OR-OBD Discussion Outline

- Off-Road OBD Proposal
  - OR-OBD system
  - Standardization Requirements Overview
    - Phase 1 Standardization
    - Phase 2 Standardization
  - Diagnostic Requirements Overview
    - On-Board Monitoring & Diagnostics (OBMD)
    - OBD
  - Implementation Schedule

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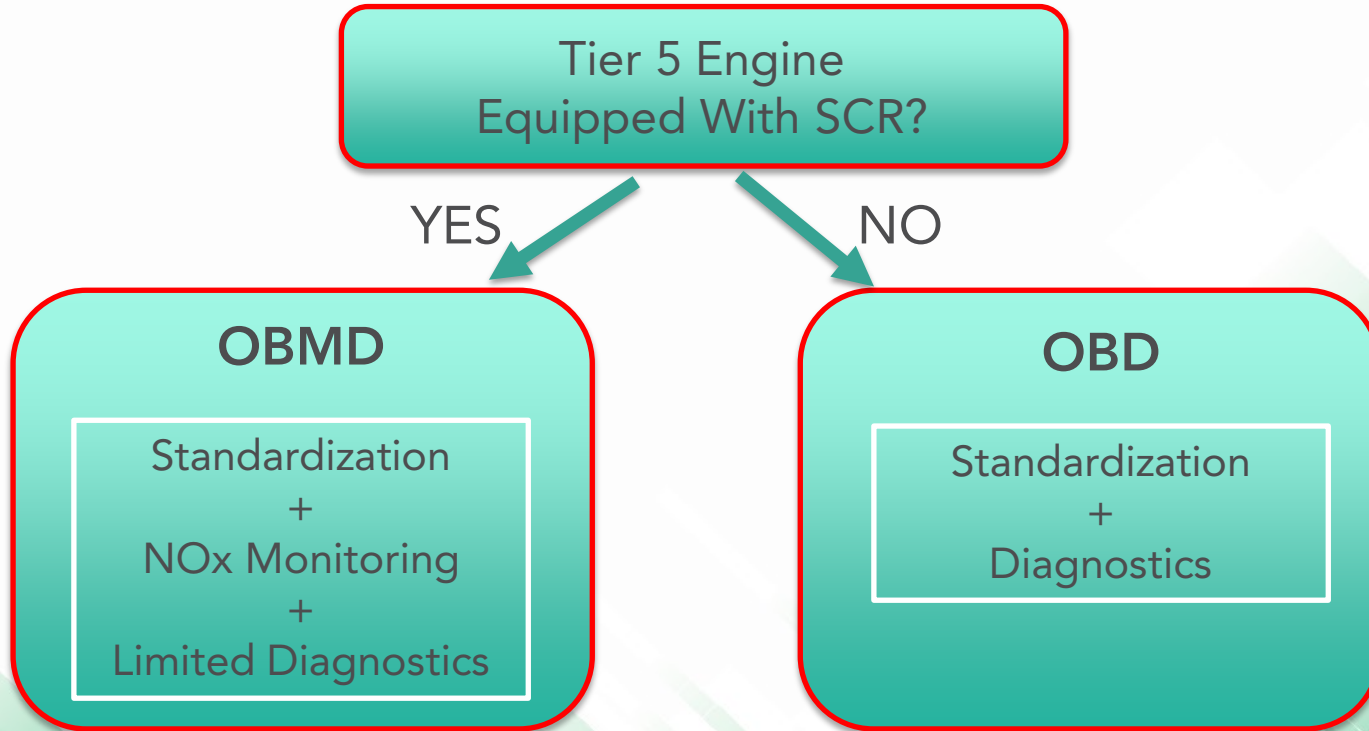
OR-OBD System

Standardization Requirements Overview

- Standardizing the OR-OBD system is key
  - Enables universal access to diagnostic information for technicians, owners, operators, regulators, etc.
  - Structures diagnostic information in a consistent, understandable format across all engine makes
- Staff proposes two implementation phases for OR-OBD standardization
  - Phase 1 Standardization
  - Phase 2 Standardization

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Phase 1 Standardization Requirements

- Applies to all Tier 5 interim and final engines with electronic control units (ECUs)
  - Begins the first model year that a Tier 5 engine is introduced
  - Covers engines in all power categories
- Elements include:
  - Communication protocol
  - Data link connector (DLC)
  - Data stream requirements
  - Off-Road Real Emissions Assessment Logging (OR-REAL) data (SCR-equipped engines only)
  - Calibration identification number (CALID) and calibration verification number (CVN)
- Diagnostic-related elements included later in Phase 2 standardization

