



# **Tier 5 Rulemaking Workshop**

## **DRAFT Potential Off-Road In-Use Testing Program**

**February 27, 2026**

*The text is draft, for purposes of discussion, and may be revised and/or reorganized in the future*

# Outline

- Background: Off-Road In-Use Programs
- Summary of the Draft Potential Changes to the Tier 4 Off-Road In-Use Compliance (ORIUC) Program
- Summary of the Draft Potential Changes to the Tier 5 Off-Road In-Use Testing (ORIUT) Program
- Engine Control Module (ECU)/Sensor Data Screening: Feedback and Changes since the Oct. 2024 workshop
- Manufacturer-Run In-Use Portable Emission Measurement System (PEMS) Testing: Feedback and Draft Potential Changes
- Request for Stakeholder Feedback

# Background on Off-Road In-Use Programs (ORIUT and ORIUC)

- Purpose: To ensure off-road engines meet emissions standards under real-world operating conditions, and that engine families (EF) comply throughout their useful life
- Under the CARB-run ORIUC program, we conduct in-use testing of Tier 4 engines
- Staff is introducing a first-time manufacturer-run test ORIUT program for Tier 5 engines
- In past workshops, staff introduced a draft potential manufacturer-run ORIUT program applicable to Tier 5 EF  $56 \leq \text{kilowatt (kW)} \leq 560$ , which includes:
  - ECU/Sensor Data Screening
  - Manufacturer-Run In-Use Testing

# Summary of the Draft Potential Tier 4 ORIUC Program Changes

- Applies to Tier 4 off-road Compression-Ignition (CI) engines and marine CI engines <37 kW certified under Title 13, CCR § 2423.
- Purpose: Clarify the language for Tier 4 ORIUC program.
- References: Incorporates relevant sections from 40 Code of Federal Regulation (CFR) Parts 86, 1036, 1039, 1065, 1068, with California provisions.
- Testing Method: PEMS testing based on Not-To-Exceed (NTE) provisions or engine dynamometer testing.
- Engine family failure criteria:
  - If 2 or more engines fail engine-pass criteria → test up to 10 engines.
  - If 3 or more of 10 engines fail → engine family fails and is noncompliant.

# Summary of the Draft Potential Tier 5 ORIUT Program Changes (1/2)

- Drafted a 2-Bin Moving Averaging Window (2B-MAW) method to evaluate Nitrogen Oxides (NO<sub>x</sub>) emission performance for both the ECU/Sensor Data Screening and Manufacturer-Run In-Use PEMS testing
- ECU/Sensor Data Screening
  - Less stringent screening compliance thresholds for both idle and non-idle bins
  - Incorporated adjustment factor values for NO<sub>x</sub> sensor bias
  - Removed the Pilot Program for ECU/Sensor Screening

# Summary of the Draft Potential Tier 5 ORIUT Program Changes (2/2)

- Manufacturer-Run In-Use PEMS Testing
  - Reduced testing burden: limiting PEMS test orders to 25% of the number of large sales volume EFs\*
  - Introduced low ambient temperature correction factors
  - Removed the interim margin from the in-use PEMS NO<sub>x</sub> emission thresholds
  - Relaxed the requirements for small and very small sales volume EFs

\*If special cases are triggered, staff may select EFs without it counting toward the 25% limit.

# ECU/Sensor Data Screening



# ECU/Sensor Data Screening Flowchart

Submit screening data for at least 75% of engines per EF annually



Annual assessment of data by Executive Officer (EO) or their designee

An EF that meets both the NOx and Particulate Matter (PM) criteria would be flagged as "clean EF", otherwise it is flagged as "dirty EF."



"Clean EFs" are exempted from ORIUT PEMS testing



"Dirty EFs" would be potentially flagged for in-use PEMS testing\*

*\* If special cases are met for the dirty EF, the EO may request additional testing that does not count towards the EF's PEMS testing cap*

# Feedback and Changes to the Minimum Reporting Requirements

- **Stakeholder Comment:** The minimum reporting requirements due to unforeseen conditions, such as no wireless connection, no satellite connection, remote location, etc., are too strict
- **Staff Response:** Staff has revised the test procedure to allow the engine manufacturer to submit data on less than 75% of engines per EF, after the engine manufacturer notifies the EO and gets approval. Approval would be based on the manufacturer demonstrating that the submitted data is representative of the engine family and providing justifications for all missing data.

