HEAVY-DUTY LOW NO\textsubscript{x} PROGRAM WORKSHOP

JANUARY 23, 2019

HEAVY-DUTY IN-USE TESTING (HDIUT)

MOBILE SOURCE CONTROL DIVISION
Current HDIUT / Not to Exceed (NTE) program

Problems with current program

Proposed changes

- Administrative and Reporting
- Testing Conditions and Exclusions
- Full Duty Cycle Control
- Moving Average Windows (MAW)
- Pass Fail Determination
**HDIUT: BACKGROUND**

- 2003: Outline of the HDIUT developed by U.S. EPA, CARB, and Engine Manufacturer's Association
- 2005: EPA adopts Manufacturer Run HDIUT
- 2006: CARB adopts HDIUT and national HDIUT pilot year
- 2007: 1st year of HDIUT criteria pollutant enforcement

https://www.dieselnet.com/standards/cycles/images/nte.png
## Current CARB & EPA HDIUT

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Request for testing</strong></td>
<td>• CARB &amp; EPA Requested</td>
</tr>
<tr>
<td><strong>Engine Selection</strong></td>
<td>• May select up to 25% of engine families certified per calendar year</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>• Annually</td>
</tr>
<tr>
<td><strong>Driver</strong></td>
<td>• Regular Fleet Driver</td>
</tr>
<tr>
<td><strong>Route</strong></td>
<td>• Regular Fleet Route</td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td>• Not-to-Exceed</td>
</tr>
<tr>
<td><strong>Exclusions</strong></td>
<td>• Ambient, 30% min power, 30% min torque, min-rpm, zero check, AT-temp, cold operations, intake manifold temperature (IMT), engine coolant temperature (ECT), On-Board Diagnostic (OBD) fault code, Engine Manufacturer Diagnostic fault codes, diesel particle filter (DPF) regeneration</td>
</tr>
<tr>
<td><strong>Window Validity</strong></td>
<td>• 30 sec continuous operation within NTE control area without entering exclusions operation</td>
</tr>
<tr>
<td><strong>Emissions</strong></td>
<td>• Brake specific [g/bhp-hr]</td>
</tr>
<tr>
<td><strong>In Use Thresholds</strong></td>
<td>• $1.5 \times \text{Std.} + \text{PEMS accuracy margin} [0.45 \text{ g/bhp-hr} \ NO_x \text{ threshold}]$</td>
</tr>
<tr>
<td><strong>Pass Determination</strong></td>
<td>• 90% of time weighted valid NTE events must emit at or less than the In Use Threshold</td>
</tr>
</tbody>
</table>
HDIUT: CURRENT ISSUES AND LIMITATIONS

1. Current HDIUT program targets sustained high speed and high load operation for gross NO$_x$ polluting offenses

2. After applying the current exclusions, valid data from testing represents a small fraction of the total test in terms of time (<5%) and NO$_x$ emissions (<6%)

3. 24% of tests pass without any valid NTE events

4. Current HDIUT does not represent the full duty cycle emissions

5. There is a discrepancy in the pass rates observed by the manufacturer (91%) and CARB-run HDIUT (44%) results. (CARB testing: 20 of 36 failed NTE)
MOVING AVERAGE WINDOWS (MAW)

- Implemented in Euro VI regulations for In-Use Conformity testing
  - Mass emissions are calculated for subsets, i.e., “windows”, of complete data set.
  - Length of windows based on the reference work or CO2 measured over the transient certification cycle [Ref Cycles: WHTC in Europe and FTP in USA]
  - Windows are started at every second of the data set given that there is enough following data to complete a window length
  - 1Hz NOx emissions are averaged over a window (highlighted in grey).
  - Window emissions are reduced to a single point Window Averages.
  - The averaged window emissions are ordered and the 90th percentile window is compared with the emission standard
  - The ratio of the 90th percentile emission to the emissions standard must not be greater than the conformity factor, 1.5
METHOD COMPARISON: MAW CAPTURES MORE OF TEST TIME AND EMISSIONS ON HDIUT DATA SET

- More operation and emissions covered with MAW method
- New method would improve real world emissions performance
CHANGES TO THE HDIUT PROGRAM

- **Remove the Following Elements:**
  - Discard the Not-to-Exceed method, NTE control area, operation exclusions, and averaging period
  - Discontinue the use of the PEMS accuracy margin allowance [0.15 g NO\textsubscript{x} /bhp-hr]

- **Proposed Changes:**
  - Use the Euro VI MAW based method
  - Window size based on the test engine’s work or CO\textsubscript{2} measured on the FTP cycle
  - Incorporate control over higher emitting windows: cold start, low load, idle operation
    - Weighted composite cold start and warm running emissions

- **Additional Reporting:**
  - CARB pre-approves manufacturer’s HDIUT test plans
  - Data quality checklist assuring valid and complete test data was collected prior to submittal
Engine Selection

- CARB and EPA will continue to work together in selection of engine families for HDIUT
- Rules for number of engine families selected annually and over a 4 year average would stay in place

Manufacturer test plan must be approved by CARB

- Test vehicle to be driven by fleet operator (manufacturer may also do testing with CARB/EPA approval)
- Test vehicle to be driven over its regular fleet route (or CARB/EPA approved test route)
- Season, ambient conditions, and other test conditions to be reviewed and require approval by CARB
Cold Start and Warm Up Conditions
- Cold start: engine must start with either:
  - Engine coolant must be less than or equal to 30 deg C
  - Engine coolant must be less than the ambient temperature by 2 deg C
- Engine warm up must be within the first 15 min from engine start by satisfying either:
  - Engine coolant reaches 70 deg C for the first time
  - Engine coolant stabilizes within plus or minus 2 deg C for 5 minutes

