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September 28, 2016

Rajinder Sahota
California Air Resources Board
1001 "I" Street
Sacramento, CA 95812

RE: Written Comments by the Southern California Gas Company and San Diego Gas & Electric on the Public Workshop on the Transportation Sector to Inform Development of the 2030 Scoping Plan Update

Dear Ms. Sahota,

The Southern California Gas Company ("SoCalGas") and San Diego Gas & Electric Company ("SDG&E") appreciate this opportunity to comment on the California Air Resources Board's ("ARB") Scoping Plan Update ("SPU" or "Update") Workshop on the Transportation Sector. We commend ARB for acknowledging that the use of natural gas vehicles in the heavy-duty sector can provide significant emission reductions of criteria pollutants, and that the addition of renewable natural gas can contribute significantly to meeting the State's greenhouse gas ("GHG") reduction targets. We believe that all alternative fuels, including renewable natural gas and electricity, must play an integral role in achieving California's 2030 goals.

In this letter, we supplement our comments filed on the previous Update documents about how natural gas can contribute to meeting the State's mid-term air quality goals and the 2050 climate goals. This letter provides greater detail pertaining to the opportunities for leveraging natural gas technology advancements in the transportation sector as mentioned in our previous workshop comment letter[1]. Specifically, we highlight the use of natural gas in low-emission vehicle technologies to help reduce emissions in the on-road and off-road sectors and further emphasize our support for the Low Carbon Fuel Standard ("LCFS"). We also provide detailed feedback on ARB's Biofuel Supply Module.

I. Sustainable Freight and Off-Road Sectors

A. Renewable Natural Gas Can Transform the Freight Sector by Reducing GHGs and NOx

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[1] SoCalGas Comments on Air Resources Board Scoping Plan Update Workshop, September 7 2016

Slides 64 through 81 of the Workshop presentation articulate ARB's strategies and measures for reducing emissions in the on-road and off-road sectors. While SoCalGas and SDG&E appreciate the inclusion of near-zero technologies in a few of the goals stated to help achieve further emission reductions (i.e. in on-road and off-road sectors and transport refrigeration unit goals), the larger majority of the goals and actions depicted in these strategies and measures seem to focus solely on accelerating deployment of zero-emission ("ZE") technologies either through incentives or regulations. We disagree that the needed reductions could be achieved solely through electrification. Rather, ARB should develop policies and commit to support technologically feasible and cost-effective technologies to meet the different duty-cycles of on-road and off-road vehicles. Near-zero natural gas technologies for both on-road and off-road sectors, when fueled by renewable natural gas ("RNG"), will considerably help achieve the State's emissions targets. Because RNG is generated from organic waste sources, its use not only helps reduce transportation emissions, but can also reduce methane emissions that would otherwise be released into the air from sources such as landfills and dairies. Utilizing organic sources of methane is also a key strategy in ARB's Short-Lived Climate Pollutant ("SLCP") Plan.

ARB's SPU must consider both climate change and air quality mandates when promulgating new regulations. The Update should integrate the policies needed to support regional air quality targets as well as the state's broader GHG targets. Both the South Coast and San Joaquin Valley Air Basins must achieve significant reductions in nitrogen oxides ("NOx") to attain ozone and particulate matter National Ambient Air Quality Standards in the next decade. Near-zero natural gas vehicles fueled by RNG in the heavy-duty Class 7 and 8 sectors can help these regions attain federal air quality standards as well as State GHG reduction goals with commercially ready technology available today.

As detailed in the Game Changer Technical Whitepaper prepared by Gladstein, Neandross & Associates ("GNA"), there is now a commercially-available heavy-duty natural gas engine that meets ARB's lowest-tier optional low-NOx emission standard at 0.02 g/bhp-hr NOx[2]. When paired with RNG, this technology will provide a commercially proven, broad-based, and affordable strategy to achieve major reductions immediately in emissions of criteria pollutants, air toxins, and GHGs. Since ARB has acknowledged that Class 7 and 8 heavy-duty electric and fuel cell electric vehicles will not be available until the 2030 timeframe,[3] RNG can provide an immediate opportunity for California to achieve its air quality and climate change goals in those heavy-duty transportation sectors. Equally important, major reductions of cancer causing toxic air contaminants can immediately be achieved in disadvantaged communities adjacent to freeways and areas of high diesel engine activity, where relief is most urgently needed. The executive summary of this white paper is provided to the record for consideration by the State Agencies in Appendix B.

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[2] Game Changer Technical White Paper, Gladstein, Neandross & Associates, May 3, 2016. http://ngvgamechanger.com/pdfs/GameChanger_FullReport.pdf.

[3] See ARB Technology Assessment: Medium and Heavy Duty Battery Electric Trucks and Buses, October 2015, available at http://www.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf and ARB Technology Assessment: Medium and Heavy-Duty Fuel Cell Electric Vehicles, November 2015, available at http://www.arb.ca.gov/msprog/tech/techreport/fc_tech_report.pdf

B. SoCalGas Encourages the Use of Natural Gas in Non-Road Freight-Related Engines

SoCalGas and SDG&E believe natural gas and RNG have an important role to play as transportation fuel for heavy duty engines in the non-road freight sector. Specifically, natural gas can significantly reduce emissions in ocean-going vessels and locomotives, which are large contributors of air pollutants in the goods movement sector. SoCalGas has conducted analysis to evaluate the specific benefits of utilizing natural gas in heavy-duty non-road engines and is pleased to share our findings here.