# Feedback and Clarification on Data Submission Frequency

- **Stakeholder Comment:** The annual sensor data submission is too frequent, and should be no more than every 3-5 years
- **Staff Response:** Testing every 3 years or more would significantly postpone PEMS testing and could possibly cause excess emissions to occur without being addressed

# Feedback and Changes to the Requirements for Very Small Sales Volume EFs

- Manufacturers have reported challenges in sourcing test articles for very small sales volume EFs
- Since this category contributes less than 5% of the overall emissions, staff is considering relaxing the PEMS testing requirements for very small sales volume EFs to prioritize testing resources.

Program	Large California Sales Volume	Small California Sales Volume	Very Small California Sales Volume
ECU/Sensor Data Screening	Mandatory	Optional	Optional
Manufacturer-Run In-Use PEMS Testing	Mandatory	Mandatory	Optional*

Power Category	Large California Sales Volume	Small California Sales Volume	Very Small California Sales Volume
$56 \leq kW < 130$	>45	$10 \leq \text{sales} \leq 45$	<10
$130 \leq kW \leq 560$	>22	$5 \leq \text{sales} \leq 22$	<5

\* This is a change from the last workshop

# Moving Averaging Window Method

- The moving average window method is used to evaluate emissions performance by averaging emission data over 300-second windows and grouping them into bins
- Depending on how the data is segmented, the method is categorized as either a 2B-MAW or a 3-Bin Moving Averaging Window (3B-MAW) method

In-Use Screening Bins	Bin Categories
<b>2B-MAW Bins</b>	Bin A: Idle Bin B: Non-idle
<b>3B-MAW Bins</b>	Bin A: Idle Bin B: Low Load Bin C: High Load

# Feedback on 3B-MAW Method

- In 2023, staff introduced a torque-based 3B-MAW method to assess in-use NOx emissions using on-board sensors. Stakeholders have provided valuable feedback, including:
  - Minimum Window Requirements: Meeting the minimum window requirements for Bins B and C would be challenging for some off-road applications
  - Effectiveness: Some stakeholders suggested that a 2B-MAW method could be equally as effective in identifying high-emitting engines

