Heavy Duty Diesel Demonstration Program Review

On April 7, 2021, 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 in Denton, Texas, and will be piloted by Walmart in their California operations later this year. Engines have 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
- Measured results show:
  - Ability to meet CARB's 2027 ultralow NO_x regulation with a substantial margin
  - 75% reduction in engine-out PM vs. benchmark diesel engines
  - 7% reduction in CO_2 vs. EPA GHG II regulations
- The measured results are achieved with conventional, underfloor aftertreatment systems providing a significant advantage in cost and complexity vs. other ultralow NO_x solutions.
- Achates Power is working with a group of organizations to commercialize a heavy-duty engine for series production in 2027.

Four individuals spoke at the Program Review:

- Bill Van Amburg, Executive Vice President, CALSTART
- Bill Robertson, Vehicle Program Specialist, California Air Resources Board
- John Wall, Chairman, Achates Power; Retired Chief Technical Officer, Cummins
- Fabien Redon, Chief Technical Officer, Achates Power

The replay can be found here https://youtu.be/Az16WAfzZbI

Highlights (timestamp in parens**):**

Bill Van Amburg, Executive Vice President, CALSTART

(5:57) "93% of the world's children grow up in polluted air"

(6:20) "Medium and heavy-duty vehicles are a key cause of a lot of that pollution"

(6:51) "71% of the NO_x globally come from medium and heavy-duty vehicles."

(7:20) "We need to push combustion engines to be as clean as they possibly can."

(12:21) "We know there will vehicles on the road for decades to come and new vehicles bought for decades to come that will use combustion engines. There will be applications and duty cycles that will be very difficult in the near term for electrification to cover. In those cases, we need combustion engines to be the lowest emitting and the lowest carbon we possibly can get."

(12:54) "This opposed piston engine is allowing us to aim and reach those target points."

(14:20) "We're very excited about [the Program]. It is showing tremendous results, better than we first thought."

Bill Robertson, Vehicle Program Specialist, California Air Resources Board

(18:45) "Even though we are pushing [clean truck initiative] as hard as we think we can, there is still quite a bit of internal combustion trucks being sold for quite a few number of years."

(19:10) "We are excited about new technology that can clean [combustion engines] up."

(19:27) "The best target for doing something to get a benefit [of reduced ozone and PM] is the on-road heavy duty. We're excited these technologies have broad applicability beyond California."

(23:18) "To get a benefit [the control technology has] to work across the range of applications and situations the truck sees, it has to do that for a very long time and there's also this operational efficiency and capital cost that together have to be at a point that allows for broad rollout and a significant uptick so that the actual emissions inventory and vehicle stock is changing and creating these benefits. That's what's exciting about [the opposed piston engine]."

(24:15) "We are looking at how all of these things we assessed for on-road can be applied to off-road, so we'll be a developing a next tier of off-road emissions standards."

(24:57): "We are excited about applications for [the opposed piston engine] applying to off-road as well."

(25:41): "[The ICE ban] has this 'where feasible caveat'"

(26:14): "[We] are looking to accelerate zero-emissions trucks and buses but [we] also call out this transition issue and we can't leave combustion behind….We are very committed to doing zero emissions everywhere we can, but the internal combustion is still very important in this transitional period."

(27:18): "The body of technology that is working on these solutions [for zero and near zero emissions] is building strong support for a meaningful heavy-duty policy out of U.S. EPA."

John Wall, Chairman, Achates Power; Retired Chief Technical Officer, Cummins

(30:54): "These are not just technical steps. These are important business decisions that have huge ramifications for the companies. For example, Detroit Diesel introduced electronic fuel systems across their product line back in the early 1990s ahead of the rest of the industry and they picked up 10-15% market share. When we moved to cooled exhaust gas recirculation in 2002…Caterpillar elected not to move to cooled EGR and by 2010 they were out of the on-highway heavy duty engine business. Similarly, Navistar elected not to move to selective catalyst reduction in 2010 and it had a huge negative impact on their business. This is not just a technology progression; it's a business progression and the decision business make as we decide how to comply with regulations and deliver value to the customer are extremely important."

