higher cost of new, cleaner technologies
- Higher incentive for the cleanest technologies (zero emissions)
- Existing programs require retirement of an older vehicle, engine or piece of equipment in order to maximize emission reductions
- Projects must achieve “surplus” emissions reductions – go beyond existing regulations
- Infrastructure to enable deployment of near-zero & zero emission heavy-duty vehicles and equipment

Incentive Project Types



Main Incentive Programs

Carl Moyer Program

- Trucks
- Transit buses
- Refuse trucks
- Public agency/utility vehicles
- Emergency vehicles
- Construction/Ag
- Marine Vessels
- Shore Power
- Locomotives
- Cargo Handling
- Infrastructure

- **1998 – Present**
- **$530 Million**
- **7,977 vehicles**
- **Emissions Reduced (tpy): NOx: 8,600 PM: 248**

Prop 1B

- Trucks
- Shore Power
- Locomotives
- Cargo Handling
- TRUs

- **2009 - Present**
- **$486 Million**
- **7,503 vehicles/equipment**
- **Emissions Reduced (tpy): NOx: 7,285 PM: 220**

Replace Your Ride

- Light-Duty Vehicles
- Alternative Mobility Options (transit passes, car sharing)
- Electric vehicle chargers

- **2015 - Present**
- **$59 Million**
- **7,424 vehicles**
- **Emissions Reduced (tpy): NOx: 34 HC: 7.9**

Lower Emission School Bus Program

- School buses
- Infrastructure
- CNG tank replacements

- **2001 - Present**
- **$325 Million**
- **5,200 vehicles**
- **Emissions Reduced (tpy): NOx: 857 PM: 59**

Other Incentive Programs

- Community Air Protection Program (supports AB 617)
- Voucher Incentive Program (for small fleets with ten or fewer vehicles)
- Commercial Electric Lawn and Garden Equipment Program
- Volkswagen Environmental Mitigation Trust Program
- Funding Agricultural Replacement Measures for Emission Reductions (FARMER)

California VW Mitigation Trust

Community Air Protection Program

- Financial incentives to support the goals of AB 617
- Approved by Governor as part of the State budget each year
- Specific bills:
  - AB 134 (2017) – $250M statewide ($107.5M to SCAQMD), for Moyer and Prop 1B projects
  - SB 856 (2018) – $245M statewide ($85.57M to SCAQMD) to reduce emissions from mobile and stationary sources
  - AB 74 (2019) - $245M statewide ($79.4M allocation to SCAQMD) to reduce emissions from mobile and stationary sources, and community-identified projects

South Coast AQMD's AB 923 Distribution of Funds

The Board approves annually how to distribute revenues from $2 DMV fee among the following programs:

- Carl Moyer on- and off-road mobile source projects
- Lower Emission School Bus Program (including zero emission buses)
- Metrolink passenger locomotive project (multiple phases)

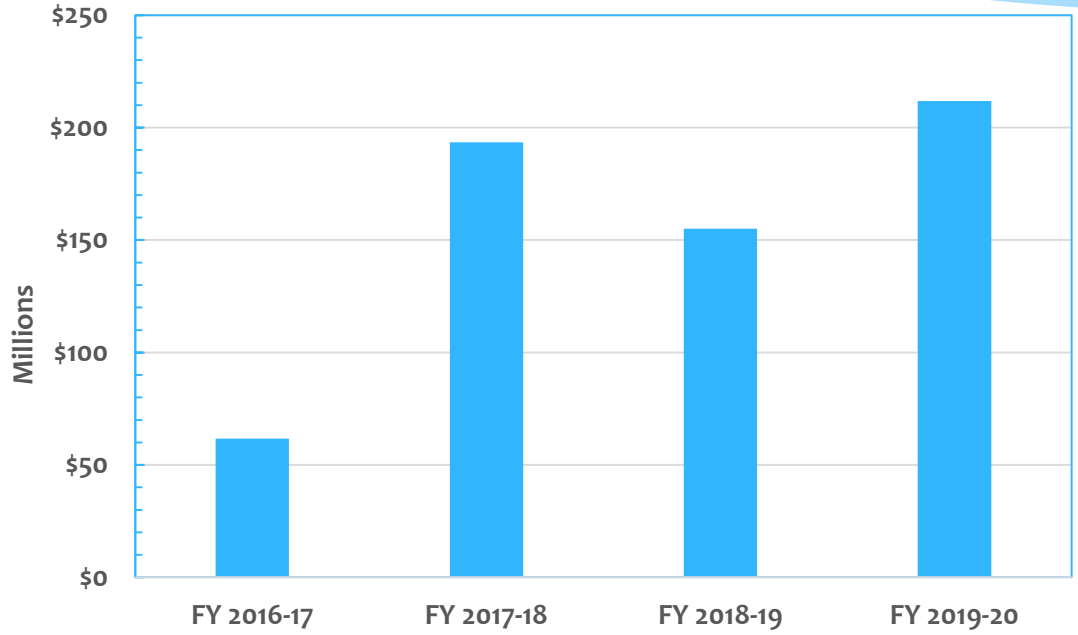
Lower-Emission School Bus Program

- Replace older, high-emitting school buses with cleaner technologies
- Participants include public school districts, including JPA, charter schools and private transportation providers under contract with a public school district
* Program strives to fund the cleanest bus technologies commercially available
* School districts must pay at least $15K as their local match
  - Funds are often combined with HVIP funds to help offset the higher cost of the new near-zero or zero-emission school bus
  - Up to $400k for an electric school bus (with HVIP funds)
  - South Coast AQMD funds also available for infrastructure

VW Mitigation Program

Project Category	Technology	Allocation (millions)	Air District Administrator
Zero-Emission Transit, School and Shuttle Buses	Battery electric or fuel cell	$130	SJVAPCD
Zero-Emission Class 8 Freight and Port Drayage Trucks	Battery electric or fuel cell	$90	SCAQMD
Zero-Emission Freight and Marine Projects	Battery electric or fuel cell	$70	BAAQMD
Combustion Freight and Marine Projects (waste haulers, dump trucks, concrete mixers, switcher locomotives, ferries, tug boats)	Low NOx engine, Tier 4, or Tier 4 equivalent	$60	SCAQMD
Light-Duty Zero-Emission Vehicle Infrastructure	Electric charger or hydrogen fueling station	$10	BAAQMD
CARB Reserve		$63	
	Total:	$423	

South Coast AQMD Incentive Programs (Past 4 Years)

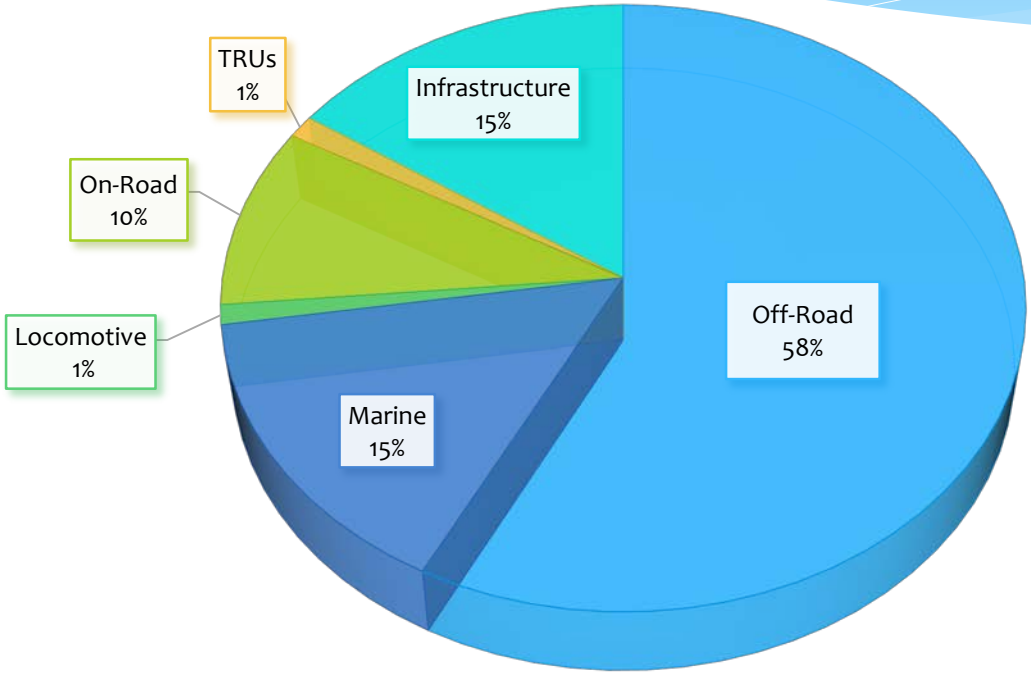


Emission Reduction Benefits from Incentive Programs (2020)

Program	Funding Amount	No. of Equipment/ Engines	NOx (tpy)	PM2.5 (tpy)
Carl Moyer	$33,959,122	162	222.1	4.0
Carl Moyer State Reserve	$1,086,505	6	3.7	0.1
AB 923 Match Funds	$4,618,441	18	6.1	0
FARMER	$706,804	2	5.8	0.4
AB 617 Community Air Protection Program (CAPP) Incentives	$37,762,509	172	123.4	6.0
EFMP (Replace Your Ride)	$13,532,012	1,649	4.2	0.3
Proposition 1B	$39,610,000	399	151.1	0
Voucher Incentive (VIP)	$2,705,000	63	43.2	0.2
VW Mitigation Program	$4,980,238	69	25.1	N/A
Total	**$138,960,631 ***	**2,540**	**584.7**	**11**

* EPA DERA/TAG awards and other smaller grants not included.

Carl Moyer Program – Funding Distribution by Project Category



HD Trucks

- Freight trucks (drayage and other)
- Solid waste collection vehicles
- Emergency vehicles
- Public agency/utility vehicles
- Any on-road vehicle >14,000 lbs GVWR (LHD to HHD)
- Other trucks (concrete mixers, dump trucks)
- Transit and school buses (included for incentive purposes)

South Coast AQMD Main Incentive Programs for HD Trucks

- Carl Moyer Program
- Community Air Protection Program (CAPP) Incentives
- Proposition 1B – Goods Movement Program (in final stage of funding)
- Voucher Incentive Program (small fleets only)
- Volkswagen Mitigation Program (statewide)

Barriers to Participation

- Requirement to scrap an older diesel truck
- Limited incentive – not qualified for maximum incentive amount
- No new purchase option (low NOx and ZE)
- Cost-effectiveness limit
- Ownership for past 2-years
- EMY eligibility
- DMV registration gaps
- No trade-down option with another fleet
- Usage records (incomplete or low mileage)

Incentive Program	Scrapping	Maximum Funding
VW	Yes	$85,000 *
Prop1B	Yes	$100,000
Carl Moyer	Yes	$100,000 **
HVIP	No	$45,000

*If non-drayage, limited to 25% of truck cost.
**May be capped at lower incentive due to C/E limit

CAPP Results

Project Category	Technology	AB 134 (CAPP Year 1)		SB 856 (CAPP Year 2)	
		Funded Amount	No. of Units	Funded Amount	No. of Units
On-Road	Zero emission	$12,566,150	66	$1,231,961	45
	Optional low-NOx	$22,858,674	415	$9,013,889	133
	Other (Emergency)	-	-	$1,187,478	19
Off-Road Agriculture	Tier 3/4F	$19,607,167	156	$4,795,672	55
Off-Road Construction	Zero emission	-	-	$2,226,833	9
	Tier 3/4F	$22,698,620	96	$2,754,835	32
Cargo Handing Equipment	Zero emission	-	-	$349,845	16
	Hybrid-Electric	-	-	$8,235,475	11
	Tier 4F	-	-	$883,702	5
Marine	Tier 3	$9,490,812	57	$17,032,908	85
Transport Refrigeration Unit	Electric	-	-	$1,411,528	31
Infrastructure	Electric charging	$122,500	1	$7,718,592	9
	Renewable natural gas	$12,243,034	13	$10,586,965	6
	Natural gas	$1,237,782	3	-	-
Locomotive	Tier 4	$11,533,500	6	$1,243,280	1
TOTAL		**$112,358,239**	**813**	**$68,672,963**	**465**

Summary of Awards – Near Zero and Zero Emission Trucks

Program	NZ Emission (0.02 g/bhp-hr)	Funding	Zero Emission	Funding
CAPP	261	$17,283,866	1	$200,000
Moyer *	31	$1,424,898	0	$0
Prop 1B	832	$80,900,000	70	$14,000,000
CEC/Port Funds	120	$12,000,000	0	$0
Volkswagen	67	$3,980,238	TBD	$27,000,000 (in process)
Total	**1,311**	**$115,589,002**	**71**	**$14,200,000**

* Many applications received under Moyer for zero and near-zero emission trucks were awarded funding through the Community Air Protection Program.

Incentives Paid for Near Zero Emission Trucks*

Engine Displacement	# of Trucks	Funding
11.9 Liter	296	$29,028,005
8.9 Liter	166	$15,220,000
6.8 Liter	42	$1,967,592
Total	**504**	**$46,215,597**

* As of January 22, 2021

Volkswagen Program Update

Funding Category	1st Installment	Open	Closed
ZE Transit, School, and Shuttle Buses	$65 million	10/21/19	Still open (Shuttle and Transit only)
Combustion Freight and Marine Projects	$30 million	12/6/19	3/4/20
Light Duty Infrastructure – Hydrogen	$5 million	2/20/20	5/22/20
ZE Freight and Marine Projects	$35 million	6/18/20	8/31/20
ZE Class 8 Freight and Port Drayage Trucks	$27 million	8/18/20	Still open (backup list)
Light Duty Infrastructure - Battery Electric	$5 million	February 2021 (Est)	TBD

School Bus Awards by County (2018/19)

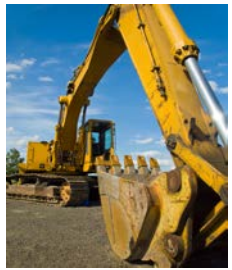
County	No. of Schools	No. of Buses	U.S. EPA Air Shed Grant	South Coast AQMD AB 923 Funds*
Los Angeles	12	36	$628,800	$5,613,200
Orange	16	100	$1,100,400	$17,162,600
Riverside	6	19	$275,100	$3,154,400
San Bernardino	7	41	$1,100,400	$6,686,100
Total	41	196	$3,104,700	$32,616,300

* In addition, $2,050,000 in HVIP funds were provided.

Note: South Coast AQMD recently closed a new Program Announcement in January 2021, and currently evaluating applications.

Off-Road Construction

* Off-Road Construction Equipment
  * Scrapers
  * Loaders/Tractors
  * Backhoes
  * Excavators
  * Rough-Terrain Forklifts
* Compression ignition or large-spark ignition engines >25 HP
* Subjected to CARB's In-Use Off-Road Diesel and/or Large-Spark Ignition Regulation



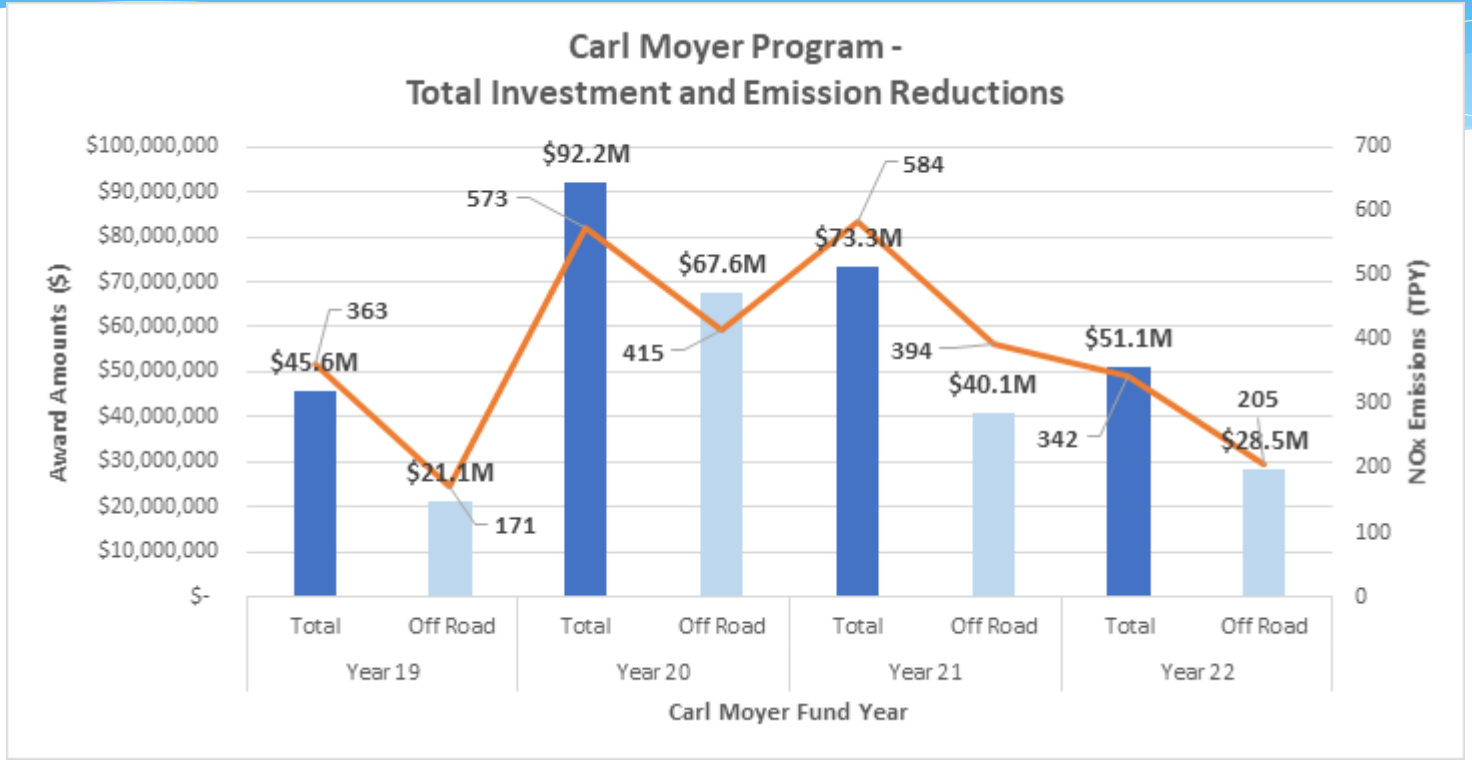
South Coast AQMD Incentive Programs for Off-Road Construction

* Carl Moyer Program
* Surplus Off-Road Opt-In for NOx (SOON) Provision
* Other Smaller Grants (including State Reserve or Voluntary NOx Remediation Measure)

Surplus Opt-In Off-Road for NOx (SOON)

* Incentive program to achieve **additional NOx** emission reductions from in-use off-road diesel fleets in California
  * Covers up to 80% of the equipment replacement cost or 85% of the repower costs
* Must maintain compliance requirements of the off-road regulation throughout contract term
* Mandatory for large fleets (>20,000 hp) with >40% Tier 0 and Tier 1 vehicles
* Other fleets may apply on a voluntary basis
* South Coast AQMD sets aside about $5M of Carl Moyer Program funds each year for SOON

Total Investment in Off-Road Construction (Past 4 Years)



Funding Opportunities in 2021

* Lower Emission School Bus Program	Closing 1/26/21
* VIP for small fleets (first-come, first-served)	February 2021 (Est)
* Carl Moyer Program (incl. SOON, FARMER and other programs if available)	March 2021
* Prop 1B – Goods Movement Program	Closing 4/30/21
* Volkswagen - Combustion and ZE Freight & Marine and Light Duty Infrastructure (Battery Electric)	Qtr. 2 2021
* AB 617 Community Air Protection Incentives	TBD
* Other Programs	Ongoing (until funds are depleted)

Useful Links

Program	Link
CAPP Incentives	www.aqmd.gov/cappincentives
Proposition 1B - Goods Movement Emission Reduction Program	www.aqmd.gov/prop1b
Volkswagen Environmental Mitigation Program	www.aqmd.gov/vw
Carl Moyer Program	www.aqmd.gov/moyer
Voucher Incentive Program (for small fleets of 10 trucks and less)	www/aqmd.gov/vip
Lower Emission School Bus Program	www.aqmd.gov/schoolbus
Commercial Lawn and Garden Equipment Incentive Program	www.aqmd.gov/lawngarden
Replace Your Ride (Clean Cars for All)	www.replaceyourride.com

Mobile Source Control Needs for Meeting Ozone Standards

Clean Fuels Program Advisory Group Meeting

February 2, 2021

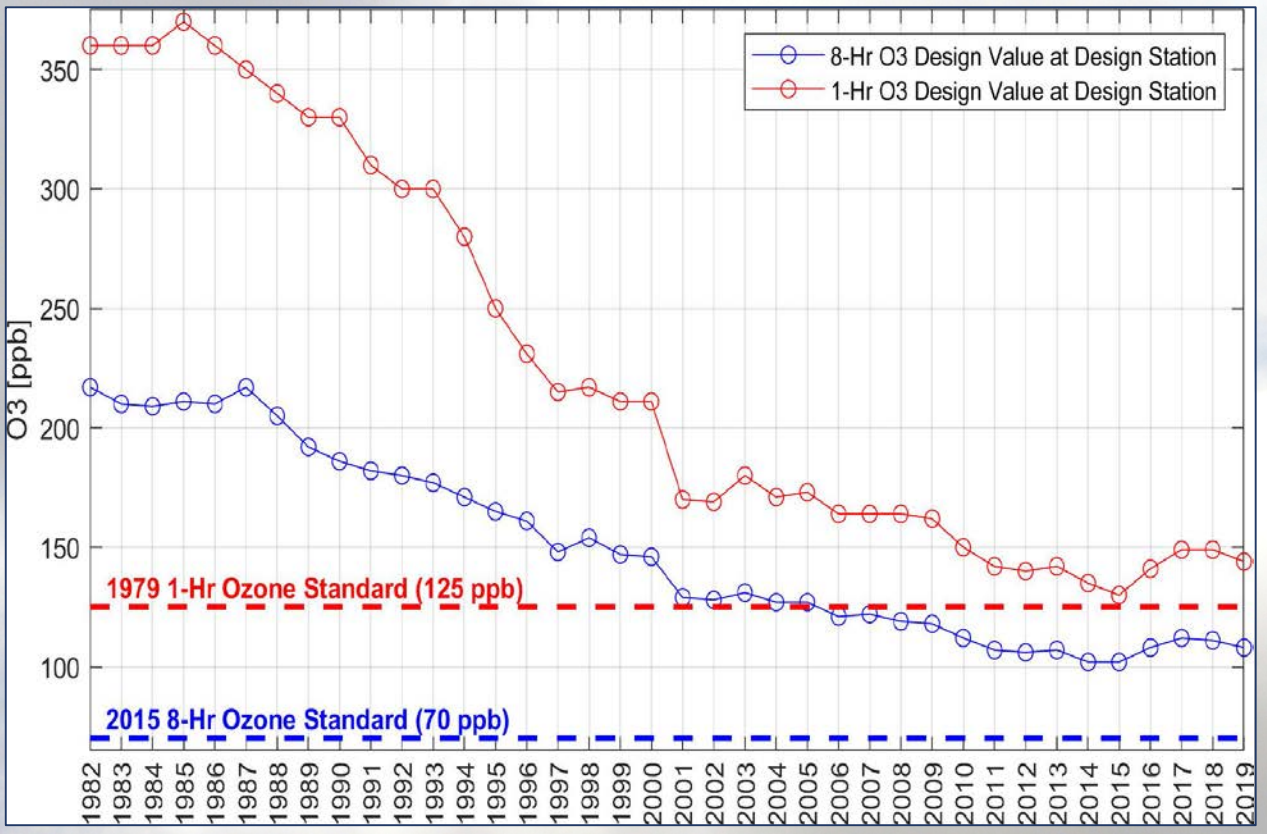
Ozone Standards Classifications

Standard	Level	South Coast Classification	Coachella Valley Classification	Attainment Date
2015 8-hour Ozone	70 ppb	Extreme	Severe	August 3, 2038 (South Coast) August 3, 2033 (Coachella Valley)
2008 8-hour Ozone	75 ppb	Extreme	Severe	July 20, 2032 (South Coast) July 20, 2027 (Coachella Valley)
1997 8-hour Ozone	80 ppb	Extreme	Extreme*	June 15, 2024 (both South Coast and Coachella Valley)
1979 1-hour Ozone	120 ppb	Extreme	Attainment	February 6, 2023 (South Coast)

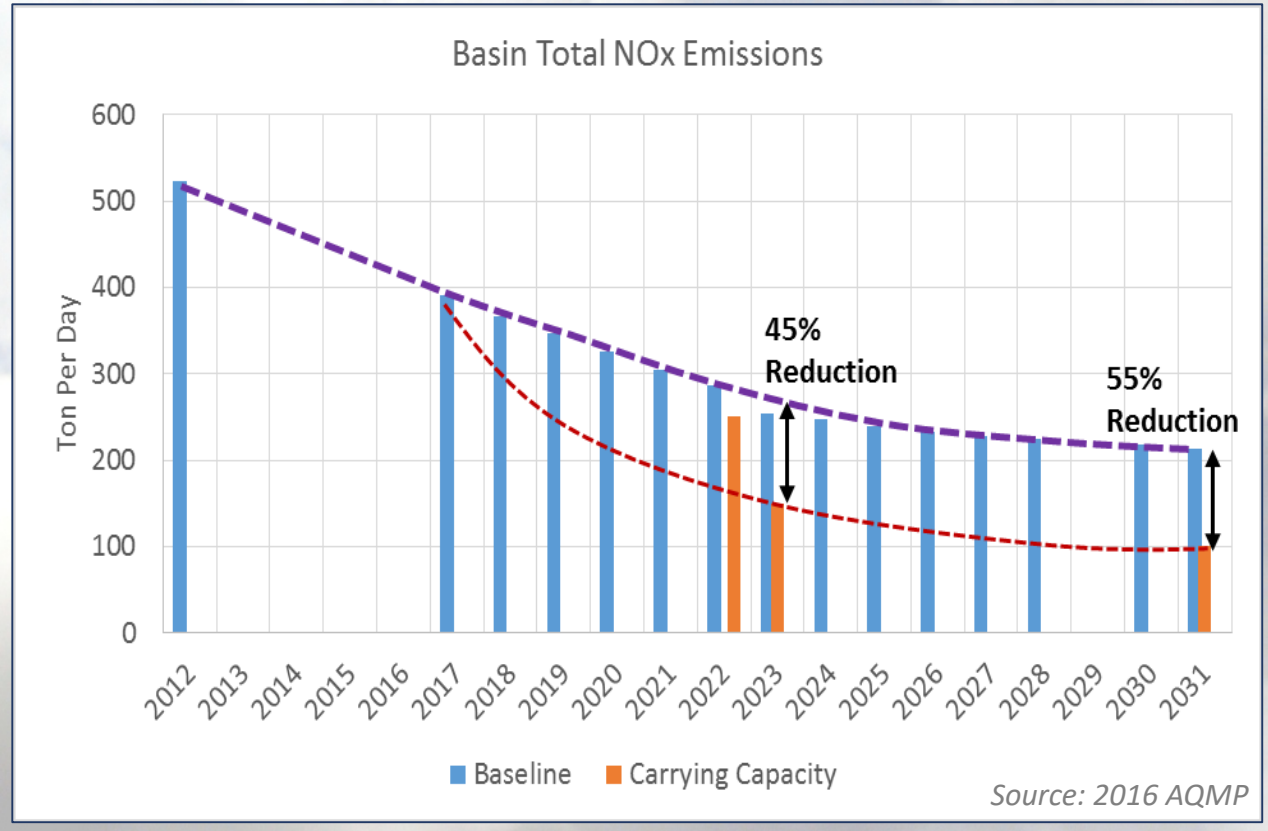
**Voluntary reclassification from severe to extreme in July 2019*

