Next Generation Heavy-Duty Natural Gas Engines Fueled by Renewable Natural Gas

Technical Fact Sheet

A comprehensive whitepaper was published in May 2016 titled, "Game Changer: Next Generation Heavy-Duty Natural Gas Engines Fueled by Renewable Natural Gas." Support for the research was provided by a number of public and private sector organizations, including: Agility Fuel Systems, American Gas Association, California Natural Gas Vehicle Partnership, Clean Energy, Pacific Gas & Electric Company, South Coast Air Quality Management District and Southern California Gas Company. The whitepaper details how the union of ultra-low NOx heavy-duty NGVs and ultra-low carbon renewable natural gas (RNG) blends can uniquely, immediately, and economically help transform America's heavy-duty transportation system, reduce petroleum dependency, improve ambient air quality, and address climate change. This fact sheet provides an overview of some of the key technical data discussed in the report.

ULTRA-LOW NOX NATURAL GAS ENGINES:
The Cleanest Available HD Engine Technology

The Cummins Westport's 8.9 liter ISL G NZ engine is the world's first heavy-duty engine certified to meet CARB's lowest-tier optional low-NOx emission standard of 0.02 g/bhp-hr NOx. Additional announcements about other heavy-duty natural gas engines certified to these extremely low levels are expected in 2017.

Key Game Changer Claim: An on-road heavy-duty vehicle powered by a near-zero-emission engine (certified to 0.02 g/bhp-hr) has tailpipe NOx emissions that are comparable to – or possibly lower than – the amount of NOx emitted to produce electricity used to charge a similar heavy-duty battery-electric vehicle (HD BEV).

HD BEV Equivalent
based on comparing NOx emissions associated with BEV charging

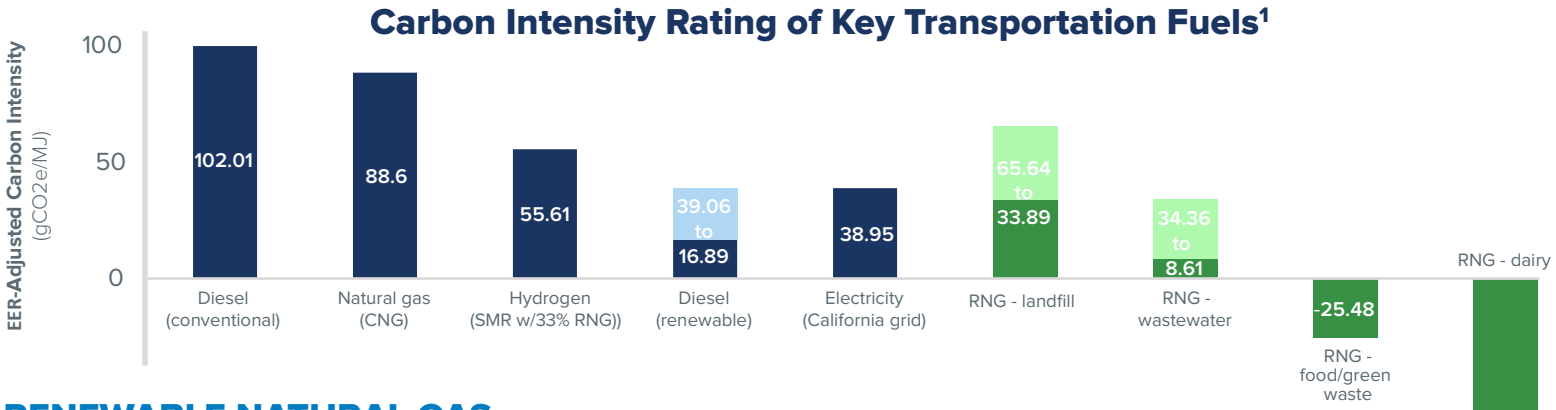
How was this comparison calculated?

As noted above, plug-in electric vehicles have NOx emissions associated with the electrical generators that supply power to the grid used to recharge them. US EPA's eGRID 2012 database was used to determine the grid-related NOx associated with charging HD BEVs. These results were then compared to the tailpipe NOx emissions from HD NGVs.

Accounting for transmission and battery charging losses, as well as an estimated 25% energy recovery from regenerative braking, the tailpipe-equivalent NOx emissions for the average grid mix was calculated for various geographic regions. Even in states with the cleanest electrical grids in the nation—California, Oregon, and Washington—NOx emission rates were 2.5 to 3.5 times higher than the near-zero emissions level of 0.02g/bhp-hr.

To learn more, read pages 165 to 171 in the Game Changer Technical Whitepaper www.ngvgamechanger.com.

Technical Fact Sheet (Continued)



RENEWABLE NATURAL GAS:
Replacing Diesel with the Lowest Carbon Intensity Fuel

Renewable natural gas (RNG) is an ultra-low-carbon fuel produced by harnessing methane produced from landfill, wastewater treatment plants, and other organic waste streams.

Key Game Changer Claim: RNG has the lowest carbon intensity rating of key transportation fuels and can reduce greenhouse gas emissions by 40 to 125% or more.

How was this comparison calculated?

The carbon intensities in the above table, sourced from the California Air Resources Board (CARB), compare the well-to-wheels GHG emissions of various fuels in heavy-duty trucking applications. Carbon intensities are adjusted to reflect the efficiency of vehicle/fuel combinations as compared to a heavy-duty diesel engine by using CARB's approved Energy Economy Ratios (EER).

Key Game Changer Claim: Studies from a range of reputable sources estimate that sufficient feedstock exists in the U.S. today to produce enough RNG to displace tens of billions of diesel gallons.

What is the basis of this information?

Various government, industry and academia studies have found that America has sufficient technically recoverable feedstock to produce from 35 to 70 billion diesel gallon equivalents (DGE) of RNG per year. Focusing on California, multiple reputable sources have found that sufficiently large volumes of RNG can be produced today to displace the state's on-road heavy-duty truck diesel usage. Here are estimates from two recent studies (whose findings varied based upon how they analyzed feedstock supply and project economics):

- In mid-2015, CARB concluded that "California generates enough organic waste and biogas each year to produce 2.4 billion gallons of transportation fuels, enough to replace 75 percent of all diesel used by California vehicles."[2]
- In 2016, the University of California-Davis in conjunction with the U.S. EPA (Region 9) found that anaerobic digestion of readily available California organic waste (dairy manure, landfill gas, municipal solid waste and wastewater) could potentially produce nearly 675 million DGE per year of RNG, or enough RNG to fuel 31 percent of California's Class 8 heavy-duty trucks.[3]

Project economics for certain feedstocks will reduce these estimates until production efficiency improves. To learn more, see the specific footnotes provided and read pages 132 to 135 in the Game Changer Technical Whitepaper. Download the whitepaper at www.ngvgamechanger.com.

1: http://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm, CARB, February 2017. Adjusted for heavy-duty truck applications.
2: California Air Resources Board, "California Biofuels Cap & Trade Initiative," April 29, 2015, https://www.arb.ca.gov/lists/com-attach/135-slcpdraftstrategy-ws-AXIGY1M1UI4AdVQw.pdf.
3: UC Davis Biomass Collaborative, U.S. EPA Region 9, & National Risk Management Research Lab Office of Research and Development, "Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies," EPA/600/R-16/099, September 2016, http://biomass.ucdavis.edu/wp-content/uploads/2016/11/EPA600R-16099_BiogasTech_Sept2016.pdf.