Atmospheric Pressure and Temperature Range
- Ambient pressure and temperatures outside the current altitude, temperature, and pressure ranges shall be excluded from evaluation

PEMS QC Exclusions
- Data collected during the periodic instrument zero or drift checks excluded from evaluation
HDIUT: MAW ANALYSIS METHOD

- **Moving Average Windows**
  - Subsets of continuous overlapping windows
  - Incremental averaging rate, 1Hz
  - Window size based on a reference Work or CO₂ mass on the FTP cycle
  - Size of windows shorter than the FTP are also being evaluated at SwRI
  - Window average power must be greater than the threshold power to be valid
    - Initially set power threshold to 10% maximum engine power [Euro VI(d)]
    - Future power threshold reduced to idle operation

- **Emission Metrics**
  - Average brake and CO₂ specific emissions of windows will be reported
  - Emissions at low loads and idle operation require a method other than brake specific emissions
  - CO₂ and fuel rate among other metrics are being evaluated by SwRI
# HDIUT: PROPOSED METHOD WITH PHASE IN TIMELINE

<table>
<thead>
<tr>
<th>Model Year</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDIUT Methodology</td>
<td>NTE</td>
<td>Euro VI(d) MAW</td>
<td>Future method</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

### 2022 to 2026 MY Engines
- Based on Euro VI(d)
- Deviations from Euro VI(d):
  - Real world fleet route and fleet driver
  - Reference window size based on FTP
  - Minimum of 3 hours of valid test data

### Potential changes for the future method (2027+ MY)
- Weighted cold starts emission inclusion [similar to Euro VI(e)]
- Expand operation down to idle
- May have different window size
- May introduce new emissions metrics
1. **Calculate the conformity factor for all windows of the test**
   - \( CF = \frac{\text{avg window emissions}}{\text{emissions std}} \)

2. **Obtain \( CF_{\text{cold}} \) for the cold portion of the trip**
   - \( CF_{\text{cold}} = \text{highest CF window value for windows between:} \)
   - Engine start and before \( T_{\text{engine coolant}} \) reaches 70 °C

3. **Obtain \( CF_{\text{warm}} \) for the warm portion of the trip**
   - \( CF_{\text{warm}} = \text{The 90th percentile window emissions for windows:} \)
   - \( 70 \, ^\circ C \leq T_{\text{engine coolant}} \)

4. **Weight results in following way**
   - The weighted summation of the cold and warm emissions shall not be greater than 1.5
   - Cold and warm start weighing factors will be similar to the composite FTP emissions
   - \( 1.5 \geq [0.14 \, (CF_{\text{cold}}) + 0.86 \, (CF_{\text{warm}})] \)
## HDIUT: Future Method Summary

<table>
<thead>
<tr>
<th>Testing Request</th>
<th>• CARB &amp; EPA</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Number of Families</td>
<td>• 25% EFs per year</td>
<td>• 25% EFs per year</td>
</tr>
<tr>
<td>Test Plan</td>
<td>• Mfr. Submitted for CARB approval</td>
<td>• Mfr. Submitted for CARB approval</td>
</tr>
<tr>
<td>Driver &amp; Route</td>
<td>• Real world fleet driver and route for a full day or mfr. testing with prior CARB/EPA approval</td>
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</tr>
<tr>
<td>Method</td>
<td>• MAW Euro VI(d)</td>
<td>• TBD</td>
</tr>
<tr>
<td>Cold Start</td>
<td>• Cold start engine coolant temp. exclusion</td>
<td>• Include composite weighting</td>
</tr>
<tr>
<td>Exclusions</td>
<td>• Extreme ambient conditions &amp; PEMS checks</td>
<td>• Extreme ambient conditions &amp; PEMS checks</td>
</tr>
<tr>
<td>Window size</td>
<td>• Work or CO$_2$ equivalent on an FTP cycle</td>
<td>• TBD</td>
</tr>
<tr>
<td>Window Validity</td>
<td>• Avg window power at or above 10% Power Threshold</td>
<td>• All operation</td>
</tr>
<tr>
<td>Test Validity</td>
<td>• 3 hours valid test data</td>
<td>• N/A (all valid operation considered)</td>
</tr>
<tr>
<td>Emissions metric</td>
<td>• Work or CO$_2$ specific</td>
<td>• CO$_2$ specific</td>
</tr>
<tr>
<td>Emissions Evaluation</td>
<td>• 90$^{th}$ percentile of valid window emissions</td>
<td>• 9X$^{th}$ percentile (TBD) of warm valid window emissions</td>
</tr>
<tr>
<td>Conformity Factor Pass Criteria</td>
<td>[ CF_{final} = 1.5 \frac{e_{90th percentile}}{e_{FTP std.}} \leq CF_{final} ]</td>
<td>• 100$^{th}$ percentile of cold start window emissions</td>
</tr>
<tr>
<td></td>
<td>0.14 x $+$ 0.86 $\leq$ 15</td>
<td>0.14 x $+$ 0.86 $\leq$ 15</td>
</tr>
</tbody>
</table>
## HDIUT: NEXT STEPS

<table>
<thead>
<tr>
<th>HDIUT Tasks</th>
<th>Estimated Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Low NO$_x$ Workshop: Rough proposal</td>
<td>Jan 2019</td>
</tr>
<tr>
<td>2. Low NO$_x$ Workgroup: window size and emissions metrics investigation by SwRI</td>
<td>Feb 2019</td>
</tr>
<tr>
<td>3. Draft proposal</td>
<td>Apr 2019</td>
</tr>
<tr>
<td>6. Low NOx Board Hearing</td>
<td>Q1 2020</td>
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</tbody>
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