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Communication Protocol

- Proposal: allow either SAE J1939 or J1979-2
  - J1939 already in widespread use in off-road engines
  - Harmonizes with on-road heavy-duty engines
- Specify 500 kbps baud rate for J1939

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Data Link Connector

- For J1939 engines: SAE J1939-13 (green 9-pin Deutsch)
- For J1979-2 engines: SAE J1962 (16-pin)
- Location
  - DLC must be near operator controls or engine's power switch and not hidden behind a panel
  - If not technically feasible, may request to apply durable label to exterior of equipment which indicates DLC location
    - Location must be easily accessible

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Data Link Connector (cont'd)

- Embedded Scan Tool concept was raised by industry as alternative to physical DLC

  - Diagnostic data provided via web browser and potentially WiFi/Bluetooth

- Staff is giving the concept consideration: perhaps allow if certain DLC "equivalence" criteria are met? E.g.:

  - Universal access (e.g., no fees or permission to access)

  - Reliable lifetime access (e.g., local wireless communication available not just web)

  - Data logging functionality

  - Data authenticity (e.g., assurance the data is directly from vehicle/equipment)

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Data Stream Requirements

- All physical inputs and outputs related to the engine and emission control system:

  - All sensor input data (e.g., temperature, pressure sensors)

  - All output data (e.g., commanded EGR valve position)

- All parameters related to PEMS testing and OR-REAL calculations if equipped, e.g.:

  - Engine speed, reference torque, actual indicated torque, nominal engine friction torque

  - NOx sensor concentrations, NOx sensor status, exhaust gas mass flow rate, fuel rate
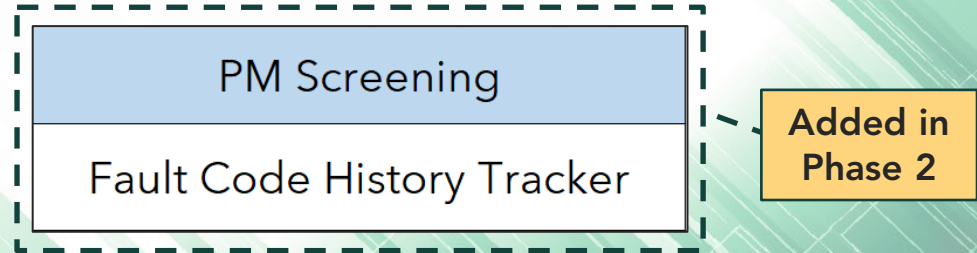
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Data Stream Requirements (cont'd)

- All parameters needed to support in-use compliance screening, e.g.:
  - Engine family name, engine serial number, engine rated power, engine hours of operation
  - OBD requirements to which the engine is certified
  - Engine run time since last code clear

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OR-REAL Data Tracking: Bin Structure

	Bin 1 Total	SCR Outlet Temperature (deg C)			
		≤ 200	> 200 & ≤ 250	> 250 & ≤ 400	> 400
Power (% of rated)	≤ 25%	Bin 2	Bin 3	Bin 4	Bin 5
	> 25% & ≤ 50%	Bin 6	Bin 7	Bin 8	Bin 9
	> 50%	Bin 10	Bin 11	Bin 12	Bin 13

DPF Regen	Bin 14
MIL-on	Bin 15

Active in Phase 2
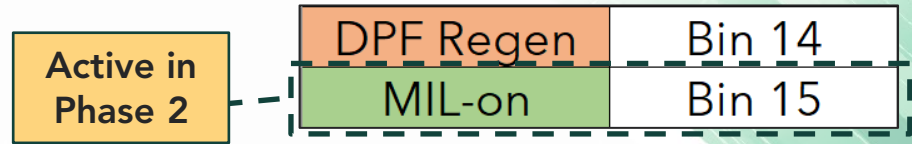
NOx Screening 3B - MAW		
Bin A	Bin B	Bin C

PM Screening
Fault Code History Tracker

Added in Phase 2

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OR-REAL Data Tracking: Parameters and Arrays

