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

Areas of South Coast AQMD Focus

1. 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
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

**Lower Emission School Bus Program**
- School buses
- Infrastructure
- CNG tank replacements

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

**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)
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
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)
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

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

FY 2016-17  FY 2017-18  FY 2018-19  FY 2019-20

Millions

FY 2016-17: $50
FY 2017-18: $150
FY 2018-19: $200
FY 2019-20: $250
# Emission Reduction Benefits from Incentive Programs (2020)

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

* EPA DERA/TAG awards and other smaller grants not included.
Carl Moyer Program – Funding Distribution by Project Category

- Off-Road: 58%
- Marine: 15%
- Locomotive: 1%
- On-Road: 10%
- TRUs: 1%
- Infrastructure: 15%
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)

<table>
<thead>
<tr>
<th>Incentive Program</th>
<th>Scrapping</th>
<th>Maximum Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>VW</td>
<td>Yes</td>
<td>$85,000 *</td>
</tr>
<tr>
<td>Prop1B</td>
<td>Yes</td>
<td>$100,000</td>
</tr>
<tr>
<td>Carl Moyer</td>
<td>Yes</td>
<td>$100,000 **</td>
</tr>
<tr>
<td>HVIP</td>
<td>No</td>
<td>$45,000</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Project Category</th>
<th>Technology</th>
<th>AB 134 (CAPP Year 1)</th>
<th>SB 856 (CAPP Year 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Funded Amount</td>
<td>No. of Units</td>
<td>Funded Amount</td>
</tr>
<tr>
<td>On-Road</td>
<td>Zero emission</td>
<td>$12,566,150</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Optional low-NOx</td>
<td>$22,858,674</td>
<td>415</td>
</tr>
<tr>
<td></td>
<td>Other (Emergency)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Off-Road Agriculture</td>
<td>Tier 3/4F</td>
<td>$19,607,167</td>
<td>156</td>
</tr>
<tr>
<td>Off-Road Construction</td>
<td>Zero emission</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Tier 3/4F</td>
<td>$22,698,620</td>
<td>96</td>
</tr>
<tr>
<td>Cargo Handing Equipment</td>
<td>Zero emission</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Hybrid-Electric</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Tier 4F</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Marine</td>
<td>Tier 3</td>
<td>$9,490,812</td>
<td>57</td>
</tr>
<tr>
<td>Transport Refrigeration Unit</td>
<td>Electric</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Electric charging</td>
<td>$122,500</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Renewable natural gas</td>
<td>$12,243,034</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Natural gas</td>
<td>$1,237,782</td>
<td>3</td>
</tr>
<tr>
<td>Locomotive</td>
<td>Tier 4</td>
<td>$11,533,500</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>$112,358,239</td>
<td>813</td>
</tr>
</tbody>
</table>
# Summary of Awards – Near Zero and Zero Emission Trucks

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

* 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*

<table>
<thead>
<tr>
<th>Engine Displacement</th>
<th># of Trucks</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.9 Liter</td>
<td>296</td>
<td>$29,028,005</td>
</tr>
<tr>
<td>8.9 Liter</td>
<td>166</td>
<td>$15,220,000</td>
</tr>
<tr>
<td>6.8 Liter</td>
<td>42</td>
<td>$1,967,592</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>504</strong></td>
<td><strong>$46,215,597</strong></td>
</tr>
</tbody>
</table>

* As of January 22, 2021
## Volkswagen Program Update

<table>
<thead>
<tr>
<th>Funding Category</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Installment</th>
<th>Open</th>
<th>Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZE Transit, School, and Shuttle Buses</td>
<td>$65 million</td>
<td>10/21/19</td>
<td>Still open (Shuttle and Transit only)</td>
</tr>
<tr>
<td>Combustion Freight and Marine Projects</td>
<td>$30 million</td>
<td>12/6/19</td>
<td>3/4/20</td>
</tr>
<tr>
<td>Light Duty Infrastructure – Hydrogen</td>
<td>$5 million</td>
<td>2/20/20</td>
<td>5/22/20</td>
</tr>
<tr>
<td>ZE Freight and Marine Projects</td>
<td>$35 million</td>
<td>6/18/20</td>
<td>8/31/20</td>
</tr>
<tr>
<td>ZE Class 8 Freight and Port Drayage Trucks</td>
<td>$27 million</td>
<td>8/18/20</td>
<td>Still open (backup list)</td>
</tr>
<tr>
<td>Light Duty Infrastructure - Battery Electric</td>
<td>$5 million</td>
<td>February 2021 (Est)</td>
<td>TBD</td>
</tr>
</tbody>
</table>
## School Bus Awards by County (2018/19)