Ozone trends in South Coast Air Basin and Needed Reductions

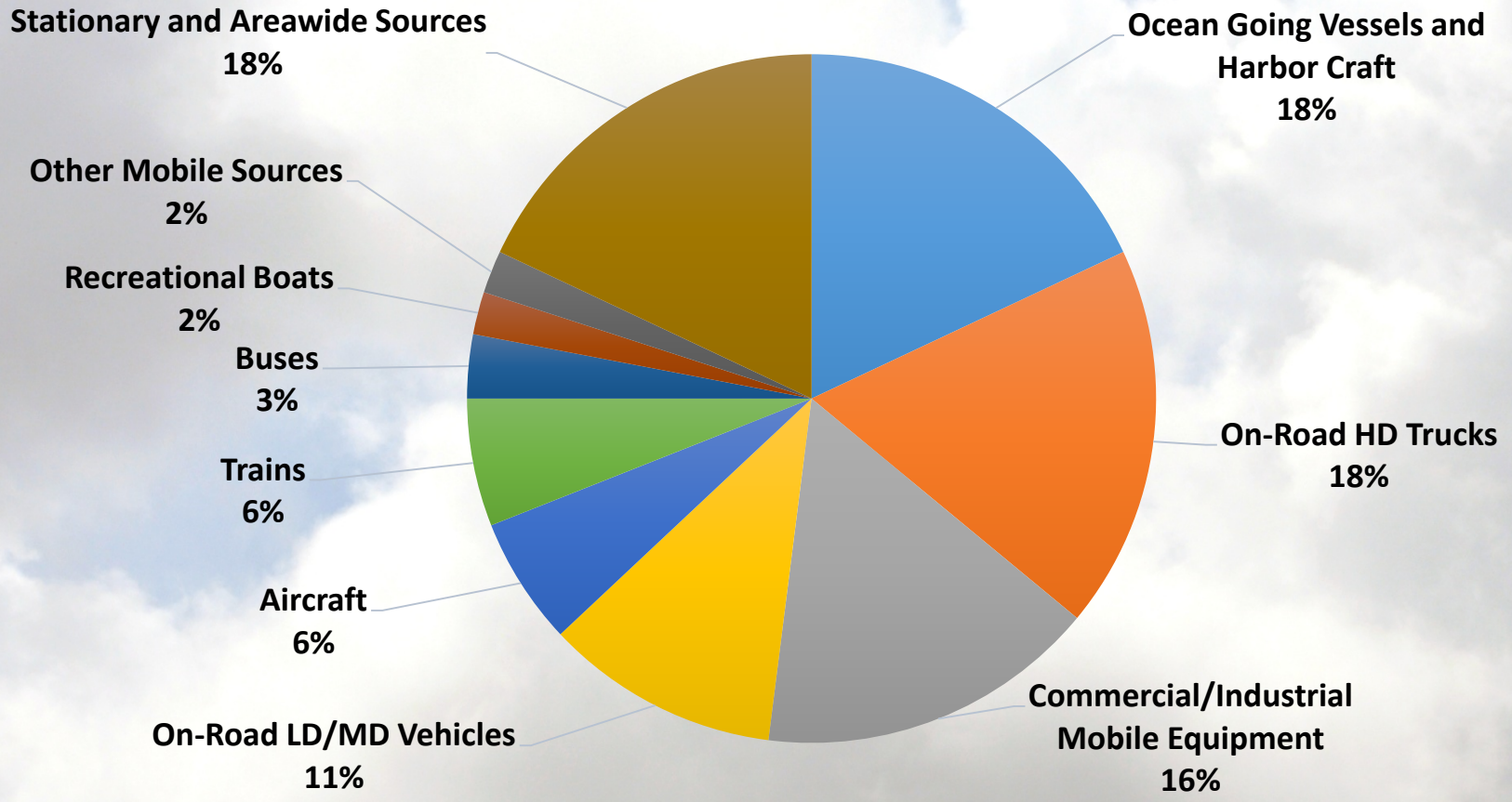
Historical Trend



NOx Reductions Needed



2023 NOx Share by Major Source Category



- NOx forms ozone & contributes to PM2.5
- Over 80% of the basin's NOx emissions from mobile sources

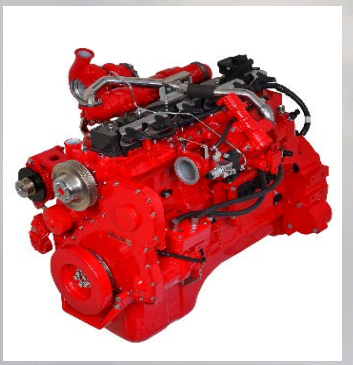
LD = Light-Duty; MD = Medium-Duty; HD = Heavy-Duty

Overall Control Strategies Needed for Attaining Ozone Standards

- Extensive transition to near-zero (NZE) and zero-emission (ZE) technologies in mobile and stationary sources, where feasible
  - Transition to cleanest available technologies if NZE/ZE not feasible
- Regulatory measures and incentive programs
- Eliminate/minimize reliance on "undefined" 182(e)(5) measures
- Seek legislative authority where applicable
- Seek new sources of funding for new/existing incentive programs
- Federal action is needed on sources California cannot address

Mobile Source Technologies Needed for Attainment

- Electric passenger vehicles
- Electric/hybrid medium-duty trucks
  - Fed-Ex, UPS, Frito-Lay
- Zero-emission heavy-duty trucks being demonstrated
  - Class 7-8 trucks
  - Challenges – range, cost, infrastructure
- Near-zero emission natural gas heavy-duty trucks (90% lower NOx)
- Near-zero, zero-emission, and cleanest technologies
  - Off-road equipment, ships, aircraft, locomotives



CARB draft 2020 Mobile Source Strategy

- Builds on 2016 Mobile Source Strategy
- Conceptual scenario approach
- Identifies technology mixes to achieve air quality and climate goals
- Pursue multiple strategies
  - Enhanced enforcement
  - Manufacturer, end-user, and facility requirements
  - Infrastructure development
  - Incentive programs and education & outreach
- Defined measures to be developed subsequently

2020 Draft Mobile Source Strategy - Heavy Duty Trucks

- Heavy Duty Vehicle Inspection and Maintenance
  - Periodic vehicle inspections/Remote sensing devices
  - Board consideration in December 2021

- Advanced Clean Fleets – transition to zero emission fleets
  - 2035 – Drayage, public fleets, last mile delivery
  - 2040 – Refuse, buses, utility fleets
  - 2045 – Other trucks and buses where feasible
  - Board consideration in December 2021

- Zero Emission Infrastructure Support
  - 180,000 MD & HD vehicles expected by 2030
  - Interagency coordination (CARB, CEC, CPUC, GO-BIZ) for infrastructure build-up

2020 Draft Mobile Source Strategy - Construction Equipment

- Full turnover of Tier 0/1/2 equipment by 2033
- Tier 5 engine standard
  - 50-90% NOx reduction from Tier 4f
  - Expected Adoption in 2024 with implementation in 2028
- Electrification and hybridization
  - On-going research in suitable off-road duty cycles
  - Identification of off-road population and horsepower range for electrification and hybridization
- Future amendments of in-use off-road diesel regulations
  - Potential ban of older, higher-emitting equipment
  - Encourage and incentivize zero-emission adoptions

2020 Draft Mobile Source Strategy - Ocean-Going Vessels

- Expansion of at-berth regulation to cover more vessel types
- Strategies to address transit, anchorage and maneuvering emissions
  - Replace Tier 0/1/2 visits with Tier 3 or Tier 2+ visits by 2031
  - Introduce Tier 4 standards by 2028
  - Collaborate with South Coast AQMD to implement OGV retrofits

2022 AQMP Overall Schedule

Preliminary 2018 emissions inventory
January 2020

Draft control measures
June/August 2021

Release Draft AQMP
Late Fall 2021

CARB Board Hearing
July 2022

April 2021
Updated base and future emissions inventory

June/August 2021
Carrying Capacity

June 2022
South Coast AQMD Board Hearing

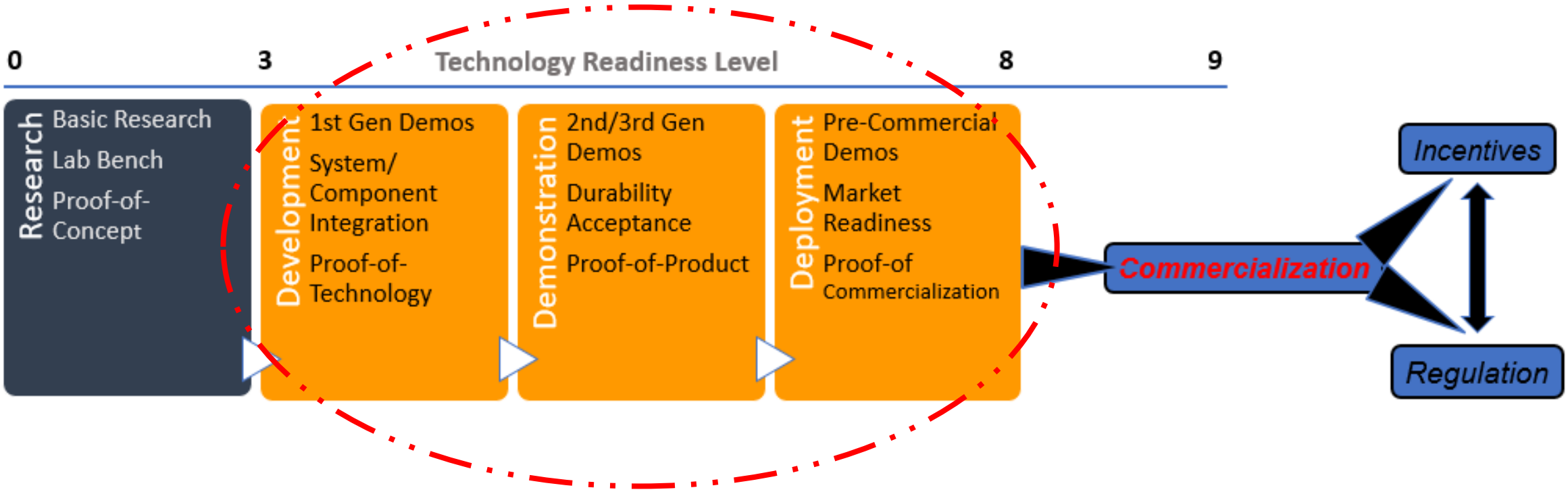
August 3, 2022
70 ppb Ozone SIP due to EPA

Mobile Source Working Groups
December 2020 – June /August 2021

Clean Fuels Program Advisory Group Meeting

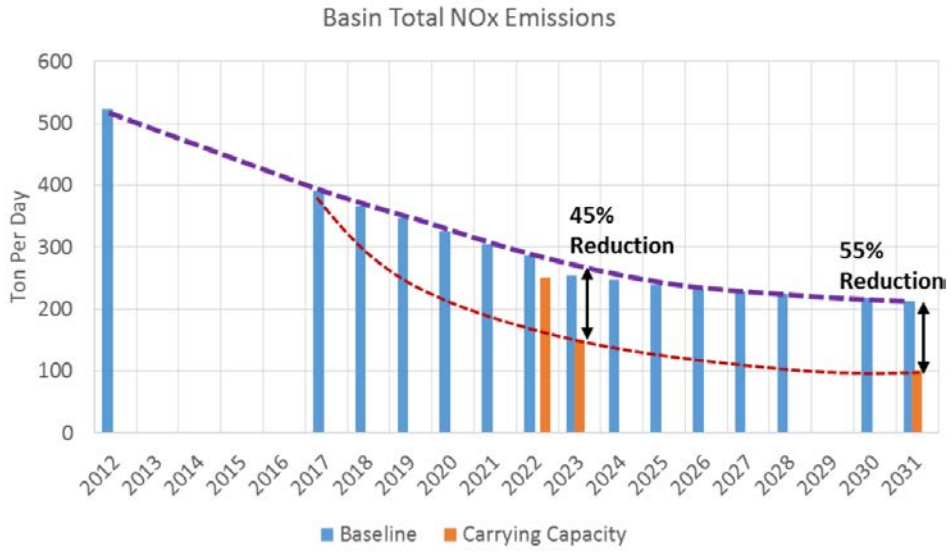
Febuary 2, 2021

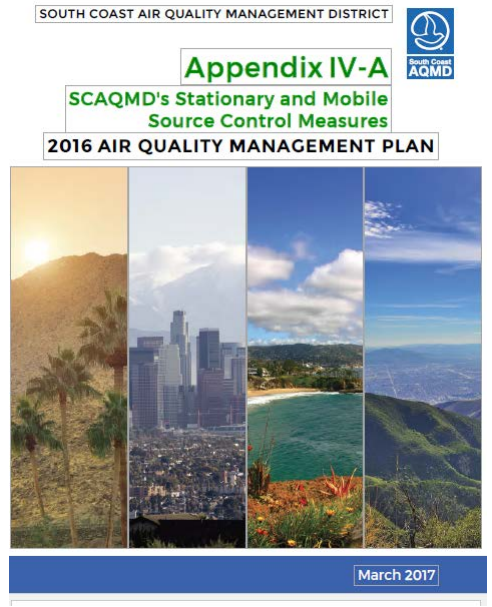
Clean Fuels Fund Program



South Coast AQMD Plans & Policies

- 2016 AQMP – NAAQS



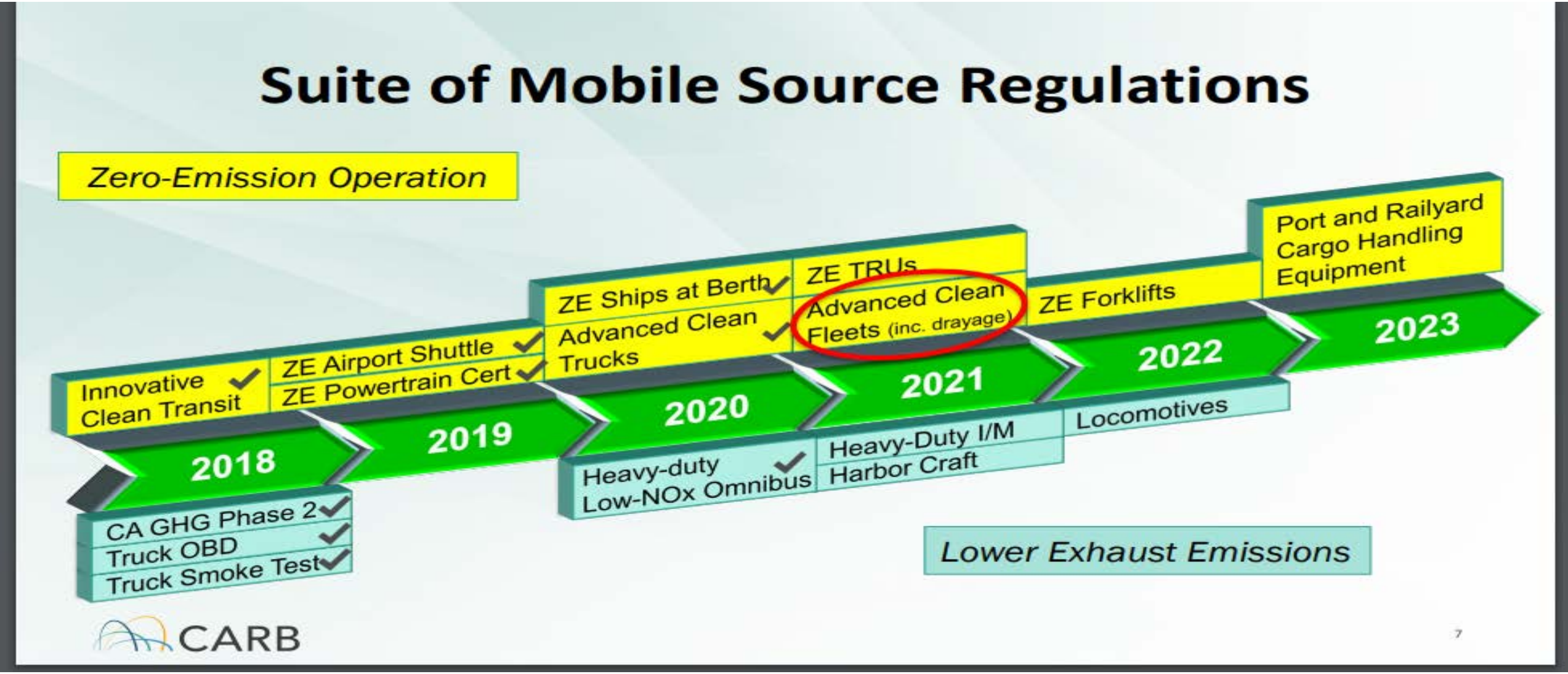


Sector	Board Direction
Commercial Marine Ports	Develop MOU with ports to implement Clean Air Action Plan (CAAP)
Railyard and Intermodal Yards	Pursue Indirect Source Regulation (ISR)
Warehouse Distribution Centers	Pursue ISR
Commercial Airports	Develop MOU with airports to create and implement Air Quality Improvement Plans (AQIPs)
New/Redevelopment Projects	Further study on potential ISR or other approaches

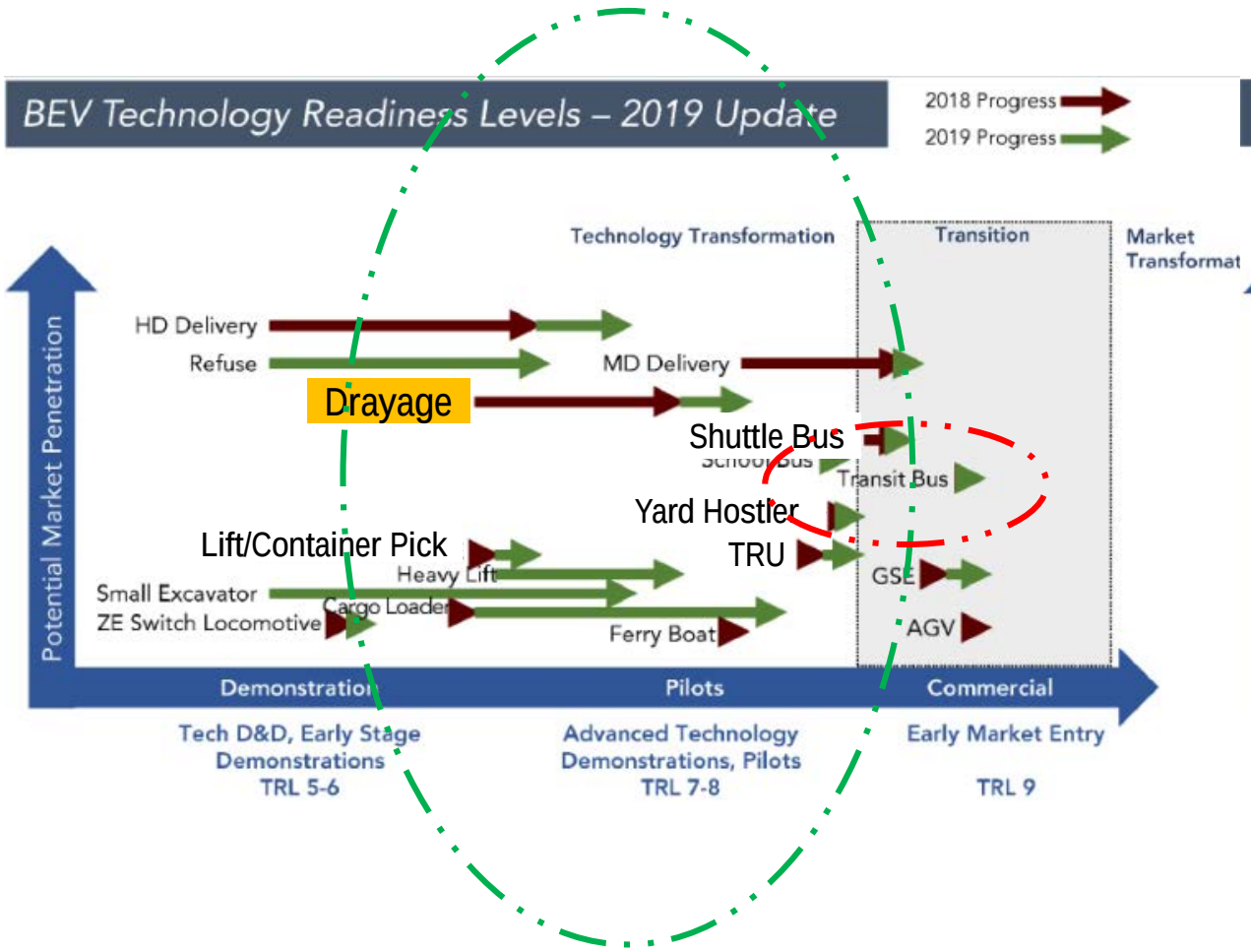
Federal/State Actions

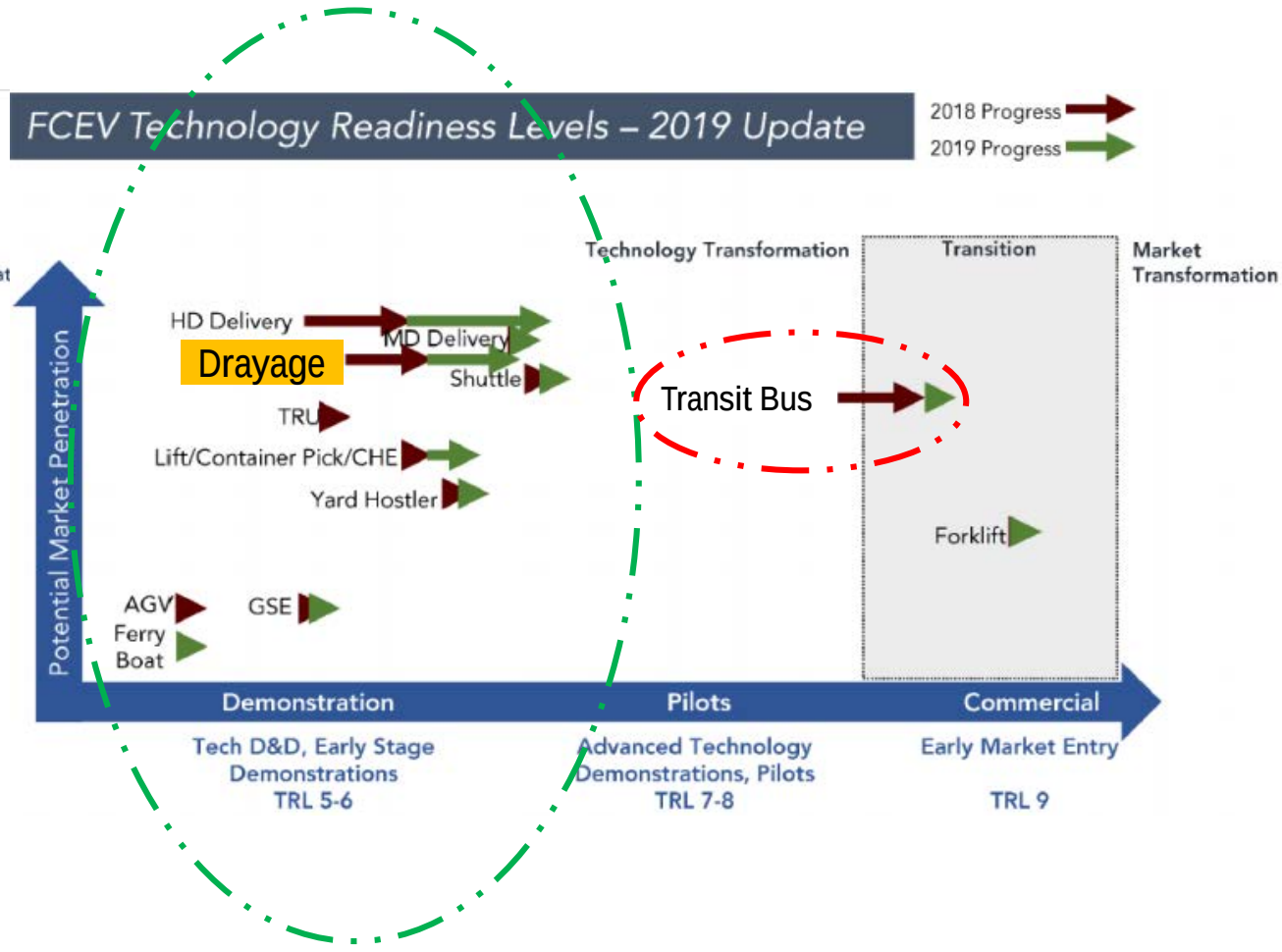
- **Feds:** FY 2021 Interior, Environment and Related Agencies funding bill – EPA & DOE increases
- USEPA – Cleaner Trucks Initiative – delayed due to COVID
- **State:** Air Districts Funding for AB 617 Program
- CEC – Low Carbon Fuel Production Program (LCFPP)
- CARB Regulations
  - Heavy-Duty On-Road "Omnibus" Low NOx Regulation
  - Advanced Clean Truck Regulation (ACT)
  - Truck and Bus Regulation (Compliance begins 2020)
  - Innovative Clean Transit (ICT) Regulation

CARB Efforts - Zero Emission Regulations



Battery Electric vs. Fuel Cell Readiness Levels





Source: Proposed Fiscal Year 2019-20 Funding Plan for Clean Transportation Incentives For Low Carbon Transportation Investments and the Air Quality Improvement Program; Appendix D: Heavy-Duty Investment Strategy" (CARB, 2019b).

2021 Plan
Key Proposed Projects

- Heavy-duty zero emission battery electric and fuel cell trucks and infrastructure
- Onboard sensor development for emissions monitoring and improved efficiency
- Microgrid research, development & demonstrations to support zero emission infrastructure
- Battery, fuel cell electric transit and school buses charging/fueling infrastructure
- Heavy-duty diesel truck replacements with near-zero emissions natural gas trucks
- Fuel and emissions studies:
  - measurements and analysis of NOx emissions
  - emissions impacts of hydrogen-natural gas fuel blends on near-zero natural gas engines

*Projects not funded in 2021 may be considered for funding in future years

Draft 2021 Plan Update
(Key Technical Areas)

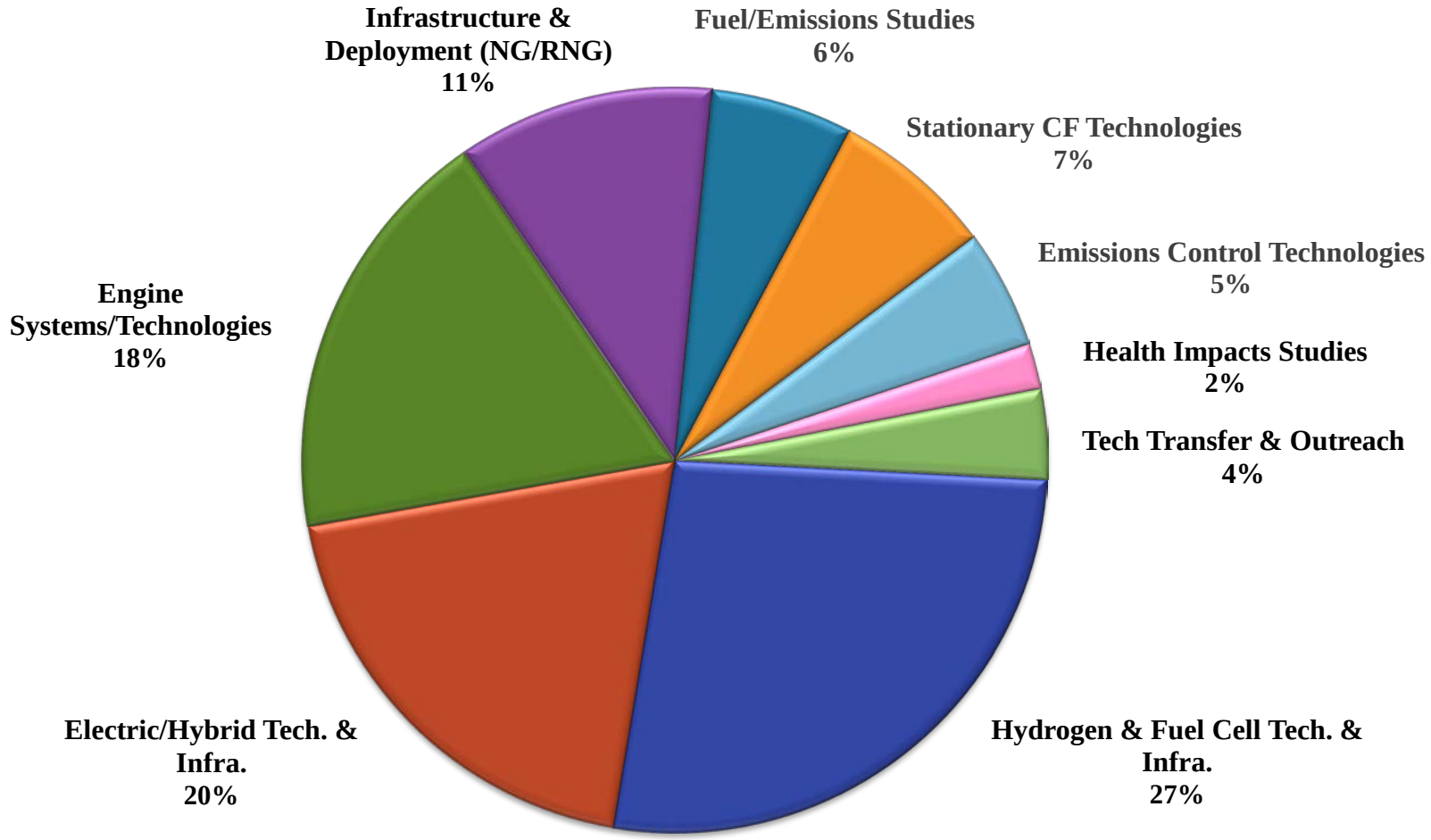
- Focus priorities on large demonstrations of zero emissions drayage trucks to test and validate OEM readiness and infrastructure viability
- Defining technology pathways via special projects - the Ultra-Low Emissions Engine Program
- Near-zero emission (gaseous and liquid fuel) engine systems, especially high HP uses

Volvo Dealership in Fontana to Service Class 8 Battery Electric Trucks

Draft 2021 Plan Update (Continued)
(Key Technical Areas)