(33:55): "The Achates two-stroke opposed piston engine will enable much more effective emissions control in lightly loaded applications as well as better efficiency, so lower cost and durable compliance with the future emissions standards and superior fuel economy for the customer…. It has inherently low CO2 and inherently efficient exhaust thermal management."

(34:59): "Inherently efficient exhaust thermal management is a huge part of this that gives inherently lower complexity and cost at ultralow NO_x and low CO_2."

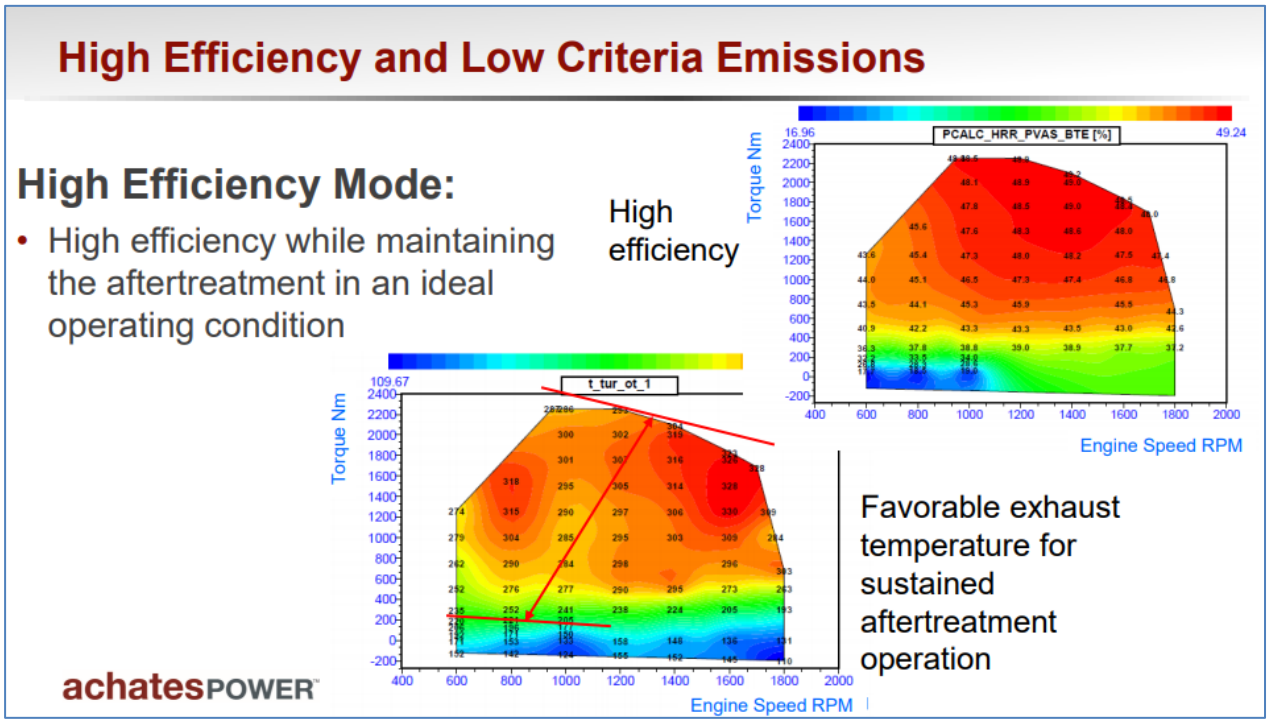
(35:37): "We are currently putting a partnership of companies together to help move into commercialization."