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

* 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)
<table>
<thead>
<tr>
<th>Program</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPP Incentives</td>
<td><a href="http://www.aqmd.gov/cappincentives">www.aqmd.gov/cappincentives</a></td>
</tr>
<tr>
<td>Proposition 1B - Goods Movement Emission Reduction Program</td>
<td><a href="http://www.aqmd.gov/prop1b">www.aqmd.gov/prop1b</a></td>
</tr>
<tr>
<td>Volkswagen Environmental Mitigation Program</td>
<td><a href="http://www.aqmd.gov/vw">www.aqmd.gov/vw</a></td>
</tr>
<tr>
<td>Carl Moyer Program</td>
<td><a href="http://www.aqmd.gov/moyer">www.aqmd.gov/moyer</a></td>
</tr>
<tr>
<td>Voucher Incentive Program (for small fleets of 10 trucks and less)</td>
<td>www/aqmd.gov/vip</td>
</tr>
<tr>
<td>Lower Emission School Bus Program</td>
<td><a href="http://www.aqmd.gov/schoolbus">www.aqmd.gov/schoolbus</a></td>
</tr>
<tr>
<td>Commercial Lawn and Garden Equipment Incentive Program</td>
<td><a href="http://www.aqmd.gov/lawngarden">www.aqmd.gov/lawngarden</a></td>
</tr>
<tr>
<td>Replace Your Ride (Clean Cars for All)</td>
<td><a href="http://www.replaceyourride.com">www.replaceyourride.com</a></td>
</tr>
</tbody>
</table>
Mobile Source Control Needs for Meeting Ozone Standards

Clean Fuels Program Advisory Group Meeting
February 2, 2021
<table>
<thead>
<tr>
<th>Standard</th>
<th>Level</th>
<th>South Coast Classification</th>
<th>Coachella Valley Classification</th>
<th>Attainment Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015 8-hour Ozone</td>
<td>70 ppb</td>
<td>Extreme</td>
<td>Severe</td>
<td>August 3, 2038 (South Coast)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>August 3, 2033 (Coachella Valley)</td>
</tr>
<tr>
<td>2008 8-hour Ozone</td>
<td>75 ppb</td>
<td>Extreme</td>
<td>Severe</td>
<td>July 20, 2032 (South Coast)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>July 20, 2027 (Coachella Valley)</td>
</tr>
<tr>
<td>1997 8-hour Ozone</td>
<td>80 ppb</td>
<td>Extreme</td>
<td>Extreme*</td>
<td>June 15, 2024 (both South Coast and Coachella Valley)</td>
</tr>
<tr>
<td>1979 1-hour Ozone</td>
<td>120 ppb</td>
<td>Extreme</td>
<td>Attainment</td>
<td>February 6, 2023 (South Coast)</td>
</tr>
</tbody>
</table>

*Voluntary reclassification from severe to extreme in July 2019*
Ozone trends in South Coast Air Basin and Needed Reductions

Historical Trend

NOx Reductions Needed

Source: 2016 AQMP
2023 NOx Share by Major Source Category

- Ocean Going Vessels and Harbor Craft: 18%
- On-Road HD Trucks: 18%
- Commercial/Industrial Mobile Equipment: 16%
- Stationary and Areawide Sources: 18%
- On-Road LD/MD Vehicles: 11%
- Recreational Boats: 2%
- Buses: 3%
- Trains: 6%
- Aircraft: 6%
- Other Mobile Sources: 2%
- Recreational Boats: 2%

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
• 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

February 2, 2021
Clean Fuels Fund Program

Technology Readiness Level

0 3 8 9

Research
- Basic Research
- Lab Bench
- Proof-of-Concept

Development
- 1st Gen Demos
- System/Component Integration
- Proof-of-Technology

Demonstration
- 2nd/3rd Gen Demos
- Durability Acceptance
- Proof-of-Product

Deployment
- Pre-Commercial Demos
- Market Readiness
- Proof-of Commercialization

Commercialization

Incentives

Regulation
South Coast AQMD Plans & Policies

- 2016 AQMP – NAAQS

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

Suite of Mobile Source Regulations

Zero-Emission Operation

Innovative Clean Transit
ZE Airport Shuttle
ZE Powertrain Cert

2018
CA GHG Phase 2
Truck OBD
Truck Smoke Test

2019
ZE Ships at Berth
Advanced Clean Trucks

2020
Heavy-duty Low-NOx Omnibus

2021
ZE TRUs
Advanced Clean Fleets (inc. drayage)
Heavy-Duty I/M Harbor Craft

2022
ZE Forklifts

2023
Port and Railyard Cargo Handling Equipment

Lower Exhaust Emissions
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
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