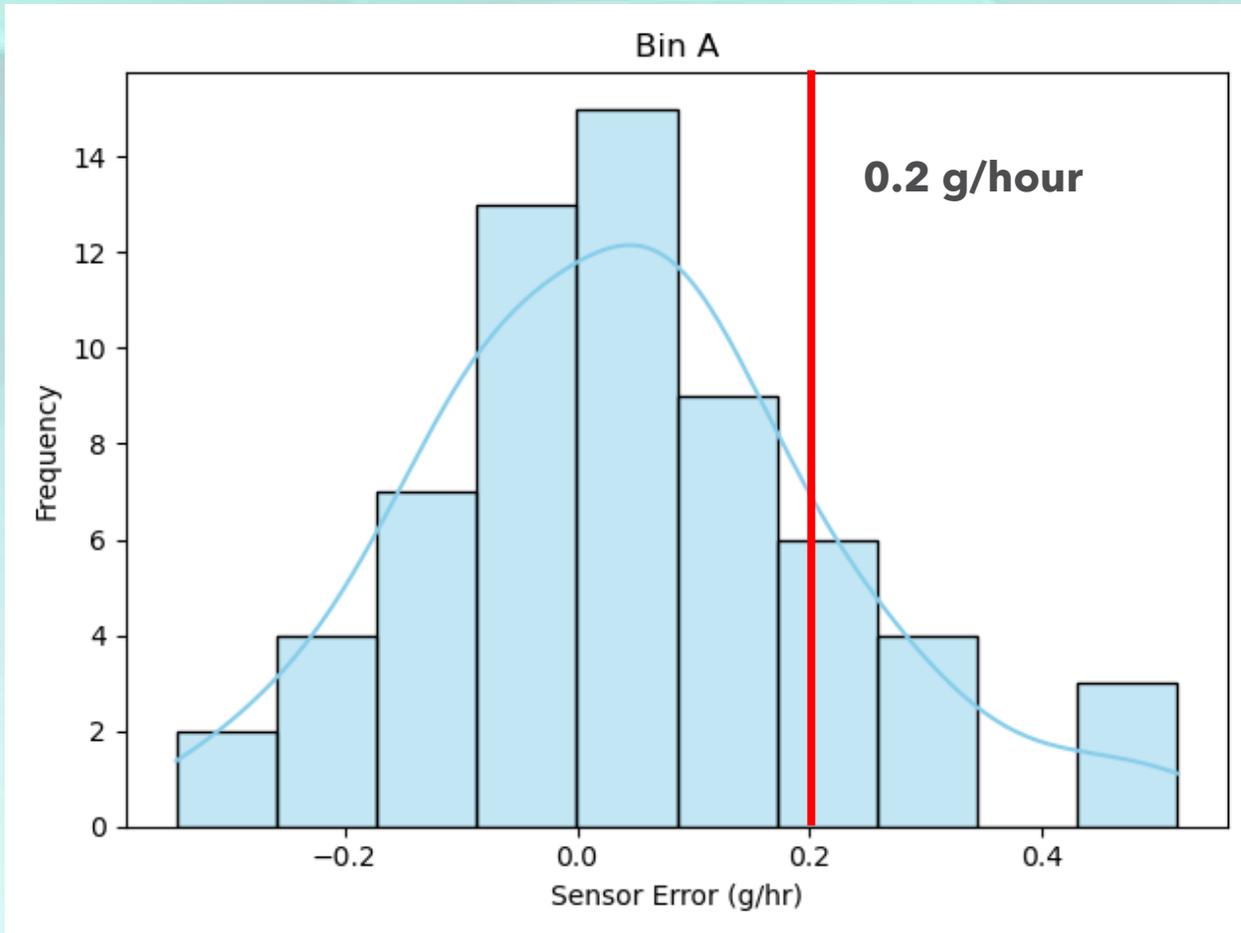
# Rationale for Selecting the 2B-MAW Method Over the 3B-MAW Method

- Southwest Research Institute (SwRI) off-cycle testing project demonstrated the 2B-MAW to be equally effective in flagging higher-emitting engines.
- The 2B-MAW method increases the likelihood of meeting minimum valid window requirements within a single day's testing
- 2B-MAW aligns with U.S. EPA

# Development of the Sensor Accuracy Margin

- In 2023, CARB staff introduced a sensor accuracy margin to account for measurement error between on-board NOx sensors and 1065-compliant laboratory instruments.
- To support this effort, SwRI conducted a two-year CARB-funded study to evaluate the performance of on-board NOx sensors. As part of the project:
  - 9 sensors from 3 different manufacturers were tested
  - All sensors were aged for at least 800 hours
  - A correction algorithm was developed using existing sensor data from both on-road and off-road applications
    - The algorithm significantly improved sensor performance, particularly at low NOx concentrations
  - The sensors were evaluated under 7 off-road in-use test cycles using the Tier 5 demonstration engine
- CARB staff analyzed the data to determine appropriate NOx sensor accuracy margins for Bin A and Bin B.

