Clean Technology Adoption in Off-Road Sector

2022 AQMP Mobile Source Working Group

April 7, 2021
Major NOx and PM$_{2.5}$ Emission Reductions Needed

- California has the worst air quality in the nation
- Key challenges
  - San Joaquin Valley – PM$_{2.5}$
  - South Coast - Ozone
- Off-road equipment are one of the largest contributors
- Actions beyond current programs needed to meet air quality goals in various regions

CARB
South Coast 2037 Attainment
(Working Draft)

Stationary and Area
Heavy-Duty Diesel Vehicles
Aircraft
Ocean Going Vessels
Off-Road Equipment and Vehicles

Baseline Carrying Capacity 2037

More than 70% Reduction

Carrying Capacity 55-85 tpd
Disadvantaged Community Focus

- Assembly Bill 617 directs CARB to identify community level strategies
- Communities seek rapid transition to zero-emissions
Zero-Emission Key to California’s Future

- Multiple criteria, air toxics, and climate pollutant emissions reduction plans
- Core strategies
  - Zero-emissions everywhere feasible
  - Cleaner fuels and cleaner combustion everywhere else
Executive Order N-79-20

100% ZEV sales by 2035

Full transition to ZEV short-haul/drayage trucks by 2035

Full transition to ZEV buses & heavy-duty long-haul trucks by 2045*

Transition of all off-road equipment operations to zero-emission where feasible by 2035

Strategies, in coordination with other State agencies, U.S. Environmental Protection Agency and local air districts, to achieve 100 percent zero-emission from off-road vehicles and equipment operations in the State by 2035.
Growing Importance of Off-Road

Statewide Mobile Source NOx Emissions

On-Road Vehicles

Off-Road Equipment

Vessels/Ships/Boats (<24nm)

Locomotives

Aircraft

Ref: CEPAM 2019 Summer
Controlling Federal Sources is Critical to Achieving our Clean Air and Climate Targets

The U.S. EPA has sole authority to establish emission standards for preempt engines used in new farm and construction equipment under 175 horsepower.

Off-Road NOx Emission Contribution

Mobile Source NOx emissions in SC in 2037

- On-Road: 43%
- OGV-100 nm: 20%
- Aircraft: 11%
- Trains: 4%
- Off-Road Equip.: 22%

Off-Road Equipment NOx emissions in SC in 2037

- Construction: 23%
- Forklifts: 10%
- GSE: 2%
- SORE: 11%
- PERP: 19%
- Recreational Watercrafts: 12%
- TRU: 11%
- CHC & CHE: 10%
- Ag: 2%
Off-Road Diesel PM Emission Contribution

Diesel PM emissions in SC in 2020

- Off-Road Equipment (Construction, Industrial, etc.) 63%
  - including <175HP preempted construction equipment
- Off-Road 63%
- On-Road Trucks & Buses 32%
- Stationary Sources 5%
- Ocean Going Vessels 15%
- Trains 14%
- Commercial Harbor Craft 4%
- Farm Equipment 4%

Diesel PM emissions in SC in 2020 including <175HP preempted construction equipment

CARB
Zero-Emission Technology

Low HP Construction & Agricultural equipment

- Most current commercialized electric equipment are under 150 HP
- Mobile battery solutions may play key role in solving infrastructure limits
- Under 100 hp tractors and forklifts have potential for electrification
- Federal preemption to set emission standards for preempt engines used in new farm and construction equipment under 175 horsepower.

Portable equipment

- Portable diesel-fueled engines with a rated brake horsepower of 50 and greater (≥ 50 bhp)
- Fuel cells have shown long term potential, additional research and demos needed

Cargo Handling Equipment

- Electric Top-pick and yard tractors at ports and intermodal railyards
- Battery electric forklifts
- Hydrogen fuel cell forklifts show potential as well

TRUs

- In-use emission regulation
- Full electrification of truck TRUs by 2034 (regulatory proposal)
- Full electrification of trailer TRUs (2020 MSS proposal)
Hybridization

**OGVs**
- Demo hybrid auxiliary engine
- If we include hybrid auto carrier and Roro vessels, the OGV sector has a potential to reduce diesel use by 35%
- Clean Off-Road Equipment Voucher Incentive Project
- Hybrid RTG cranes offer 40% fuel savings