- Hydrogen & Fuel Cell Tech. & Infra.: 27%
- Electric/Hybrid Tech. & Infra.: 20%
- Engine Systems/Technologies: 18%
- Infrastructure & Deployment (NG/RNG): 11%
- Fuel/Emissions Studies: 6%
- Stationary CF Technologies: 7%
- Emissions Control Technologies: 5%
- Health Impacts Studies: 2%
- Tech Transfer & Outreach: 4%

$17.9M
Plan Update Comparison

Distribution

- Hydrogen & Fuel Cells
- Electric & Hybrids
- Engine Systems
- Infra & Deploy NG/Renew.
- Fuel/Emiss Studies
- Stationary CF Tech
- Emissions Control
- Health Impact Studies
- Tech Transfer & Outreach

2020 Plan ($16M)
2021 Plan ($17.9M)
## Proposed Distribution

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

<table>
<thead>
<tr>
<th>Testing Phase</th>
<th>Assigned</th>
<th>Recruited</th>
<th>Completed</th>
<th>This Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable Activity Monitoring System (PAMS)</td>
<td>200</td>
<td>219</td>
<td>206</td>
<td>All</td>
</tr>
<tr>
<td>Portable Emissions Measurement System (PEMS)</td>
<td>100</td>
<td>100</td>
<td>97</td>
<td>77*</td>
</tr>
<tr>
<td>Chassis Dynamometer</td>
<td>60</td>
<td>62</td>
<td>57</td>
<td>34*</td>
</tr>
<tr>
<td>Real-World In-Use Trailer</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

*RD and non-SCR Diesel removed for NOx comparison purposes, some results still validating
Testing Elements of This Study

- **PAMS**
  - Activity, Average Speed, VMT, Idle, Starts

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

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

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

---

New Chassis Test Cycle

Route Information

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

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Fuel Type</th>
<th>Delivery</th>
<th>Goods Movement</th>
<th>Refuse</th>
<th>School Bus</th>
<th>Transit Bus</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCR</td>
<td>CNG</td>
<td>6</td>
<td>18</td>
<td>13</td>
<td>10</td>
<td>2</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>7</td>
<td>22</td>
<td>3</td>
<td>3</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>WVU</td>
<td>CNG</td>
<td>8</td>
<td>17</td>
<td>13</td>
<td>11</td>
<td>7</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>11</td>
<td>10</td>
<td>1</td>
<td>3</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Total Used</td>
<td></td>
<td>32</td>
<td>67</td>
<td>27</td>
<td>27</td>
<td>9</td>
<td>162</td>
</tr>
</tbody>
</table>

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.

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

Emission Factors for Natural Gas Vehicles

- Test data from the multi-agency 200-vehicle testing project
- PEMS testing of ~100 vehicles
- To date, received PEMS data from 24 natural gas vehicles

<table>
<thead>
<tr>
<th>Technology</th>
<th>Transit Bus</th>
<th>Refuse Truck</th>
<th>Goods Movement Truck</th>
<th>Delivery Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWC (0.2 g/bhp-hr)</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>TWC (0.02 g/bhp-hr)</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Test Cycle</th>
<th>Average Speed, mph</th>
<th>Vocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDDS</td>
<td>18.9</td>
<td>All</td>
</tr>
<tr>
<td>CARB HHDDT</td>
<td>39.9</td>
<td>Delivery, Goods Movement</td>
</tr>
<tr>
<td>Modified SCAQMD Refuse Cycle</td>
<td>9.57</td>
<td>Refuse</td>
</tr>
<tr>
<td>Goods Movement Cycle (GMC)</td>
<td>20.1</td>
<td>Goods Movement</td>
</tr>
<tr>
<td>School Bus Cycle</td>
<td>12.3</td>
<td>School Bus</td>
</tr>
<tr>
<td>Delivery Cycle</td>
<td>17.4</td>
<td>Delivery</td>
</tr>
<tr>
<td>CBD</td>
<td>12.6</td>
<td>Transit Bus</td>
</tr>
<tr>
<td>OCTA</td>
<td>12.4</td>
<td>Transit Bus</td>
</tr>
</tbody>
</table>

New for this study

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 compared 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

#### Graph

<table>
<thead>
<tr>
<th>Category</th>
<th>Emission Rate (BER) g/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>School Bus</td>
<td>0.2 Diesel</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>Diesel_Hybrid</td>
</tr>
<tr>
<td>Refuse</td>
<td>0.2 CNG/LPG</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.02 CNG/LPG</td>
</tr>
<tr>
<td>Goods Movement</td>
<td>0.2 g/bhp-hr, 2010 Std</td>
</tr>
</tbody>
</table>

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 compared 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 compared 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 compared 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 makeup.
- Lower NOx rule Ominibus and EPA CTI will dramatically change 2024+ baseline emissions factors and SCF.

