Well-to-Wheels Carbon Intensity for Ethanol Blended Fuels

Executive Summary

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The objective of this report is to compare the greenhouse gas (GHG) impact of petroleum gasoline, ethanol, and their blends when used in light duty spark ignited vehicles. Well-to-wheels (WTW) modeling seeks to quantify the carbon dioxide (CO_2) or CO_2 equivalency (including other GHG) produced by a fuel or energy source. Typically, this is presented as a WTW carbon intensity (CI) with units of grams of CO_2 per MJ of energy (g/MJ).

For petroleum fuels, the inherent chemical carbon content of the fuel is added to carbon associated with the production, transportation and refining that occur before the fuel is purchased at the pump. In contrast, bioethanol is considered to be carbon free at the source, because all of the carbon is fixed from the atmosphere and is renewable. US bioethanol is produced primarily from corn. Only the upstream emissions associated with farming, processing and transportation represent a carbon footprint that must be assigned to the ethanol. In addition, CI debits are applied to the ethanol for land use changes (LUC) that affect carbon level in the soil, and credits are applied for useful by-products made available from the corn processing.

The LUC component is difficult to quantify and represents the component with highest variability between studies. The literature presents changes in farming practice and in production energy demands that have reduced the CI for ethanol over the last decade. The GREET model from Argonne National Laboratory of the US Department of Energy has an established history in quantifying CI of fuels. GREET presents a CI of 92.6 g/MJ for gasoline and 52.4 g/MJ for ethanol. These GREET predictions, along with values from a study for the US Department of Agriculture and the current values used by the California Air Resources Board, yield an average CI for ethanol that is 40.4% below the value for petroleum gasoline. Using the 40.4% ethanol advantage, and assuming a CI of 93 g/MJ for gasoline, the CI of ethanol for the three study average is 55.5 g/MJ. A recent study led by Harvard presents a best estimate CI for ethanol of 51.4 g/MJ. The lower reduction in CI for ethanol relative to petroleum from the Environmental Protection Agency (EPA) dates back to 2010 and is used a threshold for recognition of renewable fuels.

When ethanol, with a low CI, is blended with petroleum gasoline to form E10 (a 10% blend of ethanol by volume), the ethanol reduces the CI of the mixture by displacing some gasoline. Beyond this advantage, the ethanol also offers a high octane contribution to the mix and permits the reduction by about 8% of the aromatics in the petroleum fraction while maintaining the same octane rating of the final blend. Aromatics have a high CI, and their reduction in the petroleum fraction further decreases the GHG impact of the E10. The blending effect is similar for E15 and E20 blends. This advantageous blending attribute has been neglected in prior GHG literature.

Both direct displacement and aromatic reduction can be assigned to ethanol as the enabling additive. If a pure ethanol CI of 55.5 g/MJ is adopted from the three study average, a blending CI (BCI) of 43.4 g/MJ is found for ethanol when it is used in E10. If a GREET pure ethanol CI of 52.4 g/MJ is used as the basis, the BCI of ethanol is 40.4 g/MJ. The low BCI values represent the overall benefit of using ethanol in a market gasoline blend, due to the blending octane number (BON) of the ethanol. Similarly, for anticipated market blending, both E15 and E20 also exhibit low BCI values. BCI may be computed using any specific upstream CI value, and any comparative petroleum blend compositions. If the current GREET estimation that pure ethanol CI is 43.4% lower than petroleum gasoline CI, the BCI values for E10 and E15 average at 40 g/MJ, while the BCI for E20 is 41.7 g/MJ. While the CI of pure ethanol is very attractive from a climate change perspective, the "per gallon" CI benefits of ethanol are higher in a blending strategy.

The EPA has recognized that certain fuels may offer efficiency advantage over others when a vehicle is operated through a driving cycle. The efficiency advantage reduces CO_2 production beyond that expected from the fuel composition alone. A recent EPA study showed that a Tier 3 E10 certification fuel offered an efficiency advantage over a Tier 2 purely petroleum fuel, revealing an additional GHG advantage of the ethanol blend. If this third CO_2 reduction mechanism is also assigned to ethanol, the ethanol BCI is lowered further. The low BCI of ethanol in E10, E15 and E20 encourages optimized blending of ethanol in gasoline motor fuels for immediate GHG reduction and teaches that ethanol has GHG benefits that are greater than those traditionally recognized in prior well-to-wheels studies of the pure ethanol CI.