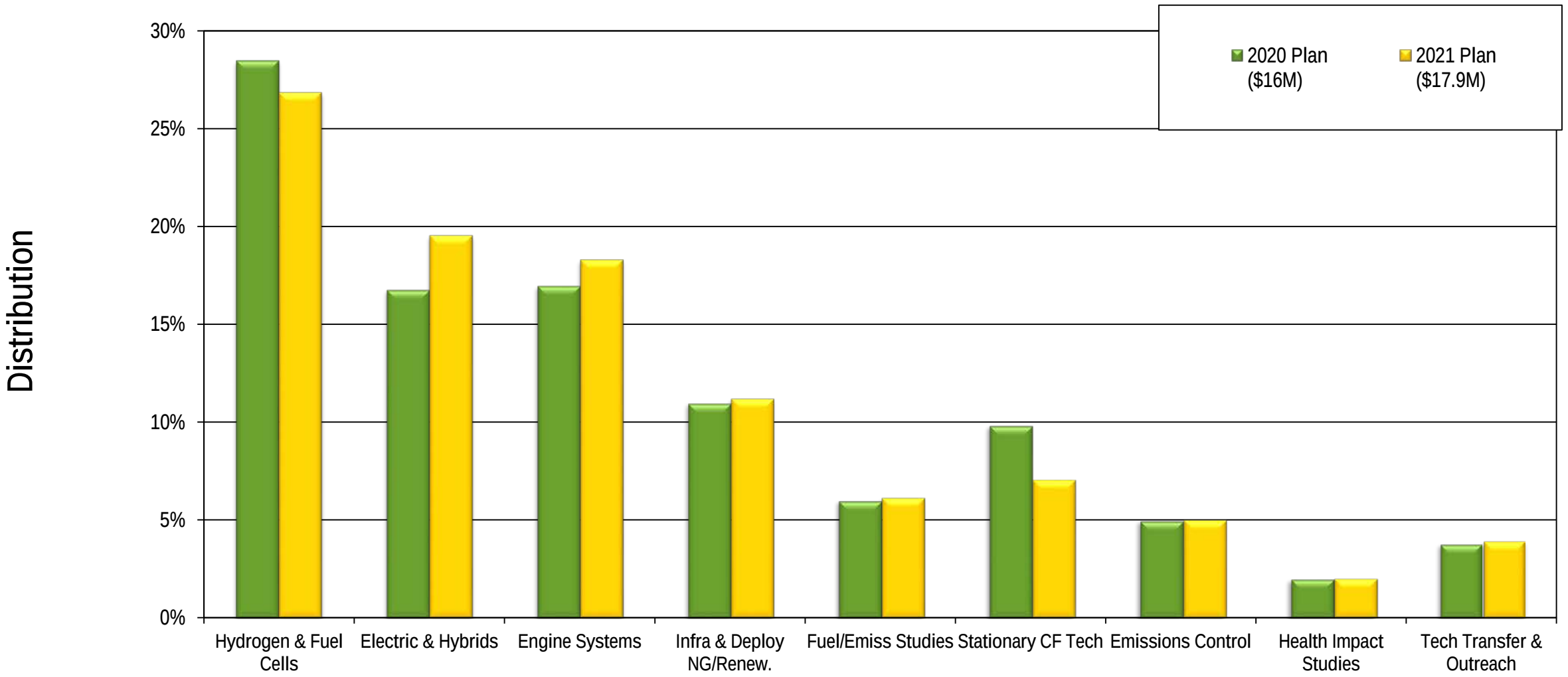
- Expand focus on local biogas production and use
- Leverage OEM partnerships to focus on continued deployment of hybrid, plug-in, electric-drive technologies and infrastructure
- Onsite hydrogen production and dispensing and mobile refueling
- Maintain other areas of emphasis

Proposed 2021 Plan Distribution



$17.9M

Plan Update Comparison



Proposed Distribution

	2020 Plan	Draft 2021 Plan
Hydrogen & Fuel Cell Tech. & Infra.	28%	↓ 27%
Engine Systems/Technologies	17%	↑ 18%
Electric/Hybrid Tech. & Infra.	17%	↑ 20%
Infrastructure & Deployment (NG/RNG)	11%	11%
Stationary CF Technologies	10%	↓ 7%
Fuel/Emissions Studies	6%	6%
Emissions Control Technologies	5%	5%
Tech Transfer & Outreach	4%	4%
Health Impacts Studies	2%	2%
	100%	100%

Feedback

Email:

Joseph Impullitti
jimpullitti@aqmd.gov

200 Vehicle In-Use Emissions Testing Program

Clean Fuels Advisory Group | Sam Cao - Air Quality Specialist | February 2, 2021

Objectives

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

Total Vehicles Recruited

219

22 Vehicle OEMs, 9 Engine OEMs, 200 PAMS, 100 PEMS, 60 Chassis, 10 On-Road Trailer

Vocations Covered

5

25 Fleet Participants: Delivery (44), Goods Movement (95), Transit Bus (21), School Bus (27) and Refuse (32)

Technologies Covered

9

Propane (4), Propane 0.02 (2), CNG 0.02 (34), CNG 0.2 (84), Non SCR Diesel (7), Diesel 0.2 (70), Diesel-Hybrid (6), BEV (10), FCEV (1), HDPI (4), RD (12)

Testing Phase Update

Testing Phase	Assigned	Recruited	Completed	This Update
Portable Activity Monitoring System (PAMS)	200	219	206 (complete)	All
Portable Emissions Measurement System (PEMS)	100	100	97	77*
Chassis Dynamometer	60	62	57	34*
Real-World In-Use Trailer	10	10	5	-

***RD and non-SCR Diesel removed for NOx comparison purposes, some results still validating**

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

EMFAC 202x Activity Updates

- 162 PAMS data sets provided new data for EMFAC 2020x's VMT speed distribution, starts/soak time, extended idle time

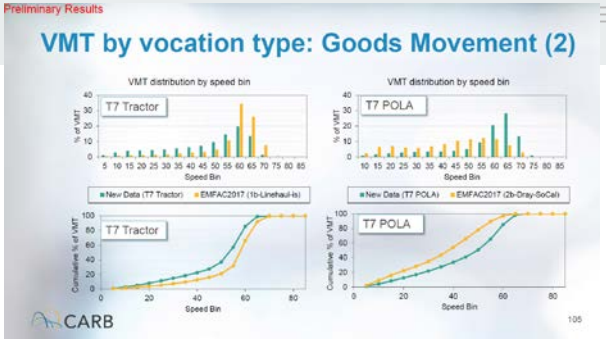
PAMS Data by Fuel and Vocational Type

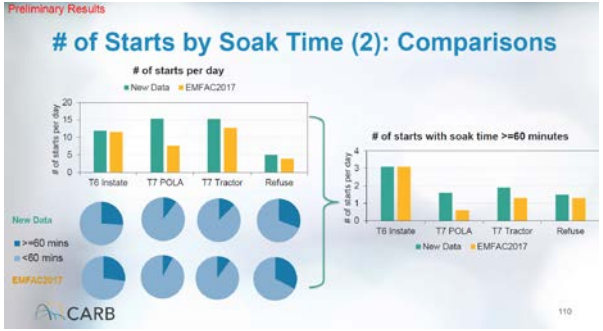
Data Source	Fuel Type	Delivery	Goods Movement	Refuse	School Bus	Transit Bus	Total
UCR	CNG	6	18	13	10	2	49
	Diesel	7	22		3		32
WVU	CNG	8	17	13	11	7	56
	Diesel	11	10	1	3		25
Total Used		**32**	**67**	**27**	**27**	**9**	**162**

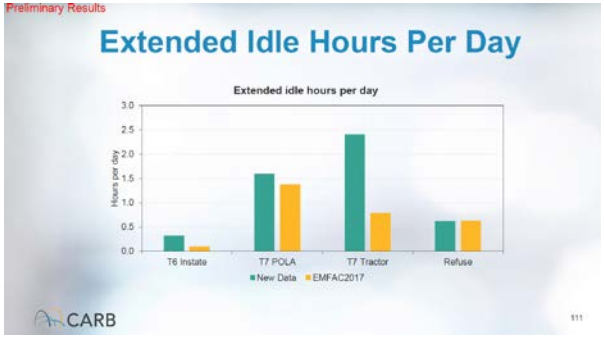
Note:

- ✓ UCR tested 86 vehicles in total. 81 vehicles are used for this preliminary analysis and 5 are excluded due to missing/invalid data
- ✓ WVU tested 95 vehicles in total. 81 vehicles are used for this preliminary analysis, and 14 are excluded due to missing/invalid data

CARB 103



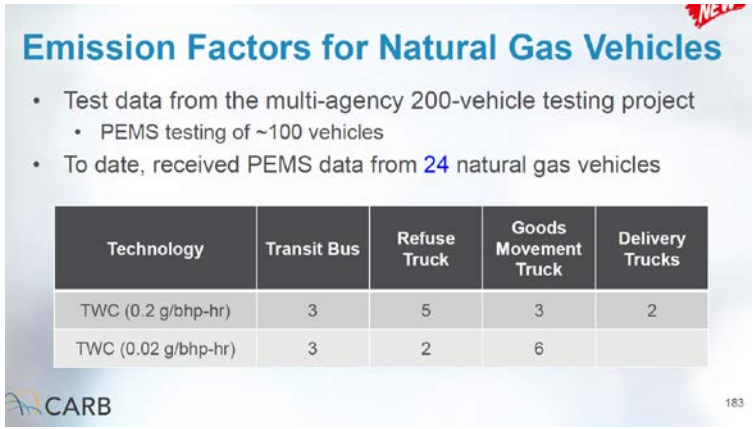


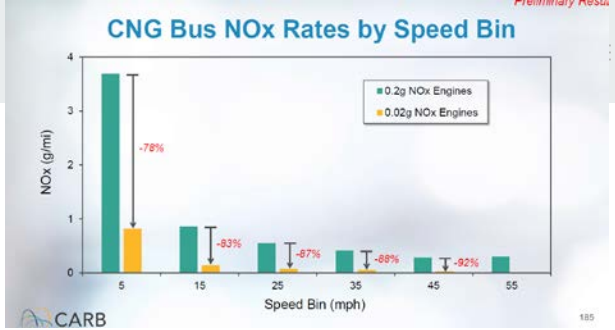


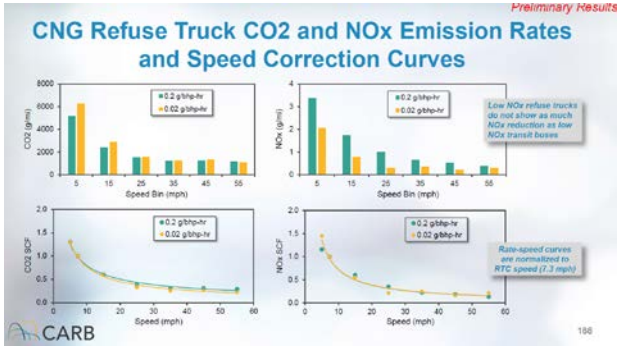
Source: CARB EMFAC 202x Workshop

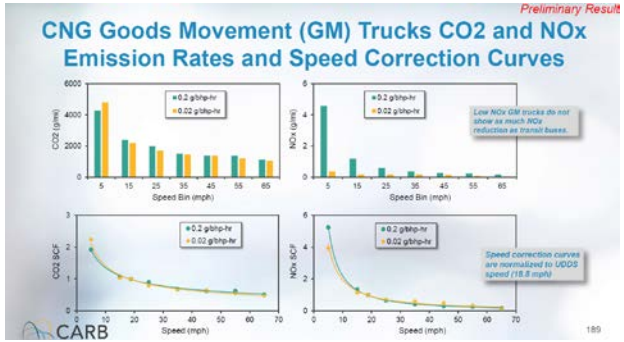
EMFAC 202x Emission Rates Updates

- 24 natural gas PEMS data provided updated emissions rates for Transit Bus, Refuse and Goods Movement Trucks
- Derived from PEMS data
- More data to be added





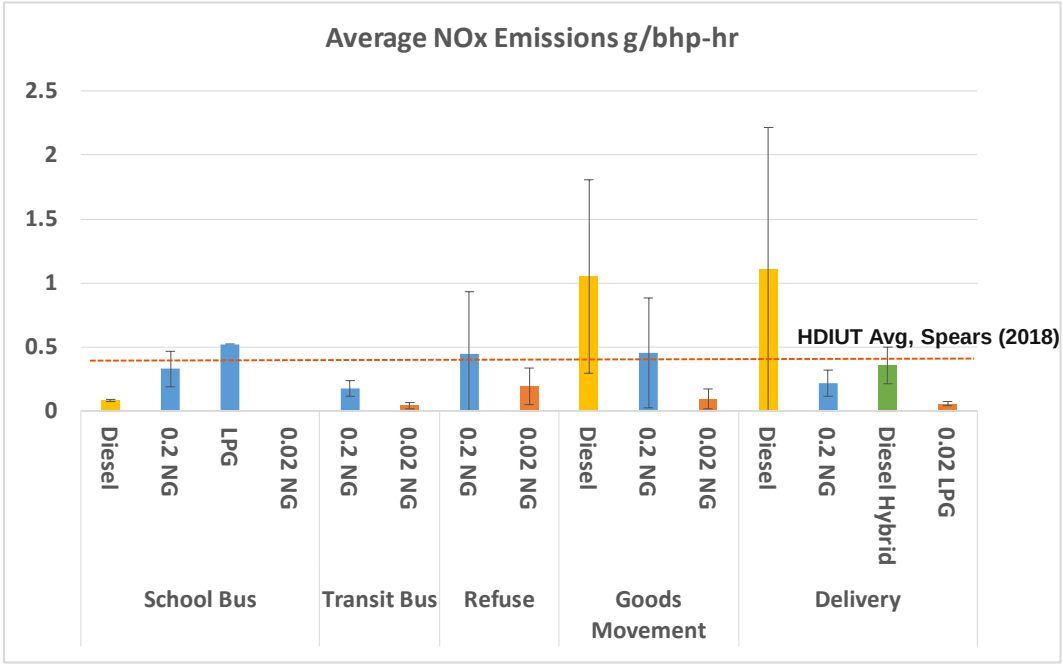




Source: CARB EMFAC 202x Workshop

Preliminary Findings – PEMS

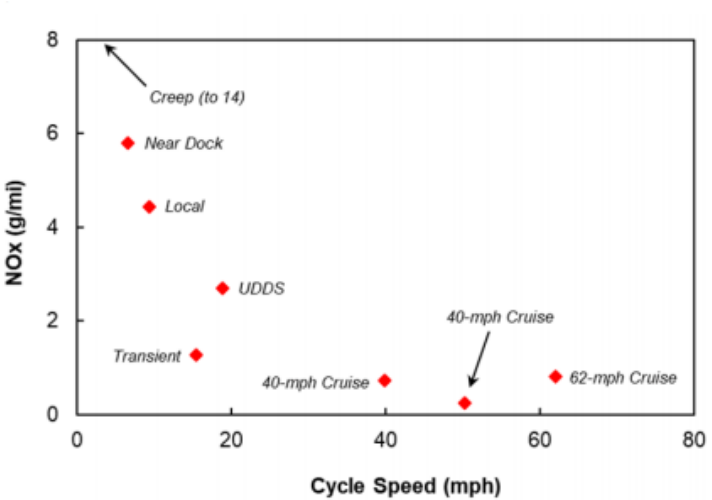
- One day of operation, gaseous only, ~ 77 vehicles, non-SCR diesel removed
- NOx emissions vary greatly by technology and vocation but in general 0.02 CNG/LPG < 0.2 CNG/LPG < 0.2 diesel
- NOx emissions higher in this study compare to publish HDIUT average (~0.37 g/hp-hr)
- Vehicles in this study has low speeds (~15 mph for school bus and GM and ~10 mph for other vocations) and high idle (2%-68%)



Final Chassis Test Cycle Matrix

New for this study

Test Cycle	Average Speed, mph	Vocation
UDDS	18.9	All
CARB HHDDT	39.9	Delivery, Goods Movement
Modified SCAQMD Refuse Cycle	9.57	Refuse
Goods Movement Cycle (GMC)	20.1	Goods Movement
School Bus Cycle	12.3	School Bus
Delivery Cycle	17.4	Delivery
CBD	12.6	Transit Bus
OCTA	12.4	Transit Bus

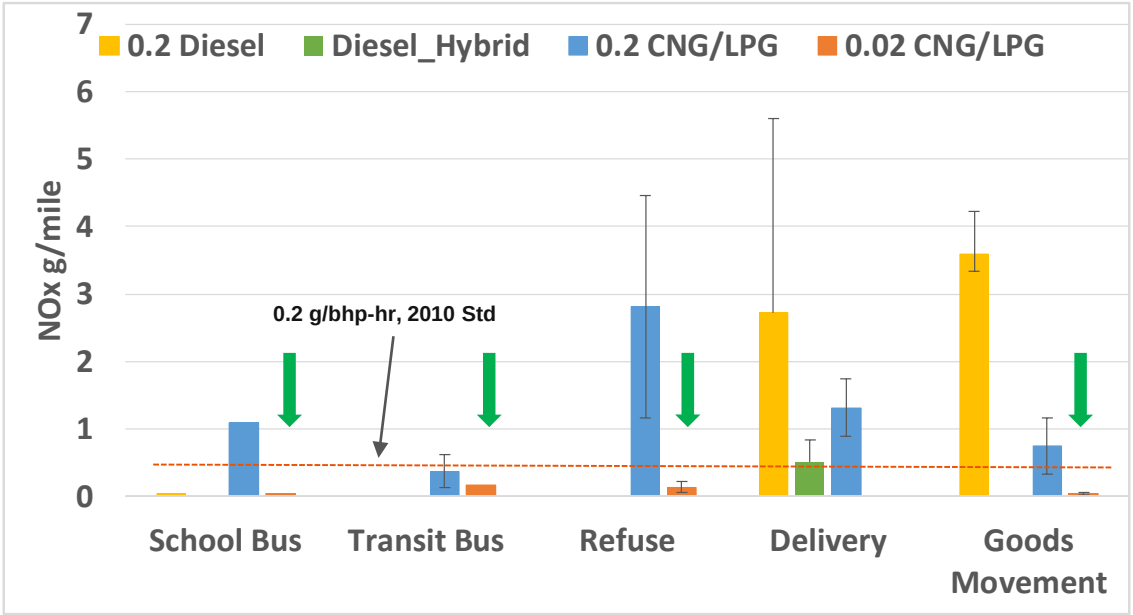


EMFAC2017 Example for NOx vs. Average Cycle Speed (Speed Correction Factor)

Source: EMFAC2017 Volume III –Technical Documentation

Preliminary Findings – Chassis – UDDS

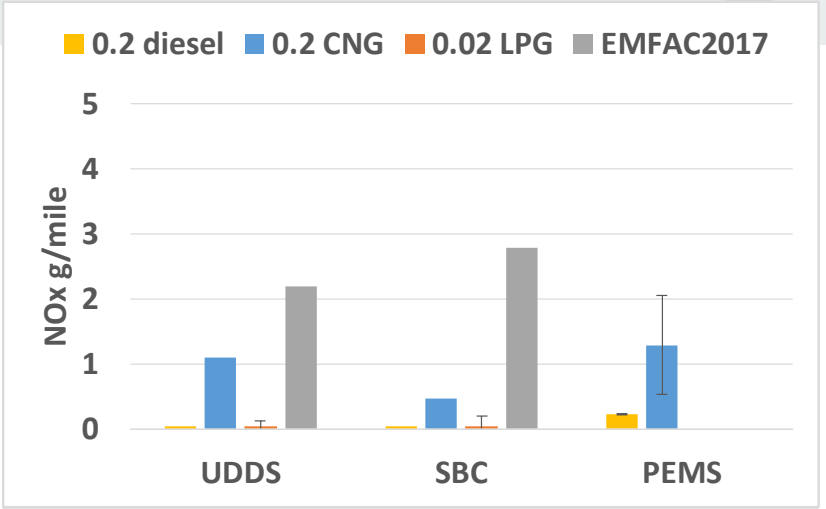
- UDDS used for EMFAC Base Emission Rate (BER) g/mile
- Pre-2010 diesel, RD removed for this comparison
- 37 datasets included
- 0.2 CNG/LPG 50%-80% lower compare to 0.2 diesel baseline
- 0.02 CNG/LPG 55%-95% lower than 0.2 CNG, more data coming
- Diesel-hybrid 80% lower than diesel baseline

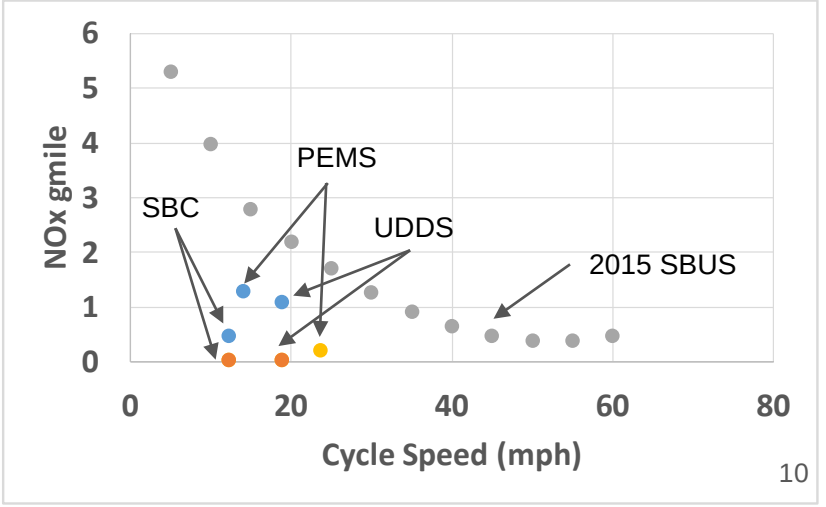


Source: UCR&WVU interim report to SCAQMD

Preliminary Findings – Chassis – School Bus

- Particular type of diesel school bus (3) showed very low emissions for PEMS (2) and Chassis (1)
- Chassis data inline with PEMS
- 0.02 Propane bus 90%+ lower than 0.2 bus, one additional 0.02 planned for chassis and PEMS
- EMFAC 2017 NOx rates higher compare to all vehicles tested in this study

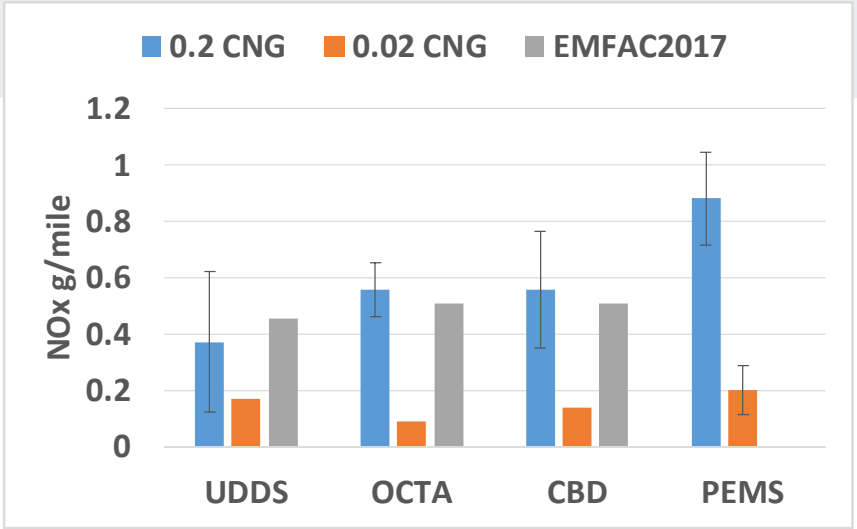


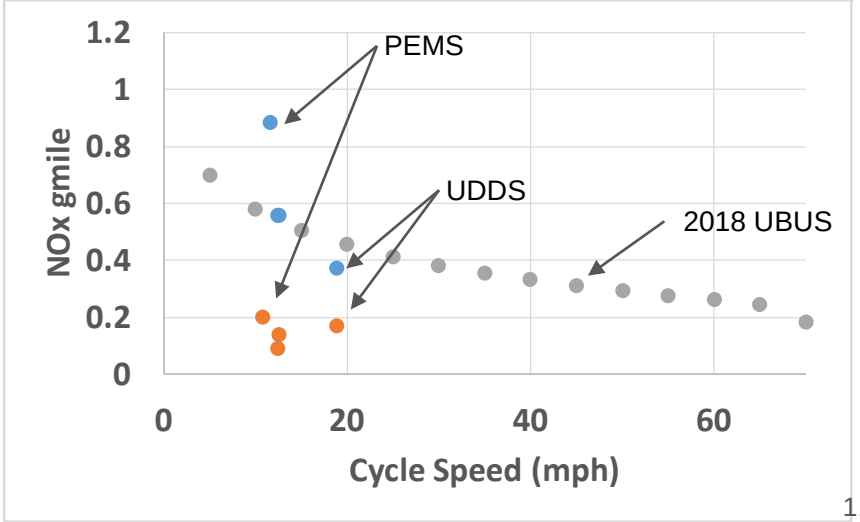


Source: UCR & WVU interim report to SCAQMD, EMFAC 2017

Preliminary Findings – Chassis – Transit Bus

- 0.02 not quite achieve 90% benefit on UDDS
- 75%-85% benefit on other cycles
- More 0.02 data processing
- EMFAC 2017 NOx rates similar to 0.2 but high compare to 0.02
- Battery electric and fuel cell buses planned for chassis

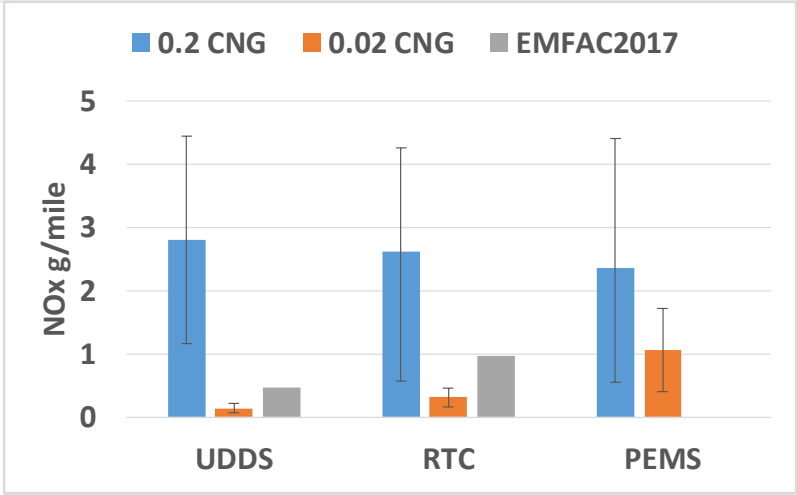


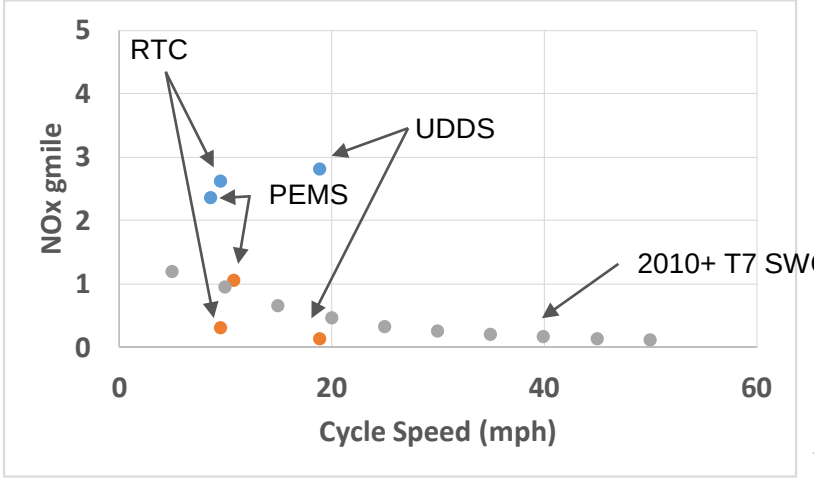


Source: UCR & WVU interim report to SCAQMD, EMFAC 2017

Preliminary Findings – Chassis - Refuse

- Refuse higher emissions compare to other vocations due to nature of refuse duty cycle
- Chassis data inline with PEMS
- 0.02 90%+ lower in chassis cycles but less benefit in PEMS (high variability)
- EMFAC 2017 NOx rates low compare to vehicles in this study

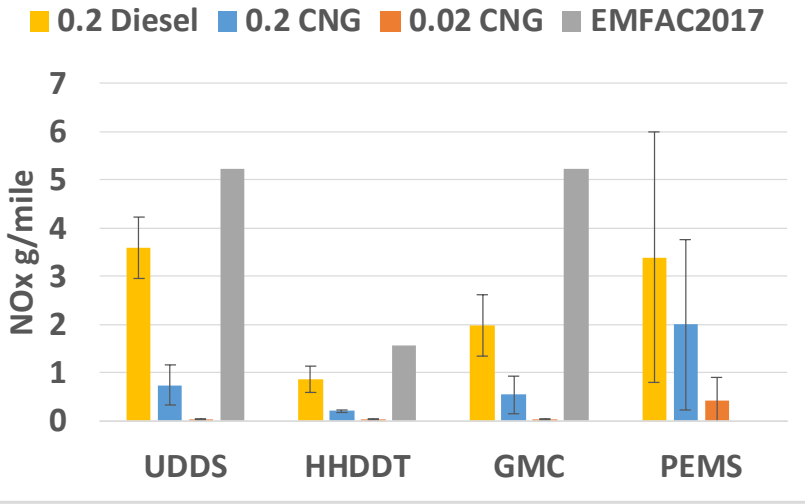


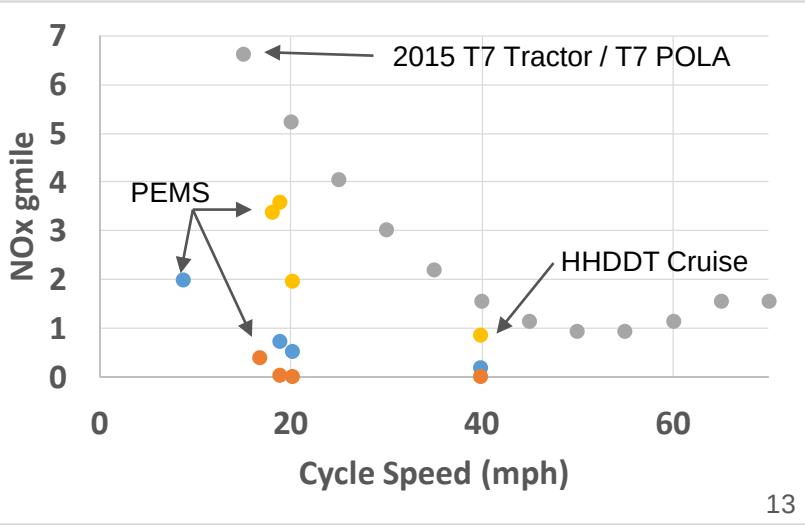


Source: UCR & WVU interim report to SCAQMD, EMFAC 2017

Preliminary Findings – Chassis - GM

- Low steady state cruise emissions for all technologies
- Lower emissions on GMC vs UDDS
- 0.2 CNG 75%+ lower, 0.02 CNG 99% lower, 95% lower compare to 0.2 CNG
- PEMS 0.02 CNG ~90% lower
- EMFAC close on diesel but high for 0.2 and 0.02 CNGs