Bus population by Fuel and Technology

- With the ZEB purchase requirements by ICT from 2023, ZEBs gradually phase-in.

Source: CARB EMFAC 202x Workshop
Team

Contractors: WVU, UCR/CE-CERT

Funding Partners: CEC, CARB, SoCalGas and 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: 47.6 mph
## HHDDT Cycle

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HHDDT Creep</th>
<th>HHDDT Transient</th>
<th>HHDDT Cruise</th>
<th>UDDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration, s</td>
<td>253</td>
<td>668</td>
<td>2083</td>
<td>1063</td>
</tr>
<tr>
<td>Distance, mi</td>
<td>0.124</td>
<td>2.85</td>
<td>23.1</td>
<td>5.55</td>
</tr>
<tr>
<td>Average Speed, mph</td>
<td>1.77</td>
<td>15.4</td>
<td>39.9</td>
<td>18.8</td>
</tr>
<tr>
<td>Stops/Mile</td>
<td>24.17</td>
<td>1.8</td>
<td>0.26</td>
<td>2.52</td>
</tr>
<tr>
<td>Max. Speed, mph</td>
<td>8.24</td>
<td>47.5</td>
<td>59.3</td>
<td>58</td>
</tr>
<tr>
<td>Max. Acceleration, mph/s</td>
<td>2.3</td>
<td>3.0</td>
<td>2.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Max. Deceleration, mph/s</td>
<td>-2.53</td>
<td>-2.8</td>
<td>-2.5</td>
<td>-4.6</td>
</tr>
<tr>
<td>Total KE, mph²</td>
<td>3.66</td>
<td>207.6</td>
<td>1036</td>
<td>373.4</td>
</tr>
<tr>
<td>Percent Idle</td>
<td>42.29</td>
<td>16.3</td>
<td>8.0</td>
<td>33.4</td>
</tr>
</tbody>
</table>
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/s²] 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
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\textsubscript{x} Aftertreatment System

Upstream SCR

Downstream System

Eaton Cylinder Deactivation (CDA) Hardware
### EPA AT 1 De-greened System

**NO\textsubscript{x} and CO\textsubscript{2} Emissions Performance – Final Values**

<table>
<thead>
<tr>
<th>Cycle</th>
<th>NO\textsubscript{x}, g/hp-hr</th>
<th>NO\textsubscript{x} Conversion</th>
<th>CO\textsubscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EO</td>
<td>TP</td>
<td>%</td>
</tr>
<tr>
<td>Cold-FTP</td>
<td>2.6</td>
<td>0.049</td>
<td>98.3%</td>
</tr>
<tr>
<td>Hot-FTP</td>
<td>3.1</td>
<td>0.008</td>
<td>99.7%</td>
</tr>
<tr>
<td>Composite FTP</td>
<td>3.0</td>
<td>0.013</td>
<td>99.6%</td>
</tr>
<tr>
<td>RMC-2021</td>
<td>3.5</td>
<td>0.009</td>
<td>99.7%</td>
</tr>
<tr>
<td>LLC</td>
<td>2.4</td>
<td>0.013</td>
<td>99.5%</td>
</tr>
<tr>
<td>RMC-2010</td>
<td>3.5</td>
<td>0.015</td>
<td>99.6%</td>
</tr>
</tbody>
</table>

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\textsubscript{2} 507 g/hp-hr (~ 1%) possible, but final tuned values chosen above to provide durability margin on tailpipe NO\textsubscript{x}.
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
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 ongoing - 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
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**
  - **ZECT1** Battery Electric and Plug-In Hybrid Electric (replaced Fuel Cell projects)
  - **ZECT2** Battery Electric, Fuel Cell, and Plug-In Hybrid Electric
ZECT1 Projects - Overview

- **ZECT1** - 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)
ZECT2 Projects - Overview

