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Achates Power Opposed-Piston Heavy-Duty Diesel Engine Demonstration Performance Results – Ultralow NO_x without additional hardware

Achates Power is part of a project led by CALSTART and funded by the California Air Resources Board (CARB) to demonstrate a low CO_2, ultralow NO_x Opposed-Piston (OP) heavy-duty diesel engine. In addition to CARB, the South Coast Air Quality Management District, the San Joaquin Valley Air Pollution Control District, and the Sacramento Metro Air Quality Management District are providing funding for the program.

Achates Power is part of an extensive team that will demonstrate the OP heavy-duty diesel engine in a Peterbilt 579 tractor. The team also includes Delphi Technologies, BASF, Corning, Eaton, Faurecia, Tenneco, Aramco Services, Exxon Mobil, Southwest Research Institute and Wal-Mart.

This document provides an update on current testing of the 10.6L OP heavy-duty diesel engine that is the subject of this project.

NO_x is a criteria pollutant, as well as a precursor to ozone and $PM_{2.5}$, and therefore contributes to ambient pollution that adversely affects human health and the environment. More than 128 million people in the U.S. live in counties designated nonattainment for ozone or $PM_{2.5}$. Worldwide, 93% of children grow up with air pollution above health guidelines.

Summary

- Achates Power's 10.6L Opposed-Piston Diesel Engine interim test results:
  - 90% reduction in NO_x to less than 0.02g/bhp-hr measured on the FTP cycle using conventional downstream aftertreatment equipment
  - 422g/bhp-hr CO_2 on the SET cycle, more than 8% lower than the current EPA requirement and lower than the 2027 EPA GHG II requirement
  - A third-party cost-assessment shows the OP engine costs less than a conventional engine of the same power and torque…even while the OP engine has 90% less NO_x and 8% less CO_2

Heavy-duty commercial vehicles are among the largest contributors of both CO_2 and NO_x among mobile sources and are particularly resistant to substitution by other powertrain sources. As such, a heavy-duty diesel engine that provides required power, torque, and reliability with substantially lower CO_2 and NO_x will substantially contribute to more sustainable transportation. The goal of the CARB project is to demonstrate such an engine.

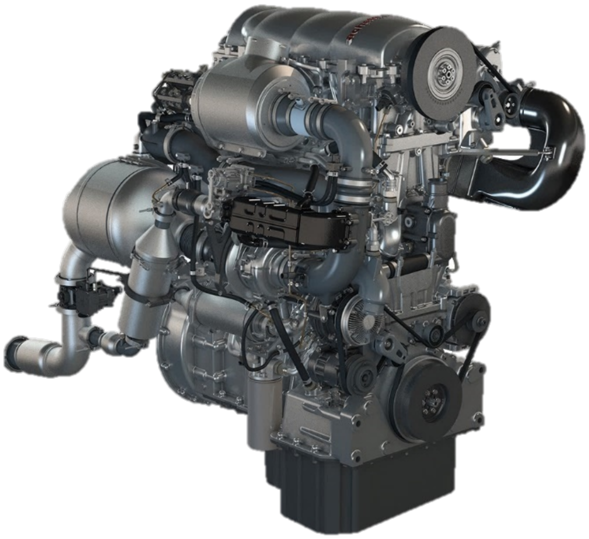
Project Goals:
Required power & torque: The engine delivers 400 hp (300 kW) and 2270 Nm.

Ultra-low NO_x ($ULNO_x$): The current U.S. EPA requirement for NO_x is that engines emit no more than 0.2g/bhp-hr on the FTP cycle. **The project goal is to reduce this by 90%**, to just 0.02g/bhp-hr. *This goal has already been achieved and demonstrated via dynamometer testing.*

Lower CO_2: The current U.S. EPA requirement for Class 8 trucks is that they emit no more than 460g/bhp-hr CO_2 on the SET cycle. The project goal is to emit no more than 437g/bhp-hrof CO_2 on the SET cycle, almost equal to the 2024 requirement (436g/bhp-hr) and within 1% of the ultimate 2027 requirement of 432g/bhp-hr. With additional refinement, the project team expects further reduction in CO2, providing best-in-class efficiency along with a 90% reduction in NO_x. *Tested results are already better than this goal.*

Practical demonstration: It is an objective to drive the Peterbilt 579 tractor in service with the OP heavy-duty diesel engine, demonstrating acceptable fit and integration, noise, vibration, harshness, drivability, and reliability. Peterbilt is currently testing the engine/vehicle integration. *Demonstration in the Wal-Mart fleet is scheduled for mid-2021.*

Engine and Aftertreatment System Design:
Engine: The team designed, built, and is testing a three-cylinder, 10.6L opposed-piston diesel engine with a stroke/bore ratio of 2.6.



Aftertreatment System: Engineers from Achates Power, Faurecia, Aramco Services, Corning, Southwest Research Institute, and BASF worked together to configure and test an aftertreatment system. Their goals included:

- Demonstrate ULNO$_x$ with a full useful life aftertreatment system.
- Hit the target on the first try, which resulted in a very capable, conservative design with significant opportunity for refinement, as discussed below.
- Ability to function on the demonstration truck indefinitely using field proven, production components.

