Tier 5 Rulemaking Workshop: Off-Road On-Board Diagnostics (OR OBD) Proposal

October 8, 2024

Agenda

- Updates to Proposal
- Workshop Discussion Topics
  - Communication Protocol
  - Embedded Service Tool
  - OBM NOx Monitor Demonstration Testing
  - Steady-State Test Cycle
  - Off-Road Engines < 56 kW
  - Unfinished Items in Draft Regulation

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Acronyms

- 3B-MAW: 3-bin moving average window
- AECD: auxiliary emission control device
- CALID: calibration identification number
- CCM: comprehensive component monitoring
- CVN: calibration verification number
- DEC-ECU: diagnostic or emission critical electronic control unit
- DEF: diesel exhaust fluid
- DLC: diagnostic link connector

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Acronyms

- DPF: diesel particulate filter
- DTC: diagnostic trouble code
- EGR: exhaust gas recirculation
- FUL: full useful life
- g/bhp-hr: grams per brake horsepower-hour
- g/kW-hr: grams per kilowatt-hour
- kW: kilowatts
- MAD: monitor activity data
- MIL: malfunction indicator light
- MY: model year

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Acronyms (cont.)

- NOx: oxides of nitrogen
- NRTC: nonroad transient test cycle
- OBMD: on-board monitoring and diagnostics
- OEM: original equipment manufacturer
- OR OBD: off-road on-board diagnostics
- PEVE: production engine/vehicle evaluation
- PM: particulate matter
- RMC: ramped-modal cycle
- SCR: selective catalytic reduction

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Updates to Proposal

- Draft OR OBD regulation language describes the details of all the proposed requirements
  - Provided on Tier 5 workshop website
- Staff revised some proposals that were presented at the Tier 5 workshop in October 2023
- Major revisions will be covered in today's workshop

OR OBD System

Tier 5 Engine Equipped With SCR *or Tailpipe NOx sensor*?

YES

NO

OBMD

Standardization
+
NOx Monitoring
+
Limited Diagnostics

OBD

Standardization
+
Diagnostics

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Communication Protocol

- Proposal: ~~allow either~~ <u>require</u> 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
- *<u>Note: deletion of SAE J1979-2 also affects information on other standardization slides (e.g., fault codes, diagnostic link connector)</u>*

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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)~~
- _Replaced with list of specific parameters including:_
  - _Certification-critical parameters_
  - _Parameters for engines so-equipped, including US EPA parameters for engines with inducements/derates_
- _Any additional physical inputs/outputs used by OR OBD system diagnostics, AECDs, OR-REAL, inducements, the engine cooling system, and the engine lubrication system_

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CALID & CVN Requirements

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, *or*

- *Controls fuel injection timing or quantity, fuel pressure level, cylinder deactivation, EGR valve position, variable geometry turbocharger position, turbocharger boost level, DEF injection quantity, aftertreatment thermal management strategies, AECD operation, PM filter regeneration, oxides of nitrogen (NOx) sensor functions, or PM sensor functions*

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Proposed Elements of MAD

- MAD uses three tracking parameters:
  - **Mini-Denominator** = 1-byte "trip" counter that increments when the **general denominator*** increments, from 0 to 255. Every DEC-ECU *that is capable of storing a fault code* has one mini-denominator
  - **Mini-Numerator** = 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)
  - **Monitor Activity Ratio (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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OBMD Proposal Overview

- OBMD Diagnostic Requirements
  - OBM NOx Emission Threshold
  - PM Filter Emission Threshold
  - Tailpipe NOx sensor Performance
  - PM Sensor Diagnostics
  - Comprehensive Component Monitoring (CCM)
  - *Diesel Oxidation Catalyst Performance*
  - *Closed Crankcase Ventilation System Performance*

OBMD Proposal Overview (cont.)

- OBMD Diagnostic Requirements
  - **OBM NOx Emission Threshold**
    - 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 & <56 kW	N/A	1.2 or "1.5 x standard," whichever is higher

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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 *or "PM standard + 0.02 g/kW-h," whichever is higher*
        - 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
  - *Frequent regeneration malfunctions*
  - *Active/intrusive injection malfunctions*

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OBD Proposal Overview

- OBD Requirements for non-SCR/tailpipe NOx sensor engines
  - Diagnostic Requirements
    - PM Filter emission threshold diagnostic
    - Performance-based monitoring for select major components (see next slides)
      - *Add closed crankcase ventilation system*
    - Comprehensive Component diagnostics (CCM)

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OBD Proposal Overview

- OBD Diagnostic Requirements
  - PM Filter Emission Threshold
  - PM Sensor and Heater Diagnostics
  - EGR System Emission Threshold
  - Diesel Oxidation Catalyst Performance
  - Fuel System Emission Threshold and Feedback Control
  - CCM
  - *Closed Crankcase Ventilation System Performance*

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OR OBD Implementation Elements

- Certification
  - OR OBD System Demonstration Requirements
    - Demonstration engine
      - OBMD:
        - tailpipe NOx sensor aged to FUL plus degreened engine and aftertreatment *or*
        - *engine and aftertreatment aged according to tailpipe certification durability requirements*
      - OBD: align with tailpipe certification durability requirements

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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.)