- **ZECT2 - 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
ZECT1 Review

TransPower

US Hybrid
<table>
<thead>
<tr>
<th></th>
<th>BET</th>
<th>PHET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Developers</strong></td>
<td>TransPower</td>
<td>US Hybrid</td>
</tr>
<tr>
<td><strong>No. of Trucks</strong></td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Chassis</strong></td>
<td>International Prostar</td>
<td>International Prostar</td>
</tr>
<tr>
<td><strong>Traction</strong></td>
<td>Dual IPM Motors</td>
<td>Induction Motor</td>
</tr>
<tr>
<td><strong>Motor/Power</strong></td>
<td>300 kW</td>
<td>320 kW</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>Automated Manual</td>
<td>Direct Drive</td>
</tr>
<tr>
<td><strong>APU Displ./Fuel</strong></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>APU Power, kW</strong></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Battery/Fuel Storage Capacity (kWh/DGE)</strong></td>
<td>215 - 311</td>
<td>240</td>
</tr>
<tr>
<td><strong>Charger On-Board, kW</strong></td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td><strong>Recharge/Refuel Time, hrs</strong></td>
<td>2.5 - 4</td>
<td>3 - 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Drayage Range (miles)</strong></td>
<td>75-100 (@215 kWh)</td>
<td>70-100</td>
</tr>
<tr>
<td></td>
<td>110-150 (@315 kWh)</td>
<td></td>
</tr>
</tbody>
</table>
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
### 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 mpGe), ~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)

#### Table: Drayage Truck Data

<table>
<thead>
<tr>
<th></th>
<th>EDD-2</th>
<th>EDD-3</th>
<th>EDD-4</th>
<th>all EDD</th>
<th>Conv. units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total recorded operation</td>
<td>201</td>
<td>171</td>
<td>197</td>
<td>569</td>
<td>615 days</td>
</tr>
<tr>
<td>Total distance</td>
<td>8,590</td>
<td>7,483</td>
<td>9,300</td>
<td>25,373</td>
<td>80,563 miles</td>
</tr>
<tr>
<td>Maximum daily distance</td>
<td>135.8</td>
<td>102.4</td>
<td>112.9</td>
<td>117.0</td>
<td>590.1 mi/day</td>
</tr>
<tr>
<td>Average daily distance</td>
<td>42.7</td>
<td>43.3</td>
<td>45.8</td>
<td>43.9</td>
<td>131.0 mi/day</td>
</tr>
<tr>
<td>Total operation time</td>
<td>933.7</td>
<td>670.2</td>
<td>0.0</td>
<td>601.3</td>
<td>6524.8 hours</td>
</tr>
<tr>
<td>Maximum daily operation time</td>
<td>10.2</td>
<td>10.2</td>
<td>11.4</td>
<td>10.6</td>
<td>24.8 hr/day</td>
</tr>
<tr>
<td>Average daily operation time</td>
<td>4.6</td>
<td>5.0</td>
<td>5.7</td>
<td>5.1</td>
<td>10.6 hr/day</td>
</tr>
<tr>
<td>Average idle time</td>
<td>2.6</td>
<td>2.9</td>
<td>3.2</td>
<td>2.9</td>
<td>2.8 hours</td>
</tr>
<tr>
<td>Average idle time &gt; 5 min</td>
<td>1.5</td>
<td>1.6</td>
<td>1.7</td>
<td>1.6</td>
<td>1.1 hours</td>
</tr>
<tr>
<td>Average overall speed</td>
<td>10.3</td>
<td>9.3</td>
<td>8.8</td>
<td>9.4</td>
<td>13.9 mph</td>
</tr>
<tr>
<td>Average driving speed</td>
<td>21.0</td>
<td>19.8</td>
<td>18.4</td>
<td>19.7</td>
<td>26.4 mph</td>
</tr>
<tr>
<td>Average kinetic intensity</td>
<td>1.08</td>
<td>1.38</td>
<td>1.28</td>
<td>1.25</td>
<td>0.72 1/mi</td>
</tr>
<tr>
<td>Average start SOC</td>
<td>96.1</td>
<td>95.6</td>
<td>82.7</td>
<td>91.5</td>
<td>— %</td>
</tr>
<tr>
<td>Average end SOC</td>
<td>59.8</td>
<td>50.5</td>
<td>52.3</td>
<td>54.2</td>
<td>— %</td>
</tr>
<tr>
<td>Average charge time</td>
<td>115</td>
<td>5.9</td>
<td>11.3</td>
<td>9.6</td>
<td>— hours</td>
</tr>
<tr>
<td>Average charge energy</td>
<td>93.93</td>
<td>116.05</td>
<td>94.60</td>
<td>101.52</td>
<td>— kWh</td>
</tr>
<tr>
<td>Average motor efficiency</td>
<td>2.02</td>
<td>2.35</td>
<td>2.04</td>
<td>2.13</td>
<td>— kW/mi</td>
</tr>
<tr>
<td>Average overall efficiency</td>
<td>2.20</td>
<td>2.68</td>
<td>2.06</td>
<td>2.32</td>
<td>7.99 kW/mi</td>
</tr>
<tr>
<td>Diesel equivalent fuel economy</td>
<td>17.12</td>
<td>14.03</td>
<td>18.23</td>
<td>16.46</td>
<td>4.71 mpGe</td>
</tr>
</tbody>
</table>
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

