Heavy-Duty Diesel Demonstration Program Review

"What's amazing is that Achates is meeting the future emissions standards today"

On May 4, 2022, CALSTART hosted an online program review of the Heavy-Duty Diesel Demonstration Program. This note summarizes some of the key conclusions.

The Heavy-Duty Diesel Demonstration Program is funded by the California Air Resources Board, the South Coast Air Quality Management District, the San Joaquin Valley Air Pollution Control District, and the Sacramento Metro Air Management District.

On the journey to more sustainable transportation, diesel engines will continue to play a large role, particularly in long-haul transit. Among the most impactful ways to rapidly improve air quality is to substantially eliminate criteria emissions from commercial vehicle diesel engines while also improving efficiency and reducing CO_2.

For the demo program, Achates Power built and tested four 10.6L opposed-piston engines. One engine is in a Peterbilt 579 truck and is being operated by Walmart in fleet service in California. Engines have also been tested on dynamometers at Achates Power in San Diego, CA, and the Aramco Research Center-Detroit. Southwest Research tested the aftertreatment system in San Antonio, TX.

Summary

- Combustion engines will be used in a variety of applications for some time; to meet our sustainable transportation goals we need to achieve near-zero tailpipe emissions and low CO_2 in a cost-effective and robust manner
- The opposed-piston (OP) engine is well suited to play an important role commercial vehicles
- Previously reports results show the ability to meet CARB's 2027 ultralow NO_x and EPA GHG II regulations with a substantial margin
- In-use results demonstration the ability to comply with CARB and EPA in-use NO_x limits with substantial compliance margin.
- In-use results also show a substantial fuel consumption reduction compared to a 2021 baseline truck.
- The measured results are achieved with conventional, underfloor aftertreatment systems providing a significant advantage in cost and complexity vs. other ultralow NO_x solutions.
- Not only does the opposed-piston avoid extra cost for additional emissions control technology, the base engine costs 6% less than a comparable conventional engine.

Four individuals spoke at the Program Review:

- Bill Robertson, Vehicle Program Specialist, California Air Resources Board
- Fabien Redon, Chief Technical Officer, Achates Power
- Kent Johnson, Principal Investigator, Emissions and Fuels Research, University of California Riverside
- Greg Kolwich, Manager, Production Development, FEV North America.

The session was moderated by Kevin Leong, Deputy Director of CALSTART.

The replay can be found here (playback options of 1.5x and 2.0x speed are available):

https://us06web.zoom.us/rec/share/bJTJHnfuheJmKW5sEJ5yAruIBsS4mRPS2U3FmHlS4Silo5Z0Y3Tj4LbFczpTLwM-.iULwdheWQtlQTbzJ

Highlights (timestamp in parens**):**

Kevin Leong, Deputy Director, CALSTART

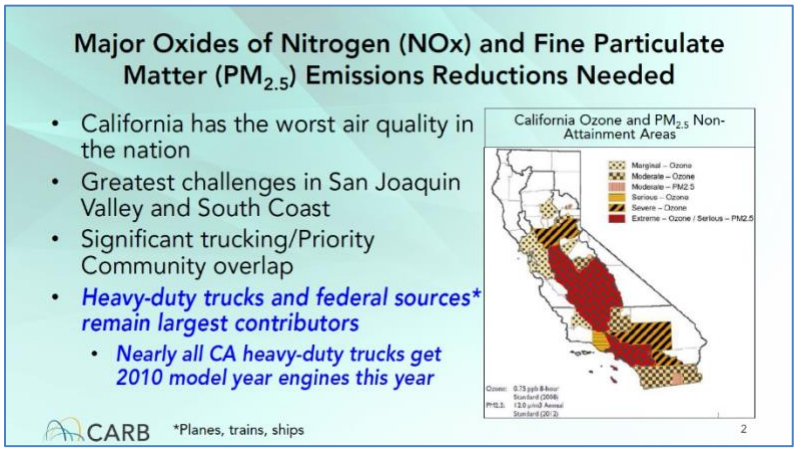
(1:24) "[CALSTART] is a consortium of more than 300 companies both nationally and internationally working to advance and accelerate clean transportation and mobility solutions."