Parameter	Active 50 Hour Array[1] (Bins)		Stored 50 Hour Array[1] (Bins)		Lifetime Array[1] (Bins)		Lifetime Engine Activity Array[2] (Bins)	
NOx mass – engine out (g)	1-15	-	1-15	-	1-15	-	-	-
NOx mass – tailpipe (g)	1-15	A, B, C	1-15	A, B, C	1-15	A, B, C	-	-
Engine output energy (kWh)	1-15	B, C	1-15	B, C	1-15	B, C	1-15	B, C
Engine Run time (hours)	1-15	A, B, C	1-15	A, B, C	1-15	A, B, C	1-15	A, B, C
Total fuel consumption (liters)	1-15	-	1-15	-	1-15	-	1-15	-

1. Tracks data only when NOx sensors are on.
2. Tracks data over all engine activity (can thus determine amount of activity with no NOx data).

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CALID & CVN Requirements

- Phase 1 Standardization
  - All ECUs associated with engine controls, emission controls, or aftertreatment controls (e.g., DEF dosing module) must support CALID and CVN
- Phase 2 Standardization
  - All diagnostic or emission critical ECUs (**DEC-ECUs**) and all ECUs associated with engine controls, emission controls, or aftertreatment controls must support CALID and CVN

  DEC-ECU definition: the engine control unit and any other on-board electronic powertrain control unit that is field reprogrammable and has primary control over any major monitor or any rationality fault diagnostic or functional check for any input or output component under OR-OBD.

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Phase 2 Standardization Requirements

- Applicability
  - Phase 2 standardization requirements are in addition to Phase 1
  - Tier 5 interim and final engines (see implementation schedule)
  - Electronically controlled engines in all power categories
- Elements
  - Fault Code Related
  - Test Results
  - Additional Data Stream Parameters
  - Tracking Data

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Fault Code Related Elements

- <u>Required</u>
- ✓ Fault Codes (pending and confirmed) - SAE J2012 or SAE J1939
- ✓ Fault Code Handling (setting and erasure) – OBMD & OBD
  - One fail -> pending code, two fails -> confirmed code (with MIL), healing protocol TBD
  - Data tracking parameter for engine run time since code clear
- ✓ Manufacturer diagnostics - standardized fault codes for emission-related parts
- ✓ Freeze Frame

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Fault Code Related Elements (cont.)

- <u>Required (cont.)</u>
  - ✓ Dedicated MIL
    - OBD – MIL activates for actual life of engine (same as "on road" OBD requirement)
    - OBMD – MIL activates for actual life of engine <u>EXCEPT</u> for OBM NOx monitor:
      - OBM NOx MIL only active during emission warranty period, fault code active for actual life of engine
- <u>Not required:</u>
  - ✓ Readiness Status
  - ✓ Permanent Fault Codes

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Test Results & Tracking Data

- **Required**

✓ Test Results – similar to "on road" OBD

  - OBD - Major OBD monitors (e.g., PM filter, EGR, PM sensors, DOC, fuel system)

  - OBMD- Major OBMD monitors (e.g., OBM NOx, PM filter, NOx and PM sensors)

✓ Monitor Activity Data (MAD) – see subsequent slides

✓ Additional Data Stream Parameters

  - OBM NOx 3B-MAW window counters (Bin B and C)

  - OBM NOx and work data

- <u>Not Required</u>: On-road monitoring frequency (IUMPR)

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Test Results & Tracking Data (Cont.)

- Required
- ✓ PM Screening - Fault Code History Tracking Parameter
  - To support In-Use PM screening program
    - Enables collection of PM filtration efficiency and PM sensor fault code data
    - PM sensor malfunctions impair ability to monitor DPF
    - High rate of fault codes is a flag for potentially high PM emissions
  - Tracked data
    - PM filtration efficiency and PM sensor fault codes, both pending and MIL-on
    - Parameter stores five most recent fault codes with engine hour timestamps

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Introduction to Monitor Activity Data (MAD)

- Simple method to track and report monitoring frequency data
    - Same as Supplemental Monitor Activity Data (SMAD) in on-road
- MAD counts the following parameters:
    - Actual monitor decisions (pass or fail), not conditions needed to detect a malfunction
    - Engine ignition cycles that meet minimum engine activity criteria (i.e., general denominator)
- No special denominators for different monitors
- Simple pause criteria
- Already implemented in SAE J1979-2, must add to J1939
- Minimum monitoring frequency under consideration

