## Past Projects (114 units tested)

<table>
<thead>
<tr>
<th>Year</th>
<th>Project Name</th>
<th>Units</th>
<th>Measurement System</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>EPA Activity</td>
<td>18</td>
<td>Loggers</td>
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<tr>
<td>2006</td>
<td>Caltrans</td>
<td>12</td>
<td>PEMS</td>
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<td>2006</td>
<td>Port of LA/LB</td>
<td>2</td>
<td>MEL</td>
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<tr>
<td>2012</td>
<td>Caltrans/CARB</td>
<td>27</td>
<td>PEMS/PAMS</td>
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<td>2013</td>
<td>CARB/AQIP</td>
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## Current Projects (150 units)

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<tr>
<th>Year</th>
<th>Project Name</th>
<th>Units</th>
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<tr>
<td>2019</td>
<td>Caltrans</td>
<td>10</td>
<td>PEMS (2days)</td>
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<tr>
<td>2020</td>
<td>ARB</td>
<td>100</td>
<td>PAMS</td>
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<tr>
<td>2021</td>
<td>ARB</td>
<td>50</td>
<td>PAMS some PEMS</td>
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1. Unit is a piece of construction equipment
2. Early version of PEMS so data is limited

PEMS  – portable emission measurement system (1 day)
PAMS  – portable activity measurement system (1-4 weeks)
MEL   – mobile emissions laboratory (1 day)
Logger – simple logger GPS and RPM plus other (1 day)
AQIP  – Air Quality Incentive Program
Caltrans – California Department of Transportation
UCR Tested Off-Road Equipment Logging RPM, Temps, and Other

Exhaust Temperature

MAP
Intake manifold to engine

Data logger stored behind operators seat

RPM Sensor attached to the tachometer.

Throttle position attached to the connecting arm of engine or the driver’s pedal and the throttle.

2001 EPA Activity

From Huai et al “MEASUREMENT OF OPERATIONAL ACTIVITY FOR NONROAD DIESEL CONSTRUCTION EQUIPMENT”, International Journal of Automot
UCR Tested Construction Equipment Before 1065 PEMS

2006 CalTrans

UCR Tested Cargo Cranes with Its MEL

2006 Port LA/LB


UCR Testing Now Involves 1065 Gas and PM PEMS

2012 CalTrans/CARB

Durbin et al “Study of In-Use Emissions from Diesel Off-Road Equipment” Final Report to ARB April 2013
Time Laps Video Setup To Capture Operation Front and Rear Facing Automatic, 3 Mo Operation

From Johnson et al “Hybrid Off-Road Equipment In-Use Emissions Evaluation”, Final Report CARB June 2013
Time Laps Video Capture Unique Modes With Long Term Logging (2-3 mo): Track Dozer

2012 CARB/AQIP

From Johnson et al “Hybrid Off-Road Equipment In-Use Emissions Evaluation”, Final Report CARB June 2013
Time Laps Video Capture Unique Modes With Long Term Logging (2-3 mo): Excavator

2012 CARB/AQIP

From Johnson et al “Hybrid Off-Road Equipment In-Use Emissions Evaluation”, Final Report CARB June 2013
Testing Under In-Service Conditions Complex and Difficult → Low Relative Data Yield

2012 CARB/AQIP

From Johnson et al “Hybrid Off-Road Equipment In-Use Emissions Evaluation”, Final Report CARB June 2013
Testing Under In-Service Conditions
Complex and Difficult $\rightarrow$ Low Relative Data Yield

2014 CalTrans

From Russell et al “Developing a Model to Quantify Emissions from Heavy-Duty Construction Equipment as Related to Job Site Activity Data”, Final Report CalTrans June 2014
Portable Emission Measurement Systems (PEMS) Are Accurate, but Complex

- Accurate and meets reference method (40 CFR part 1065)
- Pre and post calibration required
- Generators or large batteries are needed
- Report support needed (cranes and or forklifts)
- Install times min 4 hr and limited operation 6-8 hrs

Accurate, but Not Easy to Perform and Minimizes Data Capture
Primary Pollutants Of Concern NO$_x$ and PM
So let's focus more on NO$_x$ and PM measurements.