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

![Kinetic Intensity vs. Average Daily Speed](image1)

![Fuel Consumption vs. Daily Distance](image2)
ZECT 2 Trucks
Four Integrators: TP, USH, Hydrogenics, BAE/Kenworth


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
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
<table>
<thead>
<tr>
<th></th>
<th>TransPower</th>
<th>Hydrogenics (Cummins)</th>
<th>US Hybrid</th>
<th>BAE/Kenworth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Platform</strong></td>
<td>International</td>
<td>Freightliner</td>
<td>Kenworth T800</td>
<td>Kenworth T370</td>
</tr>
<tr>
<td><strong>Mfg: Fuel Cell / APU</strong></td>
<td>Hydrogenics</td>
<td>Hydrogenics</td>
<td>PureMotion</td>
<td>Ballard</td>
</tr>
<tr>
<td><strong>Fuel Cell Power, kW</strong></td>
<td>60</td>
<td>60</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td><strong>Battery Capacity, kWh</strong></td>
<td>125</td>
<td>100</td>
<td>26</td>
<td>100</td>
</tr>
<tr>
<td><strong>Battery Chemistry</strong></td>
<td>Li-ion</td>
<td>Li-ion</td>
<td>Li-ion</td>
<td>Li-ion</td>
</tr>
<tr>
<td><strong>Traction Motors</strong></td>
<td>2x 150 kW</td>
<td>1x 320 kW</td>
<td>1x 320 kW</td>
<td>2x 180 kW</td>
</tr>
<tr>
<td><strong>Range, mi (per fueling)</strong></td>
<td>200</td>
<td>150</td>
<td>150-200</td>
<td>100</td>
</tr>
<tr>
<td><strong>Fuel Cap.: H2 (kg)@350 bar / CNG (DGE)</strong></td>
<td>27</td>
<td>30</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td><strong>Plug-in Charging</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**PHET/CNG**

- Kenworth T680
- CWI 8.9L
- 1x 320 kW
- 150
- 45 DGE

**ZECT 2 - Truck Specifications**
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
Technical Issues: Development/Demonstration

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

- 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

Inspection of Battery Fuses
Transmission Repair
Deteriorated FC coolant reservoir cap
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
## Data Analysis – Summary Table

