To: ALL MANUFACTURERS OF — Mail-Out #ECC 2020-07

- ON-ROAD HEAVY-DUTY DIESEL ENGINES
- OFF-ROAD COMPRESSION-IGNITION ENGINES

ALL OTHER INTERESTED PARTIES

Date: November 24, 2020

Subject: METHODS TO VALIDATE ON-ROAD HEAVY-DUTY DIESEL AND OFF-ROAD DIESEL ENGINE DETERIORATION FACTORS FOR CARB APPROVAL

Dear Manufacturers:

The California Air Resources Board (CARB) has reviewed the results of a DF test program conducted by the Truck and Engine Manufacturers Association (EMA.) The results showed that while engine out emissions for SCR equipped engines were predictable and consistent, actual tailpipe out emission levels were higher at the end of Useful Life (UL) when compared to emission levels extrapolated to UL from lower service accumulation points (35%, 50% or 75% UL). CARB has also been analyzing base-line test results provided by manufacturers as part of On-Board Diagnostics (OBD) Manufacturers Self Testing (MST) requirements for on-road heavy-duty engines. A significant number of engines and after-treatment systems (ATS) tested at 70-80% UL have been failing applicable certification standards.

As a result, CARB believes that DFs generated by manufacturers using less than full useful life service accumulation may not be representative of full useful life deterioration. Therefore, CARB is requesting manufacturers to undertake additional steps to confirm emissions compliance with applicable standards at the end of useful life. CARB will consider methods proposed by individual manufacturers to validate their DFs for use in certifying future model year engines. To aid manufacturers in this effort, the information offered below is intended to identify and describe example methodologies for validating DFs on SCR equipped engines that will be considered acceptable by CARB.

1) Applicability

1. 2021 and subsequent model years (MY)
2. On-road SCR-equipped engines and after-treatment systems
3. Off-road SCR-equipped engines and after-treatment systems

A. MY 2021

New and carry-over (C/O) engine families: 2021 certification application plus acknowledgment that approval of a plan consistent with this document for MY2022+ DFs will be required.

B. MY 2022 – 2023

1) New engine families or engine families with DF (less than FUL) being carried-over for one MY from the immediately previous MY: DF demonstration plus an agreement for future testing of engines according to one of the options described in Section 2.

2) Engine families with DF (less than FUL) carried over for two or more model years: manufacturers should validate DFs used for the purpose of certification by showing compliance according to one of the options described in Section 2. DF validation test data is required prior to issuing a new Executive Order.

C. MY 2024 and beyond

Carryover families may continue to use the processes for MY 2022 – 2023. New On-road and Off-road engine families will need to demonstrate FUL durability using some combination of bench aging and service accumulation prior to receiving an Executive Order. Any new emission durability regulations adopted by CARB shall supersede these guidelines for MY 2024 and later engines, as applicable.

2) Acceptable Methods of DF Validation

Manufacturers should demonstrate compliance according to any of Options a. through g., which are explained below.

If a manufacturer chooses Option a., b. or c. to test or collect data from in-use engines, the selected engines should have minimum service accumulation according to Table 1. Engines are to be tested each year for six years. However, testing may be completed early as soon as passing results are achieved with engines aged to at least 85% UL.

Manufacturers may, upon informing CARB, stagger testing (e.g., testing half of the engines each year over two years) or test only those engines that have achieved the agreed-upon UL threshold.

	Minimum engine service accumulation*
3rd year of production	35% of UL
4th year of production	45% of UL
5th year of production	55% of UL
6th year of production	65% of UL
7th year of production	75% of UL
8th year of production and beyond	85% of UL

Table 1: Minimum age required for obtaining in-use engines
** Mileage-based age for On-road engines. Number of engine hours for Off-road engines.*

The in-use engines and after-treatment systems should be properly maintained and used. Engines also should use original parts in a certified configuration, without any major repair, and must be representative of the aged engine. However, engines with a reasonable number of non-emissions critical replacement parts may be used. OBD MST baseline data will be considered.

a. Engine dyno testing of in-use engines on all applicable certification cycles: Two or more in-use engines will be tested every year for six years (ref. Table 1) or until compliance at 85% UL is demonstrated. All regulated pollutants must be measured according to 40 CFR 1065. New IRAFs must be calculated for each engine tested by measuring emissions on all applicable cycles during a regeneration event or when the applicable strategy is active, and by justifying the frequency by either in-use activation data or measuring on the engine dyno. All criteria regulated pollutants of each of the two engines tested annually must pass in order to successfully utilize this option. If a manufacturer chooses to test more than two engines, at least 70% of the engines must demonstrate passing performance. As an example, if four engines are tested, at least three of the engines must demonstrate passing performance. If failing results are obtained, a manufacturer will not be allowed to use the previously established DF beyond one additional model year.