**Locomotives**
- Demonstration projects for fuel cell-powered line-haul and switcher locomotives in 2025
- Battery electric demo starts in 2021 (switcher) and 2022 (line haul)
- SBCTA Fuel-cell MU passenger locomotive demo in 2022
- Caltrans aims to reduce 35% of the total fuel usage per passenger train mile by 2030

**CHCs**
- Hybrid Tug, Ferry, and Excursion units comprise 49% of the total diesel consumption of the sector
- In-use short run ferries become zero-emission by 2028 (9% of ferries)
- Potential for all tugs to go to diesel-electric (~20% efficiency gain) by 2030, all excursion vessels go to plug-in hybrid by 2030

**Construction & Agricultural Equipment**
- Many construction and agricultural demo cases have shown common hybrid modules used with a similar range of horsepower
- On average, 25% of efficiency improvement due to hybridization
- 400 ~ 600 hp construction and agricultural equipment types may find interim solution in hybridization
Key Technical Barriers for Off-Road Electrification

• Pace of commercialization
  o Technology readily available
  o Some equipment types commercially available, others in demonstration phase

• Limited access to charging infrastructure

• Operational limitations

- High Power Demand & Activity
- Bigger Battery Size Required
- Extensive Battery Charging Time
Existing Market Potential for Zero-Emission Construction Equipment

- Various construction equipment types have demonstrated a high potential of clean technology adoption according to previous and on-going demo projects.
- Similar horsepower ranges to electrified on-road heavy-duty applications; some transferability of technologies
  - Semi-truck HP range: 400~600HP
  - 175 HP and lower CE types → higher electrification potential
- Additional demonstration projects for higher horsepower ranges are key
Hybrid Construction Equipment Demonstrations

**Caterpillar's large hybrid excavator**
- Caterpillar hybrid excavator (336F H, 2014)
- 30% fuel savings compared with the similarly sized baseline machine without hybrid technology.

**Volvo CE's electric hybrid wheel loader**
- Volvo Construction Equipment hybrid electric wheel loader (LX1, 2016)
- 50~55% fuel efficiency improvement
- 33~35% GHG emission reduction compared to Volvo CE's diesel-powered base model.
Examples of Zero Emissions Construction Equipment (1)

- PON/CAT Z-line 323F excavator
- Full battery electric
- 164 hp
- 300 kWh energy storage
- Units in service in Norway and Netherlands
- Purchasable today

https://www.pon-cat.com/no/pon-equipment/nyheter/z-line
Examples of Zero Emissions Construction Equipment (2)

- JCB 220X
- Hydrogen Fuel Cell 20 ton excavator prototype
- In proving grounds testing for >18 months

Examples of Zero Emissions Construction Equipment (3)

- Volvo EX02
- Fully electric compact excavator prototype
- 38 KWh energy storage
- Enough to operate the machine for eight hours in an intense application

Examples of Zero Emissions Construction Equipment (4)

- CASE Project Zeus Backhoe
- Battery powered electric backhoe
- 90 KWh energy storage
- Capable of typical 8hr workday
- Purchasable today


Examples of Zero Emissions Construction Equipment (5)

- Volvo L25
- Electric Compact Wheel Loader
- 39 kWh energy storage
- Enough to operate the machine for eight hours
- Expected charging time of 2 hours (Off board charging time 400 VAC 32A)

Current Technology Availability: Construction

* Based on limited market research
** Both commercial and demo models
Assessing Electrification and Hybridization Potential

Hybridization
• Current commercially available technologies and demonstration projects provide application horsepower ranges

Electrification
• Horsepower ranges of currently available commercial models and demos
• Review of current battery capacity and charging times
• Research on daily and maximum power use from different construction and off-road applications
• Determining where current battery technology could meet power requirements
AN EXAMPLE OF ELECTRIFICATION FEASIBILITY ASSESSMENT