Bill Robertson, Vehicle Program Specialist, California Air Resources Board

(6:13) "Trucks are a critically large part of our NO_x inventory that drives our air quality issues in California…A project like this is very exciting that has a lot of scaling to it."

(7:12) "We need the diesel engines that continue to be sold to be the cleanest possible."

(7:33) "Half the NO_x comes from the small number of trucks that have really large engines and go long distances every day."



(9:07) "We know that diesel is going to be a piece of the equation for a number of years."

Fabien Redon, Chief Technical Officer, Achates Power

(12:28) "The opposed piston engine not only presents a solution for improved efficiency and lower emissions but also has the opportunity to reduce the cost of the powertrain, especially in environments where ultra-low emissions are required."

(13:14) "One of the major cost benefits of the engine is that we can meet the ultralow emissions with just a single underfloor aftertreatment system without the need of added components."

(16:48) "What you can see here is we are able to achieve very high exhaust gas temperatures very quickly…and at the same time…we are able to manage that with very low engine-out NO_x. This combination is key to meeting future emissions levels – the ability to have very low NO_x while the aftertreatment system is being heated. Once it is heated, we can go into high-efficiency mode and can control NO_x very well with the aftertreatment system."

(18:00) "We fit the engine in a Peterbilt 579 truck coupled with an Eaton Cummins 12-speed transmission…We have been running in the fleet. Walmart is using the truck to deliver goods along with their other vehicles since November 2021. Up until this point we have completed about 7,000 miles of operation. In general, the drivers were quite complimentary of the engine – for example, they said the 'truck purrs like a kitten at 60 mph and over' and 'the power curve was really good up a 6-8 degree grade." One of the drivers noticed there was some opportunity for transmission calibration improvement so he did some of the shifting himself and was able to show a further improvement in fuel economy."

(20:37) "We saw pretty significant fuel economy improvements compared to a baseline 2021 4-stroke powered truck…. This is very encouraging with a lot of opportunity for [further] optimization."

(21:05): "We are very excited about the first PEMS[1] results and the ability to meet the future in-use emissions."

(21:20): "We are working on the second generation [of the engine] …and so far, are seeing pretty significant improvement. Now we have over 49% best point brake thermal efficiency and measured about 5% lower CO_2 on the SET cycle and 8% lower on the hot FTP cycle. We've seen greater capability with regard to engine-out emissions and catalyst light-off capability."

(22:20): "We are in the process of working with Southwest Research to do testing at three different levels of aging to validate that we can sustain the ultralow NO_x capability with a fully aged aftertreatment system [up to 800,000 miles]."

(23:27): "We can meet ultralow NO_x with just a conventional underfloor aftertreatment system which provide the biggest cost benefit compared to a 4-stroke engine which requires not just the base system similar to what we are using but in addition, it needs a close couple [aftertreatment] system with complex equipment…that will add cost and hurt the robustness."

Kent Johnson, Principal Investigator, Emissions and Fuels Research, University of California Riverside

(26:22): "A solution to maintain heat is really the key to the diesel problem."