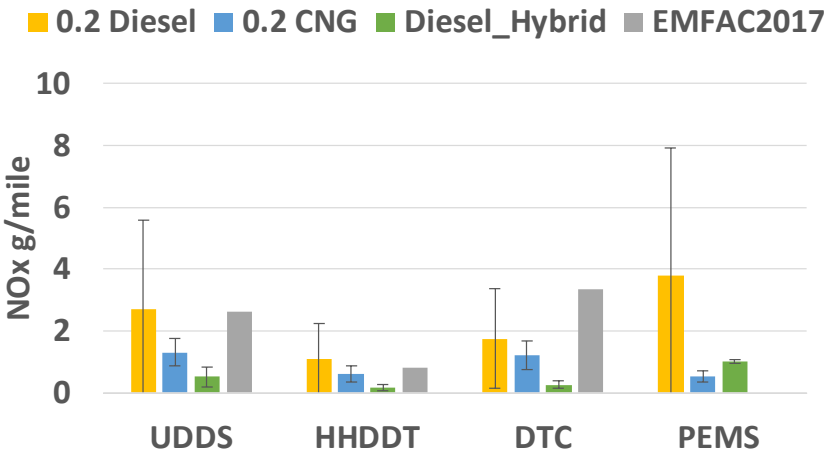


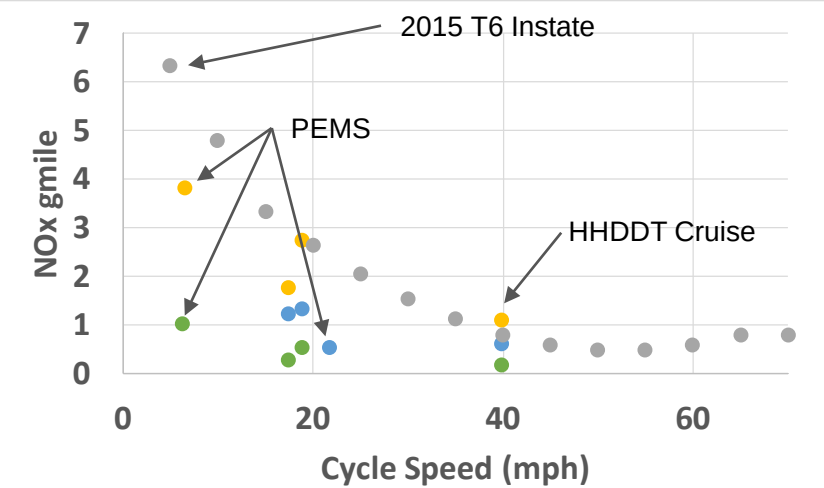


Source: UCR&WVU interim report to SCAQMD

Preliminary Findings – Chassis - Delivery

- Delivery category highest 0.2 diesel emissions and variability
- Diesel electric similar or lower emissions compare to diesel and 0.2 CNG
- 0.2 & 0.02 CNGs below EMFAC
- Diesel comparable to EMFAC

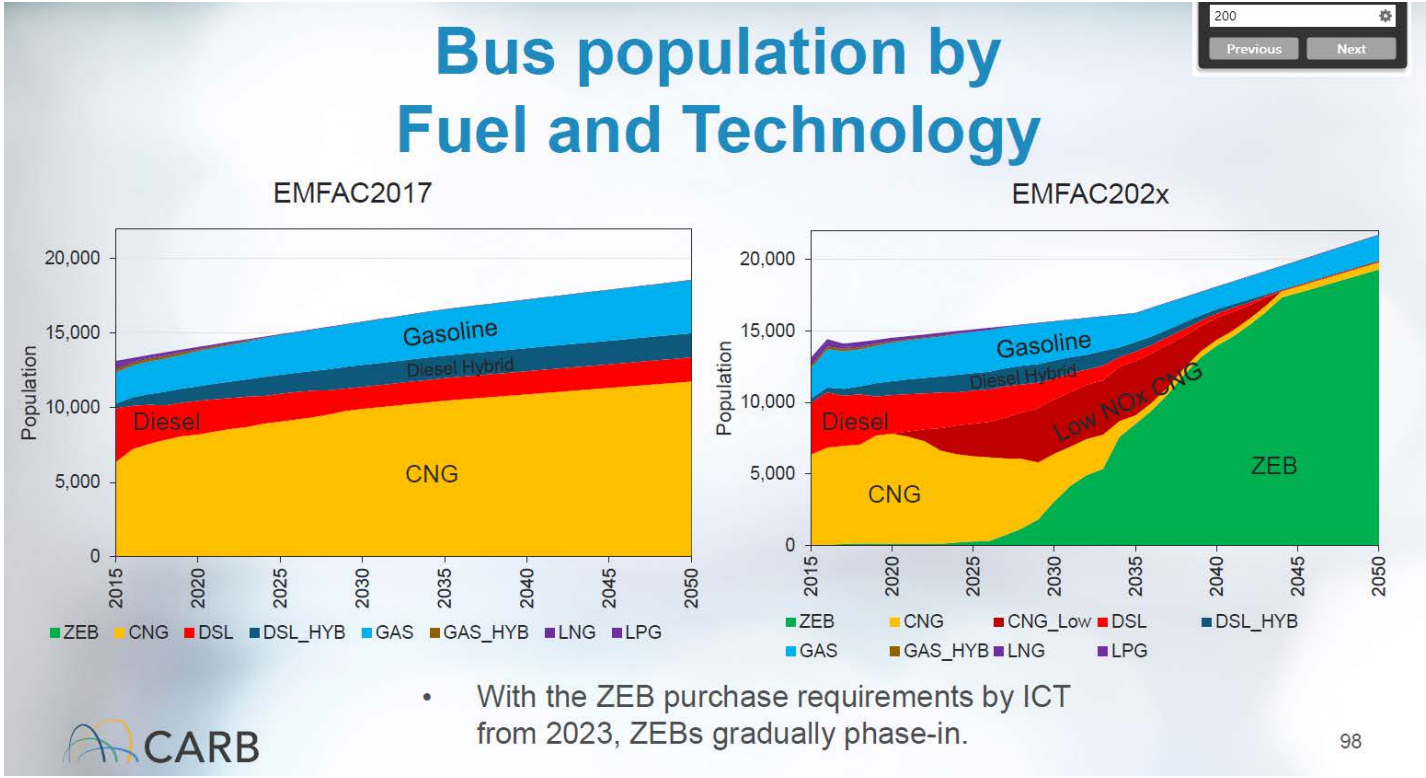




Source: UCR & WVU interim report to SCAQMD

Regulation Drives Future Emissions Inventory

- ZE rule like ICT will dramatically impact future technology make up
- Lower NOx rule Ominibus and EPA CTI will dramatically change 2024+ baseline emissions factors and SCF



Source: CARB EMFAC 202x Workshop

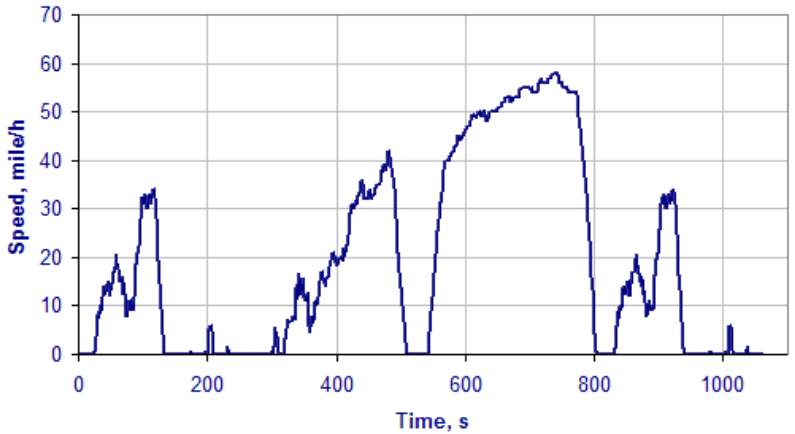
Team

Contractors: WVU, UCR/CE-CERT

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

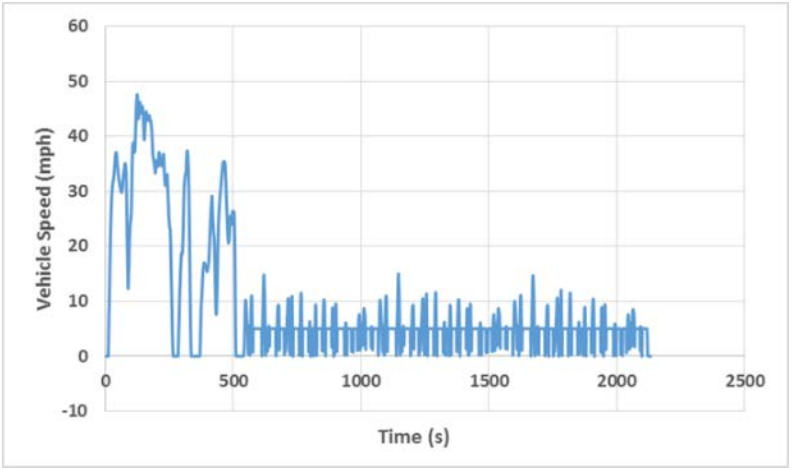

South Coast
AQMD
Thank you.

HD-UDDS Cycle



-Ave. Speed: 18.86 mph / 30.4 km/h
-Max. Speed: 58 mph / 93.3 km/h

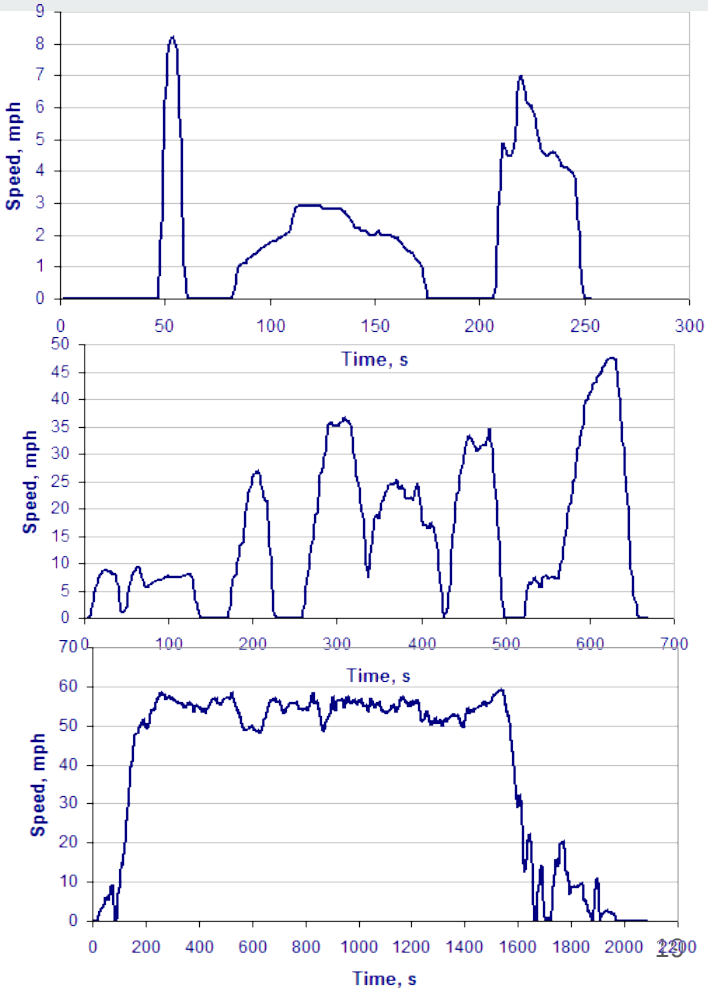
AQMD RTC Cycle

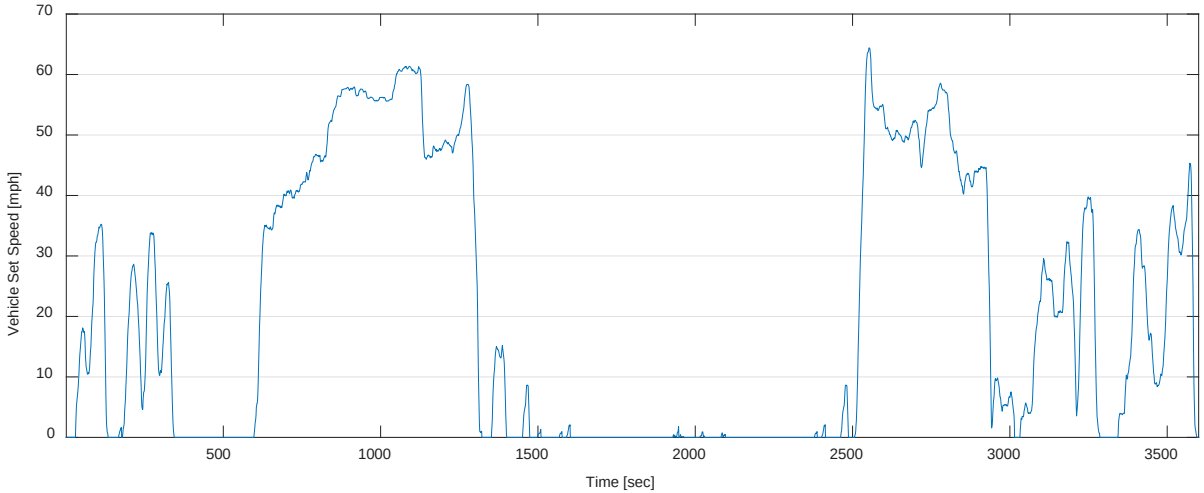


-Ave. Speed: 9.57 mph
-Max. Speed: 47.6mph

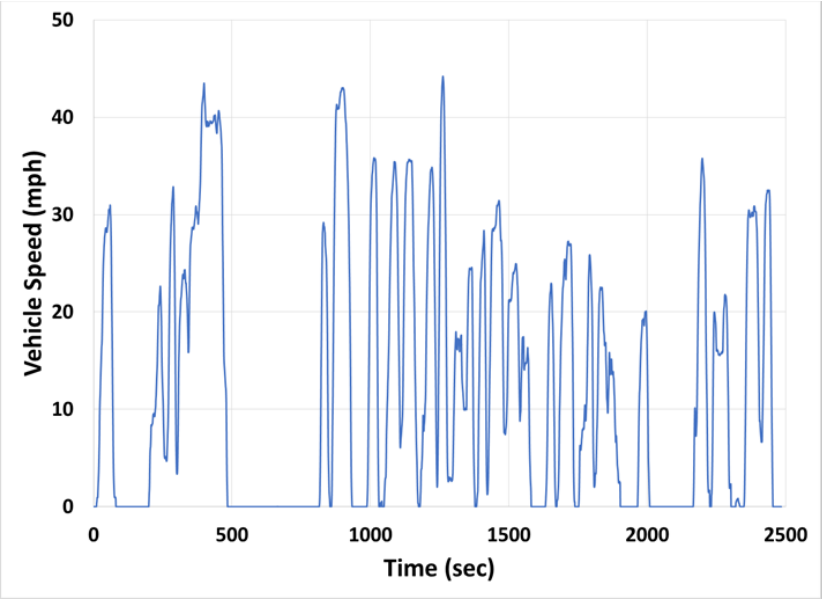
HHDDT Cycle

Parameter	HHDDT Creep	HHDDT Transient	HHDDT Cruise	UDDS
Duration, s	253	668	2083	1063
Distance, mi	0.124	2.85	23.1	5.55
Average Speed, mph	1.77	15.4	39.9	18.8
Stops/Mile	24.17	1.8	0.26	2.52
Max. Speed, mph	8.24	47.5	59.3	58
Max. Acceleration, mph/s	2.3	3.0	2.3	4.4
Max. Deceleration, mph/s	-2.53	-2.8	-2.5	-4.6
Total KE, mph^2	3.66	207.6	1036	373.4
Percent Idle	42.29	16.3	8.0	33.4

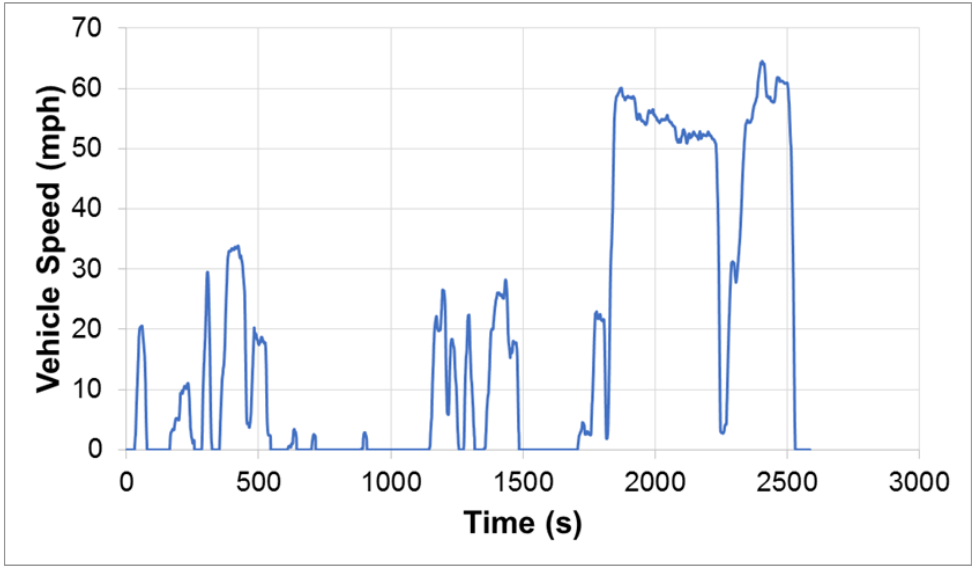




Cycle	GMC
Cycle duration [sec]	3600
Cycle distance [miles]	20.1
Avg. vehicle speed [mi/h]	20.1
Max. vehicle speed [mi/h]	64.1
Avg. RPA [1)] [m/s^2]	0.1054
Share [%] (time based)	
- idling (≤2 km/h)	42.18
- low speed (>2≤50 km/h)	22.97
- medium speed (>50≤90 km/h)	14.33
- high speed (>90 km/h)	20.52



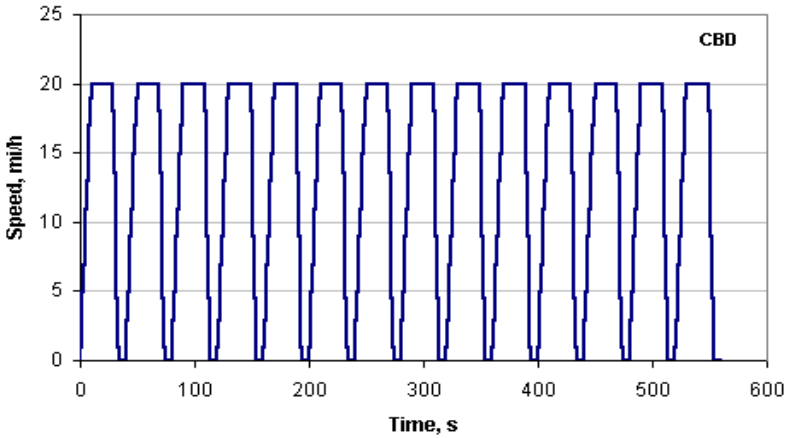
School bus cycle
Ave. Speed: 12.3 mph / 19.68km/h
Max. Speed: 45 mph / 72 km/h



Delivery cycle
Ave. Speed: 17.4 mph / 27.84km/h
Max. Speed: 64 mph / 102.4 km/h

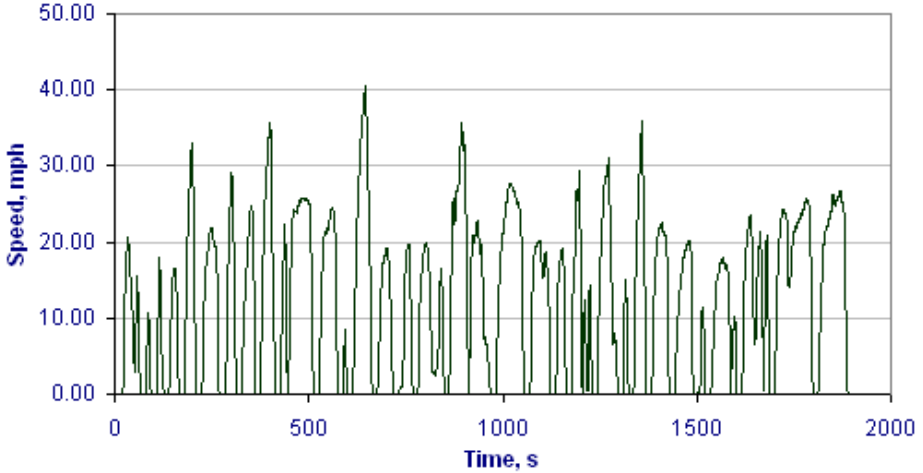
Test Cycles

CBD cycle



-Ave. Speed: 12.6 mph / 20.2 km/h
-Max. Speed: 20 mph / 32.18 km/h

OCTA cycle



-Ave. Speed: 12.4 mph / 19.8 km/h
-Max. Speed: 40.6 mph / 64.9 km/h

Lower Emissions Heavy-Duty Engines

Near Zero Technologies Update

CARB Omnibus Rule Making & EPA Clean Truck Initiative

- Significantly Lower the NOx standard: “0.02 g/bhp-hr” in CA.
- Require Low Load NOx control (including via Low Load Cycle)
- Adopt an In-Use Compliance metric spanning actual usage duty cycles (similar to Euro moving average window method)
- Increase Warranty and Useful Life definitions to reflect usage
- Improve initial Durability Demonstration procedures
- EPA is proposing a lower emissions rule change for 2021 which will set a new national low NOx standard

SwRI Heavy-Duty Low NOx Diesel Program

- Supported by CARB, SCAQMD, US EPA, MECA, and the Ports
- Developed low-load cycles for heavy-duty vehicles
- Lowered emissions effectively throughout useful life of the after treatment up to 450,000 miles in real world Test cycles on Dyno comparable to the SCAB
- Successfully demonstrated technologies that can lower NOx emissions from a heavy-duty diesel engine to near-zero
- Technologies such as Cylinder Deactivation and Heated Dosing were proven to keep the exhaust temperatures up throughout the duty cycle
- Technology transfer currently to off-road program

Cummins X15 Engine

Low NO_X Aftertreatment System

Upstream SCR

Downstream System

Eaton Cylinder Deactivation (CDA) Hardware

Results

EPA AT I De-greened System

NO_X and CO_2 Emissions Performance – Final Values

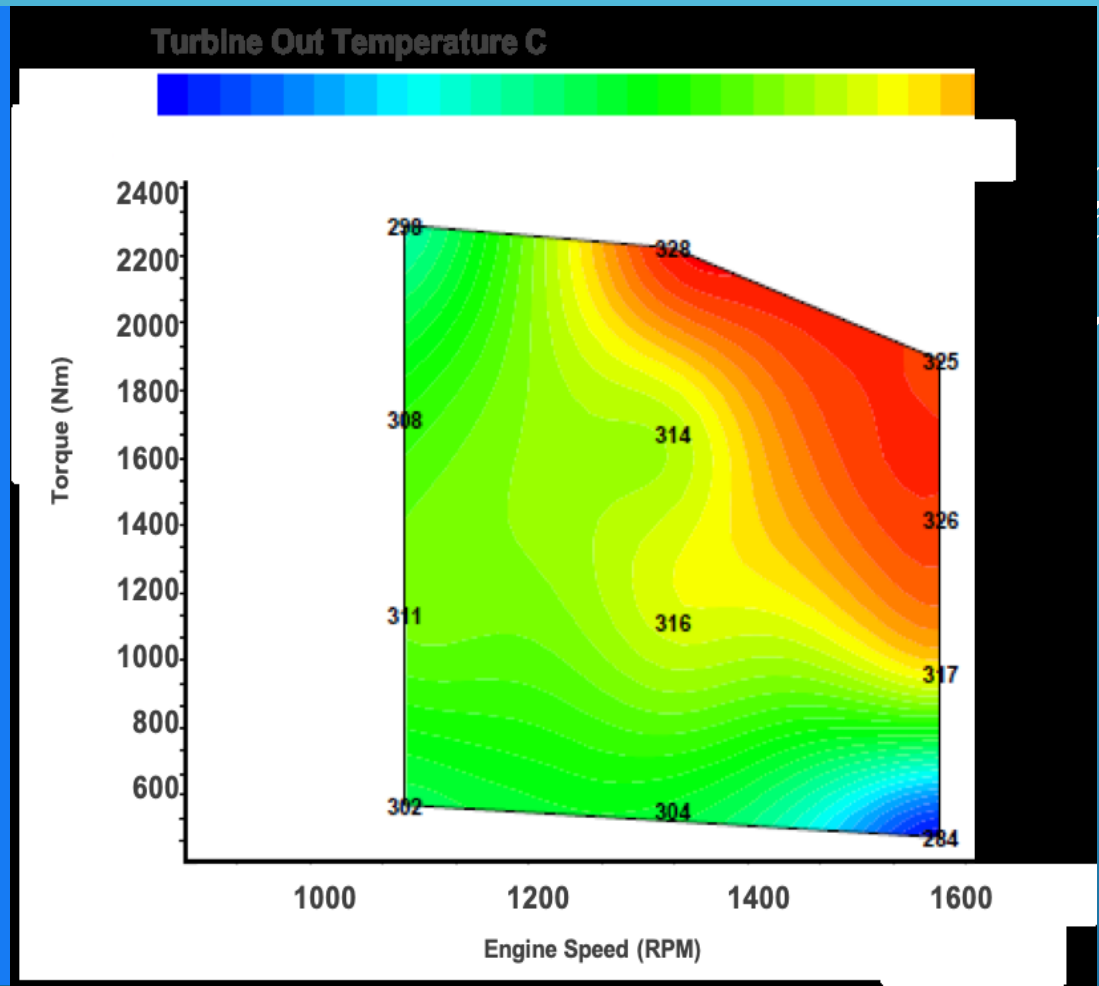
Cycle	NO_X, g/hp-hr		NO_X Conversion	CO_2	
	EO	TP		g/hp-hr	Δ from base
Cold-FTP	2.6	0.049	98.3%	541	+2.1%
Hot-FTP	3.1	0.008	99.7%	513	+0.6%
Composite FTP	**3.0**	**0.013**	**99.6%**	**517**	**+0.8%**
RMC-2021	**3.5**	**0.009**	**99.7%**	**463**	**~ +1.5%[1]**
LLC	**2.4**	**0.013**	**99.5%**	**621**	**+2.0%**
RMC-2010	*3.5*	*0.015*	*99.6%*	*467*	*~ +1.5%[2]*

[1] RMC 2021 not run Baseline engine, assumed to be ~ 1% better than 2010 at 455
[2] RMC 2010 Baseline ~ 460

- Data is average of triplicate runs (except RMC-2010…)
- Note that hot start tuning indicates 0.012 g/hp-hr at CO_2 507 g/hp-hr (- 1%) possible, but final tuned values chosen above to provide durability margin on tailpipe NO_X

Achates OP Engine

- Development continuing along with emissions testing
- Main bearing cap failure was discovered and a root cause analysis showed a hardness problem in the steel. A new supplier has been selected
- Close coupled catalyst no longer needed due to engine operating efficiency
- Demonstration by Walmart scheduled



Clean Trucks Programs

- Near-zero NOX CNG drayage truck replacement program on-going
- Market Acceleration 30 trucks in process
- Trade down program beginning.
- 2008, 2010, and other high mileage diesel trucks scrapped

Looking Forward

- CNG efficiency and near-zero emissions technology
- Low Nox target set at 0.01 g/bhp-hr
- Landi Renzo 7.3-liter near zero CNG engine in final stages of testing
- Diesel engine components which keep AT temperatures up are on-going - Components include heated dosing and electric catalyst heaters
- Renewable diesel testing near completion at UCR
- On road demonstration of a near-zero NOx heavy duty diesel powered class 8 truck