<table>
<thead>
<tr>
<th>Metric</th>
<th>Units</th>
<th>Baseline Conventional*</th>
<th>TransPower HEDD1</th>
<th>TransPower HEDD2</th>
<th>US Hybrid FC359</th>
<th>US Hybrid FC365</th>
<th>Kenworth ZECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of recorded vehicle days</td>
<td>#</td>
<td>557</td>
<td>152</td>
<td>94</td>
<td>106</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>Max daily distance</td>
<td>mi</td>
<td>—</td>
<td>106.5</td>
<td>126.9</td>
<td>122.7</td>
<td>28.0</td>
<td>123.3</td>
</tr>
<tr>
<td>Avg daily distance</td>
<td>mi</td>
<td>127.9</td>
<td>5.8</td>
<td>21.0</td>
<td>21.0</td>
<td>6.4</td>
<td>25.1</td>
</tr>
<tr>
<td>Avg operating time (key-on)</td>
<td>hr</td>
<td>10.1</td>
<td>10.0</td>
<td>5.8</td>
<td>2.0</td>
<td>0.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Avg driving time</td>
<td>hr</td>
<td>4.5</td>
<td>0.3</td>
<td>1.1</td>
<td>0.9</td>
<td>0.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Avg speed</td>
<td>mph</td>
<td>14</td>
<td>1.3</td>
<td>3.5</td>
<td>7.0</td>
<td>6.2</td>
<td>5.1</td>
</tr>
<tr>
<td>Avg driving speed (speed&gt;0)</td>
<td>mph</td>
<td>26.5</td>
<td>10.6</td>
<td>14.4</td>
<td>17.8</td>
<td>14.1</td>
<td>12.3</td>
</tr>
<tr>
<td>Kinetic intensity</td>
<td>1/mi</td>
<td>0.64</td>
<td>1.4</td>
<td>0.8</td>
<td>1.6</td>
<td>2.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Avg stops/day</td>
<td>#/day</td>
<td>124.9</td>
<td>14.2</td>
<td>62.9</td>
<td>50.0</td>
<td>17.4</td>
<td>86.8</td>
</tr>
<tr>
<td>Avg stops/mi</td>
<td>#/mile</td>
<td>1.38</td>
<td>24.6</td>
<td>18.1</td>
<td>13.5</td>
<td>17.7</td>
<td>—</td>
</tr>
<tr>
<td>Median stop duration</td>
<td>sec</td>
<td>40.8</td>
<td>346.7</td>
<td>39.2</td>
<td>9.5</td>
<td>27.4</td>
<td>8.3</td>
</tr>
<tr>
<td>Avg daily fuel use (H2)</td>
<td>kg</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>3.2</td>
<td>0.9</td>
<td>5.1</td>
</tr>
<tr>
<td>Avg daily fuel use (diesel equiv.)</td>
<td>gal</td>
<td>23.7</td>
<td>—</td>
<td>—</td>
<td>2.8</td>
<td>0.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Avg fuel economy (diesel equiv.)</td>
<td>mi/gal</td>
<td>5.7</td>
<td>—</td>
<td>—</td>
<td>8.3</td>
<td>9.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Avg fuel cell efficiency</td>
<td>%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>53.3%</td>
<td>56.4%</td>
<td>52.3%</td>
</tr>
</tbody>
</table>
Questions
Progression of Zero Emission Truck Development

Technology Advancement Office
Program Supervisor

Seungbum Ha
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

<table>
<thead>
<tr>
<th>Developer</th>
<th>TransPower</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Trucks</td>
<td>4</td>
</tr>
<tr>
<td>APU Displ./Fuel</td>
<td>N/A</td>
</tr>
<tr>
<td>APU Power</td>
<td>N/A</td>
</tr>
<tr>
<td>Battery/Fuel Storage Capacity</td>
<td>215 kWh</td>
</tr>
<tr>
<td>Charger On-Board</td>
<td>70 kW</td>
</tr>
<tr>
<td>Recharge/Refuel Time</td>
<td>2.5-4 hrs</td>
</tr>
<tr>
<td>Drayage Range (miles)</td>
<td>75-100 (@215 kWh)</td>
</tr>
</tbody>
</table>

### ZECT II

<table>
<thead>
<tr>
<th>PHET/ NZ-CNG</th>
<th>Fuel Cell</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Developer</th>
<th>BAE/Kenworth</th>
<th>Hydrogenics</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Vehicles</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Fuel Cell Power</td>
<td>-</td>
<td>60kW</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>100 kWh</td>
<td>100kWh</td>
</tr>
<tr>
<td>Range (per fueling)</td>
<td>150 miles</td>
<td>150 miles</td>
</tr>
<tr>
<td>Plug-in Charging</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

GGRF Peterbilt BET

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

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

Up to 8 battery modules
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
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; 8-13,000lbs 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

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*

<table>
<thead>
<tr>
<th>Customer</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEC</td>
<td>TEC Fontana – TEC La Mirada 90 miles, mostly flat</td>
</tr>
<tr>
<td>NFI</td>
<td>NFI Chino – Ports 102 miles, mostly flat (170m)</td>
</tr>
<tr>
<td>DHE</td>
<td>DHE – mixed drop off locations 80 miles, mostly flat</td>
</tr>
<tr>
<td>DHE</td>
<td>DHE – mixed drop off locations including Apple Valley 110 miles, big mountain climb (600m)</td>
</tr>
<tr>
<td>NFI</td>
<td>NFI Chino – Ports 102 miles, mostly flat</td>
</tr>
<tr>
<td><strong>TOTAL Mileage</strong></td>
<td>~40,000 miles</td>
</tr>
</tbody>
</table>
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.
Pilot project for Drayage Service