Following combinations of engine and ATS can be used:

- In-use engine and ATS from the same vehicle or equipment
- Original durability engine + in-use ATS
- Stabilized emissions testing engine + in-use ATS

b. PEMS testing of in-use engines: Five or more in-use engines to be tested every year for the next six years (according to Table 1) or until compliance at 85% UL is demonstrated. At any time, testing may be completed with the passing results of engines aged to at least 85% UL as detailed below. Details of PEMS testing, analysis method and passing criteria are explained in *Attachment A*. All regulated criteria pollutants with the exception of PM, must pass in order for the test to be considered a passing. At least four of the five annually tested engines must demonstrate passing characteristics in order to successfully utilize this option every year as applicable. If a manufacturer chooses to test more than five engines, at least 70% of the engines tested must demonstrate passing characteristics. As an example, if eight engines are tested, six will have to pass. To further clarify, if a manufacturer tests five engines and one engine fails NOx and another engine fails NMHC, both engines are considered failed and DF validation using PEMS testing is considered failed for that engine family. If DF validation using PEMS results fails, the manufacturer will have the options to concede or use Option a. (i.e., engine dyno testing of two engines) for DF validation of the same year. If DF validation using this option fails, the manufacturer will not be allowed to use the previously established DFs beyond one additional model year.

c. Data collected from on-board NOx sensors of in-use engines: Seven or more in-use engines to be tested every year for the next six years (according to Table 1) or until compliance at 85% UL is demonstrated. At any time, testing may be completed with the passing results of engines aged to at least 85% UL as detailed below. Details of NOx sensors data collection, analysis method and passing criteria are explained in Attachment A. At least five of the seven annually tested engines must demonstrate passing characteristics in order to successfully utilize this option every year. If a manufacturer chooses to test more than seven engines, at least 70% of the engines tested must demonstrate passing characteristics. As example, if fourteen engines are tested, ten will have to pass for the engine family to pass. If less than 70% of engines demonstrate passing characteristics, a manufacturer will have the option to concede or use Option a. (i.e., engine dyno testing of two engines) for DF validation of the same year. If DF validation using this option fails, a manufacturer will not be allowed to use the previously established DF beyond one additional model year.

d. Conduct a demonstration to FUL using an approved DF plan. A manufacturer would need to propose a DF plan that would age an engine to FUL (i.e., no extrapolation to project FUL compliance.) Emission compliance at FUL would need to be demonstrated prior to issuing Executive Order.

e. After conducting an approved durability demonstration at less than FUL, bench-age ATS to FUL, or continue the durability demonstration out to FUL according to an approved test procedure. Use the bench-aged ATS in conjunction with the same DDE to represent emissions at FUL after 100 hours of stabilizing operation and test on the engine dyno. Emission compliance would need to be demonstrated prior to issuing an Executive Order.

f. FUL durability demonstration using upcoming on-road procedures (On-road and Off-road.)

g. An alternate method proposed by the manufacturer and approved by CARB.

3) Other Considerations

a. The initially approved durability demonstration engine family and its approved carry-across engine families will remain valid. If DFs were carried across to multiple engine families for certification, DF validation must be conducted on the same durability demonstration engine family and the same rating as the initial durability demonstration. If DF validation results are passing, all the families covered under the initial carry-across will be considered passing. If DF validation results are failing, all the families covered under the initial carry-across will be considered failing.

b. Manufacturers shall submit all test data including passing, failing, valid, and invalid data, and justification why they deem a specific set of data invalid.

c. CARB will review requests for consideration that an unrepresentative measured criteria pollutant result (other than NOx) be excluded from consideration.

d. Upon receiving and reviewing all data from a manufacturer, CARB will make a determination whether the validation, according to the manufacturers' approved plan has adequately been met, and will inform the manufacturer of the results.

e. Data must be compliant with the applicable standards, test procedure and other provisions of Title 40 of the CFR.

f. Expected details of test plans are explained on Attachment A.

g. In case there are failed test data:

i. CARB will not invalidate previously issued Executive Orders based solely on manufacturers' supplied data.

ii. Carryover will not be allowed beyond one additional model year after the failure. Manufacturer will have to establish new DF for any requests for Executive Orders beyond such. Following are two examples for clarification:

- Example 1: a manufacturer performs a new durability demonstration to certify a MY2022 engine family. The manufacturer does not need to validate the DF to be able to carryover the DFs to MY2023 (i.e., 2nd year of production). However, DF validations are needed for certification of MY2024 and beyond (i.e., 3rd year of production, Ref Table 1) using the same DFs. If DF validation results fail, the MY2022 DFs will be only allowed for certifying the MY2024, and new DFs will be needed for MY2025 and beyond.