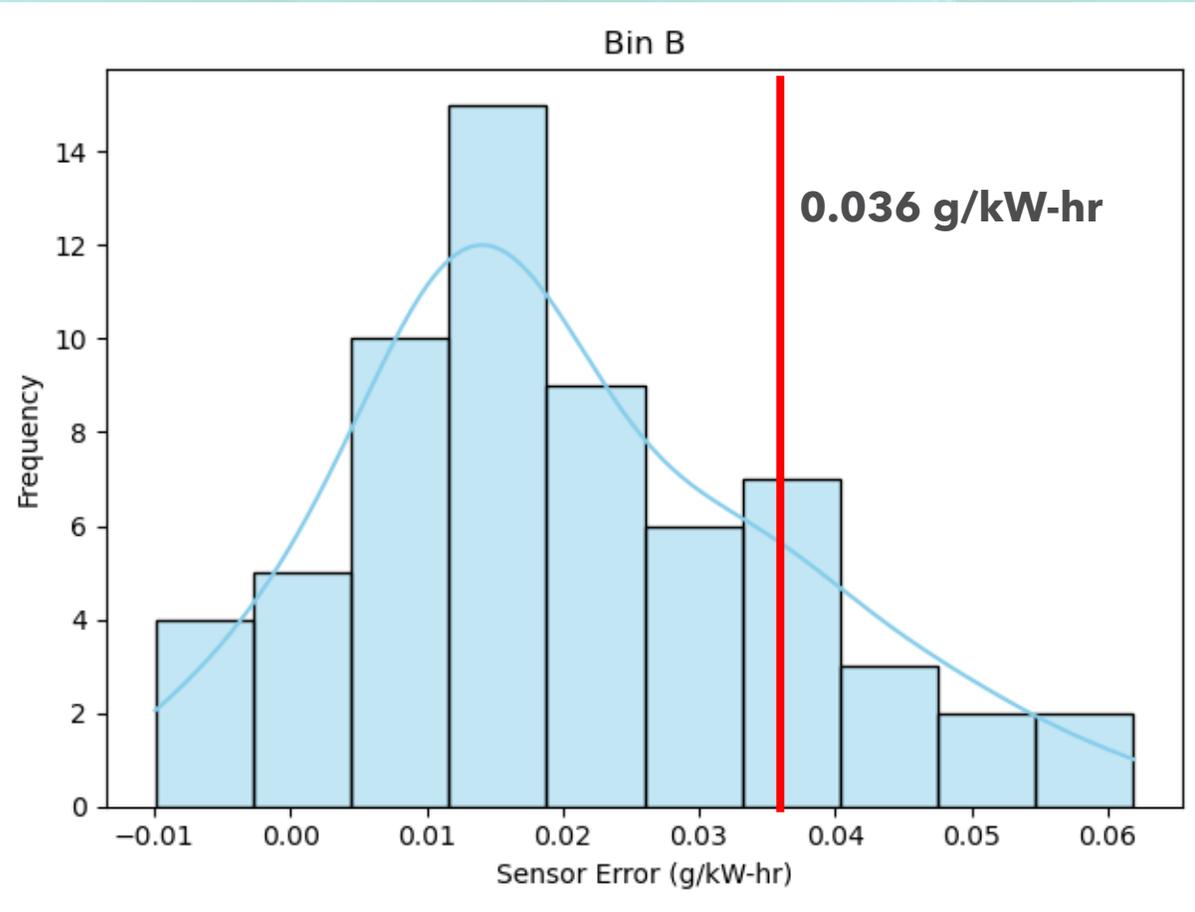
# Draft Potential Sensor Accuracy Margin for ECU/Sensor Data Screening-Bin A



- Staff accounted for sensor technology, production variability, sensor aging, duty cycle, and ammonia interference in setting a sensor accuracy margin
- We estimated the sensor measurement error for Bin A, after applying the correction algorithm.
  - Positive offset: 0.04 grams per hour (g/hour)
  - Standard Deviation (SD): 0.18 g/hour
- Staff is considering a sensor accuracy margin for Bin A of **0.2 g/hour**

Request for feedback from stakeholders on this margin and your rationale, including data

# Draft Potential Sensor Accuracy Margin for ECU/Sensor Data Screening-Bin B



- We estimated the sensor measurement error for Bin B, after applying the correction algorithm.
  - Positive offset: 0.020 grams per kilowatt-hour (g/kW-hr)
  - SD: 0.016 g/kW-hr
- Staff is considering a sensor accuracy margin for Bin B of **0.036 g/kW-hr**