Pilot project for Regional Service

Opportunity Charging required

H₂ station at origin/destination

Technology Readiness Level

Tier 2 manufacturer developed EV technology

Battery Electric /CNG Hybrid

Fuel Cell /CNG Hybrid

Battery Electric /Hybrid

Daimler Battery Electric

Volvo

CARB/CEC Pilot
Barriers for Battery electric and Fuel Cell HD vehicles

<table>
<thead>
<tr>
<th>Battery Electric</th>
<th>Fuel Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>Infrastructure</td>
</tr>
<tr>
<td>High cost</td>
<td>Cost of hydrogen fuel</td>
</tr>
<tr>
<td>Limited vendors</td>
<td>High Cost</td>
</tr>
<tr>
<td>Limited range</td>
<td>Limited vendors</td>
</tr>
<tr>
<td>Heavy batteries and axle loads</td>
<td>Unknown business case</td>
</tr>
</tbody>
</table>

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 the 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, NH₃, and H₂,
  - 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

Source: CARB 2020 Mobile Source Strategy
Mix Of Off-Road Mobile Sources

Figure 27 - 2017 Statewide NOx Emissions by Sector

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

<table>
<thead>
<tr>
<th>Category</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Bobcat T76e Electric Skid Loader</td>
</tr>
<tr>
<td></td>
<td>CAT D6 XE Hybrid Dozer</td>
</tr>
<tr>
<td>Medium</td>
<td>JCB 220x Fuel Cell Excavator</td>
</tr>
<tr>
<td>Large</td>
<td>Komatsu 930E-4 Hybrid Mining Truck</td>
</tr>
<tr>
<td>Heavy</td>
<td></td>
</tr>
</tbody>
</table>

- **Small**: Battery Electric, Hybrid
- **Medium**: Battery Electric, Fuel Cell, Hybrid
- **Large**: Hybrid, Fuel Cell, Energy Management
- **Heavy**: Hybrid, Grid, Energy Management
Feasibility of Full Electrification

Data removed from the web by the author
EVSE Considerations

Data removed from the web by the author
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
- Prototype Mobile Power Pack Charger for DC fast charge at site
Volvo Battery-Electric Equipment Demo

- eExcavator demo started 3Q2020 currently onto 2\textsuperscript{nd} demo fleet
- eLoader demo started 4Q2020
- Mobile charger 1Q2021 arrival
  - DC fast charge \( \sim 15\text{kW} \)
Thank you.
Data removed from the web by the author
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: Full transition to ZE off-road equipment by 2035*, *where feasible

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

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

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

Statewide 2031 - Existing Programs

- 1105 tpd of NOx
  - Stationary
  - On-Road
  - Off-Road

Statewide 2037 - Existing Programs

- 1083 tpd of NOx
  - Stationary
  - On-Road
  - Off-Road

2031 with MSS Concepts

- 591 tpd of NOx
  - Stationary
  - On-Road
  - Off-Road

2037 with MSS Concepts

- 496 tpd of NOx
  - Stationary
  - On-Road
  - Off-Road

Reduction of 514 tpd of NOx

Reduction of 588 tpd of NOx

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

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

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

- Battery electric top handlers
  - 931 kWh battery pack
  - 200 kW charging station
  - Being demonstrated at the Ports of Los Angeles and Long Beach
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
Year Founded: 2016

Service: Closed-loop lithium-ion battery resource recovery

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

Key Investors: TECHMET, bdc, DELPH25, PELLA Resources Limited, Bioindustrial Innovation Canada

Recognitions: Start Up Energy Transition, CV Innovation Awards 2019, Clean16, 2020 Global Cleantech 100, 2020 - Global Cleantech 100, 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.
The Electric Vehicle Revolution Is Just Beginning

<table>
<thead>
<tr>
<th>Year</th>
<th>EV Sales</th>
<th>% of New Car Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>1.7M</td>
<td>2.7%</td>
</tr>
<tr>
<td>2025</td>
<td>8.5M</td>
<td>10%</td>
</tr>
<tr>
<td>2030</td>
<td>26M</td>
<td>28%</td>
</tr>
<tr>
<td>2040</td>
<td>54M</td>
<td>58%</td>
</tr>
</tbody>
</table>

Source: BloombergNEF Electric Vehicle Outlook 2020
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 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
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
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
Addressing the Recycling Gap
- Holistic logistics coordination service
- Handle damaged batteries
- Advise on packaging requirements
- Manage battery replacement campaigns

Industry-leading Recovery Rates
- >90% recycling efficiency rate
- >95% functional recovery rate
- Safe and sustainable process

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

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
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.
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:** 365 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:** 50 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

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

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

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

**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