Zero Emission Cargo Transportation

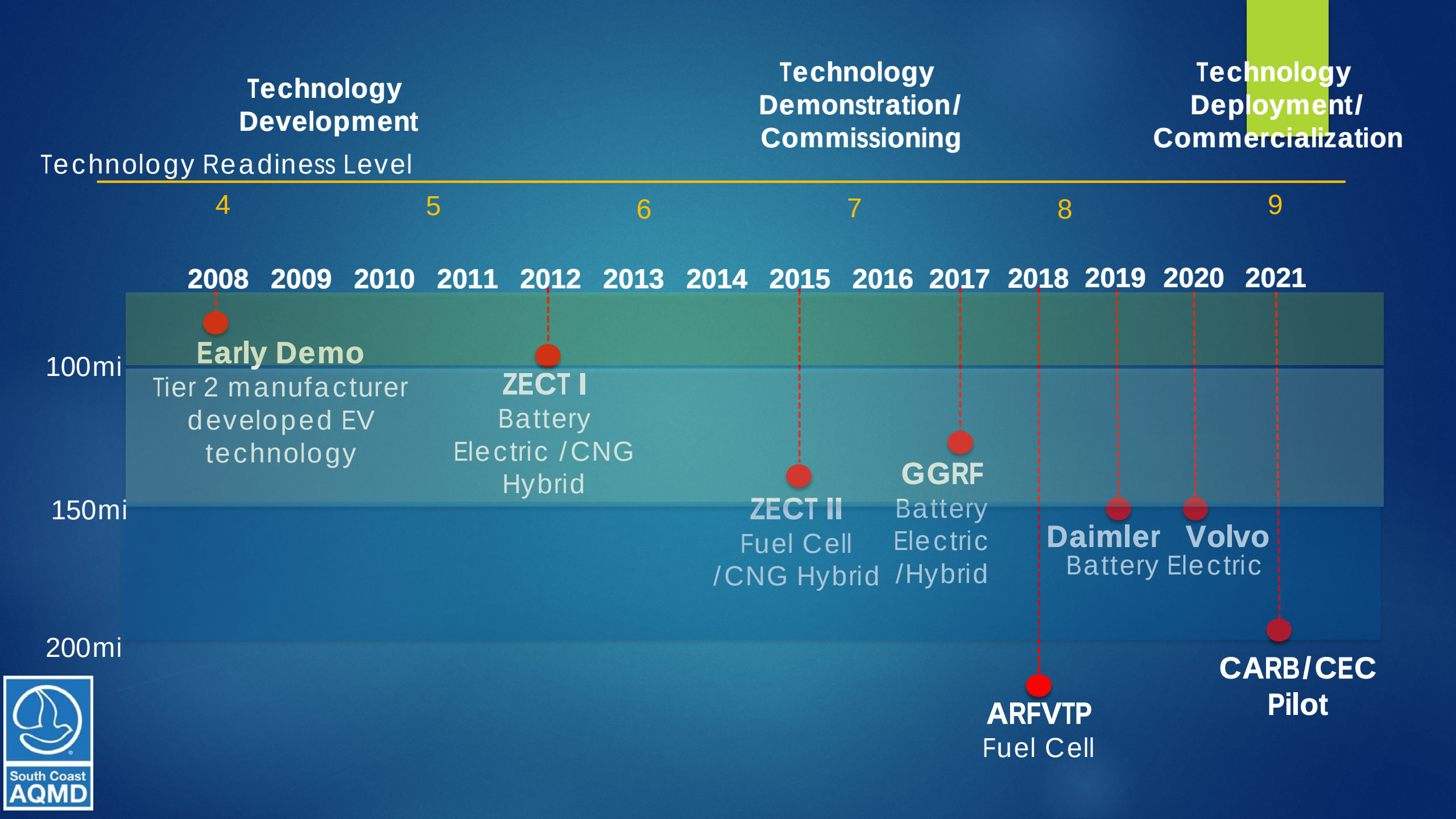
ZECT 1 and ZECT 2

Clean Fuels Advisory Meeting

South Coast Air Quality Management District
February 2, 2021

Phil Barroca
Program Supervisor, Technology Demonstration
Technology Advancement Office

South Coast AQMD


Technology Development
Technology Demonstration/ Commissioning
Technology Deployment/ Commercialization
Technology Readiness Level
4
5
6
7
8
9
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
100mi
150mi
200mi
Early Demo
Tier 2 manufacturer developed EV technology
ZECT I
Battery Electric /CNG Hybrid
ZECT II
Fuel Cell /CNG Hybrid
GGRF
Battery Electric /Hybrid
Daimler
Volvo
Battery Electric
ARFVTP
Fuel Cell
CARB/CEC Pilot
South Coast AQMD

ZECT Projects - Overview

- **Objective -** Develop zero-emission Class 8 On-Road technologies and demonstrate in goods movement activities at Ports and near-dock rail yards
- DOE-sponsored ZECT Projects: South Coast Air Basin and Houston, TX
- **ZECT Projects in the SCAQMD**
  - **ZECT 1** Battery Electric and Plug-In Hybrid Electric (replaced Fuel Cell projects)
  - **ZECT 2** Battery Electric, Fuel Cell, and Plug-In Hybrid Electric

South Coast AQMD

ZECT 1 Projects - Overview

- **ZECT 1 – Awarded: 2012; Kickoff: 2012; Concluded: 2020**
  - Three technologies: Battery Electric and two Plug-in Hybrid Electric
  - Two technology integrators: TransPower and U.S. Hybrid
  - Data Analysis: NREL, UC Riverside
  - Fleet participation: Port drayage fleets
  - Funding:
    - DOE: $4,169,000
    - Match Share (Contractor/SCAQMD): $8.48 million / $688k
    - Project Cost: $13.3 million (final)

South Coast AQMD

ZECT 2 Projects - Overview

- **ZECT 2 – Awarded: 2014; Kickoff: 2015; Concludes 2021**
  - Three Technologies: Fuel Cell, Battery Electric with Fuel Cell, Battery Electric with near-zero-emission CNG
  - Four technology integrators: TransPower, U.S. Hybrid, Hydrogenics, BAE
  - Data Analysis: NREL
  - Fleet Participation: Drayage fleets, Kenworth Trucks
  - Funding:
    - DOE: $10,000,000
    - Match Share: $7,183,979
    - Contractors: $3,075,841
    - Total Cost: $20,259,820

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ZECT 1 Review

TransPower

US Hybrid

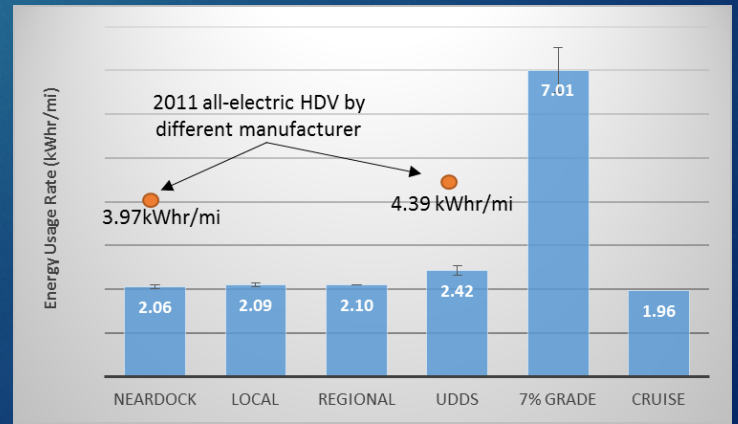
ZECT 1 - Specifications

	BET		PHET	
Developer	TransPower	US Hybrid	TransPower	US Hybrid
No. of Trucks	4	2	2 Series Hybrid	3 Parallel Hybrid
Chassis	International Prostar	International Prostar	International Prostar	Peterbilt 384
Traction	Dual IPM Motors	Induction Motor	Dual IPM Motors	IPM Motor
Motor/Power	300 kW	320 kW	300 kW	222 kW (402 kW total)
Transmission	Automated Manual	Direct Drive	Automated Manual	Automatic
APU Displ./Fuel	N/A	N/A	3.7L / CNG	8.9L / LNG
APU Power, kW	N/A	N/A	65-110	180
Battery/Fuel Storage Capacity (kWh/DGE)	215 - 311	240	138 / 60 DGE	80 / 72 DGE
Charger On-Board, kW	70	60	70	20
Recharge/Refuel Time. hrs	2.5 - 4	3 - 4	2 / 10-15 min	3 - 4 / 10-15 min
Drayage Range (miles)	75-100 (@215 kWh) / 110-150 (@ 315 kWh)	70-100	250+ / 35-50 AER	250+ / 30 AER

South Coast AQMD

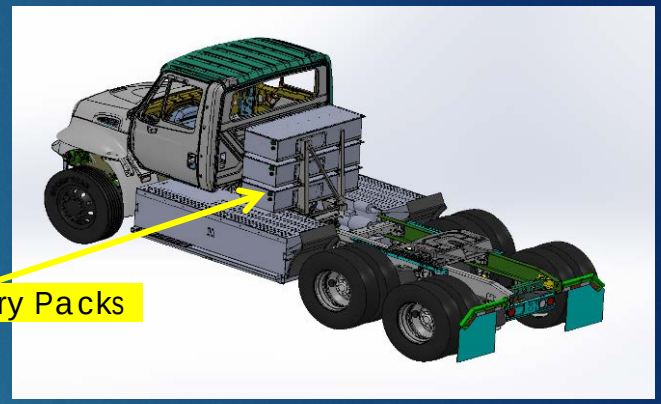
TransPower BET

- Four Electric Drayage Demonstration (EDD) trucks built, EDDs 1 – 4
- Achieved higher reliability than previous generation of Class 8 BETs
- Zero emissions and higher energy efficiency
- Driver's responses:
  - performance and quietness favorable
  - range and recharge time less favorable
- Cumulative Vehicle Performance Data (NREL)
  - 579 days; 2660 hrs; 25,786 miles; 44.6 miles/day (avg.)
  - 60-70 mile range full load, single charge
  - 2.32 kWh/mi average efficiency; 16.5 mi/DGE (calc.)
- After Project Life
  - Three EDD's upgraded with fuel cell range extender and NMC batteries



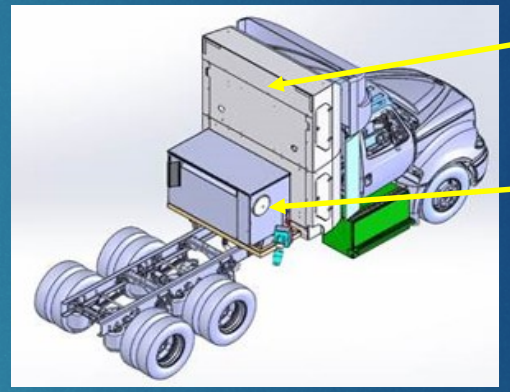
US Hybrid BET

- Two BETs in Project
- First BET Q2 2016 - LFP battery; 300 kWh ; 11 packs in parallel
- Performed pre deployment chassis dyno testing at UCR Q1 2017
- 48 days & 412 hrs. of operation
- 1,479 miles of usage
- 2.43 kWh/mi average efficiency
- Second BET Q2 2020 NMC battery; 300 kWh ; 6 packs in parallel
  - 30% higher energy density
  - 600V operation



TransPower Series PHET

- Series Hybrid architecture based on EDD drive train
- APU: 3.7L Ford SI; CNG; 62 – 110 kW
- Hybrid system optimized with APU dynamometer
- Lessons Learned
  - 80-120 kW from APU
  - Engine codes for efficiency and emissions
  - Rear mounted APU reduces cooling efficiency
- First PHET Q3 2018 – Q2 2019
- Second PHET Q2 2020 upgraded NMC batteries

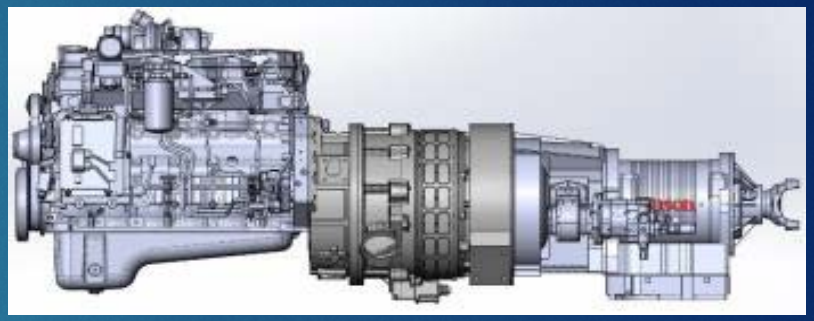


US Hybrid PHET

- Three PHETs in Project
- APU: 8.9L Cummins ISL-G
- PHET tested at UC Riverside chassis dynamometer
- Design/Performance
  - Power and Torque comparable to ISX12 or ISX15
  - 30 miles AER (250 miles total range)
  - Positive Driver Feedback
- Hybrid Control Unit (HCH)
  - Seamless transition from All Electric to Hybrid
  - Senses load and battery charge level to engage ICE for motive and electrical power
  - Electric only during queuing and traffic
- 185 days; 7,167 miles of usage
- 4.29 kWh/mi average efficiency

US Hybrid

Cummins ISL-G



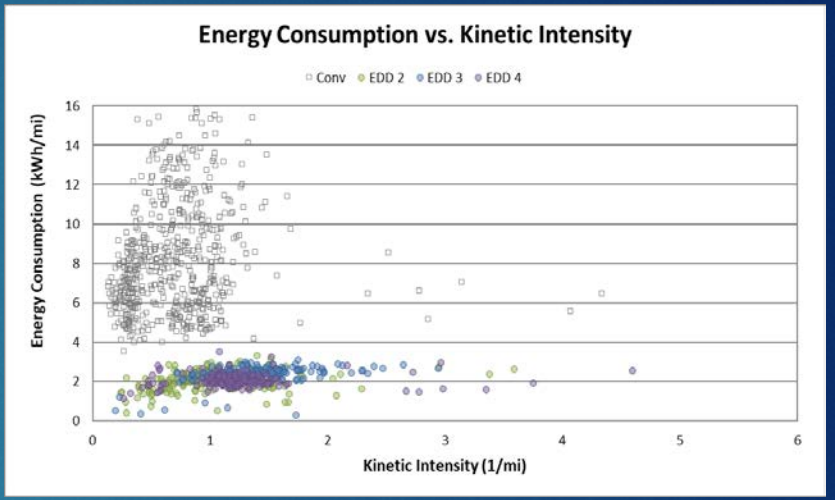
Engine-Auto-Clutch-Motors-Transmission

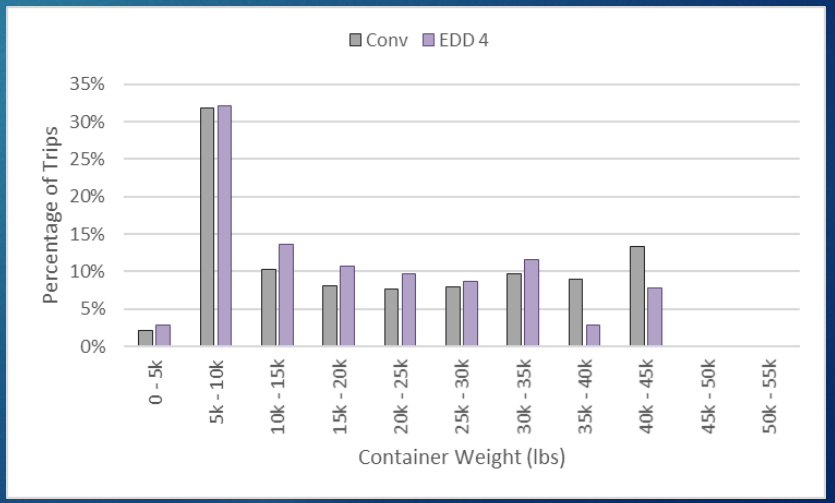
South Coast AQMD

NREL Data – Zero Emission Drayage Truck Evaluation (TransPower)

- Evaluated performance of 3 Electric Drayage Demonstration Trucks from TransPower team, accumulating more than 25,000 miles
- EDDs averaged 2.32 kWh/mi (16.46 mpDGE), ~3.5x more efficient than diesel baseline fleet
- Average daily VMT was ~44 mi; average daily SOC range was 91.5% (start) to 54.2% (end)

	EDD-2	EDD-3	EDD-4	all EDD	Conv.	units
Total recorded operation	201	171	197	569	615	days
Total distance	8,590	7,483	9,300	25,373	80,563	miles
Maximum daily distance	135.8	102.4	112.9	117.0	590.1	mi/day
Average daily distance	42.7	43.3	45.8	43.9	131.0	mi/day
Total operation time	933.7	870.2	0.0	601.3	6524.8	hours
Maximum daily operation time	10.2	10.2	11.4	10.6	24.8	hr/day
Average daily operation time	4.6	5.0	5.7	5.1	10.6	hr/day
Average idle time	2.6	2.9	3.2	2.9	2.8	hours
Average idle time > 5 min	1.5	1.6	1.7	1.6	1.1	hours
Average overall speed	10.3	9.3	8.8	9.4	13.9	mph
Average driving speed	21.0	19.8	18.4	19.7	26.4	mph
Average kinetic intensity	1.08	1.38	1.28	1.25	0.72	1/mi
Average start SOC	96.1	95.6	82.7	91.5	—	%
Average end SOC	59.8	50.5	52.3	54.2	—	%
Average charge time	11.5	5.9	11.3	9.6	—	hours
Average charge energy	93.93	116.05	94.60	101.52	—	kWh
Average motor efficiency	2.02	2.35	2.04	2.13	—	kWh/mi
Average overall efficiency	2.20	2.68	2.06	2.32	7.99	kWh/mi
Diesel equivalent fuel economy	17.12	14.03	18.23	16.46	4.71	mpdge

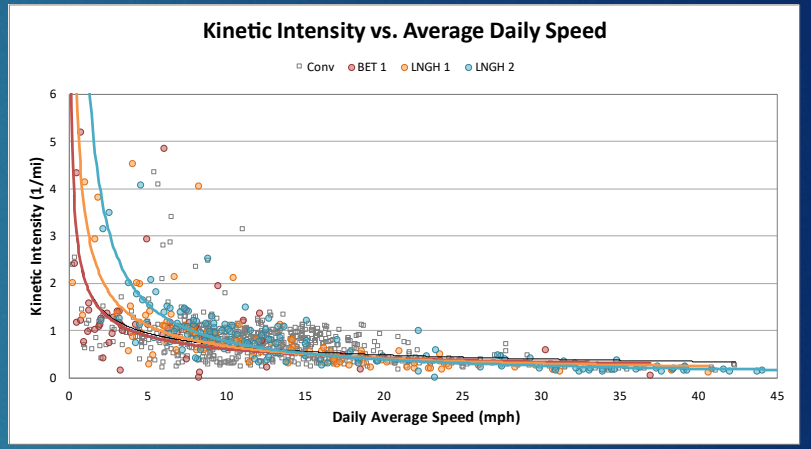


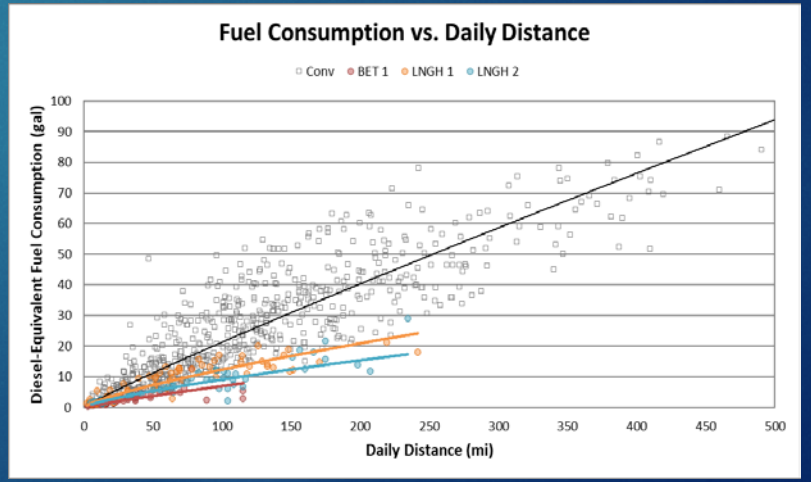


NREL Data – Zero Emission Drayage Truck Evaluation (US Hybrid)

- Evaluated performance of 2 PHETs and 1 BET from US Hybrid team, accumulating more than 13,800 miles and nearly 1,800 miles, respectively
- BET-1 averaged 2.43 kWh/mi (15.49 mpDGE), PHETs averaged 4.29 kWh/mi (8.97 mpDGE) compared to 4.71 mpDGE for diesel baseline fleet
- PHETs traveled ~53 miles/day and consumed ~9.7 gal/day LNG

	LNGH-1	LNGH-2	all LNGH	BET-1	Conv.	units
Total recorded operation	109	160	269	61	615	days
Total distance	6,830	7,011	13,841	1,798	80,563	miles
Maximum daily distance	241.7	234.6	238.1	115.5	590.1	mi/day
Average daily distance	62.7	43.8	53.2	29.5	131.0	mi/day
Total operation time	619.9	396.0	508.0	598.2	6524.8	hours
Maximum daily operation time	21.7	14.2	17.9	24.0	24.8	hr/day
Average daily operation time	5.7	2.5	4.1	9.8	10.6	hr/day
Average overall speed	11.0	17.7	14.4	3.0	13.9	mph
Average kinetic intensity	0.94	0.89	0.9	1.89	0.72	1/mi
Average charge time	—	—	—	2.6	—	hours
Average charge energy	—	—	—	71.65	—	kWh
Average motor efficiency	—	—	—	2.13	—	kWh/mi
Average overall efficiency	4.94	3.65	4.29	2.43	7.99	kWh/mi
Average daily LNG consumption	10.61	8.80	9.71	—	—	gal
Average LNG fuel economy	6.65	9.00	7.82	—	—	mpgge
Diesel equivalent fuel economy	7.62	10.31	8.97	15.49	4.71	mpdge





ZECT 2 Trucks

BAE SYSTEMS
INSPIRED WORK
KENWORTH
A PACCAR COMPANY

HYDROGENICS
SHIFT POWER | ENERGIZE YOUR WORLD

US Hybrid

South Coast AQMD

ZECT 2

- Four Integrators: TP, USH, Hydrogenics, BAE/Kenworth
- Three Technologies: Battery and Fuel Cell dominant Fuel Cell Trucks (FCT), Plug-in Series Hybrid Electric Near Zero Emission CNG
- Seven Trucks: 2 TP FCTs; 2 USH FCTs ; 1 BAE/Kenworth FCT; 1 Hydrogenics FCT; 1 BAE/Kenworth Series Hybrid with Near Zero-Emission CNG engine



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Hydrogen Infrastructure

- Hydrogen supplier: Air Products delivered and commissioned fueling stations at Kenworth test sites in Renton and Mt. Vernon, WA and demonstration site at Port of LA, San Pedro, CA

- Trailer mounted Hydrogen Station at Ports
  - Capacity - 300 kg
  - Fill Pressure - 350 bar

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ZECT 2 - Truck Specifications

	FUEL CELL TRUCKS				PHET/CNG
	BATTERY DOMINANT		FUEL CELL DOMINANT		
	TransPower	Hydrogenics (Cummins)	US Hybrid	BAE/Kenworth	
# of Vehicles	2	1	2	1	1
Platform	International	Freightliner	Kenworth T800	Kenworth T370	Kenworth T680
Mfg: Fuel Cell / APU	Hydrogenics	Hydrogenics	PureMotion	Ballard	CWI 8.9L
Fuel Cell Power, kW	**60**	**60**	**80**	**100**	n/a
Battery Capacity, kWh	125	100	26	100	100
Battery Chemistry	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion
Traction Motors	2x 150 kW	1x 320 kW	1x 320 kW	2x 180 kW	1x 320 kW
Range, mi (per fueling)	200	150	150-200	100	150
Fuel Cap.: H2 (kg)@350 bar / CNG (DGE)	27	30	20	30	45 DGE
Plug-in Charging	Yes	Yes	Yes	Yes	Yes

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Relevance: Goals & Objectives

2019/2020 Objectives

- Complete vehicle builds
- Operate portable hydrogen refueling for demonstration
- Continue vehicle demonstration and data collection & analysis

Results

- Six demonstration trucks including fuel cell range extended and CNG hybrid truck deployed
- Portable hydrogen fuel onsite is in operation
- Debugging and improvement while demonstrating by lessons-learned from the first demo trucks
- Vehicle performance data provided from demonstration trucks

Impact

- Pushing Zero Emission Technology and industry envelope by demonstrating first fleet of FCEV's in drayage service in California

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Demonstration Issues and Lessons Learned

Technical Issues: Development/Demonstration

- **Typical issues of a demonstration**
  - Blown fuses, damaged sensors
  - Data Upload Technical Difficulties

High
Moderate
Low

- **New technology specific improvement & issues**
  - Software Updates
  - Battery Disconnect Failures
  - Blown Internal Battery Fuses
  - Inconsistent Traction Motor Resolver
  - Transmission Shift Position Sensor
  - Fuel cell coolant contamination
  - Cooling system control for fuel cell stack
  - Leakage of Hydrogen tank valves

Deteriorated FC coolant reservoir cap

Inspection of Battery Fuses

Transmission Repair

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Lessons-Learned Development/Demonstration

- Positive feedbacks from drivers for drivability and performance, but reliability is an issue
- Supply base is not ready and suppliers do not have broad knowledge in applications
- Too many connections (HV, LV, CAN, Cooling) and routing design is integral to chassis layout
- Cooling (particularly for FC) is challenging
- Battery technology and management systems for heavy-duty vehicles are evolving and maturing
- Power electronics firmware needs to become more automated
- Design validation is required for single larger FC stack and modular multi-stack

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Data Analysis – Summary Table

Metric	Units	Baseline Conventional*	TransPower HEDD1	TransPower HEDD2	US Hybrid FC359	US Hybrid FC365	Kenworth ZECT
Date Range		2014-2015	11/3/2017 – 9/5/2019	10/24/2018 – 9/9/2019	5/6/2019 – 3/30/2020	5/8/2019 – 3/2/2020	6/13/2019 – 1/7/2020
Number of recorded vehicle days	#	557	152	94	106	31	29
Max daily distance	mi	—	106.5	126.9	122.7	28.0	123.3
Avg daily distance	mi	127.9	5.8	21.0	21.0	6.4	25.1
Avg operating time (key-on)	hr	10.1	10.0	5.8	2.0	0.7	3.4
Avg driving time	hr	4.5	0.3	1.1	0.9	0.3	1.2
Avg speed	mph	14	1.3	3.5	7.0	6.2	5.1
Avg driving speed (speed>0)	mph	26.5	10.6	14.4	17.8	14.1	12.3
Kinetic intensity	1/mi	0.64	1.4	0.8	1.6	2.7	2.4
Avg stops/day	#/day	124.9	14.2	62.9	50.0	17.4	86.8
Avg stops/mi	#/mile	1.38	24.6	18.1	13.5	17.7	—
Median stop duration	sec	40.8	346.7	39.2	9.5	27.4	8.3
Avg daily fuel use (H2)	kg	—	—	—	3.2	0.9	5.1
Avg daily fuel use (diesel equiv.)	gal	23.7	—	—	2.8	0.8	4.5
Avg fuel economy (diesel equiv.)	mi/gal	5.7	—	—	8.3	9.5	7.4
Avg fuel cell efficiency	%	—	—	—	53.3%	56.4%	52.3%

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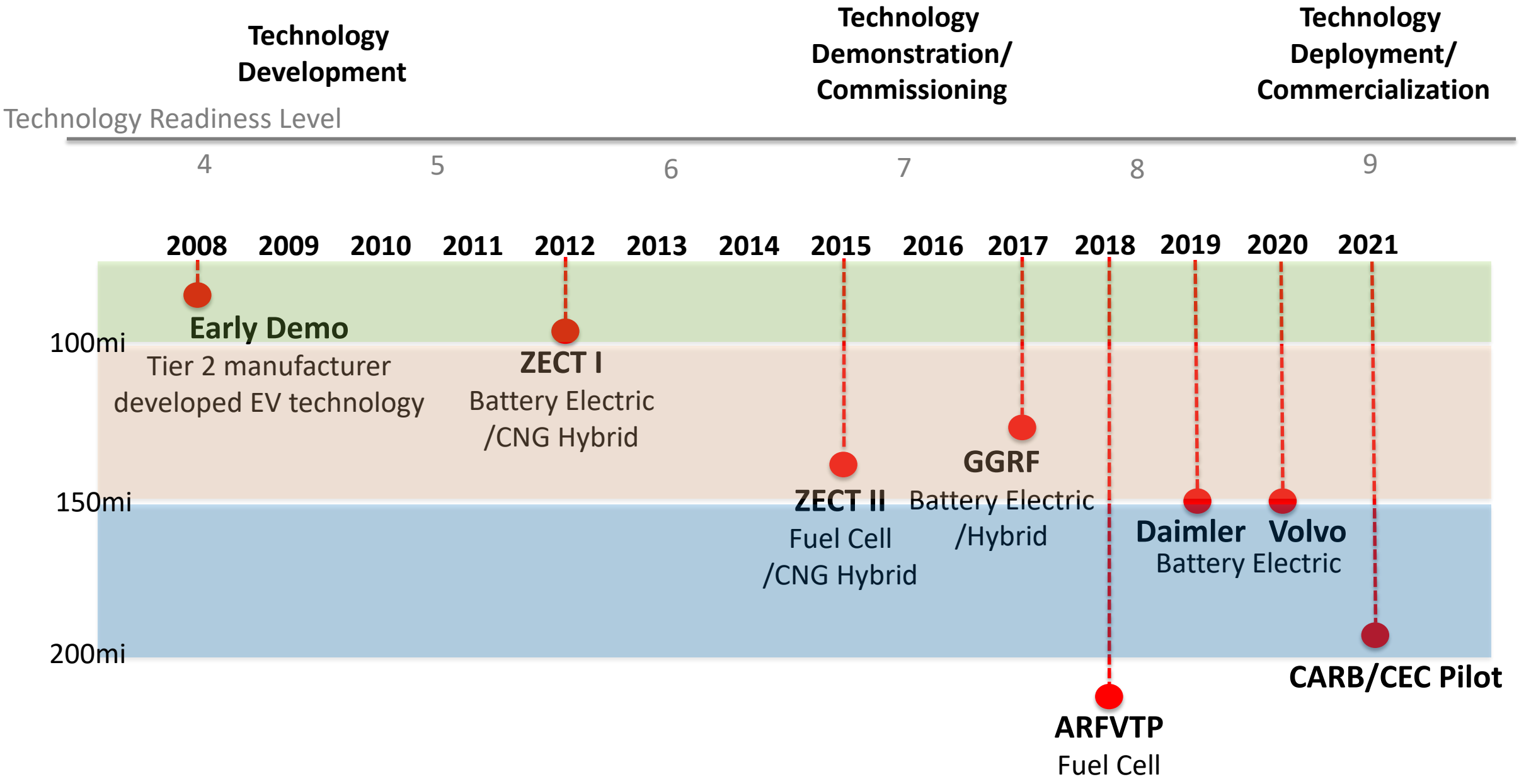
Questions