The original design included a light-off SCR using gaseous ammonia, closely coupled to the engine in the engine compartment, and an under cab ATS that includes a DOC and SCR on filter. During the development the project team was able to exceed the program expectation for engine out NOx and exhaust temperature control in the catalyst warm-up mode and concluded that the tailpipe NOx targets can be met without the close coupled light-off SCR. For program continuity, the downstream ATS with DOC and SCRf continues to be used, but as outlined below future designs can replace SCRf with a more conventional DPF and SCR configuration to further reduce cost, complexity, and compliance risk.

Testing results:
Four prototype engines have been built. One is being tested and developed at Achates Power in San Diego, CA. A second is being tested and developed at the Aramco Research Center-Detroit. A third has been integrated into a Peterbilt 579 tractor in Denton, TX where it is undergoing vehicle testing. The fourth is a spare.

After about a year of testing and development, the engine has:

- Achieved the program goal of a 90% reduction in NO$_x$ on the FTP cycle, the transient cycle used in regulation of criteria emissions, without the close coupled light-off SCR. The OP engine is able to achieve these substantial and important reductions in NO$_x$ without any of the additional hardware being considered for conventional engines (cylinder deactivation, close-coupled SCR, heated DEF….)
- Exceeded the program's CO_2 goal, measuring 422g on the SET cycle, the cycle used in regulation of CO_2. This is below the terminal EPA requirement of 432g that commences in 2027, and is well below the current requirement of 460g. Further refinements are expected to reduce the CO_2 to around 5% lower than the lowest (2027) EPA regulation, while also achieving a 90% reduction in NO$_x$.

- In addition, FEV undertook a cost study and concluded that OP engines cost 11% less than conventional engines of the same power and torque, even while the OP engine has much lower NO_x and CO_2. NREL and ACT research estimated that conventional engines will add $4-5k[1] in cost to meet the 2027 NO_x regulations. If an electric DEF heater and an upgraded electrical system are required, those elements could add another $3-5k in costs. The OP engine would cost at least $10k less than a conventional engine meeting the same NO_x regulations.

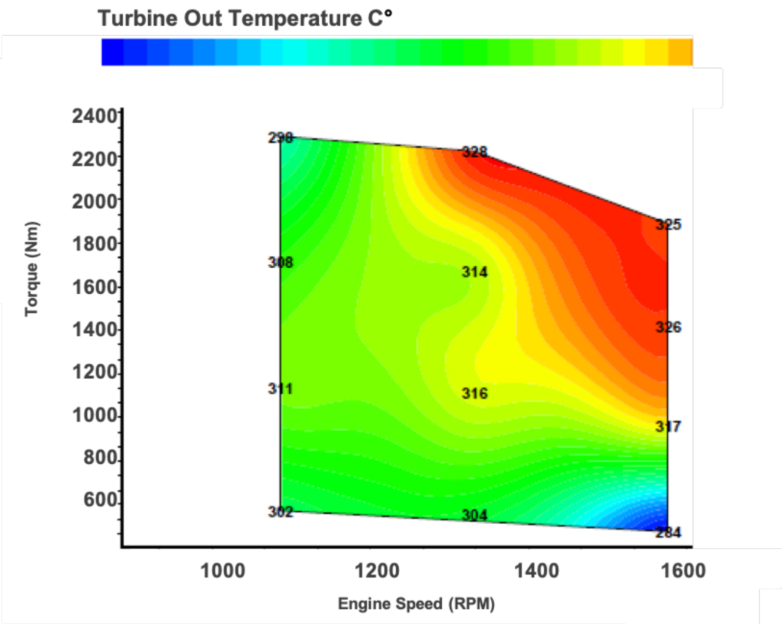
Aftertreatment System Simplification

To even further reduce aftertreatment system cost and complexity, the project team looked at how to further simplify the ATS. The team studied a commercially available, current production aftertreatment system consisting of a DOC/DPF/SCR/ASC. BASF aged catalyst model, using engine turbine-out gas speciation, flow and temperature, predicts the engine + ATS will achieve 0.016g/bhp-hr NO_x on the FTP cycle.

Three features of the new system design have the potential to substantially reduce compliance risk and cost. First, the conventional ATS is much simpler than other designs being pursued to achieve ultralow NO_x that typically include split SCR, heated DEF, and, in the case of conventional engines, cylinder deactivation. None of these technologies are required in the contemplated design, reducing both cost and opportunity for component failure.

Second, the configuration of OP engine + conventional ATS preserves the ability to passively regenerate the particulate filter and is expected to substantially reduce the number of active DPF regenerations required, substantially reducing the thermal degradation of the ATS.

Finally, the OP engine operates at nearly ideal temperature range. As depicted in the chart at the right, post-turbine exhaust gas temperature was between 284°C and 328°C everywhere between 25% load and 100% load. According to Dave Youngren, Senior Application Engineer at BASF, "Standard calibration is…**ideal for feeding the SCR**. [Its] typical temperatures [are] between 250°C and 400°C for efficient SCR function. [The] high floor [is] ideal for NO_x reduction over proposed Low Load Cycle. Mild thermal exposure is easy on the aftertreatment. [The] temperature range [is] also **ideal for DOC function** with moderate precious metal loadings [for] low cost. [It has] **ideal engine-engine out conditions to reach ULNO$_x$**."



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[1] https://www.arb.ca.gov/lists/com-attach/8-hdomnibus2020-1jACGvmafqDgElXk.pdf