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Proposed Elements of MAD

- MAD uses three tracking parameters:
  - **<u>Mini-Denominator</u>** = 1-byte "trip" counter that increments when the **general denominator*** increments, from 0 to 255. Every DEC-ECU has one mini-denominator.
  - **<u>Mini-Numerator</u>** = 1-byte counter assigned to every MIL-relevant DTC that increments when the monitor runs and completes (resets when mini-denominator reaches 255 and the "Monitor Activity Ratio" is updated).
  - **<u>Monitor Activity Ratio</u> (MAR)** = 1-byte value assigned to every MIL-relevant DTC. Ratio of mini-numerator to mini-denominator (updates when mini-denominator reaches 255).

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Proposed Elements of MAD (cont'd)

- <u>Pause criteria</u>: all counters on a DEC-ECU pause for the rest of an ignition cycle if a MIL-relevant pending or confirmed fault code is present.

  * **General denominator**: a measure of the number of times an engine has been operated such that certain criteria are satisfied within an ignition cycle (e.g.,10 min engine run time with at least 5 min > 8% rated power).

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OR-OBD System

```
┌─────────────────────────────┐
│      Tier 5 Engine          │
│   Equipped With SCR?        │
└─────────────────────────────┘
```

YES ↙   ↘ NO

OBMD

Standardization
+
NOx Monitoring
+
Limited Diagnostics

OBD

Standardization
+
Diagnostics
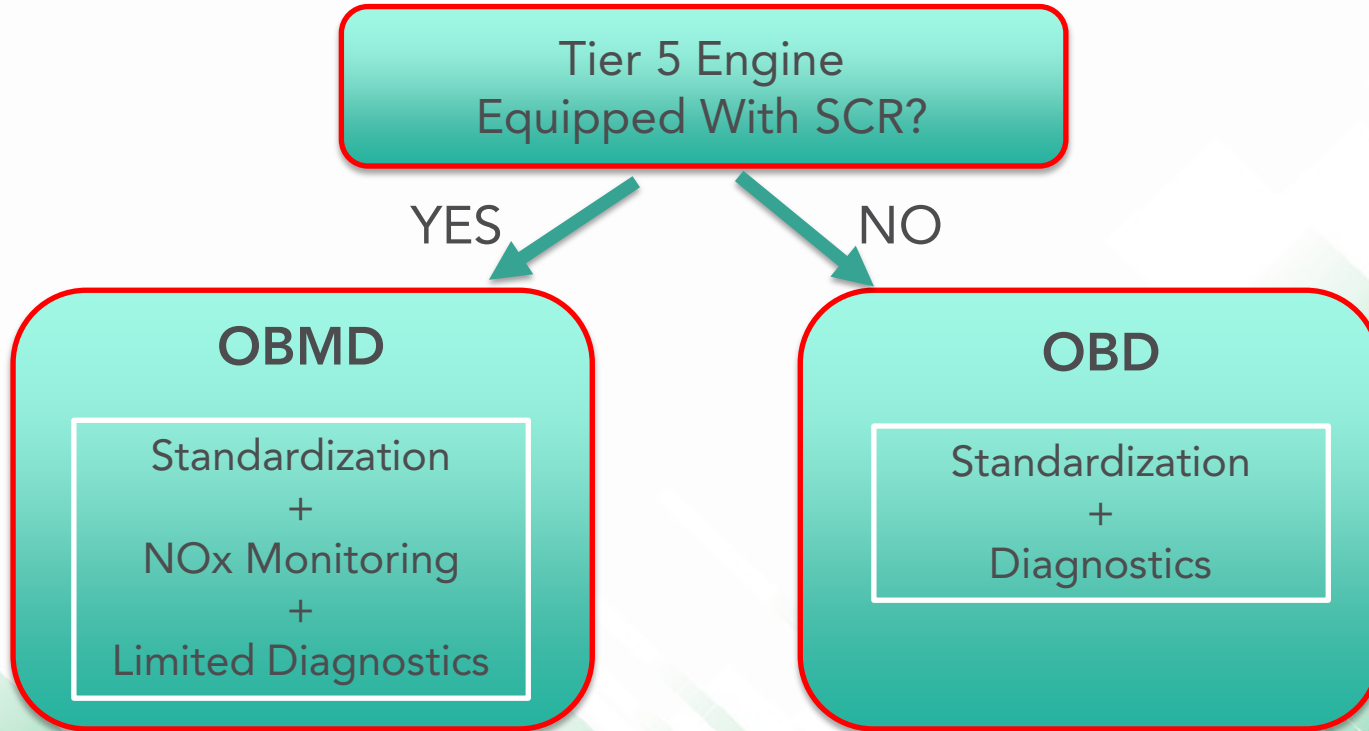
OBMD Proposal Overview