Request for feedback from stakeholders on this margin and your rationale, including data

# Summary of the Draft Potential NOx Emission Screening Threshold for 2B-MAW Bins

2B-MAW Bins	NOx Emission Screening Threshold
Bin A: Idle	$CF^4 \times \text{Idle Standard}^1 + m_{\text{Sensor Accuracy}}^2$
Bin B: Non-idle	$CF^4 \times (0.75^5 \times \text{NRTC standard}^3 + 0.25^5 \times \text{OR-LLC standard}^3) + m_{\text{Sensor Accuracy}}^2$

1. Idle NOx Standards for  $56 \leq \text{kW} < 130$  is 5.0 g/hr or 0.0769 g/kW-hr \* Power, whichever is greater, and for  $130 \leq \text{kW} < 560$  is 10.0 g/hr or 0.0282 g/kW-hr \* Power, whichever is greater.
2.  $m_{\text{Sensor Accuracy}}$  is 0.2 g/hr for Bin A and 0.036 g/kW-hr for Bin B
3. For constant speed engines, replace the NRTC and OR-LLC standard with the standard for the applicable steady-state duty cycle
4. Conformity Factor (CF) = 1.5 for criterion 1 and CF = 2.0 for criterion 2
5. Considering weighting factors of 75% Non-Road Transient Cycle (NRTC) and 25% Off-Road Low Load Cycle (OR-LLC)

# Summary of the Draft Potential NOx Emission Evaluation Method - Pass Criteria

- In 2023, staff introduced a screening approach for evaluating NOx emissions with two criteria.
- A clean EF would be identified if both criteria 1 and 2 are met for both the Stored 50-hour and Lifetime Array\*:
  - Criterion 1: The arithmetic average emissions of the EF is less than the screening thresholds for Bin A and Bin B ( $CF_{\text{screening } 1} = 1.5$  plus an accuracy margin) **and**;
  - Criterion 2: The combined number of engines with no reported data<sup>†</sup> and engines with emissions higher than the screening threshold for Bin A or Bin B ( $CF_{\text{screening } 2} = 2.0$  plus an accuracy margin) is less than or equal to 25% of total California sales
- Staff received feedback indicating that the pass criteria needed further clarification. In response, we provided an example of how the draft criteria would be applied.

\*The lifetime array will be used when the stored 50-hr array is not available.

<sup>†</sup> Except those engines that are demonstrated to meet criteria such as low usage, remote location, etc.

# NOx Emission Screening Threshold: Example for a 187 kW Variable Speed Engine

2B-MAW Bins	Criteria 1: NOx Emission Screening Threshold	Criteria 2: NOx Emission Screening Threshold
Bin A: Idle	8.1* g/hour	10.7 g/hour
Bin B: Non-idle	0.104** g/kW-hr	0.126 g/kW-hr

\*Example Criteria 1 Calculation for Bin A :

$$1.5 \times (0.0282 \text{ g/kW-hr} \times 187\text{kW}) + 0.2 \text{ g/hour} = 8.1101 \text{ g/hour} \approx 8.1 \text{ g/hour}$$

\*\*Example Criteria 1 Calculation for Bin B:

$$1.5 \times (0.04 \text{ g/kW-hr} \times 75\% + 0.06 \text{ g/kW-hr} \times 25\%) + 0.036 \text{ g/kW-hr} = 0.1035 \text{ g/kW-hr} \approx 0.104 \text{ g/kW-hr}$$

# Pass Criteria for Bin B NOx Emissions Evaluation: Example for Large EFs

EF number	California Sales Volume	Reporting Rate: Pass if > 75%		Criterion 1: Pass if < 0.104 g/kW-hr	Criterion 2: Pass if < 25%		Flagged for Potential PEMS Testing?
		Number of engines reported	Percentage of engines reported	Average of NOx emissions for this EF	Sum of the unreported engines <sup>†</sup> and engines exceeding thresholds (CF=2.0)	Percentage of the unreported engines <sup>†</sup> and engines exceeding thresholds (CF=2.0)	
EF1	46	44	96%	0.040	4	9%	No
EF2	98	95	97%	<u>0.150</u>	5	5%	Yes
EF3	37	35	95%	0.081	9	<u>26%</u>	Yes
EF4	40	25	<u>63%</u>	0.072	20	<u>50%</u>	Yes

- Red underlined text indicates example EFs that would fail the NOx screening criteria.
- EF2, EF3, and EF4 are flagged for potential manufacturer-run in-use PEMS testing.

