Heavy-duty vehicles (HDVs) are the fastest growing segment of U.S. transportation in terms of energy use, greenhouse gas (GHG) emissions, and smog-forming emissions. To combat global climate change and to restore healthful air quality for the approximately 166 million Americans who reside in areas with exceedingly poor air quality, according to the American Lung Association, the United States must aggressively reduce emissions. This cannot be achieved without a systematic and wide-scale transformation of today’s diesel-fueled HDVs, especially high-fuel-use heavy-heavy-duty vehicles (HHHDVs), to zero- and near-zero emission vehicle technologies fueled with low-carbon fuels.
There are four unique fuel-technology combinations that currently hold the most promise to successfully achieve this transformation (see Table 1). They include two types of advanced low-emission internal combustion engines (fueled increasingly by renewable natural gas or renewable diesel); and two types of electric-drive systems (powered by batteries or hydrogen fuel cells). In looking at the next several decades, it is likely that all four of these HDV fuel-technology combinations will contribute to meeting air quality and climate change goals in varying capacities. However, when considering the emissions profiles and the timeline of commercialization, especially in the HHDV application, only one fuel-technology option can immediately begin this transformation: near-zero emission heavy-duty natural gas vehicles fueled by ultra-low GHG renewable natural gas (RNG).

**‘Near-Zero NOx’ HDV**

Earlier this year, Cummins Westport (CWI) installed a 9-liter natural gas engine in a Southern California heavy-duty truck. What was a seemingly routine installation—one that takes place in approximately two out of every three heavy-duty trucks ordered in the United States today—is changing the future of heavy-duty commercial transportation forever.

This engine is the world’s first heavy-duty engine certified to meet the California Air Resources Board’s lowest-tier optional low-NOx emission standard of nitrogen oxides (NOx) emissions of 0.02 gram per brake horsepower hour (g/bhp-hr), or below, making it more than 90 percent cleaner than the most stringent U.S. Environmental Protection Agency (EPA) heavy-duty on-road emission standard on the books today. With such incredibly low emissions, this engine is considered “near-zero NOx.” In fact, it has a similar air emissions profile to that of a heavy-duty battery electric truck plugged into the California electrical grid, one of the cleanest electrical grids in the United States.

**Super Fuel: RNG**

To complement the NOx reductions, replacing diesel fuel with traditional natural gas will reduce lifecycle GHG emissions by approximately 15 percent (see Figure 1). However, when using RNG, which is natural gas produced from renewable

### Table 1. Four leading fuel-technology pathways for zero- or near-zero emission HDVs.

<table>
<thead>
<tr>
<th>Prime Mover Technology</th>
<th>Assumed Fuel/ Energy Source</th>
<th>Proven Regulated Emissions Profile (Direct HDV Emissions)</th>
<th>Proven GHG Emissions Profile</th>
<th>Timeline for Commercialization as HD ZEVs or NZEVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-NOx Diesel Internal Combustion Engine (possible hybridization with electric drive, plug-in capability)</td>
<td>Renewable Diesel (RD) (increasing blends with fossil diesel)</td>
<td>Baseline: meets 2010 federal heavy-duty emissions standard (modest NOx reduction using RD)</td>
<td>Very Low: RD has an excellent combination of low carbon intensity fuel/high engine efficiency</td>
<td>Unknown (lower-NOx engines expected by about 2018, but achievement of near-zero emission levels will be very challenging)</td>
</tr>
<tr>
<td>Low-NOx Natural Gas Internal Combustion Engine (possible hybridization with electric drive, plug-in capability)</td>
<td>Renewable Natural Gas (increasing blends with fossil gas)</td>
<td>Near-Zero-Emission: engine(s) certified to 90% below existing (2010) federal -NOx standard</td>
<td>Extremely Low: ultra-low (some negative) carbon intensity fuel options/good engine efficiency</td>
<td>Immediate for 9-liter HDV applications (trucking, refuse, transit); 2018 for HHDV 12L applications</td>
</tr>
<tr>
<td>Battery Electric Drive (possible hybridization with range extending fuel cell, other options)</td>
<td>Grid Electricity (increasing percentages made from renewables)</td>
<td>Zero Emission: meets CARB’s definition (no direct-vehicle emissions)</td>
<td>Very Low: excellent combination of low carbon intensity fuel/ very high drivetrain efficiency</td>
<td>10 to 20 Years in HHDV applications; Immediate for use in short-range MHDV and transit applications</td>
</tr>
<tr>
<td>Fuel Cell Electric Drive (likely hybridization with batteries for regenerative braking and peak power)</td>
<td>Hydrogen (increasing percentages made from renewables)</td>
<td>Zero Emission: meets CARB’s definition (no direct-vehicle emissions)</td>
<td>Very Low: excellent combination of low carbon intensity fuel/ very high drivetrain efficiency</td>
<td>10 to 20 Years in HHDV applications; Potentially Near-Term for use in short-range MHDV and transit applications</td>
</tr>
</tbody>
</table>
The combination of near-zero-emission natural gas engine technology and RNG fuel provides the single best opportunity for the United States to achieve immediate and substantial NOx and GHG emission reductions in the on-road heavy-duty transportation sectors.