Progression of Zero Emission Truck Development

Technology Advancement Office
Program Supervisor

Seungbum Ha


Technology Development
Technology Demonstration/ Commissioning
Technology Deployment/ Commercialization
Technology Readiness Level
4
5
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9
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
100mi
150mi
200mi
Early Demo
Tier 2 manufacturer developed EV technology
ZECT I
Battery Electric /CNG Hybrid
ZECT II
Fuel Cell /CNG Hybrid
GGRF
Battery Electric /Hybrid
Daimler
Volvo
Battery Electric
CARB/CEC Pilot
ARFVTP
Fuel Cell

CARB GGRF Electric Truck Projects

- $23.6M Award from ARB, $10.4M State Air Districts, $6M In Kind – Total of $40.1M

- 44 pre-commercial Class 8 zero- and near-zero emission drayage trucks and infrastructure
  - 25 Battery Electrics - BYD
  - 12 Battery Electrics – Peterbilt

- In addition to the Battery electrics:
  - 4 CNG Hybrids - Kenworth
  - 3 Diesel Hybrids - Volvo

CARB GGRF Electric Truck Projects

- Take the legacy from previous demo project

ZECT I

	BET
Developer	**TransPower**
No. of Trucks	4
APU Displ./Fuel	N/A
APU Power	N/A
Battery/Fuel Storage Capacity	215 kWh
Charger On-Board	70 kW
Recharge/Refuel Time	2.5-4 hrs
Drayage Range (miles)	75-100 (@215 kWh)

GGRF Peterbilt BET

ZECT II

	PHET/ NZ-CNG	Fuel Cell
Developer	**BAE/Kenworth**	**Hydrogenics**
# of Vehicles	1	1
Fuel Cell Power	-	60kW
Battery Capacity	100 kWh	100kWh
Range (per fueling)	150 miles	150 miles
Plug-in Charging	Yes	Yes

GGRF KW PHEV

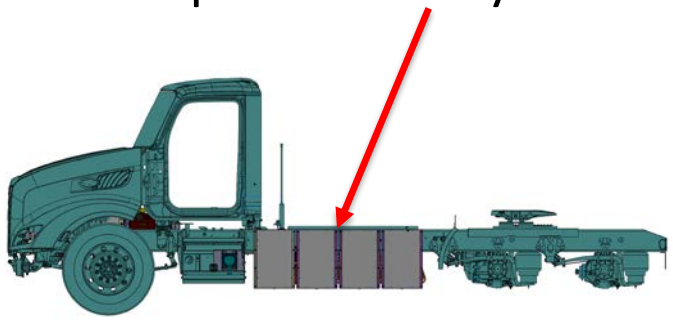
CEC ARFVTP Cummins FC

CARB GGRF Electric Truck Projects
- Peterbilt Electric Drayage Truck

- TransPower/Peterbilt to develop 12 BETs based on EDD drivetrain
- Total Capacity: NMC up to 352 kWh

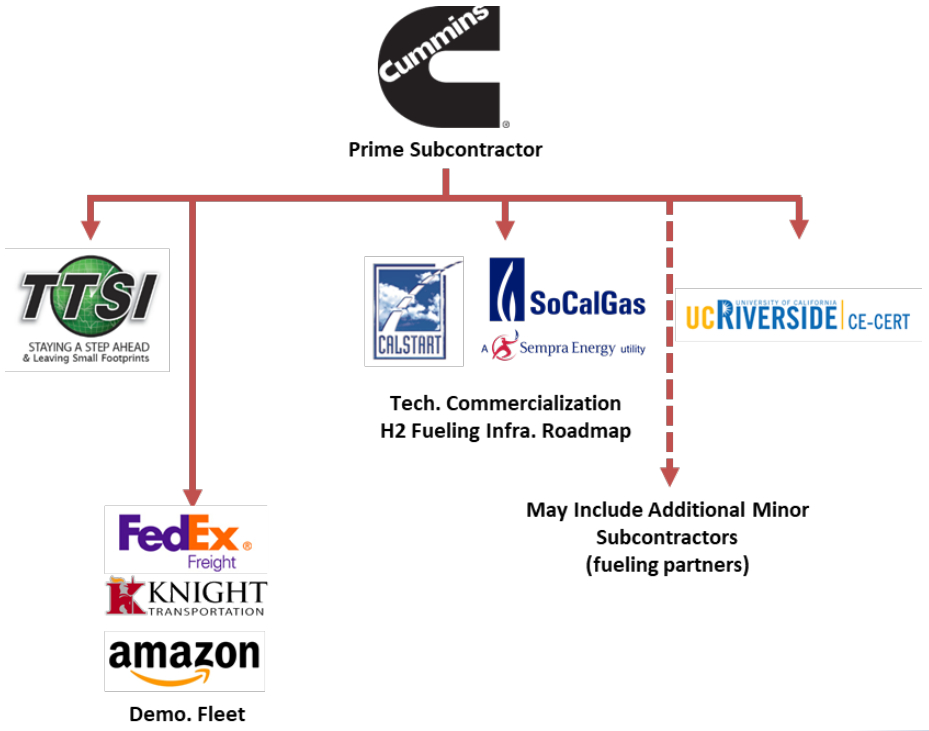
Truck#	Battery Capacity	Fleet
1	308	TTSI
2	264	LADWP/BAE
3	264	NFI
4	308	ESTES
5	264	So Cal Edison
6	264	PepsiCo
7	264	Biagi
8	264	Harris R.
9	308	AJR
10	352	Daylight
11	352	Werner
12	352	Oak H.

Up to 8 battery modules



CEC ARFVTP – Cummins Fuel Cell Drayage Truck

- In 2019, Cummins acquired EDI and Hydrogenics
- 4 Fuel Cell Class 8 drayage trucks (200+ mile ZE range)
- Complete and deliver vehicles in 2021 with 12 month demonstration



CEC ARFVTP – Cummins Fuel Cell Drayage Truck

- PEM fuel cells - commercial vehicle applications – long daily range needs
- Modular and scalable
- Plug-and-play design
- Fully integrated to pair with commercially available traction systems
- short and regional haul applications

MY2020 Kenworth T680 Day Cab
82,000 lbs. (Class 8)
Hydrogenics 2 x HyPM HD90 180 kW
Cummins Motor/Inverter w/ 4-speed Trans.
Agility 23.5 kg @ 350 bar
10-15 minutes
150-200 mi. depending on duty cycle
Pilot / pre-production. Commercialization planned in 2022-2023.

Daimler / Freightliner

- Heavy-Duty Battery Electric Trucks & Infrastructure

- 15 Class 8 - eCascadia DTNA (Portland, OR)
- 5 Class 6 - eM2 Agility/DTNA (Fontana, CA)
- Infrastructure
- 2.5 MW, 11 DC Fast Charge Locations
- 800 kWh Energy Storage System
- Demonstration/Outreach
- Penske and NFI
- Cost Sharing: $31MM
- DTNA, SCAQMD,POLA, POLB, EPA

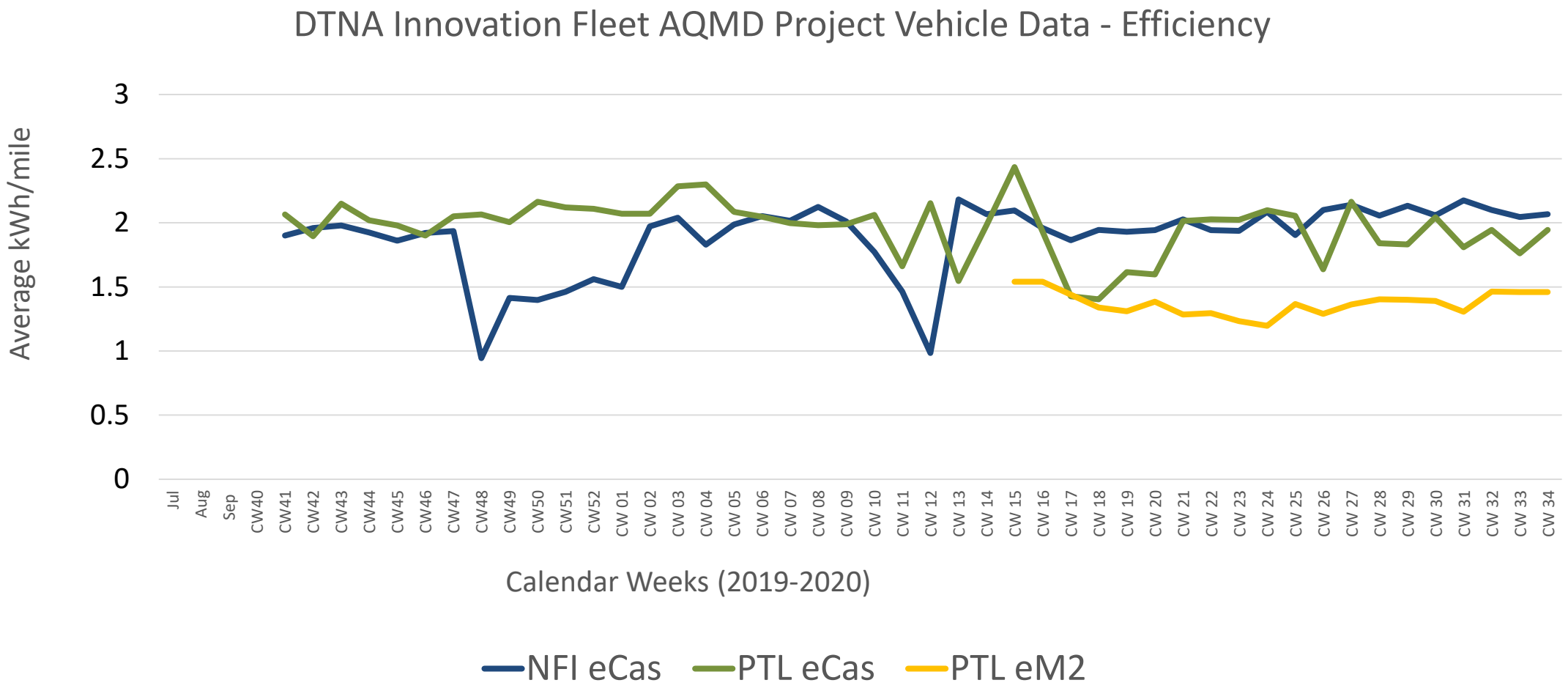
Daimler / Freightliner
- Heavy-Duty Battery Electric Trucks & Infrastructure

Metrics – eCascadia & eM2

- Total Miles Accrued all vehicles: ~ 300,000 miles thru August 2020
- eCascadia: 270,000 miles; 2.08 kWh/mile; 20-50,000-lbs
  - Penske:
    - 25,000 miles/mo. (avg.) ; 120 miles/day/vehicle ; 5.3 hrs/day operation
    - 48% SOC used per shift ; 3.3 hrs/day charging
  - NFI:
    - 15,000 miles/mo. (avg.) ; 160 miles/day/vehicle ; 6.7 hrs/day operation
    - 57% SOC used per shift ; 3.9 hrs/day charging
- eM2: 25,000 miles; 1.35 kWh/mile 8-13,0000lbs payload
  - Penske:
    - 5,000 miles/mo. (avg.) ; 80 miles/day/vehicle ; 9.4 hrs/day
    - 67% SOC used per shift ; 2.3 hrs/day charging

Daimler / Freightliner

- Heavy-Duty Battery Electric Trucks & Infrastructure



Daimler / Freightliner

- Heavy-Duty Battery Electric Trucks & Infrastructure

EV Infrastructure

- 150 kW, 62.5 kW, 50 kW
- 11 Locations, 21 DC Fast-Chargers
- 2550 kW install
- Energy Storage System – Ontario
  - 300 kW Power
  - 800 kWh storage
  - Simulating Utility rates with Demand periods

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

Volvo LIGHTS

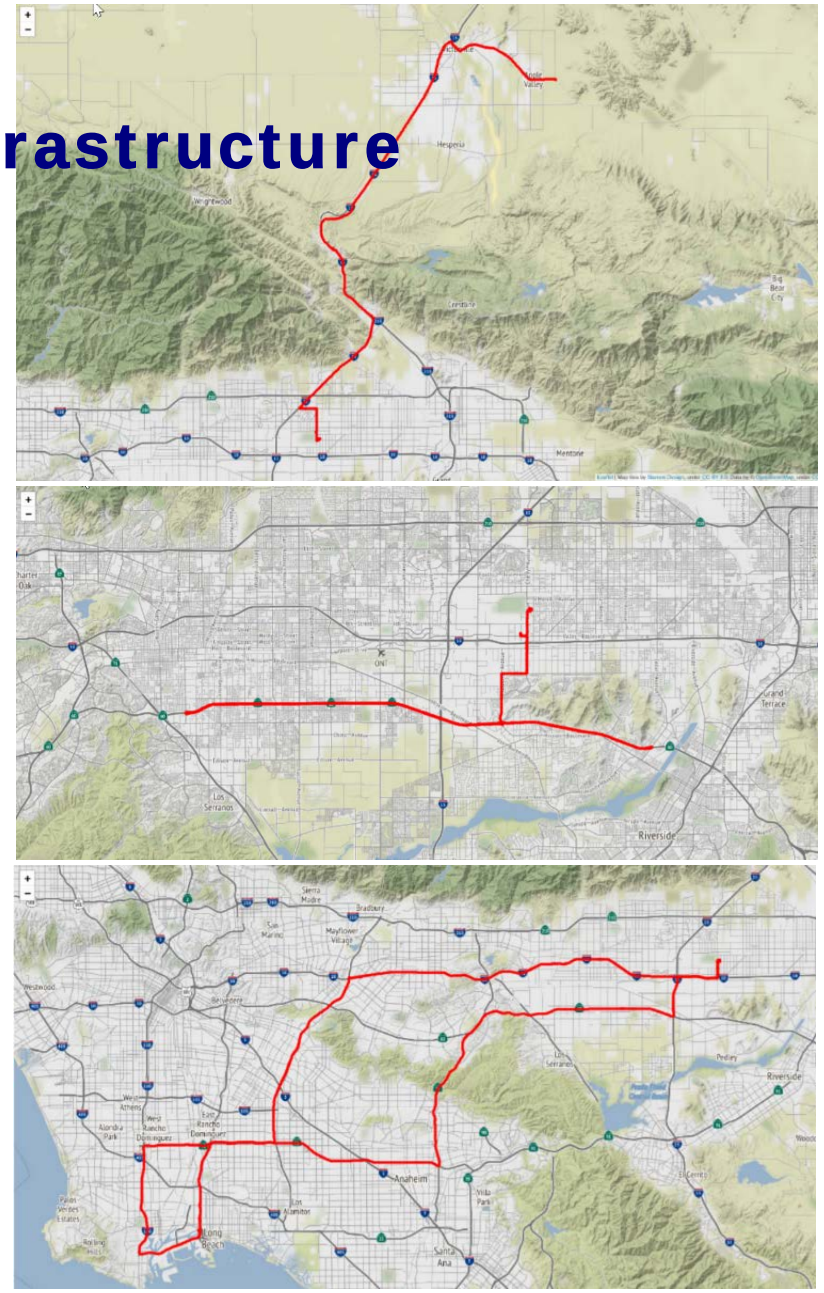
- Heavy-Duty Battery Electric Trucks & Infrastructure

- 5 Trucks under operation (TEC, NFI, DHE)
- Chargers installed at fleets, SCE Charge Ready Transport
  - 7.2 kW, 15 kW for EVs, forklifts
  - 22 kW AC, 50 kW DCFC for yard tractors
  - 150 kW DCFC for trucks
- Solar installed at DHE
- Completed additional 15 trucks

Volvo LIGHTS

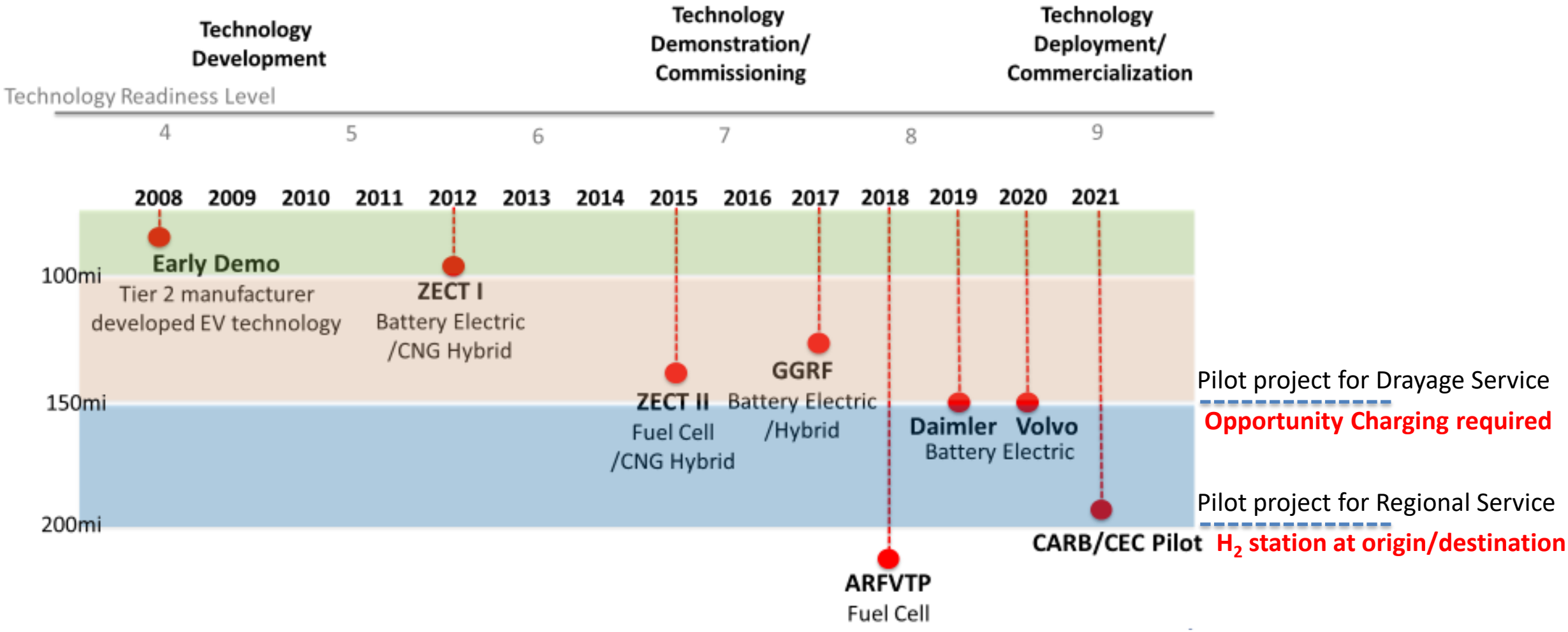
- Heavy-Duty Battery Electric Trucks & Infrastructure

Customer	Route
TEC	TEC Fontana – TEC La Mirada 90 miles, mostly flat
NFI	NFI Chino – Ports 102 miles, mostly flat (170m)
DHE	DHE – mixed drop off locations 80 miles, mostly flat
DHE	DHE – mixed drop off locations including Apple Valley 110 miles, big mountain climb (600m)
NFI	NFI Chino – Ports 102 miles, mostly flat
TOTAL Mileage	~40,000 miles



CARB-CEC Pilot Project

- $44.1 million in funds to support large-scale deployments of on-road, zero-emission Class 8 drayage and regional haul trucks as well as the necessary zero-emission vehicle fueling infrastructure needed for service operation
- Deploy around 50 on-road zero-emission (battery-electric and/or hydrogen) Class 8 trucks in a single fleet along with the necessary infrastructure
- The goal of this solicitation is to assess the ability of fleets and the electrical grid to recharge or refuel large numbers of trucks daily at a single location.


Technology Development
Technology Demonstration/ Commissioning
Technology Deployment/ Commercialization
Technology Readiness Level
4
5
6
7
8
9
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
100mi
150mi
200mi
Early Demo
Tier 2 manufacturer developed EV technology
ZECT I
Battery Electric /CNG Hybrid
ZECT II
Fuel Cell /CNG Hybrid
GGRF
Battery Electric /Hybrid
Daimler
Volvo
Battery Electric
ARFVTP
Fuel Cell
CARB/CEC Pilot
Pilot project for Drayage Service
Opportunity Charging required
Pilot project for Regional Service
H2 station at origin/destination

Summary

- Barriers for Battery electric and Fuel Cell HD vehicles

Battery Electric	Fuel Cell
Infrastructure	Infrastructure
High cost	Cost of hydrogen fuel
Limited vendors	High Cost
Limited range	Limited vendors
Heavy batteries and axle loads	Unknown business case

- Temporary hydrogen refueling supporting vehicle testing and demonstration
  - Assessment of feasible pathway for hydrogen fueling in near and long term
  - Mobile refueler
  - Renewable hydrogen station
- Continue demonstration and data analysis for comparison to conventional diesel trucks
- TCO analysis and commercialization roadmap will be accomplished
- More OEMs' participation is required

Emission Reduction Technology Demonstration

Ocean-Going Vessels & Locomotives

Mei Wang
Program Supervisor

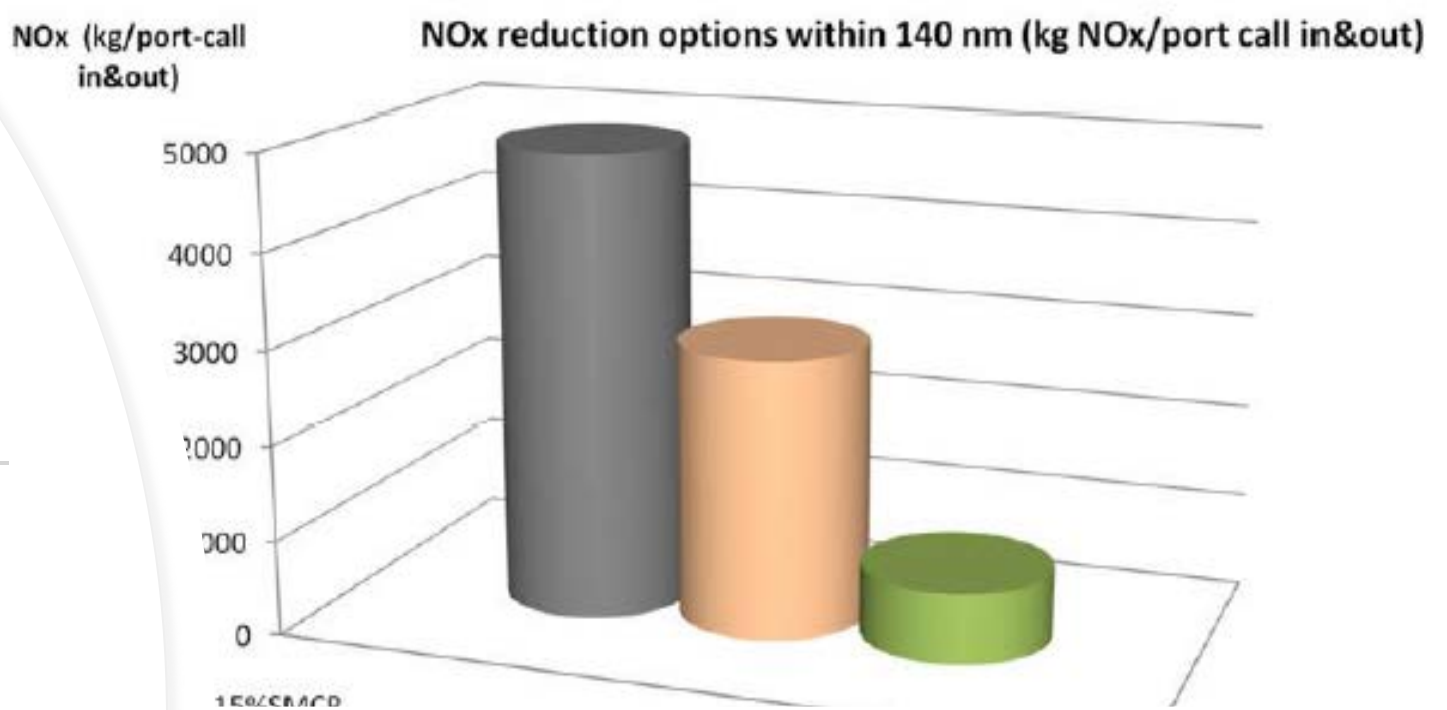
Ocean-Going Vessel Retrofits

- Background
  - OGVs are expected to be one of biggest NOx emission source in 2023
  - NOx reductions needed to meet federal standard
  - Upgrading OGVs is costly and OGV remain in service for over 25 Years
  - Only vessels built after 2016 are required to have Tier 3 engines and seeing limited number of Tier 3 calling our ports
  - Needs to develop retrofit technologies

- Engine Retrofit technologies
  - Selective catalytic reduction (SCR)
  - Exhaust gas recirculation (EGR)
  - Water-in-Fuel (Wif)
  - Alternative fuel conversion
  - Battery and fuel cell

OGV WiF Retrofit

- WiF emulsion injection
  - 40% NOx reduction
  - <50% engine load
  - 140NM
  - Marine Diesel Oil (MDO) with 0.1% Sulfur
- Project Cost and Partners
  - $3.2M
  - SCAQMD, Ports, MAN ES, and MSC
- Project Period:
  - August 2020 to August 2022

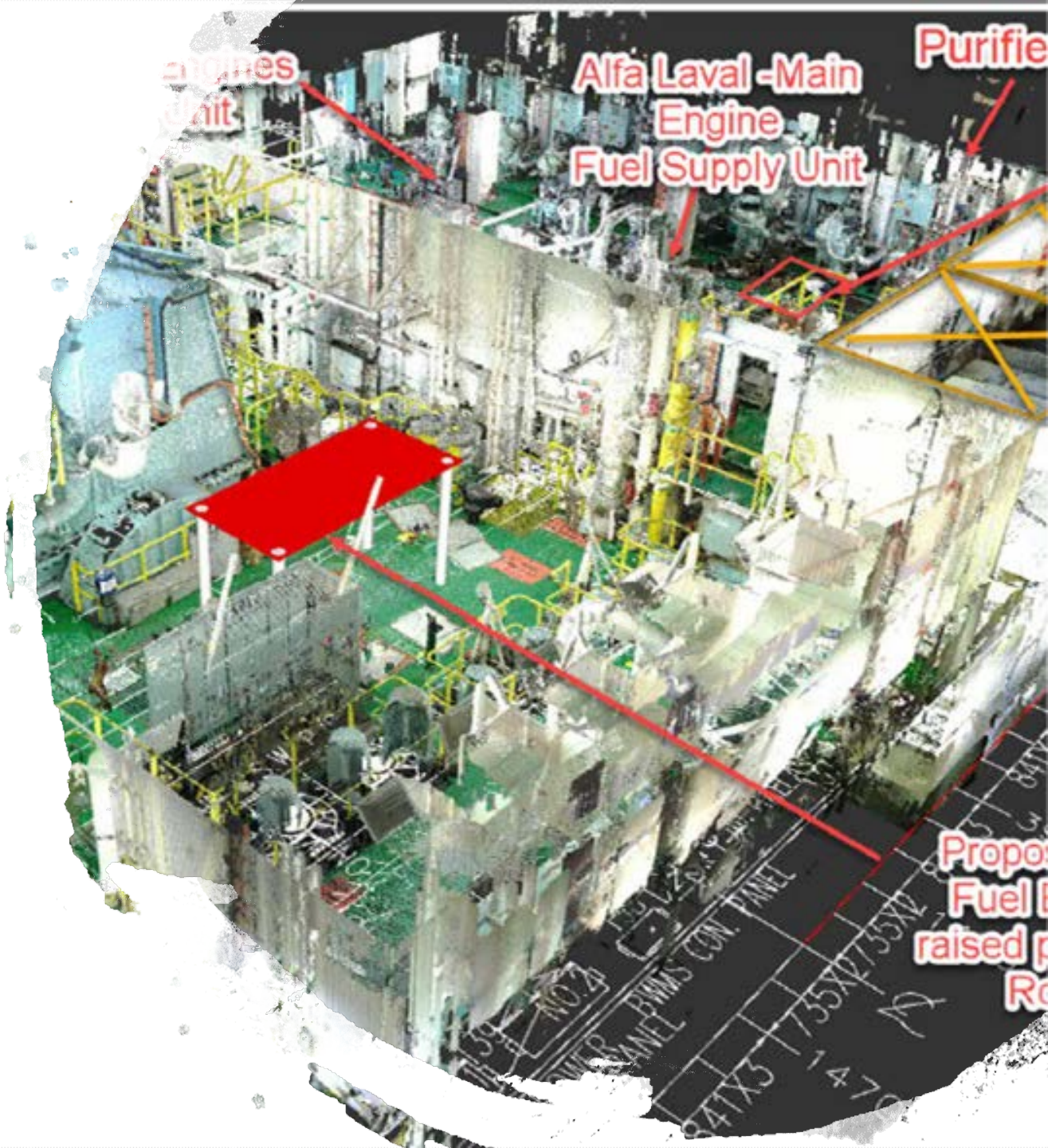


OGV WiF Retrofit

- Vessel Information
  - MSC ANZU
  - IMO Tier II
  - 9000TEU container vessel
  - MAN 9S90ME 2-stroke main engine, 52,000kW and 4 auxiliary engines
  - Built in 2015
  - Deadweight Tonnage (DWT): 100,000
- Vessel routes
  - European ports to Western North America ports