1. Assess power needs from ECU data, including peak power and daily energy use

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Equip. ID</th>
<th>HP Bin of the equipment</th>
<th>Total Operating Hours (hrs)</th>
<th>Mean Daily Fuel Use (gal/day)</th>
<th>Hours per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavator</td>
<td>3</td>
<td>175</td>
<td>256.1</td>
<td>20.21</td>
<td>1.75</td>
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<tr>
<td>Grader</td>
<td>4</td>
<td>300</td>
<td>13.3</td>
<td>0.98</td>
<td>0.15</td>
</tr>
<tr>
<td>Off-Highway Tractor</td>
<td>9</td>
<td>600</td>
<td>223.7</td>
<td>137.04</td>
<td>7.99</td>
</tr>
</tbody>
</table>

2. Determine battery size and charging times required to meet demand (in some cases, current technology has prohibitive battery size or charging needs for full electrification)

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Battery Size (kWh)</th>
<th>Charging Time with 50 kW Charger (Hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Excavator</td>
<td>387</td>
<td>420</td>
</tr>
<tr>
<td>Grader</td>
<td>54</td>
<td>60</td>
</tr>
<tr>
<td>Off-Highway Tractor</td>
<td>2,283</td>
<td>2,711</td>
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</table>
Horsepower Ranges for Existing Clean Technologies

Excavators (15%)

Population share (%)
- 57% for 25 HP
- 41% for 300 HP

Diesel fuel use (%)
- 2% for 300 HP

HP bins:
- 25
- 50
- 75
- 100
- 175

HP ranges with higher electrification potential
- 25, 50, 75

HP ranges covered by hybrid CE demo projects
- 100, 175

CARB
Horsepower Ranges for Existing Clean Technologies

- HP ranges of commercial and demo electric models
- HP ranges based on the battery capacity study
- HP ranges with higher electrification potential
- HP ranges covered by hybrid CE demo projects

CARB
The coverage of HP ranges do not exclusively determine the feasibility of ZE and hybrid construction equipment. HP ranges can definitely expand to adjacent areas with innovative power supply solutions and advanced battery technology.
### Potential Fuel Savings

#### Construction & Mining Equipment Type

<table>
<thead>
<tr>
<th>Horsepower Range</th>
<th>Fuel Use by Segment (gpy)</th>
<th>Fuel Share (%)</th>
<th>Baseline Fuel Use (gpy)</th>
<th>Alt. Fuel Use (gpy)</th>
<th>Fuel Reduction (gpy)</th>
<th>% of Reduced Fuel Use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electrification Hybridization</td>
<td>Elec.</td>
<td>Hybrid.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crawler Tractors</td>
<td>- -</td>
<td>0%</td>
<td>0%</td>
<td>15,853,308</td>
<td>15,853,308</td>
<td>-</td>
</tr>
<tr>
<td>Excavators</td>
<td>25-300 600</td>
<td>57%</td>
<td>41%</td>
<td>28,525,577</td>
<td>3,487,686</td>
<td>25,037,891</td>
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<tr>
<td>Graders</td>
<td>300 (100-175)</td>
<td>95%</td>
<td>0%</td>
<td>10,731,276</td>
<td>572,943</td>
<td>10,158,333</td>
</tr>
<tr>
<td>Off-Highway Tractors</td>
<td>175 (300-600) 751 &lt;</td>
<td>59%</td>
<td>15%</td>
<td>36,179,004</td>
<td>10,920,025</td>
<td>25,258,980</td>
</tr>
<tr>
<td>Rollers</td>
<td>25-50</td>
<td>22%</td>
<td>0%</td>
<td>4,931,572</td>
<td>3,860,075</td>
<td>1,071,497</td>
</tr>
<tr>
<td>Rough Terrain Forklifts</td>
<td>25-100</td>
<td>79%</td>
<td>0%</td>
<td>5,353,663</td>
<td>1,107,512</td>
<td>4,246,152</td>
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<tr>
<td>Rubber Tired Loaders</td>
<td>50-175 &amp; 751 &lt; 300-600</td>
<td>31%</td>
<td>66%</td>
<td>43,489,540</td>
<td>8,309,160</td>
<td>35,180,379</td>
</tr>
<tr>
<td>Scrapers</td>
<td>(100-300)</td>
<td>13%</td>
<td>0%</td>
<td>28,325,209</td>
<td>24,659,142</td>
<td>3,666,067</td>
</tr>
<tr>
<td>Skid Steer Loaders</td>
<td>25 50-100</td>
<td>0%</td>
<td>99%</td>
<td>5,185,890</td>
<td>1,352,307</td>
<td>3,833,583</td>
</tr>
<tr>
<td>Tractors/Loaders/Backhoes</td>
<td>50-300 600 (300-600)</td>
<td>87%</td>
<td>9%</td>
<td>39,626,931</td>
<td>2,310,928</td>
<td>37,316,003</td>
</tr>
</tbody>
</table>