sources using either biological or chemical processes, GHG emissions benefits increase.

RNG provides the lowest carbon intensity of any heavy-duty transportation fuel available in the market today with lifecycle GHG emission benefits increasing to 80 percent or more and, in some cases, greater than 100 percent reduction in GHG emissions. Various forms of waste streams that are otherwise environmental hazards requiring costly treatment or processing are instead converted to energy-rich, locally-produced renewable energy sources that ultimately displace higher-pollution non-renewable fuels. This simultaneously generates significant economic value and multiple other benefits.

Even if RNG is not used as a transportation fuel and is instead used to produce electricity, it can offer several important societal benefits; these include reduction of upstream methane leakage and flaring, mitigation of catastrophic wildfires, and improvements to agricultural processes and yields. Additionally, RNG production facilities can help create local jobs and economic development in virtually any community across America.

Near-zero emission natural gas engines using RNG provide a commercially proven strategy to immediately achieve reductions in emissions of criteria pollutants, air toxins, and GHGs from the U.S. on-road HDV sector. The 9-liter,

Figure 1. Carbon intensity score of heavy-duty truck pathways.5
medium-heavy-duty version of this ultra-low-NOx engine technology is being deployed today in the refuse, transit, and short-haul delivery applications. A 12-liter, heavy-heavy-duty version of the engine will be commercially available in the next year, providing diesel-like performance for tractor-trailer trucks used in goods movement trucking throughout the nation.

The combination of near-zero-emission natural gas engine technology and RNG fuel provides the single best opportunity for the United States to achieve immediate and substantial NOx and GHG emission reductions in the on-road heavy-duty transportation sectors. Equally important, major reductions of cancer-causing toxic air contaminants can immediately be realized in disadvantaged communities adjacent to freeways and areas of high diesel engine activity, where relief is most urgently needed. The alternative fuels industry has always agreed that there is no “silver bullet” when it comes to fuels and advanced transportation technologies. However, it is clear that the commercial introduction of near-zero NOx emission engines fueled by ultra-low-GHG RNG is an achievement for air quality and petroleum displacement goals that is as close to a “holy grail” solution as has ever been seen in the heavy-duty truck sectors.

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References
5. “LCFS Illustrative Fuel Pathway Carbon Intensity Determined using CA-GREET2.0” discussion presented by California Air Resources Board staff on September 17, 2015; and/or “LCFS Final Regulation Order, Table 6”; Note: “HASD pathway has been EER-adjusted per CARB’s formula (-22.93 base CI divided by EER of .9). For negative CI scores, the formula should require multiplying by the EER. Thus, -22.93 X 0.9 = -20.64 for the correct EER-adjusted CI score.”