- OBMD Requirements
  - Standardization Requirements (see previous slides)
  - OBMD Diagnostic Requirements
    - OBM NOx Emission Threshold
    - PM Filter Emission Threshold
    - Tailpipe NOx sensor Performance
    - PM Sensor Diagnostics
    - Comprehensive Component Monitoring (CCM)

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OBMD Proposal Overview (cont.)

- OBMD Diagnostic Requirements
  - **<u>OBM NOx Emission Threshold</u>**
    - Fixed threshold based on 3B-MAW bins B and C

OBM NOx THDs (g/kw-hr)		
Power	Bin B	Bin C
>56 kW & <560 kW	0.6	0.6
>560 kW	N/A	1.2

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OBMD Proposal Overview (cont.)

- OBMD Diagnostic Requirements (cont.)
  - **<u>OBM NOx Emission Threshold</u>** (cont.)
    - Monitor uses same 3B-MAW window data that is stored in OR-REAL bins
    - Tracks Bin B and Bin C windows separately: two independent monitors
      - Decision made when 2,400 windows have accumulated
    - Fault code handling: One fail = pending code, two fails = confirmed (MIL on), healing protocol TBD
    - Monitoring only pauses for critical malfunctions e.g., MIL is on for a tailpipe NOx sensor fault

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OBMD Proposal Overview (cont.)

- OBMD Diagnostic Requirements (cont.)
  - **<u>Tailpipe NOx sensor diagnostic</u>**
    - Performance for OBM (NOx measurement error)
      - Detect malfunction before sensor failure/deterioration (e.g., offset, gain) causes measurement error to exceed **+/- TBD g/kW-hr**
    - Circuit Faults
    - NOx sensor measurement readiness: detect when the NOx sensor is inappropriately offline

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OBMD Proposal Overview (cont.)

- OBMD Diagnostic Requirements (cont.)
  - **PM Filter Filtering Performance Diagnostic**
    - Malfunction Criteria
      - Proposing same emission threshold level as on-road HD OBD: 0.04g/kW-h
        - On-road HD engine OEMs have met this requirement using resistive PM sensors since 2016 MY
    - PM Filter diagnostic requirements will be identical for both OBMD and OBD proposals

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OBMD Proposal Overview (cont.)

- OBMD Diagnostic Requirements (cont.)
  - **Comprehensive Component Monitoring (CCM) requirements**
    - All inputs and outputs associated with major monitors, AECDs, **OBM**, or **OR-REAL tracking** must be monitored for:
      - Circuit continuity, out-of-range, and full rationality (Input components)
      - Circuit continuity and functionality (Output components)
    - All DEC-ECU inputs and outputs not described above must be monitored for:
      - Circuit continuity, out-of-range, and limited rationality (Input components)
      - Circuit continuity and functionality (Output components)

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OBMD Proposal Overview (cont.)

- **OBMD Fault Code and MIL Requirements**
  - OBM MIL illumination required only during warranty period
  - OBM fault code storage protocol applies over engine's actual life
  - OBM fault code and MIL not tied to inducements
  - MIL and fault codes associated with other diagnostics apply over engine's actual life

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OBD Proposal Overview

- OBD Requirements for non-SCR engines
  - Standardization Requirements (see previous slides)
  - Diagnostic Requirements
    - PM Filter emission threshold diagnostic
    - Performance-based monitoring for select major components (see next slides)
    - Comprehensive Component diagnostic (CCM)

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OBD Requirements (cont.)

- Diagnostic requirements for select major components:
  - PM Filters (PM emission threshold of 0.04 g/kW-hr)
  - PM Sensor and heater
    - Monitoring capability (e.g., voltage, resistance, current response rate, offset)
      - Must detect any malfunction that prevents detection of a threshold PM filter
    - Heater performance – not within manufacturer's limits
    - Circuit diagnostics
  - Exhaust Gas Recirculation (EGR) system emission threshold 2x emission standard (NMHC, CO, NOx, PM) except for 19-56 kW eng: PM threshold (0.04 g/kW-h)

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OBD Requirements (cont.)