**Diesel use of the TOP 10 equipment types (gpy) (87% of the entire sector)**

- 218,201,971
- 72,433,086
- 145,768,885

**Diesel use of the entire Construction and Mining sector (gpy)**

- 251,421,757
- 105,652,873
- 145,768,885

• If the entire population of the target segments are fully electrified or hybridized (i.e., by 2050), it is expected to achieve 58% fuel savings
Need for Zero-Emission Infrastructure Planning

• A reliable infrastructure system is essential for zero emission technologies to achieve widespread growth

• Infrastructure needs, charging standards/connections, and power capacity needs vary widely, and are under various stages of development by source category

• In some off-road applications such as construction or agriculture, access to the grid may be nonexistent

• Innovative solutions are needed to overcome these barriers: mobile and ground power units

• Collaborate and engage facilities, utilities, and other agencies in zero-emission planning discussions
Mobile Battery Solution for Construction Equipment

- Much of the equipment is too heavy to make re-charging trips every day
- Various construction sites may not have stationary power supply
- Mobile batteries provide on-site charging solutions
- 7 mobile and ground power units are available through CORE

Charging station

Mobile battery pack on wheels

Work-zone
Potential Mobile Power Supply Solutions

- Portable hydrogen fuel cell power generator
- Charging service van
- Portable off grid solar chargers
- Efficient fast charging strategy for peak-shaving in a limited grid connection condition
- Battery and tank swapping technologies
The Olav Vs Gate construction site in Oslo, Norway, is a zero-emissions project with ZERON ZE85US (9t) and ZE160LC (17.5t) electrified excavators built by NASTA AS. Courtesy of NASTA AS
Potential Strategies

Voucher Incentives for Clean Off-road Equipment
Expand eligibility for voucher incentives through Clean Off-Road Equipment. Funding for zero-emission off-road construction equipment.

Zero-Emission Forklift Requirements
(Board Date: 2022)
In-Use Requirements for forklifts to transition to zero emissions. Zero emissions equipment is option for replacement.

In-Use Off-Road Diesel Vehicle Amendments
(Potential Board Date: 2023)
Focused on phasing out Tier 0 to Tier 2 equipment
Potential Strategies (continued)

Green Fleet Recognition Program  
(Action by: 2025)  
Voluntary program for recognition of cleanest fleets, with an emphasis on zero emissions. Would allow public agencies and partnerships to choose fleets with minimal environmental impact.

Off-Road Tier 5 Engine Standards  
(Potential Board Date: 2024)  
New NOx, PM, and GHG standards, and considering off-road diesel OBD requirements. May include powertrain certification, and/or credits.

Targeted Zero-Emission Off-Road Equipment Production  
(Potential Board Date: 2025)  
Manufacturer requirements for production of zero-emission off-road equipment. Sales/production mandate levels based on the projected feasibility of zero-emission technology in the various off-road equipment types.
Strategies Timeline

- **SORE Gasoline 2021**
- **Zero-Emission Forklifts 2022**
- **In-use Off-Road Diesel Regulation (Off-Road 2.0) 2023 Including Start to Green Fleet Recognition**
- **Off-Road Tier 5 Engine Standards 2024**
- **Targeted Manufacturer Rule ~2025**

**Expand eligibility for voucher incentives through Clean Off-Road Equipment**

**In-use Off-Road Diesel Regulation (Off-Road 2.0) 2023 Including Start to Green Fleet Recognition**

**Targeted Manufacturer Rule ~2025**
Questions, Comments, Feedback

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Metro’s Green Construction Policy: Program Overview

April 7th, 2021

Shannon Walker, ENV SP
Senior Environmental Specialist, LA Metro
About the GCP

Why was the GCP created?