Fabien Redon, Chief Technical Officer, Achates Power

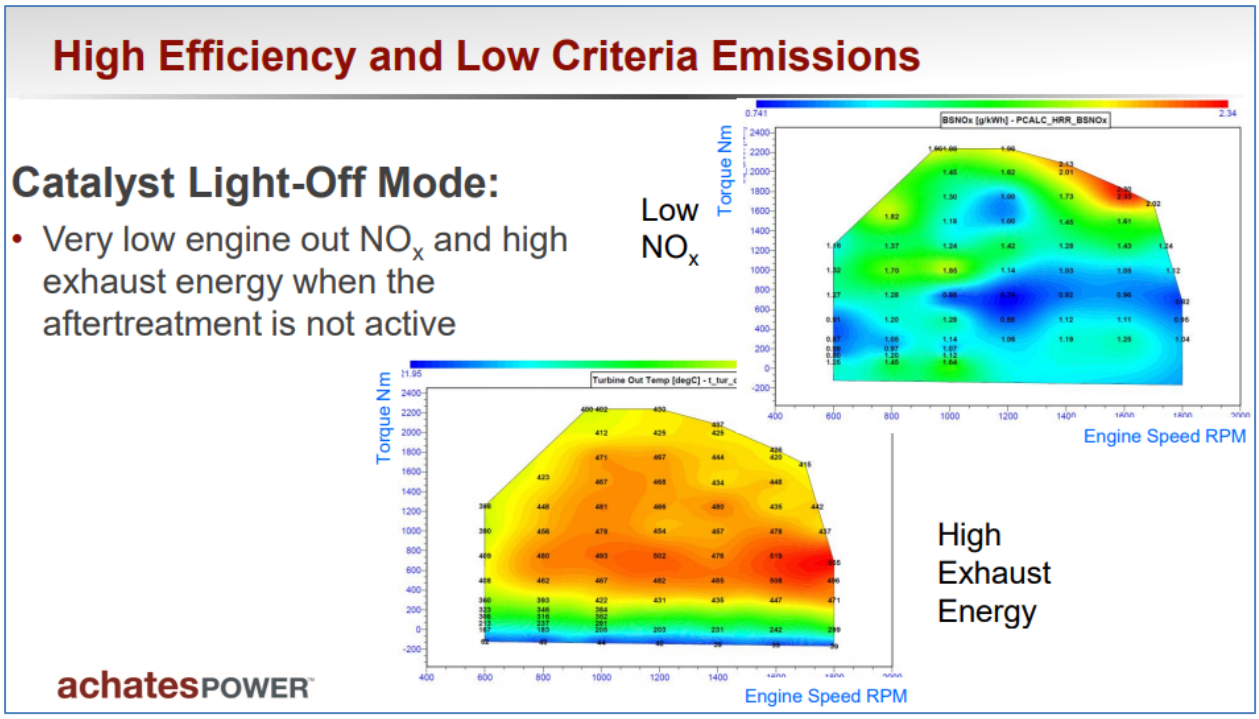
(39:51): "We've been able to demonstrate with our first prototype heavy duty engine a 7% CO_2 reduction compared to 2021 standards and a 96% reduction in NOx from the current standards."

(40:35): "In the end, we end up with a product that achieves this CO2 and NOx reduction with a lower cost in a big part because we are able to achieve this ultralow NOx level with a conventional underfloor aftertreatment system."

(41:35): "We are able to achieve very high efficiency. You can see here [below] the brake thermal efficiency…with efficiencies very close to 50%....with a flat fuel map which is important for real life fuel efficiency and at the same time we are able to manage exhaust gas temperatures in a range that is very suitable for continuous aftertreatment system operation



(42:35): "The catalyst light off mode delivers the capability that allows us to manage extremely low engine-out NO_x and also very high exhaust gas temperatures. This mode is what we use when the aftertreatment system is not yet active to make sure the tailpipe emissions remains very low."



(43:17) "At idle, [the NO_x] is already below the 5 grams per hour clean idle so we don't even need an SCR activated to manage that."

(44:35): "We are combining internal and external EGR to achieve what we need. For example, in some of the lower load operation we are running upwards of 60% of EGR in total."

(45:13): "At the same NO_x level, our engine is operating with a quarter of the soot compared to a four-stroke engine so that's another illustration of the quality of our combustion system."