- Diagnostic requirements for select major components:
  - Diesel Oxidation Catalyst (DOC)
    - Cannot achieve exotherm to regenerate PM filter
  - Electronically-controlled fuel systems
    - Emission threshold 2x standard (NMHC, CO, NOx, PM) except for 19-56 kW eng: PM threshold (0.04 g/kW-h)
      - Pressure control
      - Injection quantity
      - Injection timing
    - Feedback control

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OBD Requirements (cont.)

- CCM requirements
  - All inputs and outputs associated with major monitors, or AECDs, must be monitored for:
    - Circuit continuity, out-of-range, and full rationality (Input components)
    - Circuit continuity and functionality (Output components)
  - All DEC-ECU inputs and outputs not described above must be monitored for:
    - Circuit continuity, out-of-range, and <u>limited </u>rationality (Input components)
    - Circuit continuity and functionality (Output components)

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OR-OBD Implementation Elements

- Certification
    - Applications submitted to CARB eFILE
    - OR-OBD System Demonstration Requirements
        - Demonstration engine
            - OBMD: tailpipe NOx sensor aged to FUL plus degreened engine and aftertreatment
            - OBD: align with tailpipe certification durability requirements
            - Number of demonstrations per year TBD
        - Demonstration of OBD system tailpipe NOx mass vs. lab results
            - Proposal: require **+/- TBD g/kW-h** over NRTC

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OR-OBD Implementation Elements

- Certification (Cont.)
  - OR-OBD System Demonstration Requirements (Cont.)
    - Limited diagnostic demonstration testing
      - OBMD
        - Emission threshold testing: OBM NOx, DPF, NOx sensor
        - Performance monitors (similar to "on-road" J2/L2): NOx sensor, PM sensors, CCM
      - OBD
        - Emission threshold testing: DPF/Fuel System/EGR
        - Performance monitors (similar to "on-road" J2/L2): PM sensors, DOC, CCM

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OR-OBD Implementation Elements (cont'd)

- Post-certification: Verification of Standardized Requirements – similar to "on-road" PEVE J1/L1

- Deficiencies & fines

    - Similar to on-road OBD requirements/allowances

- Conditions that prohibit certification

    - Any issue that adversely impacts in-use programs (e.g., missing parameters for PEMS testing, in-use screening, standardized connector, 3B-MAW bin implementation errors)

    - > 3X diagnostic emission threshold for first 3 years of "Stage 2" (see next slide)

        - >2X diagnostic emission threshold thereafter

    - Emission threshold monitor does not run

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OR-OBD Implementation Schedule

- Stages and Phase-in
  - Stage 1: Phase 1 Standardization begins as early as 2029 MY
  - Stage 2: Phases 1+2 Standardization, OBD/OBMD, and PEVE begins as early as 2032 MY
- Sufficient Lead Time and Stability
  - Lead time aligns with Tier 5 emission standards
    - Child ratings* have additional lead time for Stage 2
  - Stability
    - 3-4 years (Parent ratings)
    - 6-7 years (Child ratings)
- Grace period
  - Deficiency fines delayed to 4th year of Stage 2 (for parent engines)

CARB * Parent/Child engine definition –TBD

Implementation Schedule

Parent Engines Implementation Plan (Phases 1+ 2 Standardization, OBD/OBMD, PEVE)

Power Category	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
< 8 kW										
8 ≤ kW < 19										
19 ≤ kW < 56										
56 ≤ kW < 130										
130 ≤ kW ≤ 560										
> 560 kW (Gensets)										
>560 kW (Mobile Machines)*										

Child Engines Implementation Plan (Phases 1+ 2 Standardization, OBD/OBMD, PEVE)

Power Category	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
< 8 kW										
8 ≤ kW < 19										
19 ≤ kW < 56										
56 ≤ kW < 130										
130 ≤ kW ≤ 560										
> 560 kW (Gensets)										
>560 kW (Mobile Machines)*										

Legend:
- Tier 5 not started yet
- Tier 5 Emission Cert + Phase 1 Standardization
- OBD + Phases 1+2 Standardization + PEVE
- OBMD + Phases1+ 2 Standardization + PEVE
- Deficiency fines begin

* For >560 kw (mobile machines), OBD or OBMD depends on emission control system

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