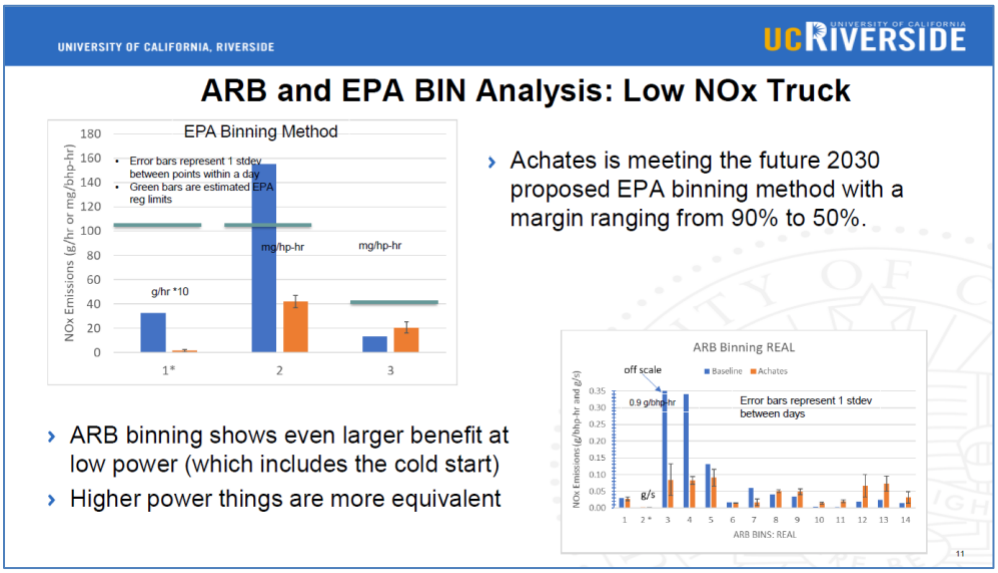
[1] Portable Emissions Measurement System

(27:03): "The ability to manage temperature is critical and what can happen [with a conventional diesel engine] is that if they idle…it will cool off and then you have the problem with high NO_x again…. Anything we can do to increase the heat to the SCR and control under these conditions of low power is critical and that's really been the difficulty for the current diesel product."

(28:43): "These brake-specific [NO_x] emissions [for conventional engines] were fairly high. They average anywhere between 0.17 g/bhp-hr all the way up to ten times higher at 1.8 g/bhp-hr…. It really comes down to the exhaust temperatures and managing it. Some of these exhaust temperatures are getting as low as 113° C."

(29:58): "In-use testing with PEMS is critical. We can do things on a chassis dyno or in a laboratory with certification cycles or low-load cycles but it's really hard to manage these things on road on the real type of duty cycle that is happening over the course of maybe 10 hours."

(30:15): "I think the neatest thing to show is I took these model 2015 trucks, and I applied the future 2030 proposed standards…. These current trucks were not designed for it so we wouldn't expect them to meet it, but I want to show how much lower we should be expecting NO_x emissions to be for the new products. What's amazing is Achates is meeting those emissions today were a lot of the brand-new trucks are struggling to meet those."



(32:30): "A lot of the technology that is advancing is not just for the trucks but for the equipment to measure those trucks…. I want to be sure you are comfortable believing these PEMS measurements are valid…. The new [2022] AVL PEMs is drifting around 0.1 ppm….I am confident we can quantify the emissions under 0.02 with these PEMS."

(34:19): "Here are the results...Achates is meeting the future 2030 standard with a margin between 90% and 50%... The emissions at the lower bins, 3 and 4, really show you Achates is able to manage heat better…. The baseline is way off scale, around 0.9 while Achates was around 0.1 [g/bph-hr NO_x]."

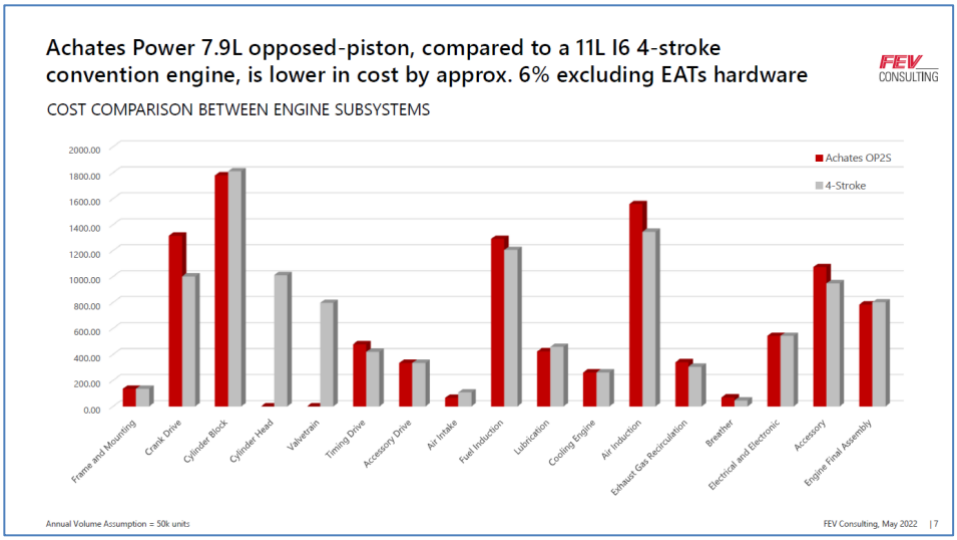
Greg Kolwich, Manager, Production Development, FEV North America.