(55:04): "We are able to achieve 97.5% [SCR] conversion efficiency on the FTP cold cycle and 99.7% on the hot, which for an underfloor [aftertreatment] system is really exceptional. That is enabled by the temperature and NO_x control of our engine."

(56:35): "Because with our engine we have a very narrow [exhaust] temperature range – typically a maximum temperature of 300°C – that allows us to be more aggressive with ammonia storage [on the SCR] which allows us to achieve continuously and under a broader range of conditions very high SCR conversion efficiency and also allows us to set up the SCR in a way that when the next cold start happens it will be activated very quickly and achieve very high efficiency quickly."

(1:02:10): "We are expecting 0.007 [g/bhp-hr NO_x on the FTP cycle]…much lower than the 0.02 [Ultralow NO_x regulation]." NOTE: This is with a current underfloor aftertreatment system in a conventional DOC/DPF/SCR/ASC layout.

(1:04:47): "On the SET cycle we are at 415 g / hp-hr [CO_2] which is much below the 2027 EPA regulation of 432 so provides a significant margin even to 2027 regulations."

(1:09:14) "The opposed piston engine with [a] much simpler aftertreatment system is able to achieve much lower tailpipe NO_x."

(1:11:54): "We expect that the opposed-piston engine base cost will be about $10,000 less at the 2027 emissions levels compared to the solution that the four-stroke engine will need to deploy.

Question & Answer

(1:17:41) (Redon): "We are assembling a team of partners to support and develop the engine with us and prepare it for production."

(1:20:04) (Robinson): "It's necessary to continue to clean up the combustion engine technologies as we move forward. We are talking about quite a number of years of transition here. We're definitely prioritizing cleaning up the combustion along the way."

(1:20:32) (Van Amburg): "We can't afford as a society to put dollars into things that can't get us down [a] dual path….On the combustion side it has to show, as this engine does - which is why we've been so supportive of it - that it can make the movement towards low criteria emissions and carbon at the same time. The dollars from

public agencies are going to focus on things that are deeply decarbonized fuels and highly efficient, very low emission engines on the combustion side. There's just not enough public dollars to mess with anything else."

(1:22:31) (Van Amburg): "I'm really excited about the use of this kind of engine architecture in off-road and being able to get to ultralow emissions particularly in construction and other applications that are going to be really hard for infrastructure and other reasons to fully electrify. I also think this engine would be an ideal engine for a hybridization scheme….I see this architecture as powerful in a number of different venues."

(1:26:02) (Redon): "We are still operating at a compression ratio of 18:1 which is very similar to conventional engines today. There is still a lot of opportunity to continue developing the engine to explore even higher efficiencies."

(1:26:26) (Wall): "Having the flexibility to be able to control the air flow through the engine and thereby control the exhaust temperature, to be able to elevate it at light loads, to be able to control it a peak loads, is a very unique capability of the opposed-piston two-stroke engine. That optimization is what lets you break this connection between tailpipe NO_x and efficiency and the deliver the AND of low NO_x AND good efficiency."

(1:27:40) (Redon): "Currently we are coupling the engine with the Eaton-Cummins 12 speed transmission, basically the one that came out of the four-stroke engine donor. The speed range of the engine, the torque response of the engine is basically mimicking what the four-stroke engines are doing today….As we look at the characteristics of our engine we see that the efficiency map is less peaky and a lot flatter and broader that four-stroke engines so we can see the opportunity to maybe simplify the transmission by not having to systematically run at the very specific operating condition in the engine map to extract the highest efficiency….In terms of engine brake, we have developed an engine brake for the opposed-piston engine. It is a relatively simple system. It is a small valve we open between the two pistons and that provides a continuous leakage of the cylinder pressure during braking and that in combination with the air system that we can manipulate to increase the boost pressure, the load on the system is available to achieve engine braking that are equivalent to what compression brakes are achieving on four-stroke engines and all of that with a very simple system.

(1:29:33) (Wall) "It all works without the POP-POP-POP you get from compression release on a Jake brake on a conventional engine so in areas where there are noise regulations that prevent the use of current compression brakes this one would actually work fine."

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