\*This Bin B threshold is used for illustration purposes only.

† Assuming unreported engines do not meet the conditions, such as low usage, remote location, etc.

# Draft Potential Changes to ECU/Sensor Data Screening Pilot Program

- Staff has re-evaluated the need for a pilot program because:
  - The implementation start date would start with Model Year (MY) 2036, providing manufacturers with additional time for research and development.
  - There will be no On-Board Diagnostics requirements for Tier 5 interim
- As a result, staff removed the ECU/Sensor Data Screening pilot program

# Manufacturer-Run In-Use PEMS Testing



# Feedback and Changes to PEMS Testing Rate (1/2)

- **Stakeholder Comment:** PEMS testing is overly burdensome. It is not appropriate for off-road to use a heavy-duty on-highway benchmark to test 25% of the number of EFs.
- **Staff Response:** Staff is reducing the burden by limiting PEMS testing requirement to large sales volume EFs, which have a greater overall emissions impact. Annual test orders will not exceed 25% of the average number of large-volume EFs certified over the past four years,\* rounded to the nearest whole number.
- Staff analyzed certification data from 2018 to 2024 to estimate the scope of PEMS testing in the future
  - For example, the highest number of large sales volume EFs per manufacturer is 8. Under the 25% cap on PEMS testing for EFs, a manufacturer would test at most 2 EFs per year.\*

\*Except special cases

## Feedback and Changes to PEMS Testing Rate (2/2)

- **Stakeholder Comment:** Stakeholders suggest providing more flexibility for finding test articles for off-road equipment.
- **Staff Response:** Staff recognizes the challenge in locating test articles in the off-road sector. Staff is considering allowing manufacturers to request either a modification to the requirements or the selection of a different engine family with EO approval.

## Feedback on PEMS Testing for PM

- **Stakeholder Question:** Is there a need to require PEMS testing for PM, since on-road vehicles that have malfunctioning Diesel Particulate Filters (DPF) are excluded from in-use testing?
- **Staff Response:** Because diesel PM is an air toxic, PM testing is necessary to identify when excess emissions occur without triggering the Malfunction Indicator Lamp (MIL). For example, a degraded DPF may not trigger a MIL fault code and could lead to increased PM emissions.

# Feedback on Emission Evaluation Method for PEMS Testing

- Staff is considering a 2B-MAW method to evaluate emission performance for both the in-use screening and PEMS programs
  - For the ECU/Sensor Data screening, the 2B-MAW would be used for NOx emissions only
  - For Manufacturer-Run In-Use PEMS Testing, the 2B-MAW would be used for evaluating all criteria pollutant emissions
- Stakeholders raised concerns that the emission evaluation method for PEMS testing does not account for the low ambient temperature adjustment factor. Staff evaluated the need for an adjustment factor.

# Low Ambient Temperature Adjustment Factors

- Cold ambient temperatures could potentially impact tailpipe NOx performance
- SwRI conducted a study funded by the Truck and Engine Manufacturers Association (EMA) to evaluate the potential effects of ambient temperatures on NOx emissions. The testing conditions included:
  - The Tier 5 demonstration engine with a modified aftertreatment configuration (Configuration 1: Shorter transfer tube from engine, longer intermediate pipe)
  - Average cell temperature: 3 - 28 °C
  - With and without wind (12 miles/hour)
  - With and without dynamic skip fire
  - Nominal rating (186 kW) and child rating (126 kW)
  - EMA Field Cycle 2 created from manufacturer field data (~4 hours; average torque 16.7%)
  - Tests were also conducted for the NRTC and LLC

