Written input for California Air Resources Board (CARB) August 27, 2020 hearing to consider approving for adoption proposed Heavy- Duty Engine and Vehicle Omnibus Regulation and Associated Amendments (HD Omnibus Regulation).

**High Efficiency Flexible Fuel Gasoline-Ethanol Engines as an Affordable and Robust Solution for CARB Goal for a 90% Reduction in NOx from Heavy Duty and Medium Duty Vehicles**

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The proposed Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments (HD Omnibus Regulation) discusses in-use-testing and a goal for a 90% reduction in nitrogen oxide (NOx) emissions relative to NOx emissions from diesel engines with state-of-the-art exhaust treatment. One of the challenges for diesel engines is assuring in-use-testing and compliance of Real Driving Emissions (RDE) because of the active exhaust treatment role that is needed; injection of the reducing agent needs to be controlled to both assure selective catalytic reduction of NOx, as well as prevention of release of the reagent. A technology that does not face this challenge and should be considered for baseline emissions, achievable today, is the use of spark ignited (SI) flexible fuel gasoline-ethanol engines for heavy duty and medium duty vehicles.

We have been using computer simulations to investigate the use of high efficiency, flexible fuel gasoline-ethanol engines for achieving low NOx RDE compliance. These computer simulations have been benchmarked with experimental studies of light duty vehicle engines.1,2 This approach can provide an important additional option for an affordable and robust solution for a near term attainment of the low NOx goal. It can also provide substantial near term progress in reducing greenhouse gas emissions.

Use of a three-way catalytic converter which is enabled by stoichiometric fuel/air operation in these spark ignition (SI) engines can robustly reduce NOx by around 90% relative to emissions from present diesel engines that employ complex and expensive state-of-the-art exhaust treatment that uses selective catalytic reduction (SCR) and diesel exhaust fluid (DEF).

The high efficiency gasoline-ethanol engines can provide a flexible operation range from mainly or entirely gasoline or E10 use to E85 and potentially E100 ethanol use. The capability to operate on mainly gasoline insures the option of using an affordable, readily accessible fuel. The capability to operate with a substantial ethanol fraction can provide a significant greenhouse gas reduction. The ethanol for initial deployment is corn-based, with substantial production and distribution infrastructure. Various assessments including CARB assessments have indicated that corn-based ethanol can provide around 30% lower carbon intensity than diesel fuel .3,4,5 The carbon intensity of ethanol could potentially be further reduced by use of carbon sequestration and capture of the relatively pure CO2 stream from a biorefinery or by using municipal solid waste (MSW) and/or biomass waste as a feedstock for ethanol production.

In addition, these flexible fuel engines can provide significant cost advantages relative to diesel engines because of the much less expensive exhaust treatment cost. This can reduce the upfront cost of engine + exhaust treatment by around 30 to 40% relative to the cost for a diesel engine. The lower cost of the engine+ exhaust treatment system in SI gasoline-ethanol powered vehicles relative to that in present diesel powered vehicles could facilitate the use of electric hybrid powertrains. This could provide higher efficiency and lower emissions in heavy and medium duty trucks and could be especially effective for vehicles with frequent changes in power demand, as in urban driving cycles.

The replacement of diesel powered vehicles by SI gasoline powered vehicles has already been occurring in a segment of the medium duty truck market. In 2010, 95% of Class 4 trucks sales were diesel; in 2015, the numbers were reversed, gasoline class 4 truck sales were 76%. A smaller trend is seen in class 5 vehicles where a larger number of vehicles were sold than in the class 4 market and where the diesel fraction of sales decreased from 92% to 78% in a 5-year period.6

 High compression ratio and a downsized turbocharged engine is used in the high efficiency gasoline-ethanol engines to provide an energy-based efficiency which approaches that of a diesel engine; and can be comparable to it when energy consumption of the diesel emission fluid (DEF) for NOx exhaust aftertreatment is taken into account. High knock resistance is required for this type of SI engine operation. For operation on high concentration ethanol (*e.g.* E85 and higher ethanol concentrations) the high knock resistance is provided by the high chemical octane of ethanol and also by increased knock resistance from vaporization cooling when liquid ethanol is introduced into the cylinder by direct injection or by open-valve port fuel injection. High Efficiency direct injection E85 engine operation has been shown in the 2.8 liter Cummins Ethos engine in a medium duty truck in a program supported by the California Energy Commission. 5

For operation mainly or entirely on gasoline or on E10, the requirement to prevent knock in the high compression ratio, turbocharged engine can be provided by a number of techniques. One technique is the variable injection of water (which could be recovered from the exhaust) and/or by ethanol from a second tank. The injection of water and/or water from the second tank is used to provide increased knock resistance at higher values of torque, enabling high compression ratio, turbocharged operation that provides comparable efficiency and torque to a diesel engine in a smaller size engine. As an alternative to anhydrous ethanol which is presently used in the US, the ethanol can be a hydrous ethanol (ethanol and water). Hydrous alcohol use can reduce the fraction of fuel that must be provided by ethanol by knock suppression through evaporative cooling.

Another technique is to reduce the knock requirement by selective use of engine upspeeding. When engine upspeeding is utilized higher rpm, lower torque operation is employed to provide the same amount of power (and same torque at the wheels through gearing) as would be provided at high torque engine operation; selective use of this mode of operation can reduce the knock resistance requirement with a small decrease in engine efficiency. A future option is to use a modestly increased ethanol concentration blend (*e.g*. E20 or E30) in combination with these approaches.

Additional options, which would require a longer time for substantial scale deployment, would be to use a flexible fuel gasoline-ethanol engine operated in the high efficiency region of the engine map in combination with power that is provided by a battery that is charged with externally produced electricity (a plug-in hybrid). This type of powertrain could use a wide range of combinations of battery power, ethanol power and/or gasoline power. One of these combinations could be as a low emissions range extender for a mainly battery powered electric vehicle over a drive cycle. At the other end of the spectrum the powertrain could be configured for a mainly engine powered vehicle.

 Powertrains that use high efficiency flexible fueled gasoline -ethanol engines can thus provide an important option for robustly addressing the challenging near term goal for improved air quality through NOx reduction and can also provide significant near term progress in greenhouse gas reduction. CARB should consider this option in its planning. SI engines powered by gasoline and ethanol can meet RDE compliance across a wide range of the driving cycles.

**References**

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