**PM2.5 (Primary)**

- Aircraft: 27%
- Locomotives: 10%
- Nonroad - Diesel: 6%
- Nonroad - non-Diesel: 2%
- Commercial Marine Vessels: 18%
- Onroad - Diesel: 14%

**Mobile Sources**

- Aircraft: 27%
- Locomotives: 10%
- Nonroad - Diesel: 6%
- Nonroad - non-Diesel: 2%
- Commercial Marine Vessels: 18%
- Onroad - Diesel: 14%

**NO$_x$**

- Aircraft: 31%
- Locomotives: 8%
- Nonroad - Diesel: 13%
- Nonroad - non-Diesel: 4%
- Commercial Marine Vessels: 15%
- Onroad - Diesel: 27%

Source: CRC 2019
Simple Emissions Measurement Systems (SEMS) Simplifies Testing

- NOx Sensors Commercially available
- PM shows promise and is available (5 years devel.)
- Autonomous operation (multiple days, weeks, mo…)
- Regulatory pathway for sensors
  - Real Emissions Assessment Logging (REAL)
  - UCR’s version Onboard Sensing, Analysis, and Reporting (OSAR)

NOx, PM, AFR, CO2, and ECM SEMS
CA Emission Inventories Similar for the Top 10

2018 Construction Equipment NOx Emissions in CA

- Rubber Tired Loaders
- Tractors/Loaders/Backhoes
- Off-Highway Trucks
- Scrapers
- Crawler Tractors
- Excavators
- Graders
- Cranes
- Other Construction Equipment
- Rubber Tired Dozers
- Off-Highway Tractors
- Rollers
- Skid Steer Loaders
- Rough Terrain Forklifts
- Sweepers/Scrubbers
- Pavers
- Trenchers
- Bore/Drill Rigs
- Paving Equipment
- Surfacing Equipment

Total NOx (tons/day)

2018 Construction Equipment Total PM Emissions in CA

- Tractors/Loaders/Backhoes
- Rubber Tired Loaders
- Scrapers
- Off-Highway Trucks
- Crawler Tractors
- Excavators
- Graders
- Cranes
- Other Construction Equipment
- Rollers
- Off-Highway Tractors
- Rubber Tired Dozers
- Skid Steer Loaders
- Rough Terrain Forklifts
- Sweepers/Scrubbers
- Trenchers
- Pavers
- Bore/Drill Rigs
- Paving Equipment
- Surfacing Equipment

Total PM (tons/day)

Source OFFROAD2017; CA Statewide; Calendar Year 2018
CA Load/Activity and Population Inventories Vary for the Top 10

2018 Construction Equipment Activity Emissions in CA

- Rubber Tired Loaders
- Tractors/Loaders/Backhoes
- Off-Highway Trucks
- Excavators
- Scrapers
- Crawler Tractors
- Graders
- Cranes
- Skid Steer Loaders
- Off-Highway Tractors
- Rough Terrain Forklifts
- Rollers
- Rubber Tired Dozers
- Bore/Drill Rigs
- Pavers
- Sweepers/Scrubbers
- Trenchers
- Paving Equipment
- Surfacing Equipment

Total Activity (hp-hr/year)

- Tractors/Loaders/Backhoes
- Excavators
- Forklifts
- Skid Steer Loaders
- 39 other, <1% of total

Other Construction Equipment

- Aerial Lifts
- Rough Terrain Forklifts
- Other Construction Equip.
- Rubber Tired Loaders
- Rollers
- Crawler Tractors
- Scrapers
- Graders
- Cranes
- Off-Highway Tractors
- Off-Highway Trucks

Total Population (#)

Source OFFROAD2017; CA Statewide; Calendar Year 2018

Source 2017 CA Doors database
# National Population Shows Trends by Tier

## Model Year

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*EPA NRCl exhaust emission standards at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA05.pdf*
California Equipment Population Shows Similar Trend as Federal by Tier and Type