# Results of Low Ambient Temperature Emissions Testing

- The worst-case temperature effects on the EMA Field Cycle 2 were observed for the child-rating engine:

In-Use Bins	Cold (3 °C)	Nominal (27 °C)
Bin A (g/hr)	2.2	0.12
Bin B (g/kW-hr)	0.079	0.030

- Higher emissions were observed for the OR-LLC duty cycle with the child-rating engine
- Although the OR-LLC had higher emissions, staff is considering the field cycle results to be the most relevant because low ambient temperatures are only encountered during field testing

# Draft Potential Low Ambient Temperature Correction Factors for PEMS In-Use Bin Thresholds

- Based on the worst-case low ambient temperature effects in the field cycle testing demonstration, the following low ambient temperature correction factors ( $m_{\text{low amb } T}$ ) were added to the PEMS NOx emission thresholds:

PEMS In-Use Bin	$m_{\text{low amb}}$	Unit
PEMS Bin A	$(20.0 - T_{\text{amb}}) \times 0.122^*$	g/hr
PEMS Bin B	$(20.0 - T_{\text{amb}}) \times 0.00288^{**}$	g/kW-hr

- The slope was calculated assuming that temperature corrections are needed when ambient temperature ( $T_{\text{amb}}$ ) falls below 20 °C

\*Calculated from 2.2 g/hr at 3 °C and 0.12 g/hr at 20°C

\*\*Calculated from 0.079 g/kW-hr at 3 °C and 0.030 g/kW-hr at 20°C

# Feedback on PEMS Testing Failure

- **Stakeholder Question:** Will an EF that fails the PEMS testing criteria automatically trigger a recall?
- **Staff Response:**
  - Yes, after PEMS testing, if it is determined that an EF is non-compliant with the Sum-Over-Sum (SOS) Emissions In-Use Thresholds in Part II, Subpart A, section 3.5.1.2 of the Test Procedures, the manufacturer shall take steps to correct the non-compliance in accordance with title 13, CCR, sections 2113.1 and 2125.1
  - Examples of corrective action include updating the calibration of the engines, replacing defective parts, or taking additional measures that reduce emissions from the engines

# Removal of the Interim Allowance for In-Use PEMS Testing

- Staff has re-evaluated the need for an interim allowance for PEMS testing, given that Tier 5f implementation would start with MY 2036
- Staff anticipates that this new timeline will provide manufacturers with sufficient opportunity to continue technology development and prepare for compliance
- Therefore, we are considering removing the interim allowance

# Summary of the Draft Potential SOS Emissions In-Use Thresholds for PEMS Testing

PEMS In-Use Bin	SOS Emissions In-Use Threshold	Example: NO <sub>x</sub> Emission Threshold for a 187 kW Variable Speed Engine at 20 °C
PEMS Bin A: Idle	$1.5 \times \text{Idle Standard} + m_{\text{PEMS Accuracy Margin}} + m_{\text{low amb}}$	8.3 g/hr
PEMS Bin B: Non-idle	$1.5 \times (0.75 \times \text{NRTC standard} + 0.25 \times \text{OR-LLC standard}) + m_{\text{PEMS Accuracy Margin}} + m_{\text{low amb}}$	0.075 g/kW-hr

PEMS In-Use Bins	$m_{\text{PEMS Accuracy Margins}}$			
	NO <sub>x</sub>	PM	NMHC	CO
PEMS Bin A	0.4 g/hr	n/a	n/a	n/a
PEMS Bin B	0.007 g/kW-hr	0.008 g/kW-hr	0.013 g/kW-hr	0.034 g/kW-hr

NMHC: Non-Methane Hydrocarbons

CO: Carbon Monoxide

# Request for Stakeholder Feedback

## ECU/Sensor Data Screening Program

- Feedback on the NO<sub>x</sub> sensor accuracy margins for Bin A and Bin B
- Comments on the minimum annual reporting rate and flexibility for small and very small sales EFs
- Comments on removing pilot program for ECU/Sensor Data Screening