- Air quality impacts human health.
- The U.S. EPA and the International Agency for Research on Cancer (IARC) have classified diesel exhaust as a potential human carcinogen.
- Diesel engines are a major source of harmful air pollutants.
- Increased planned construction activity from passing of Measure R in 2008.
GCP Purpose and Goal

Purpose

• To identify and mitigate diesel exhaust emission impacts on human health and the environment to the greatest extent feasible.

Application

• Applies to on-road vehicles, off-road equipment, and portable generators used for Metro Construction Projects and at Metro Rights-of-Way.
• Part of the requirements for funding capital projects for other jurisdictions when applying for transportation funds.

Goal

• To reduce harmful diesel exhaust emissions such as Particulate Matter (PM), Nitrogen Oxides (NO$_x$), and Carbon Dioxide equivalent (CO$_2$e) while minimizing impact to construction project costs and schedules.
GCP Regulatory Compliance

California Air Resources Board (CARB) Compliance
- Truck and Bus Regulations
- Off-Road Diesel Regulation
- Large Spark Ignition Fleet
- DOORS Reporting
- PERP
GCP Specification Requirements

Metro Construction Specifications

- The GCP was incorporated into Metro Construction Specifications in May 2012.

Key Requirements

Off-Road Diesel-Powered Construction Equipment
- ≥ 50 BHP, Must Meet Tier 4 Off-Road Emission Standards

On-Road Diesel-Powered Vehicles
- GVWR ≥ 19,500 lbs.
- Must Meet EPA 2010 or greater On-Road Emission Standards

Portable Generators
- ≥ 50 BHP, Permitted/Registered w/ BACT for PM Emissions
GCP Specification Requirements

Additional Requirement: Renewable Diesel

- Mandated use of Bulk Renewable Diesel (R-99) in lieu of Petroleum Diesel (exceptions may apply based on start date of project).
- Aligned with Department of General Services (DGS) MM 15-07.

Best Management Practices

- Use electric power instead of diesel power (when available).
- Limit idling to five (5) consecutive minutes.
- Maintain 1000 feet between Truck Traffic and Sensitive Receptors.
GCP Specification Requirements

Exceptions

• Construction equipment that is part of a small fleet (less than or equal to 2,500 HP).

• Construction equipment required for use at locations defined as “gassy” per Cal/OSHA (must contain lowest emitting MSHA-approved engines or technically feasible)

• On-road equipment or vehicles part of a small fleet (fleet size of 1-3 vehicles); must comply with CARB requirements for small fleets.

• The Contractor has attempted to lease the vehicle or equipment that would comply with this policy, but that vehicle or equipment is not available for lease or short-term rental within 200 miles of the project site

• Exceptions are valid for one year from time of equipment use on-site – updated exception letters must be annually resubmitted to Metro for review.
GCP Specification Requirements

Conformance

• Metro conducts periodic inspections of sites and construction equipment.
• Metro provides assistance to help contractors to meet requirements.

Key Submittals

• Certification of Compliance
• Construction Equipment Information List
• Monthly Fuel Use Log for all equipment used on-site.
• CARB Registration or SCAQMD Permits for Portable Equipment
• Notification within 14 days of new equipment and/or vehicles
GCP Specification Requirements

GCP On-Site Inspections

- CARB EIN numbers
- Gross Vehicle Weight Rating
- Portable Equipment Registration Program
GCP Training

On-Site Training for Contractors

• Training is provided to contractors on Metro’s GCP specification and applicable CARB regulations regularly and often.

• Training is always available on an as-needed basis and is determined by the project’s assigned Metro Environmental PM.

• For all segments pertaining to CARB, a CARB representative conducts the training.
GCP Emissions Impacts

Emissions Calculations

- Fuel usage as reported by each project is compiled to calculate annual emissions of NO\textsubscript{x}, PM, and CO\textsubscript{2}e.
- Emissions are compared between baseline emissions (Tier 2) and specific/actual emissions (Tier 4).
Emissions Impacts

• It is estimated that the use of renewable diesel across multiple construction projects in 2019 resulted in a GHG emissions reduction of 98% compared to petroleum diesel, preventing 2,421 MTCO$_2$e of GHG emissions.

• Similarly, it is estimated that the deployment of renewable diesel at Metro projects reduces PM emissions by ~25-35% and NO$_x$ emissions by ~10% on projects by deploying renewable diesel, compared to petroleum diesel (based on CARB estimates).
Thank you.

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