(40:14): "I am painting the picture of the why the work we do is accurate and reliable and deliver results you can trust…. We do a lot of strategic costing…and we do a lot of benchmarking. We have a procurement supply chain

group…so we have a pretty good grip on what components in a diesel engine would cost….A good chunk of our group is made up of manufacturing engineers so when we do a costing study we start with the grassroots [including] what kind of equipment you would need, what kind of investments…all that drives overhead rates and what kind of people work on the lines, and material costs. All that goes into the cost model."

(42:39): "We put the work where the detail is required so if it's a complex new part that doesn't have a lot of historical should-costing on it we like to a detailed costing so it is grass-roots, start from the bottom, build up the process flows, gather the overhead rates, material costs, labor and step-by-step identify the operations that go into the process….For the Achates project…all the big areas of concern were where we spent a lot of time and effort."

(45:09): "In some cases, the baseline technology and the Achates engine are very similar and in other cases, say where you don't have a conventional valve train, you don't have a cylinder head, you can see where the big savings are [for the Achates engine]. Overall, without the aftertreatment system, we think the Achates engine is definitely competitive. It's a lower-cost application overall compared to [a conventional engine of similar power and torque]. We think it's a 6% cost reduction over a baseline technology."



Question & Answer

(48:54) (Redon): "[Off road] is a very good application of our technology."

(50:50) (Robinson): "We've recently kicked off our Tier 5 [off road] tailpipe emissions standard update. [The opposed piston] is a very interesting technology for the reasons Fabien just mentioned."

(53:45) (Redon): "We are the in the process of aging [aftertreatment system] components that we will be able to evaluate after 800,000 miles…. In addition, a lot of the work we have done on subsystem verification has shown we should have similar and sufficient durability as four-stroke engines. The components are quite similar to what are on four-stroke engines that are quite reliable. It is important to remember we don't have a lot of components on our engine. We don't have a valve train which tend to be problematic at high mileage and requires a lot of adjustments. We don't have cylinder head gaskets which is one of the most troubling components in a four-stroke engine. So, there are a lot of aspects that offer potential for improved durability and reliability of our engine."

(55:44) (Redon): “It takes about six to seven years to prepare an engine for production, so we anticipate that amount of time to bring this heavy-duty opposed-piston engine to market.”

(56:18) (Redon): “The aftertreatment system we are using is one that is already proven. There is no new technology compared to what is currently in production. Four-stroke engines will require a closely coupled SCR and additional heaters that will create additional challenges in terms of reliability and durability.”

(57:07) (Robertson): “About half of our truck miles in California come from trucks that weren’t originally sold under the California standard so it's critically important that we get federal help to meet our ambient air quality standards.”

(59:12) (Redon): “We see a 6% reduction in [base engine] cost. Most of the cost reduction comes from the ability to not have to add aftertreatment system components. There was a recent study by Ricardo that shows it will be about $35,000 of additional costs compared to current technologies to meet the future standards. A lot of that cost we can avoid.”

For more information about Achates Power contact Larry Fromm fromm@achatespower.com