## Manufacturer-Run PEMS Testing Program

- Comments on removing the interim margin, considering the updated Tier 5f timeline and industry readiness
- Comments on the 25% cap for large sales volume EF and criteria for selecting test articles
- Feedback on the low ambient adjustment factors for NO<sub>x</sub> emissions

Comments may be submitted via email to **[tier5@arb.ca.gov](mailto:tier5@arb.ca.gov)**

**Questions?**

# Appendix

# Appendix-1 Overview of the Draft Potential In-Use Test Procedures for Tier 4 Engines

- Tier 4 engines are subject to CARB-run ORIUC, not manufacturer-run ORIUT

Tier 4 ORIUC (All Power Categories)	Location in the Tier 4 In-Use Test Procedures	Adopted with Modification
Selection & Screening	Part II, Subpart A, Section 4	CFR §1036.410
Preparing & Testing Engines	Part II, Subpart A, Section 5	CFR §1036.415
NTE Test Procedures	Part II, Subpart A, Section 6	CFR §86.1370
NTE Emission Limits	Part II, Subpart A, Section 7	n/a*
Engine Pass Criteria	Part II, Subpart A, Section 8	CFR §86.1912
Engine Family Pass Criteria	Part II, Subpart A, Section 9	CFR §1036.425

**Tier 4 Code of California Regulation (CCR) References:** Title 13 CCR §2423 (Tier 4 standards); Title 13 CCR §2137-2138 (engine selection & maintenance); Title 13 CCR §2113-2135 (recall & corrective action)

\* California Provisions

# Appendix-2 Overview of the In-Use Test Procedures for Tier 5f Engines <56 kW & >560 kW, all Tier 5i Engines, and MY2031+ Marine Engines <37 kW

- These engines are only subject to CARB-run ORIUC, not manufacturer-run ORIUT

Tier 5f (kW<56 & kW>560, Tier 5i and MY2031+ Marine Engines <37 kW ORIUC	Location in the Tier 5 In-Use Test Procedures	Adopted with Modification
Selection & Screening	Part II, Subpart B, Section 1.2	CFR §1036.410
Preparing & Testing Engines	Part II, Subpart B, Section 1.3	CFR §1036.415
NTE Test Procedures	Part II, Subpart B, Section 1.4	CFR §86.1370
NTE Emission Limits	Part II, Subpart B, Section 1.5	n/a*
Engine Pass Criteria	Part II, Subpart B, Section 1.6	CFR §86.1912
Engine Family Pass Criteria	Part II, Subpart B, Section 1.7	CFR §1036.425

**Tier 5 CCR References (wherever applicable):** Title 13 CCR §2423.1 (Tier 5 standards); Title 13 CCR §2423.2 (Marine standards); Title 13 CCR §2422 (Off-Road On-Board Diagnostic (OR OBD)); Title 13 CCR §§2113.1-2135 (Recall & Corrective action) \* California Provisions

# Appendix-3 Overview of the Test Procedures for Tier 5f Engines ( $56 < \text{kW} < 560$ )

- These engines are subject to both manufacturer-run ORIUT and CARB-run ORIUC.

Tier 5f ( $56 < \text{kW} < 560$ ) ORIUT & ORIUC	Location in the Tier 5 In-Use Test Procedures	Adopted with Modification
ECU & Sensor Data Screening and Reporting Requirements	Part II, Subpart A, Section 1 and Section 2	n/a*
In-Use PEMS Testing	Part II, Subpart A, Section 3	CFR §1036.401-§1036.440
Engine Pass Criteria for PEMS Testing	Part II, Subpart A, Section 3.5	CFR §1036.420
Engine Family Pass Criteria for PEMS Testing	Part II, Subpart A, Section 3.6	CFR §1036.425
Moving Average Window Test Procedures	Part II, Subpart C	CFR §1036.530

**Tier 5 CCR References:** Title 13 CCR §2423.1 (Tier 5 standards); Title 13 CCR §2422 (OR OBD & Off-Road Real Emissions Assessment Logging); Title 13 CCR §§2113.1-2135 (recall & corrective action)

\* California Provisions