- Post-certification:
  - Verification of Standardized Requirements – similar to "on-road" PEVE J1/L1
  - *Verification of Diagnostic Requirements - similar to "on-road" PEVE J2/L2*
    - *Testing of all non-emission threshold diagnostics (i.e., diagnostics not tested during demonstration testing)*
  - *Verification of Monitor Activity Data – similar to "on-road" PEVE J3/L3*
    - *Collection/submission of monitor activity data and "snapshot" data*

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Communication Protocol

- CARB proposes to remove SAE J1979-2 as an option for communication protocol
  - Removed because 1979-2 not a popular choice among off-road engine manufacturers
  - Leaves only one required protocol: SAE J1939
- Allow an ethernet-based protocol as an alternative?
  - Issue: would require further development of communication standards to support OR OBD
  - Timeframe of that effort?

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Embedded Service Tool

- Embedded service tool (i.e., wireless diagnostic data) concept was raised by industry as alternative to physical DLC

- Need to resolve question raised last October: can DLC "equivalence" criteria be adequately met? E.g.:
  - Universal access (e.g., no fees or permission to access)
  - Reliable lifetime access (e.g., supports local wireless communication, not just via remote web server)
  - Data logging functionality (e.g., supports PEMS testing)
  - Data authenticity (e.g., assurance the data is directly from the specific piece of equipment being examined)

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OBM NOx Monitor Demonstration Testing

- Monitor uses 3B-MAW Bin B and Bin C
  - 2,400 windows required for a diagnostic decision
  - Windows can span > 1 operating cycle
- Proposal:
  - Demonstrate NOx monitor for both Bin B and Bin C
  - Allow double-length test cycles to expedite malfunction detection
- Example sequence for Bin C monitor detection demo:
  - 2xNRTC, 5-min soak, 2xNRTC → Pending fault code
  - 2xNRTC, 5-min soak, 2xNRTC → MIL-on fault code

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Steady-State Cycle Considerations

- Two versions of the steady-state test cycle available in certification:
    - <u>RMC</u>: defined duration, defined speed/load trace
    - <u>Discrete-mode cycle</u>: undefined duration, no speed/load trace
- Discrete-mode cycle problematic for malfunction detection testing
    - Does not provide uniform, repeatable conditions over which a monitor's performance can be evaluated
    - Different manufacturers can run the test differently

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Steady-State Cycle Considerations (cont.)

- Proposal for malfunction detection testing when a steady-state test cycle must be used:
  - Variable-speed engines $\leq$ 560 kW:
    - Require RMC (discrete-mode cycle not allowed)
    - No technical concerns since NRTC emissions test is required
  - Variable-speed engines > 560 kW <u>and</u> constant-speed engines:
    - Manufacturer chooses either discrete-mode or RMC
    - If discrete-mode, manufacturer to attempt following RMC as closely and repeatably as possible

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Unfinished Items in Draft Regulation

- SAE Standards and Dates
- Required Data in Freeze Frame
- <u>NOx Mass Accuracy Requirements</u>
- <u>OBMD Tailpipe NOx Sensor Diagnostic Threshold</u>
- <u>OBMD Demonstration Engine: Method to Produce a FUL Tailpipe NOx Sensor</u>
- Non-Compliance Criterion for Monitor Activity Ratio

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Off-Road Engines < 56 kW

- Engines < 56 kW may have special challenges
  - Propose less stringent requirements?
- Current scope for OR OBD: all Tier 5 electronically-controlled engines
  - Specify a minimum "degree" of electronic control?
- CCM rationality monitoring requirements
  - Allow reduced rationality (e.g., stuck sensor) for wider range of input components?
- Staff open to other ideas from industry

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NOx Mass Accuracy Requirements

- On-road OBD NOx mass accuracy requirement:
  - +/- 20%   OR   +/- 0.1 g/bhp-hr relative to lab result
  - Developed for 0.2 g/bhp-hr NOx on-road engines
  - On-road manufacturers comply with large margin
- Need to identify requirement for Tier 5 engines
  - One reference: Southwest Research Institute NOx sensor project
  - Staff is interested in industry feedback

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OBMD Tailpipe NOx Sensor Diagnostic Threshold

- Tailpipe sensor diagnostic threshold is unique:
  - Detect malfunction if sensor failure/deterioration causes NOx mass calculation error to exceed +/- **TBD** g/kW-hr as measured over applicable cycle (NRTC or steady-state cycle)
- Requires multiple offset, gain, etc. monitors to be calibrated with thresholds that correspond to this TBD level of error
- Staff is interested in industry feedback

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OBMD Demonstration Engine: Method to Produce a FUL Tailpipe NOx Sensor

- Demonstration engine options:
  - Engine aged according to emissions certification requirements (i.e., harmonized with tailpipe cert), or
  - Low-hour emissions-stabilized engine <u>with FUL tailpipe NOx sensor</u>

- Need to identify method to create a FUL sensor
  - E.g., age multiple sensors simultaneously during aging of the emissions engine, use one sensor for OBMD testing
  - Other methods?

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