- Example 2: a manufacturer has performed a less than FUL durability demonstration for certification of a MY2017 engine family. In order to be able to carry-over the MY2017 DFs to certify MY2022 engine, they need to validate the DFs on engines with the minimum service accumulation according to Table 1 which is 65% of UL (6th year of production.) If DF validation results fail, the MY2017 DFs will be only allowed for certifying the MY2022, and new DFs will be needed for MY2023 and beyond.

iii. CARB will initiate further review of the already certified engine families that used the affected DFs at time of certification (i.e., in-use testing.)

h. CARB will make accommodations, on a case-by-case basis, for engine families that generally are not operated to full regulatory UL levels (i.e., low mileage/hours.)

i. If parent rating for a given family is not reasonably available, CARB will work with the manufacturers to agree upon and select another family in the grouping that is available.

For questions concerning this Mail-Out, please contact Ms. Jackie Lourenco, Chief, New Vehicle/Engines Programs Branch, at Jackie.Lourenco@arb.ca.gov.

Sincerely,

Allen Lyons, Chief
Emissions Certification and Compliance Division

cc: Babak Pazokifard, Manager
Emissions Certification and Compliance Division

Attachment A
Details of PEMS testing, NOx sensors data collection and
Moving Average Window (MAW) calculations

A. Test plan

1. Manufacturers must submit their test plans and receive approvals by CARB prior to conducting the tests.
2. Test plans to include the following at a minimum: EF to be tested, EFs that will be covered by the test, engine rating, engines' serial numbers, VIN (for On-road) / equipment serial numbers (for Off-road), vehicle / equipment type, vehicle mileages / engine hours, season and ambient condition of test, vehicles' and engines' maintenance histories, fleet information, testing operator, testing route, and etc.
3. CARB reserves the right to request to witness the test.
4. If PEMS testing or NOx sensors data options are chosen, test vehicle or equipment are expected to be from an independent fleet (i.e., not manufacturers' demo fleet) and driven or operated by fleet operator. Operation should be in the same fashion as its regular fleet route or equipment activity. Manufacturer may also conduct testing using their own demo fleet and operator, with CARB's prior approval.

B. Data Collection – for PEMS and NOx sensor data testing

1. Cold start: engine must start with engine coolant temperature (ECT) either:

    a. ECT ≤ 30°C
    b. ECT ≤ T_{amb} - 2°C

2. Valid Data: pass-by-default provision does not apply. All of the following conditions need to be satisfied:

    a. Minimum of 4 hours of valid windows
    b. Minimum of 50% of all windows to be valid (i.e. not excluded)
    c. Engine reaches warmed up condition within 15 minutes from the cold-start, otherwise the entire collected data set is invalid. See section C. 1. g. below.

3. Following signals to be collected and provided (live Excel file containing the 1Hz data)
    - Engine speed and torque
    - DEF dosing rate

- Targeted NH3 storage value
- Actual NH3 storage value
- Ammonia to NOx ratio (ANR)
- System-out NOx target
- Actual system-out NOx (from down-stream NOx sensor)
- Engine-out NOx target
- Actual engine-out NOx (from up-stream NOx sensor)
- When PEMS tested: NOx, HC and CO obtained from PEMS unit
- NOx mass flow, upstream of SCR
- NOx mass flow, downstream of SCR
- Charge air cooler temperature
- Turbine upstream temperature
- EGR rate
- Exhaust mass flow
- DOC upstream temperature
- DPF upstream temperature
- SCR space velocity
- SCR mid-bed temperature
- NH3 slip values
- Modeled DPF soot mass loading
- Status of any AECDs that increase emissions
- Date and time of tests
- Engine mileage / hours

C. Data Analysis

1. Data exclusion: Any invalidated data shall not be considered for the calculation of the work and the emissions of the averaging window. The data collected during any of the following conditions shall be considered invalid data:

    a. Zero drift check of the PEMS instruments
    b. NOx sensors data prior to the sensor delayed activation due to protection
    c. Atmospheric pressure less than 82.5 kPa
    d. Altitudes greater than 5,500 feet above sea-level
    e. Ambient temperature less than -7°C
    f. Temperature greater than determined by the following equation at the specified altitude
    $T_{amb}=-0.00254 \times h+100$
    Where:
    T_{amb} is the ambient air temperature, °F
    h is the altitude above sea level, ft

g. The operation prior to warm engine coolant conditions. Warm engine coolant conditions are satisfied after a cold engine start when either of the following conditions is met within 15 minutes of engine start:
    i. ECT reaches 70°C for the first time or
    ii. ECT stabilizes within ±2°C for 5 minutes

2. MAW calculations
    a. Subsets of continuous overlapping windows
    b. Incremental average rate: 1Hz
    c. Window size based on a reference work on the applicable transient cycle (FTP or NRTC)
    d. Window average power must be greater than the threshold power equal to 20% maximum engine power

D. Data Submission

1. Final report
2. Emissions metrics
    a. Average brake emissions of windows
    b. All collected 1 Hz raw data. Include invalidated and excluded data per criteria mentioned above in the **Data Analysis**.
3. Passing criteria: 90th percentile of valid window emission is less than 1.5 X applicable standard