Source 2017 CA Doors database
Overview of What Has Been Tested and The Data Gaps

- **Scrapers**
- **Excavators**
- **Crawler Tractors**
- **39 other, <1% of total data**
- **Cranes**
- **Off-Highway Trucks**
- **Tractors/Loaders/Backhoes**
- **Graders**
- **Rubber Tired Loaders**
- **Off-Highway Tractors**
- **Rollers**
- **Other Construction Equip.**
- **Rough Terrain Forklifts**
- **Aerial Lifts**
- **Skid Steer Loaders**
- **Forklifts**

Source 2017 CA Doors database
## What Has Been Tested and Where Are The Data Gaps

<table>
<thead>
<tr>
<th>Vehicle Type in California</th>
<th>Number in CA</th>
<th>% &gt; 1%</th>
<th>Tested W/PEMS</th>
<th>Tier</th>
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<td>Tier 4I</td>
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<td>Skid Steer Loaders</td>
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<td>Aerial Lifts</td>
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<td>Tier 4F</td>
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<td>Rough Terrain Forklifts</td>
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<td>Tier 4I</td>
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<td>Off-Highway Tractors</td>
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<td>Rubber Tired Loaders</td>
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<td>Graders</td>
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<td>Off-Highway Trucks</td>
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<td>Cranes</td>
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<td>39 other, &lt;1% of total</td>
<td>11611</td>
<td>9.3%</td>
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<td>Crawler Tractors</td>
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<td>Excavators</td>
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<td><strong>Total</strong></td>
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</table>

a) hybrids (3), b) one with a DPF, c) 2 engines in the scraper (280 and 540 hp), d) There are 39 units in other. One of which is the rubber dozer.

Source 2017 CA Doors database
UCR Collaborations with EPA

- EPA is providing data loggers and support funding for CARB study to data log 100 pieces of construction equipment.

- EPA is providing funding for UCR to identify non-road database sources on equipment type, size range, and any usage information.

- UCR has provided EPA costing information for additional data logging and mini-PEMS and PEMS measurements of fleets UCR is already working with.
CARB study of Potential Electrification of Non-road Applications

- UCR is in contracting for a program to evaluate the potential for the electrification or hybridization of non-road applications.

- Hybridization/electrification feasibility analysis.

- Off-road activity and emissions analysis.

- Hybridization/electrification cost/benefit analysis.

- Development recommendations for future activity collection and demonstration programs.
Studies of Non-Road Equipment being used at Ports

- UCR is supporting several different demonstration programs for non-road equipment being used at Ports in LA, Long Beach, Oakland, and Stockton.

- Work being done in support of CARB Low Carbon Transportation and Fuels Investment and Air Quality Improvement Programs.

- Activity characterization from over 50 pieces of port-related non-road equipment, including yard tractors, top handlers, rubber tire gantry cranes, and forklifts.

- Emissions testing on a smaller subset of this equipment.
THANK YOU

Acknowledgement

• California Department of Transportation (CalTrans)
• California Air Resources Board
• Environmental Protection Agency
Previous Studies Details

- CARB – Caltrans – Study #2
  - PEMS on 27 pieces of equipment (2003 – 2012) – 1 day of testing (some from AQIP below)
- CARB AQIP Study of Hybrid bulldozers and excavators
  - PEMS on 5 pieces of equipment (2007 – 2012) – 1 day of testing (video + logger)
### Previous Studies Details

- **Caltrans PM modeling – PEMS**
  - 5 equipment (2011 – 2013) – PEMS 45 pieces of T2 to T4i equipment (many for only a few hours to one or more weeks)
- **Caltrans – Emissions study #3**
  - 10 pieces of equipment (Tier 4 final) – 2 days of staged testing

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<th>Project Year</th>
<th>Agency</th>
<th>Model</th>
<th>Type of Equipment</th>
<th>Tier</th>
<th>Tech Group</th>
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Previous Studies Details

- Caltrans – Emissions study #3
- 10 pieces of equipment (Tier 4 final) – 2 days of staged testing

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