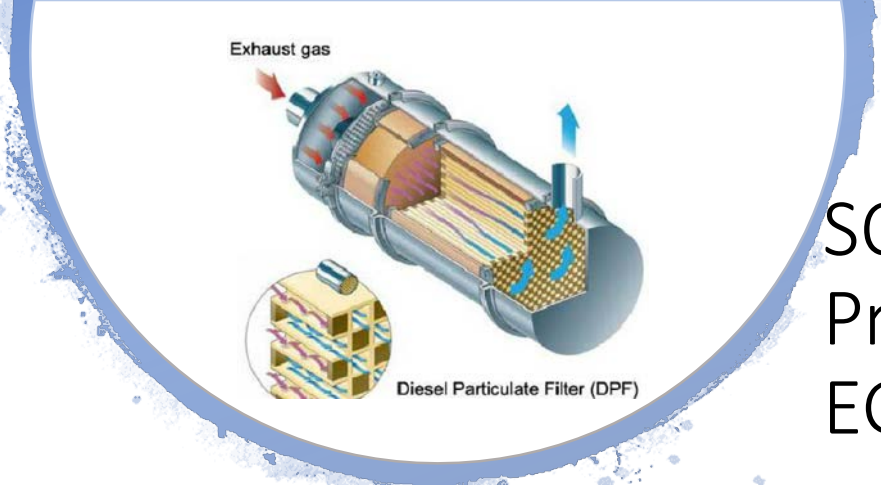
OGV WiF Retrofit

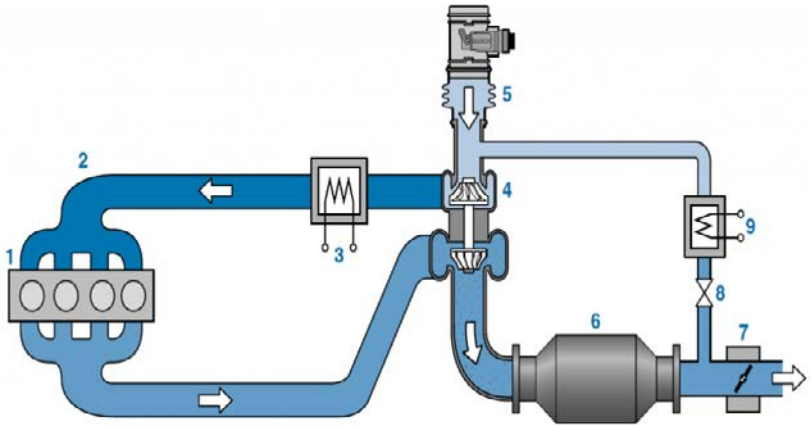
- Initial engineering assessment
  - Software and ship control
  - Cross-check vessel arrangement drawings
  - Ship fuel system
  - ARB emission test procedure submittal
- On-board vessel
  - 3D scanning and survey of engine room in November 2020
  - Verifying design and configuration
  - MSC approved WiF design and location



OGV WiF Project

- Next Steps
  - Obtain ARB approval of the test plan
  - WiF development and manufacturing
  - Ship WiF unit to a port for the installation
  - Commissioning and testing



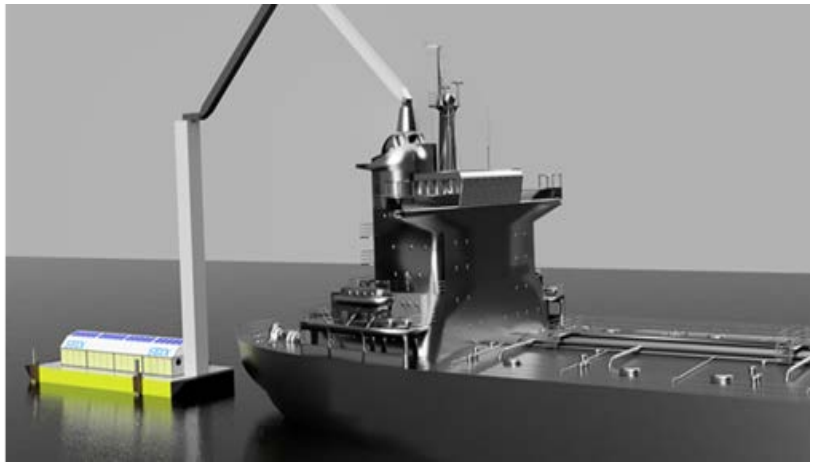


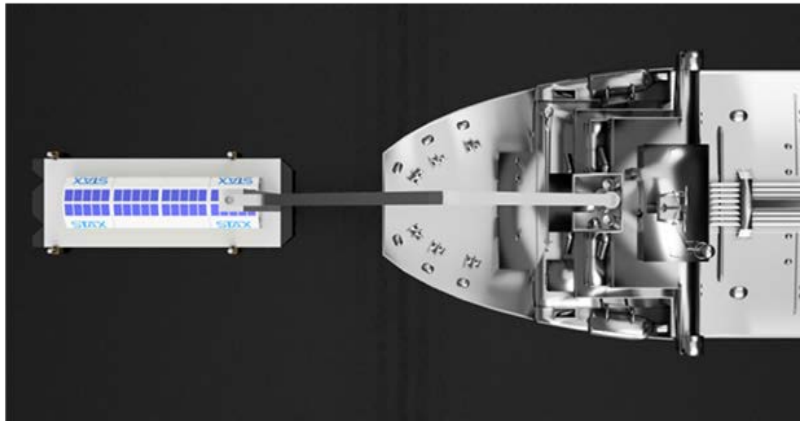
SCAQMD Ocean–Going Vessel Project Awards
EGR Retrofit

- US EPA Year 20-21 Targeted Airshed Award: $11.4M
  - Total project cost: $12.4M
  - Cost-share by POLA, POLB, and SCAQMD
- Low-Pressure Exhaust Gas Recirculation (LPEGR)
- Add-on Particulate Filter
- 90% PM reduction and 75% NOx reduction from a Tier II OGV
- Project completion: 12/31/2025

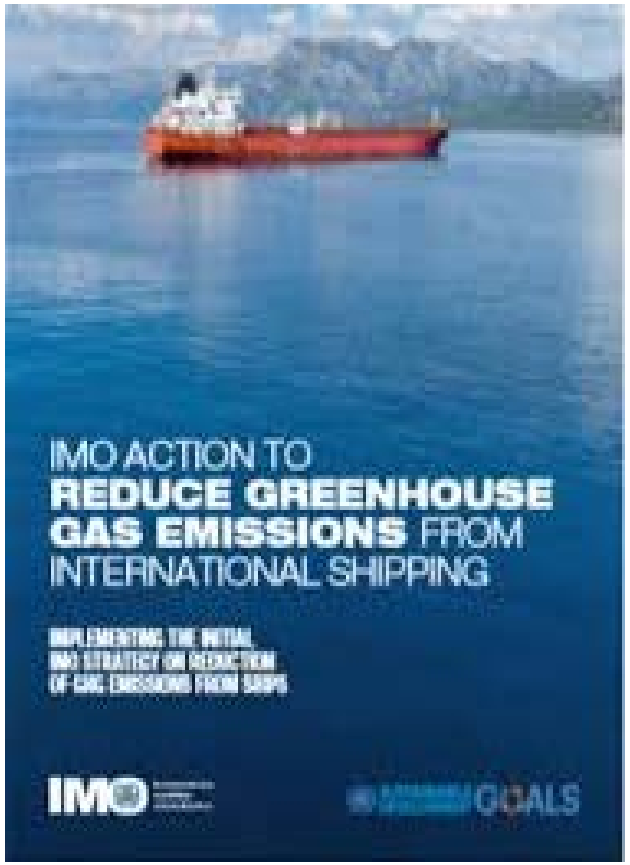
SCAQMD Ocean–Going Vessel Project Awards Capture and Control System for Oil Tankers

- FY 19-20 CARB Clean Transportation award of $10M
  - Total project cost $13.5M
  - Funding partners: STAX Engineering, POLA and POLB
- Self-propelled Spud Barge
  - Powered by renewable diesel and fuel cell
  - Solar and battery storage
- Exhaust capture system and purification units
- Carbon-capture
- At least 90% reduction of NOx, PM2.5 and ROG from both auxiliary engines and boilers
- Obtain CARB executive order
- Demonstration partner: Tesoro Logistics located in POLB
- Project completion: 12/31/2023



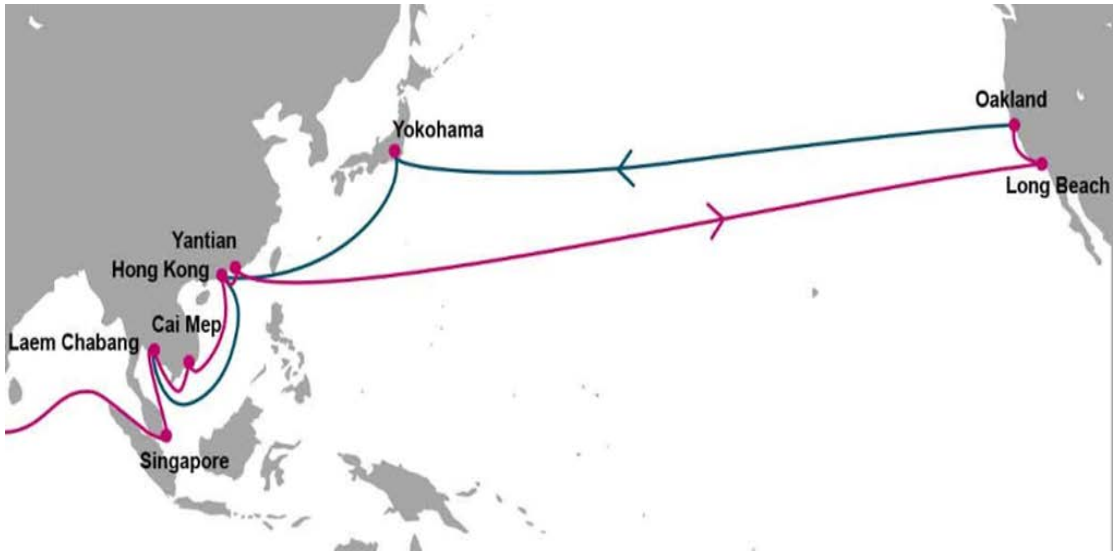


Future Technologies for OGV

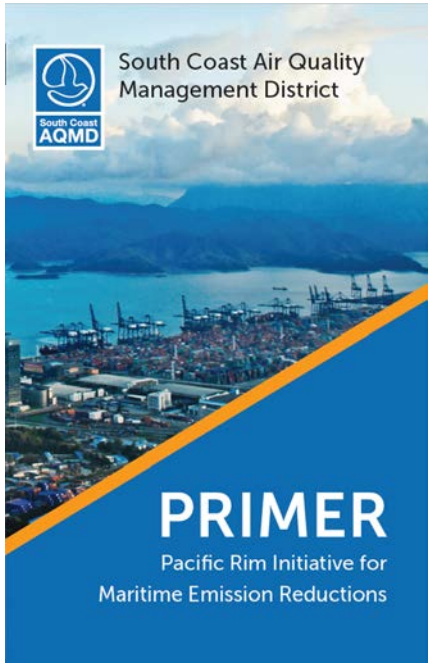


- Regulations driven:
  - IMO current standards and targets
  - CARB At Berth regulation
- Hybridization
- Battery technology
- Fuel cell
- Nuclear energy
- Alternative and renewable
  - LNG, LPG, methanol, ethanol, NH_3, and H_2,
  - Biofuels, and synthetic
- Shore side infrastructure

Pacific Rim Initiative for Maritime Emission Reductions (PRIMER)

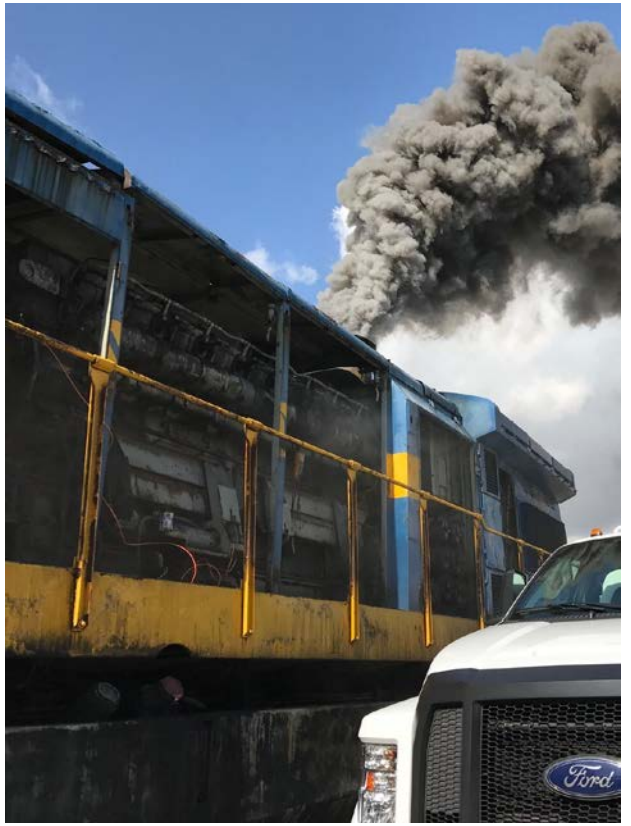


- Trans-Pacific partnerships of multiple port regions around the Pacific Rim
  - Engagement with Asia
  - Develop policy paper
  - Industry partnerships
- Efforts to incentivize cleaner ocean-going vessels
  - Coordinate region-specific programs to attract cleaner OGVs on shared routes
  - Voluntary incentive-based programs



Locomotives Technologies

- Current Tier 4 technologies:
  - SCR
  - EGR
  - Alternative Fuel
- AQMD awarded Metrolink over $100M to deploy 40 Tier 4 passenger locomotives using SCR technology
- Near-Zero and Zero-Emission
  - Hybrid
  - Alternative fuel
  - Zero-Emission
    - Battery powered
      - Electrification of rail lines
    - Hydrogen



SCAQMD-RPS Battery-Switcher Demonstration

- Diesel switcher conversion
  - 1200HP replaced with 600-volt 300 kW-hour
  - 2nd Use Batteries
- Project Timeline
  - April 2018 – July 2021
- Project cost $1 M
  - US EPA -$210,000
  - RPS - $790,000
- Project status
  - Battery pack and rack design and fabrication
  - Integration of battery and electronic control

SCAQMD-RPS Battery-Switcher Demonstration

Potential Next Steps

- Install charging infrastructure
- Perform substantial validation and durability testing
- Enhancement stage
  - Pre-Commercialization

- Challenges
  - Battery load control with duty cycle and charging equipment
  - Starting tractive effort

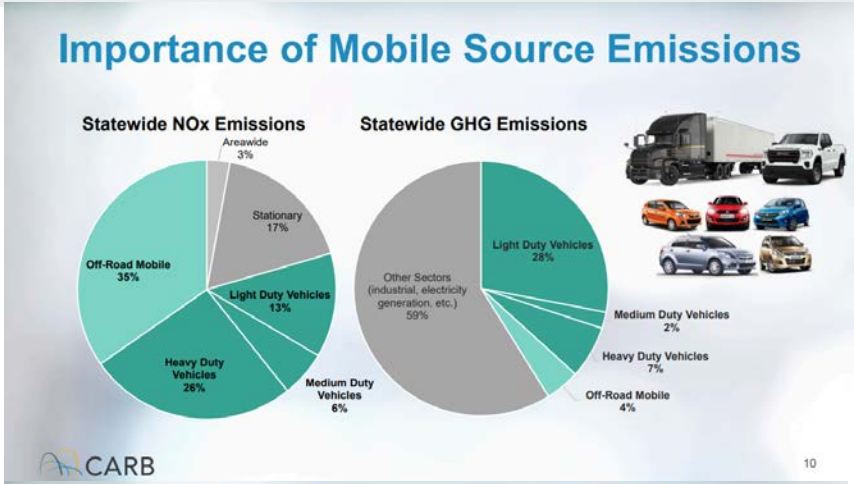
Questions

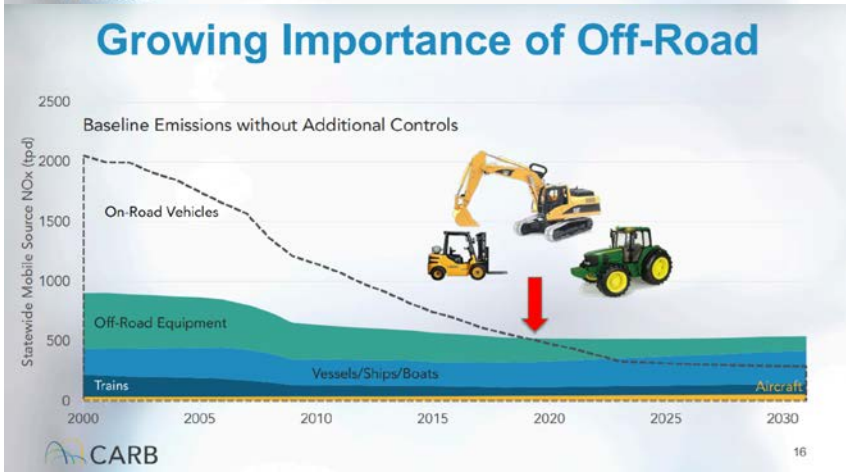
Off-Road Equipment Low & Zero Emission Technology

Clean Fuels Advisory Group | Sam Cao - Air Quality Specialist | February 2, 2021

Setting the Stage

- Off-road emissions growing
- 2016 AQMP: Top three NOx sources in 2023
- Statewide: off-road contributes to 4% of GHG but 35% of NOx
- 2020 MSS calls programs to cut NOx emission by ~1/2 for on-road source but ~2/3 reduction for off-road sources by 2031
- 90% lower NOx Tier 5 Standard starting MY 2028-2030
- Governor's EO: full transition to ZE off-road equipment by 2035 where feasible





Full transition to ZE off-road equipment by 2035* *where feasible

Source: CARB 2020 Mobile Source Strategy

Mix Of Off-Road Mobile Sources

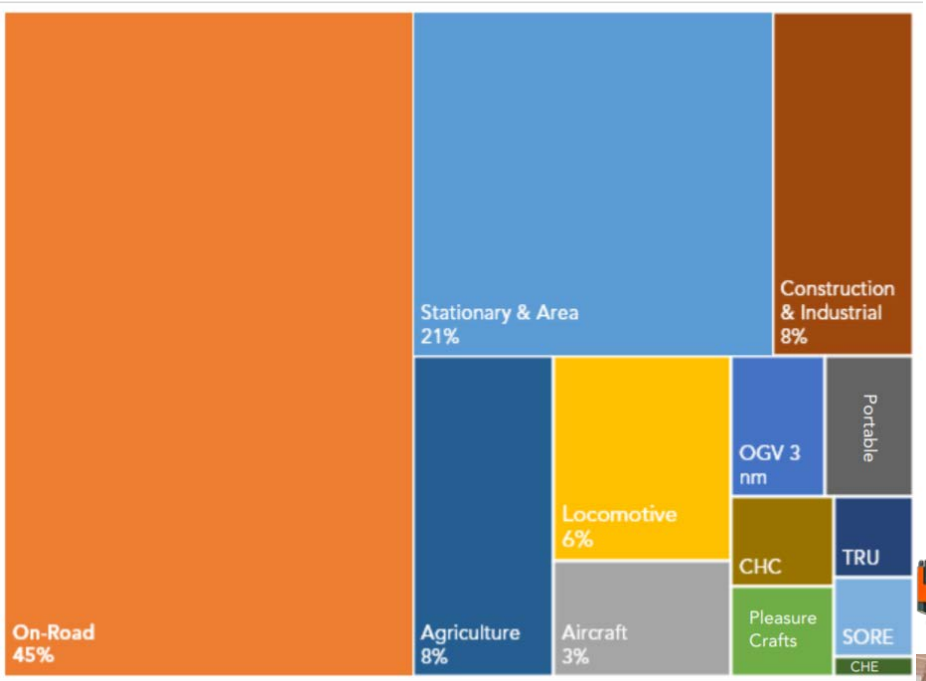
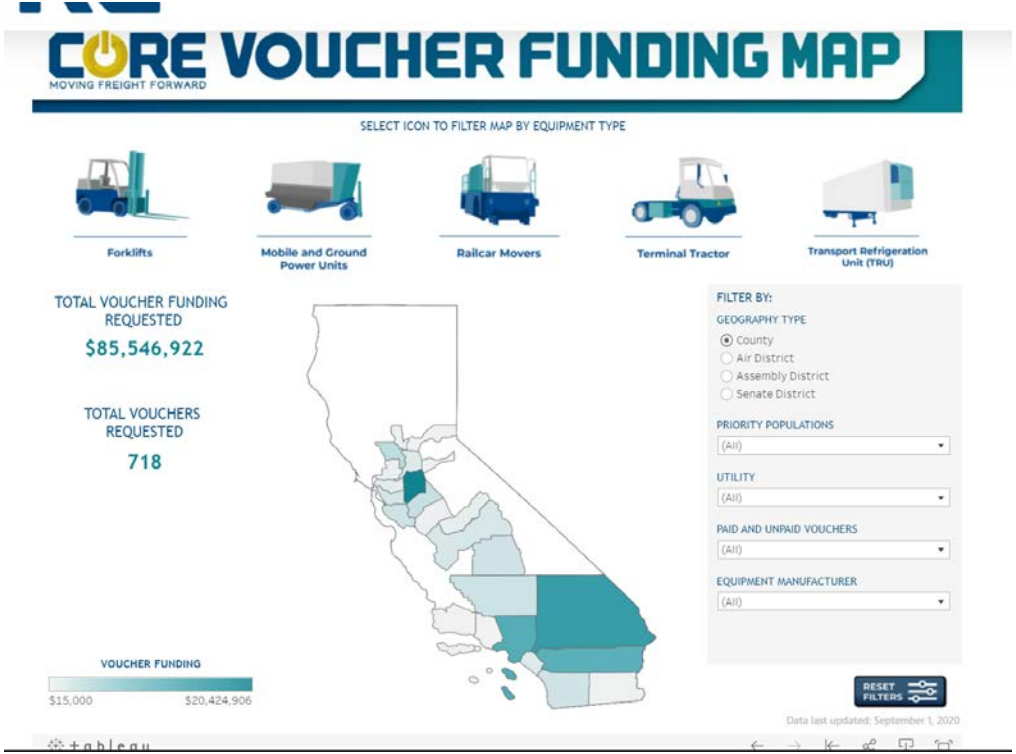
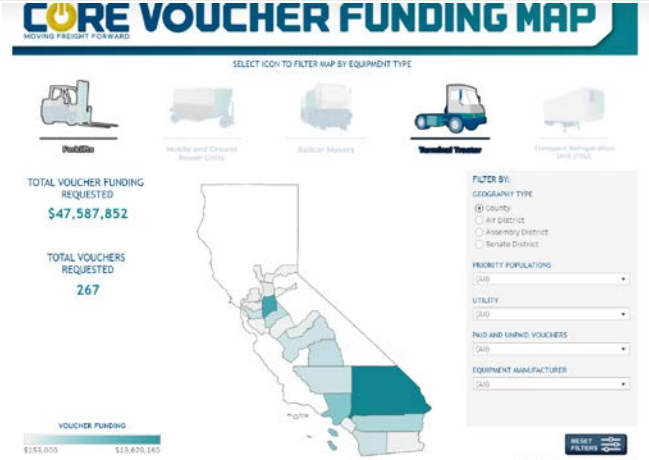


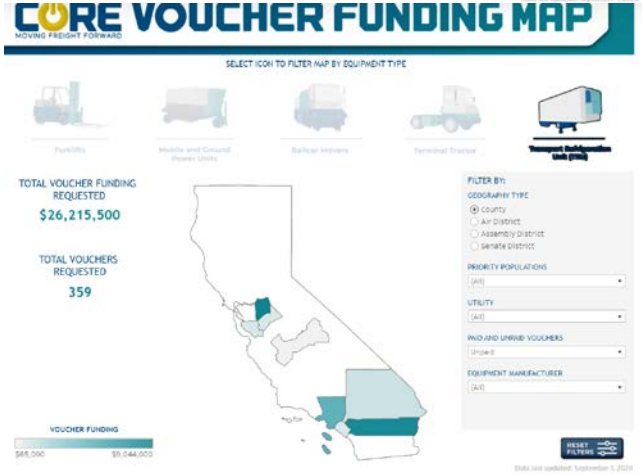
Figure 27 - 2017 Statewide NOx Emissions by Sector[129]

Source: CARB 2020 Mobile Source Strategy

CARB CORE Program







Source: https://californiacore.org/voucher-funding-map/, as of 1/22/2021

Technology Options for Off-Road Equipment

Bobcat T76e Electric Skid Loader

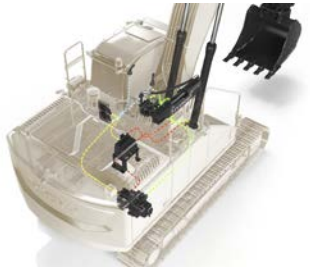
CAT D6 XE Hybrid Dozer

JCB 220x Fuel Cell Excavator

Komtasu 930E-4 Hybrid Mining Truck

Small	Medium	Large	Heavy
Battery Electric, Hybrid	*Battery Electric, Fuel Cell, Hybrid*	*Hybrid, Fuel Cell, Energy Management*	*Hybrid, Grid, Energy Management*

JCB 19C-1E Electric Excavator



Volvo EC300E Hydraulic Hybrid

Deere automated electric tractor

Skanska x Volvo AI + Electrification Concept

Feasibility of Full Electrification

Data removed from the web by the author

Source: UCR Progress Report to CARB

EVSE Considerations

Data removed from the web by the author

Source: UCR progress report to CARB

Volvo Battery-Electric Equipment Demo

- U.S. EPA 2017 Targeted Air Shed award to South Coast AQMD
- Develop and demonstrate electric excavator and wheel loader
- 6 month in-service demonstration for each machine at three different fleets
- Porotype Mobile Power Pack Charger for DC fast charge at site

Volvo Battery-Electric Equipment Demo

- eExcavator demo started 3Q2020 currently onto 2nd demo fleet
- eLoader demo started 4Q2020
- Mobile charger 1Q2021 arrival
  - DC fast charge ~ 15kW

Thank you.

2021 and 2037 Off-Road Inventory

Data removed from the web by the author

Source: 2022 AQMP Mobile Source Working Group, 1/27/2021

2020 MSS

Electrification & Hybridization

- Numerous hybrid technologies are commercially available and zero-emission technologies are expanding
  - Hybridization increases fuel efficiency by around 25% on average
  - CARB's Clean Off-Road Equipment Voucher Incentive Project (CORE) is designed to accelerate deployment of cleaner off-road freight technologies
- Governor's Exec Order in Sept. 2020 (N-79-20) requires CARB to develop and propose:

CARB

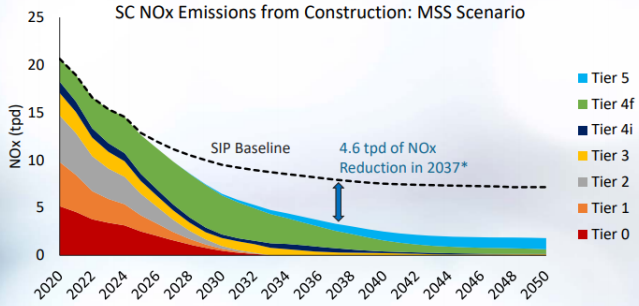
2020 Mobile Source Strategy (MSS) Concepts for Construction Equipment

- Phase out of Tier 0 to Tier 2 equipment by 2033
- Penetration of Tier 5 certified engines
- Electrification/hybridization wherever feasible

CARB

2020 Mobile Source Strategy Scenario

- **MSS Scenario**: Full turnover of Tier 0 to Tier 2 equipment by 2033, with Tier 5 penetration beginning in 2028



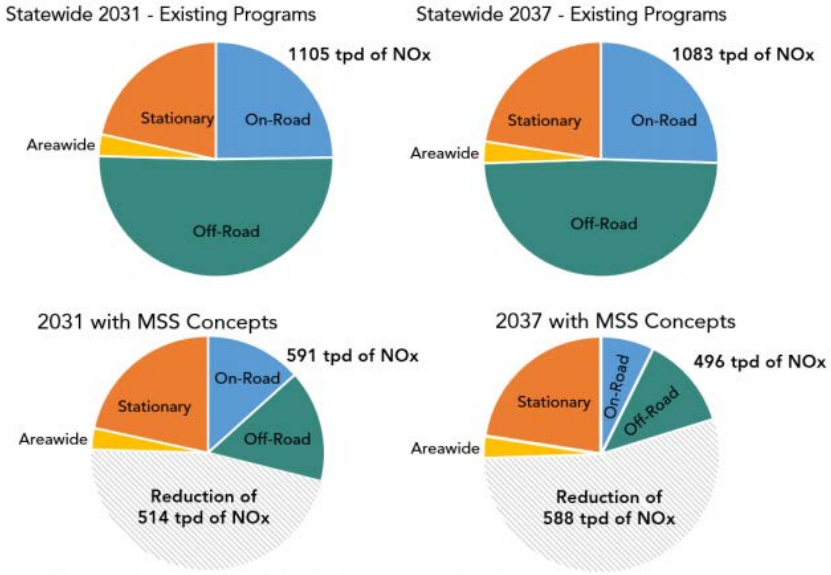
CARB *Reductions incorporate Tier 5 for all horsepower groups, which would require US EPA action

Source: 2022 AQMP Mobile Source Working Group, 1/27/2021

2020 MSS

will be necessary to achieve carbon neutrality by mid-century.

Figure 3 - Impact of 2020 Strategy Scenarios on Statewide NOx Emissions in 2031 and 2037



* Emissions from ocean going vessels are considered out to 100 nm

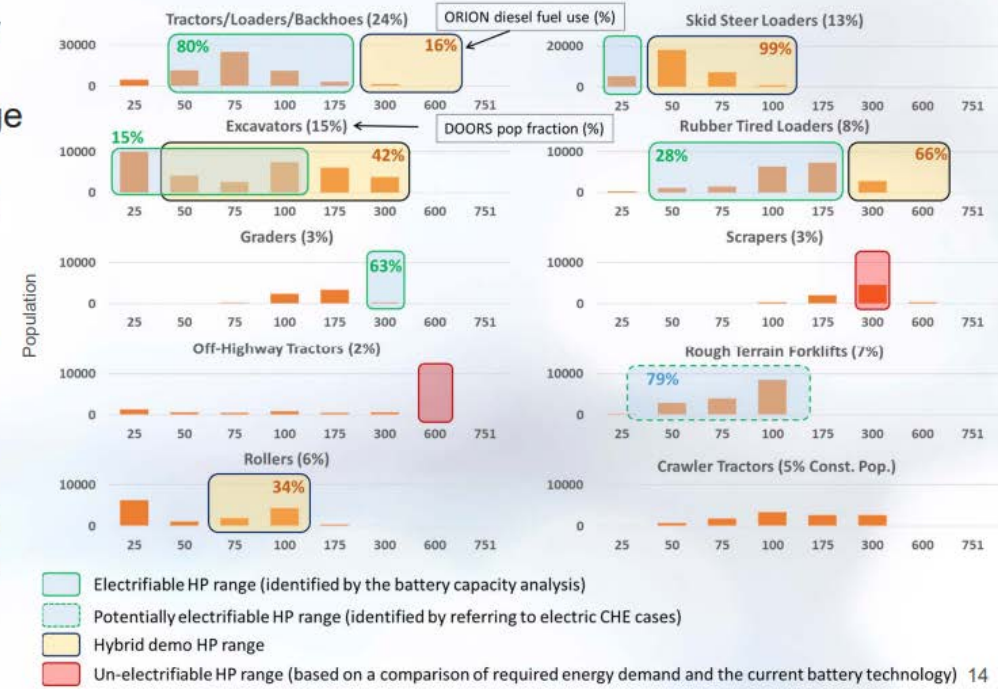
	Category	Scenario Assumptions
Off Road	SORE	• 100% of new sales will be zero-emission equipment (ZEE) starting 2025
	Aircraft	• 25 percent derate during take-off • 40 percent reduction in Taxi time • Single engine taxiing • 40 percent reduction in APU usage
	Transport Refrigeration Units	• Accelerated penetration of electric TRU (from 10% in 2024 to 100% in 2033)
	Commercial Harbor Craft	• All vessels (including commercial fishing) being Tier 4/5 by 2031 • Introduction of Plug-in hybrid for excursions and diesel-electric for tugs by 2030
	Cargo Handling Equipment	• Begin transition to full electric operation beginning in 2026 (accelerated turnover)
	Agriculture	• An incentive based concept consistent with the 2018 SJV SIP
	Airport Ground Support Equipment	• Full electrification transition from 2025-2034
	Forklifts	• Transition to zero-emission technology starting in 2025 with fully electric fleet by 2034
	Recreational Watercraft	• New THC + NOx standards of 40 and 70 percent below current levels • Electrification of small outboard and PWC engines
Off Road	Off-Road Efficiency Improvement[52]	• Zero-emissions and hybridization where feasible with the goal of 12 percent reduction in GHG by 2030, and 30 percent by 2040
	Off-Road Tier V Standard	• Tier 5 being introduced starting in 2028-2030 • 50 – 90% NOx reduction from current Tier 4f standard
	Rail	• 100% of replaced locomotive will be Tier 4 • Remanufacturing limit • Tier 5 being introduced in 2028
	Ocean Going Vessels *(out to 100 nm)*	• 100% of Tier 0/1/2 visits are phased out by 2031 • Tier 3 visits begin in 2025 (begin replacing all Tier 0-2) • Tier 4 visits begin in 2028 (no additional Tier 3 visits)
	Construction	• Full turnover of Tier 0/1/2 to Tier 4f by 2033

Source: CARB 2020 MSS Draft Dec 2020

UCR Work On Potential for Electrification

Potential Electrification & Hybridization Application

- Draft study to identify off-road population and horsepower range for electrification/ hybridization through sample equipment duty cycle study
- Other zero-emission technologies being explored
- Chart shows conceptual approach to identify equipment targets



CARB

Source: 2022 AQMP Mobile Source Working Group, 1/27/2021

Large Battery Electric Equipment

- Battery electric dump truck
  - 700 kWh battery pack
  - 100 kW charging station
  - https://insideevs.com/news/362547/edumper-8-ton-battery-pack/

- Battery electric top handlers
  - 931 kWh battery pack
  - 200 kW charging station
  - Being demonstrated at the Ports of Los Angeles and Long Beach

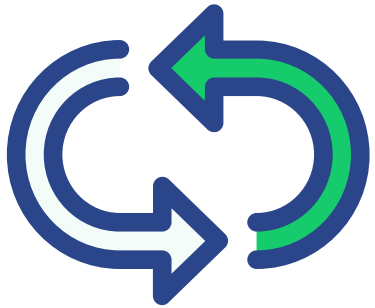
Li-Cycle®

Corporate Presentation

January 2021

Non-Confidential

VISION & MISSION



MISSION

Providing sustainable and safe customer-centric solutions and technology to solve the global end-of-lifecycle lithium-ion battery problems/opportunities.

Meeting the rapidly growing demand for critical battery materials

VISION

To be the most sustainable, vertically integrated, and globally preeminent lithium-ion battery resource recovery company

LI-CYCLE OVERVIEW

Year Founded: 2016

Service: Closed-loop lithium-ion battery resource recovery

Key Partners: CALSTART, MaRS, Responsible Battery Coalition, NAATBatt International, Suppliers Partnership for the Environment

Key Investors: TECHMET, bdc, DELPH25, Pella Resources Limited, Bioindustrial Innovation Canada – A Sustainable Chemistry Alliance

Recognitions: Solar Impulse Efficient Solutions – Our Challenge 1000, 2020 Global CleanTech 100, 2020 Clean 16, CV Magazine Energy Innovator Awards 2019, Start Up Energy Transition, CleanEquity Monaco 2018

EXECUTIVE TEAM

Ajay Kochhar

President & CEO, Co-Founder, Executive Director

- 10+ years experience. Chemical Engineer
- Formerly co-led the lithium practice in North America at Hatch
- Successfully executed multibillion-dollar capital projects

Tim Johnston

Executive Chairman, Co-Founder

- 13+ years experience. CFA, Mechanical Engineer
- Former CEO of Desert Lion Energy, the largest lithium producer in Africa
- Co-authored 7 technical publications in the lithium sector

Kunal Phalpher

Chief Commercial Officer

- 10+ years experience. MBA, Electrical Engineer
- Former Director of Business Development at a lithium-ion battery manufacturer
- Experience in the lithium-ion battery and renewable energy sectors

Bruce MacInnis

Chief Financial Officer

- 30+ years experience. CA, CPA
- Depth of experience in raising capital for both publicly-traded and privately-held emerging technology companies

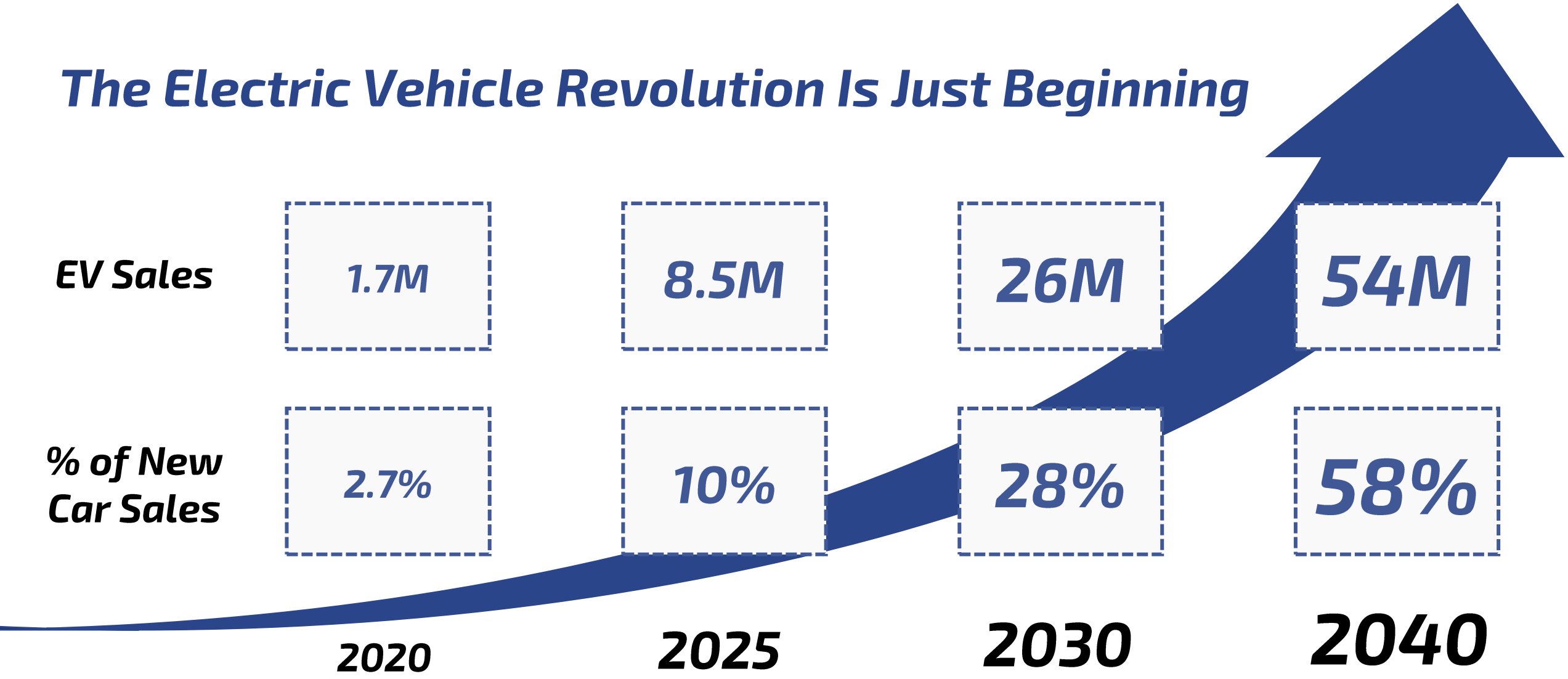
Chris Biederman

Chief Technical Officer

- 12+ years experience. Chemical Engineer
- A strong history leading multi-disciplinary engineering teams
- extensive experience managing scoping and feasibility studies, and detailed design and execution projects.

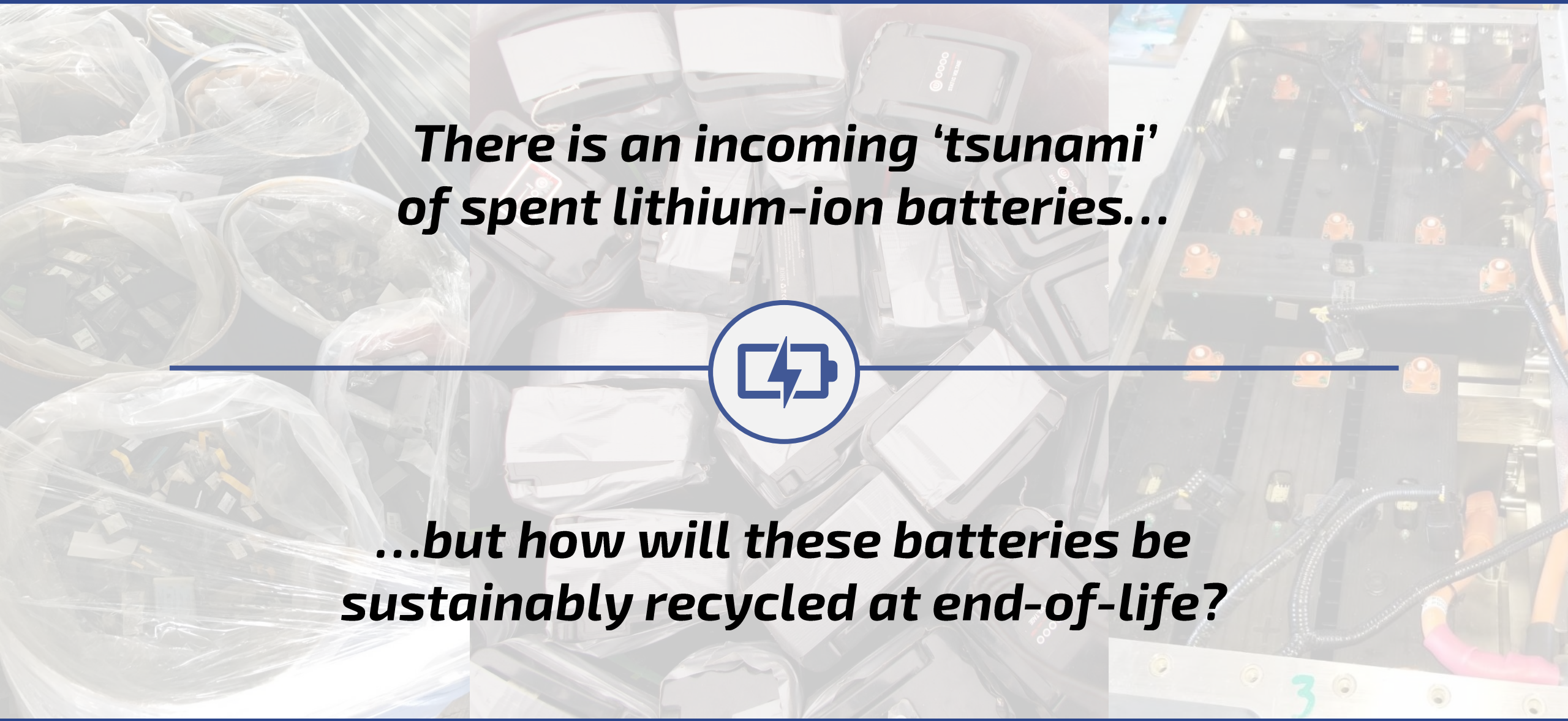
ELECTRIFICATION REVOLUTION

The Electric Vehicle Revolution Is Just Beginning



Source: BloombergNEF Electric Vehicle Outlook 2020

THE MISSING SUPPLY CHAIN STEP



There is an incoming 'tsunami' of spent lithium-ion batteries...

...but how will these batteries be sustainably recycled at end-of-life?

END-OF-LIFE OPTIONS: BEFORE LI-CYCLE

Export it

Batteries are shipped blindly overseas and are often lost, landfilled abroad, or lead to fires

Trash it

"Nationally we're losing a facility a month, burned to the ground by battery fires"

President, Dem-Con Waste Management

Reuse it

The business case for reuse is rapidly eroding as the price of new li-ion batteries falls rapidly to <$100/kWh

"Recycle" it

Current methods recover under 50% of raw battery materials, and only 30% of raw material costs

EXISTING CAPACITY

As of 2020 Li-Cycle's current capacity in Canada and the U.S. positions the company as

The largest lithium-ion battery recycler in North America

Spoke 1 – Kingston, ON
5,000 tonnes/year

Spoke 2 – Rochester, NY
5,000 tonnes/year
Commissioning Q4 2020

Demo Hub – Kingston, ON
365 tonnes/year

PROVEN LI-CYCLE TECHNOLOGY

Li-Cycle's patented Spoke & Hub technologies recover 95% of all li-ion battery materials — extracting high-grade materials for battery reproduction, at a cost lower than mined and refined material

Spoke

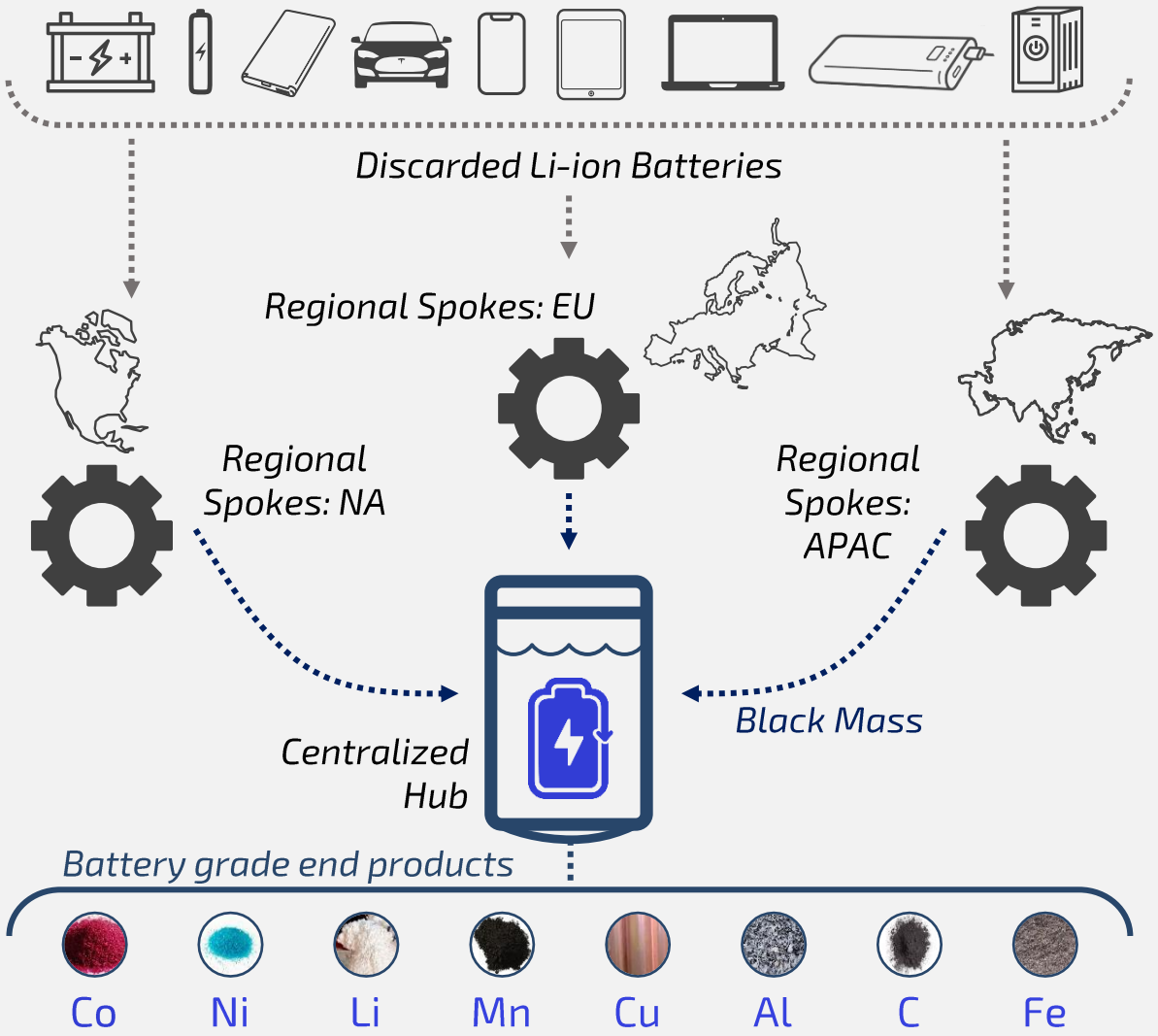
Input: All li-ion batteries at any state of charge, without manual sorting

End products: Black mass, shredded Cu/Al, mixed plastics

Hub

Input: Black mass

End products: Battery grade end products, including Co, Ni, Li, Mn, Cu Al, C, Fe



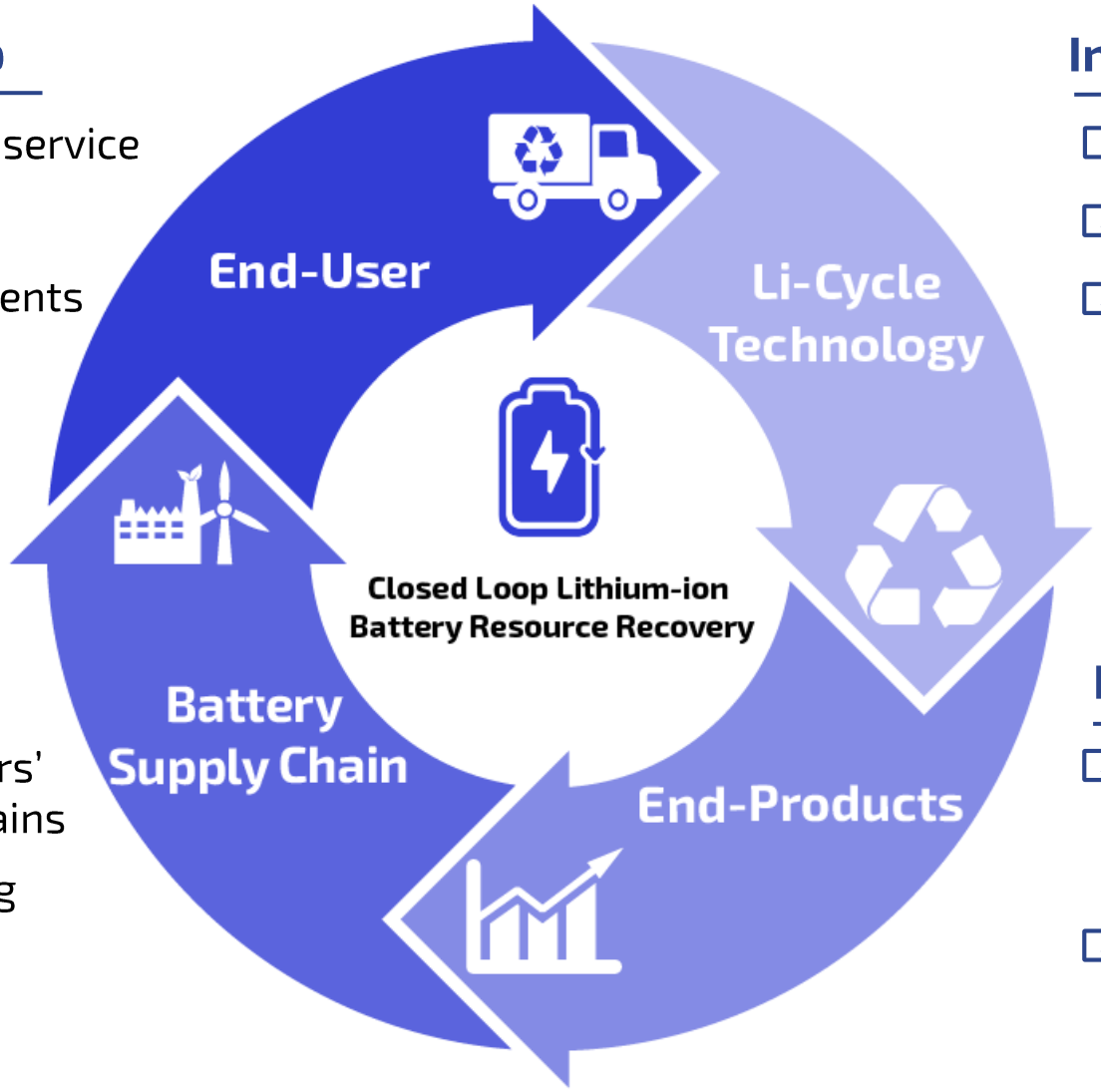
LI-CYCLE CAPABILITIES

Addressing the Recycling Gap

- Holistic logistics coordination service
- Handle damaged batteries
- Advise on packaging requirements
- Manage battery replacement campaigns

Closing the Loop

- Close the loop in our customers' lithium-ion battery supply chains
- Strategic advantage vs. mining and refining primary supply



Industry-leading Recovery Rates

- >90% recycling efficiency rate
- >95% functional recovery rate
- Safe and sustainable process

High Value End-Product Sales

- Produce battery-grade end-products for re-use in battery or other technical applications
- Produce by-products reusable in the general economy

EXISTING SPOKES: CANADA & NY

Patented Li-Cycle Spoke technology intakes all li-ion battery chemistries at any charge state, without manual sorting, discharging, or dismantling

Saves circa 50 person-hours per tonne

Spoke plants safely reduce the size of battery mass in an automated fashion, eliminating the risk of fire through inherently safe technology. Key to securing supply

Local to each region, reducing the safety risk and cost associated with battery transport

Modular & Scalable: starting size equivalent to 4 shipping containers, capable of 5,000 tonne/yr

Low cost and economically viable on a standalone basis

Fully sustainable with no solid or liquid waste and zero impact air emissions

EXISTING HUB: CANADA

Patented Li-Cycle Hub technology intakes the black mass produced at Spoke plants globally, and outputs high-purity battery chemicals—with 95% recovery

Each Hub plant can support a network of Spokes across the globe. Key structural advantage for Li-Cycle into the future, enabling a circular economy approach

Sell all products & by-products: only plant globally able to recover battery grade lithium

Centralized & optimized: maximizing economies of scale and efficiencies

Economically viable on a standalone basis

Fully sustainable with no solid or liquid waste and zero impact air emissions

ROADMAP & MILESTONES

✔ **Q4 2016:** Pre-seed investment round.
Li-Cycle proof of concept
Capacity: 5 tonne/year

✔ **Q3 2017:** Seed investment round. Mini-piloting complete in Canada
Capacity: 50 tonne/year

✔ **Q1 2018:** Series A investment round

✔ **Q4 2018:** Spoke demo complete in Kingston, Ontario
Capacity: 50 tonne/year

✔ **Q3 2019:** Series B investment round
Capacity: 2,500 in Q3 2019 → 5,000 tonne/year in Q3 2020

✔ **Q4 2019:** Hub Demo complete in Kingston, Ontario
Capacity: 365 tonne/year

✔ **Q4 2020:** Second Commercial Spoke established in Rochester, New York
Capacity: 5,000 tonne/year

Q4 2021: Third Commercial Spoke established in Nevada
Capacity: > 5,000 tonne/year

Q4 2022: First Commercial Hub established in North America
Capacity: 60,000 tonne/year
Enough to serve our 5-year goal

THE LI-CYCLE ADVANTAGE RECAP

The Li-Cycle® Advantage

Proven Technology — *Industry-leading 95% recovery from all types of lithium-ion batteries*

Commercial Today — *Significant secured battery supply and growing rapidly*

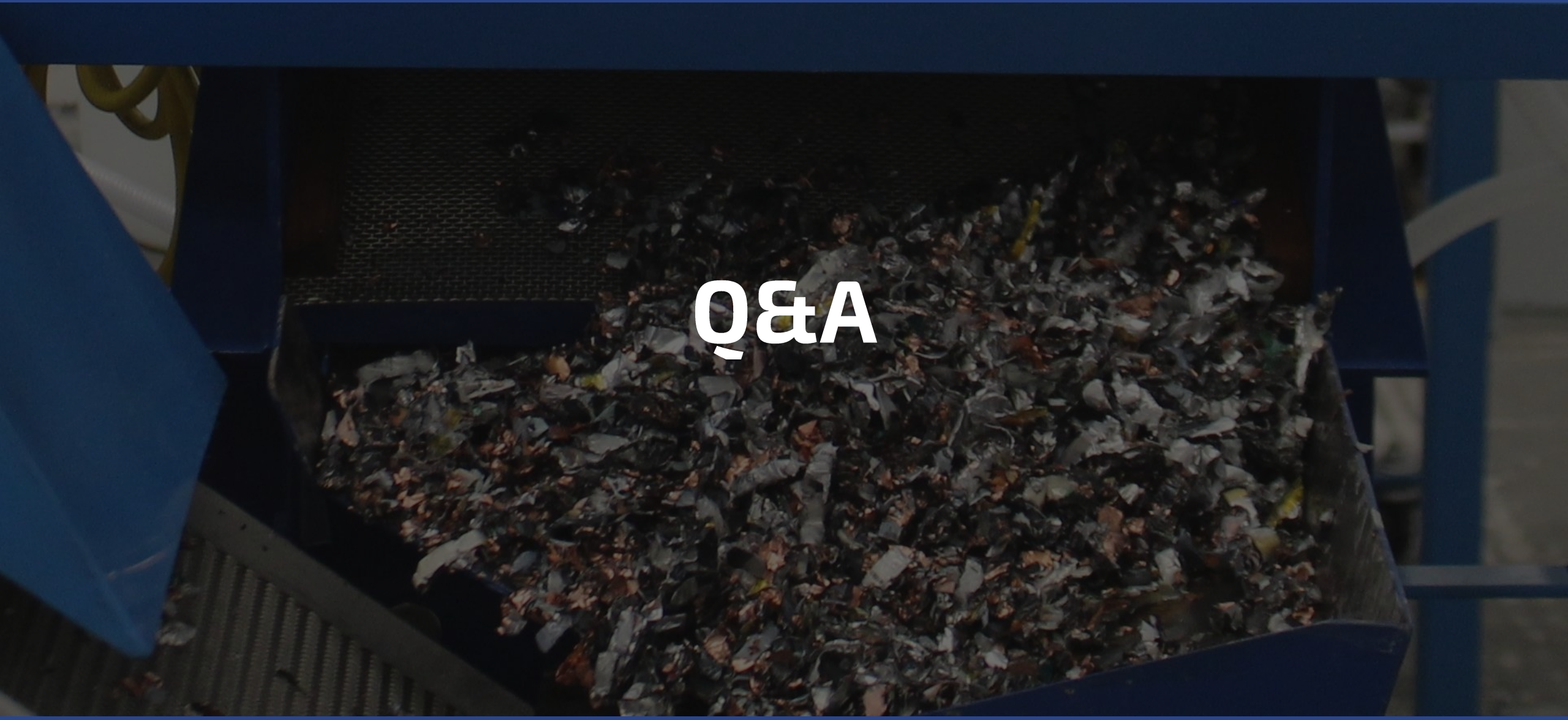
Growing Market — *15+ M tonnes of li-ion batteries worth >$96 Bn globally from 2020-2030*

Strategic Advantage — *Lowest cost, secure, and sustainably sourced supply of critical materials*

Robust Pipeline — *Secured access for end-product sales; virgin grade-equivalent products*

Experienced Team — *Technical, business, specialties/commodities, project execution*

THANK YOU




Li-Cycle®