1. Ocean-Going Vessels ("OGVs") Running on Liquefied Natural Gas Reduce Criteria Pollutants and Black Carbon Emissions

Emission estimates for an International Maritime Organization ("IMO") Tier III diesel-fueled 8,000 twenty-foot equivalent ("TEU") OGV and a similar liquefied natural gas ("LNG") OGV travelling from Los Angeles to Shanghai are shown in Table 1 of the attached Appendix B. Two different estimates were made for the diesel OGV - one before 2020 and the other for 2020 and beyond to capture the change in emissions resulting from the switch in fuel oil sulfur content to 0.5% required by IMO Regulation 14. **The results show a reduction of 92% in PM_{10}, 85% in NO_X, >99% in SO_X, and 39% in black carbon prior to 2020.** For calendar year 2020 and beyond, we see a smaller reduction in PM_{10} of 69% due to the use of lower sulfur fuel oil; however, reductions in black carbon emissions increase from 230 pounds per one-way trip (or 39%) to 330 pounds per one-way trip (or 49%).

To understand the potential impact of such a fuel switch, consider a scenario of LNG OGVs increasingly replacing diesel OGVs for container cargo transport between Southern California and Asia. Southern California Association of Governments' ("SCAG's") 2016-2040 Regional Transportation Plan/Sustainable Communities Strategy ("RTP/SCS") estimates that the Ports of Los Angeles and Long Beach will handle around 36 million TEUs in 2035.[4] More than 90% of this cargo (around 32.4 million TEUs) would be traffic to/from Asia.[5] If LNG OGVs started replacing diesel OGVs in 2020 and carried half of projected 2035 Asian cargo, black carbon emissions from OGVs would be reduced every year after introduction up to approximately 340 tons/year by 2035.

2. LNG-Fueled Line-Haul Locomotives Reduce Black Carbon Emissions

Emission estimates for a 100 rail car double-stacked intermodal container train powered by three Tier 4 diesel locomotives and a similar train powered by three LNG locomotives travelling from Los Angeles to Chicago are provided in Table 2 of the attached Appendix B. Both locomotives

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[4] SCAG, 2016 to 2040 RTP SCS - Transportation Goods Movement System Appendix, Adopted April 2016. Available at http://scagrtpscs.net/Documents/2016/final/f2016RTPSCS_GoodsMovement.pdf. Accessed May 2016.

[5] Fact sheets for Ports of Los Angeles and Long Beach. Available at: https://www.portoflosangeles.org/pdf/POLA_Facts_and_Figures_Card.pdf and http://www.polb.com/about/facts.asp. Accessed: May 2016.

(diesel and LNG) meet the United States Environmental Protection Agency ("EPA") Tier 4 standard; as a result, there are no reductions in PM_{10} or NO_X for the LNG locomotives as compared to the diesel locomotive. We do however see a **thirteen pound per one-way trip or 87% reduction in black carbon emissions with the use of LNG in place of diesel.**

Consider a scenario of LNG replacing diesel for freight trains from Southern California to and from the Midwest (e.g., Chicago). Historically, about 40% of the intermodal container cargo coming into the Ports of Los Angeles and Long Beach went to the Midwest/Chicago by rail. These ports are projected to handle container volumes of around 36 million TEUs in 2035[6] of which around 12.8 million TEUs are estimated to be transported by on- and off-dock intermodal trains.[7] If we assume that 40% of these TEUs travel to Chicago/Midwest region and a 100% of these trains are LNG-fueled,[8] black carbon emissions would be reduced every year after the fuel switch up to approximately 85 tons/year by 2035.

For these reasons, SoCalGas and SDG&E would be pleased to partner with State agencies to urge the federal EPA and the International Maritime Organization to speed their fuel requirements in these sectors and provide for improved air quality and lower GHGs and other emissions from these non-road sectors of freight movement.

3. Ultra-Low Emission Natural Gas Locomotives are 90% Cleaner than Current Tier 4 NOx Emissions Standard

SoCalGas has partnered with the Ports of Long Beach and Los Angeles, as well as the EPA, to contract with VeRail Technologies, Inc., for the development and demonstration of an ultra-low NOx emission natural gas switcher locomotive[9] that will be tested on the Pacific Harbor Line. These locomotives combine ultra-low NOx emission natural gas engines with on-board high-storage capacity Compressed Natural Gas ("CNG") fuel storage tanks. With this technology, the locomotives can achieve 90% lower NOx and particulate matter ("PM") emissions than the new Tier 4 diesel switcher locomotives, while still being comparable in cost, horsepower and refueling interval. The results of this project will support the implementation of advanced alternative fuel technology and promote their use and deployment at rail yards in the South Coast Air Basin, ultimately helping SCAQMD to attain its air quality goals.

C. Dairy Biogas for Freight Vehicles Pilot Project

The Sustainable Freight portion of the Scoping Plan Transportation Workshop highlighted several pilot projects, including the Dairy Biogas for Freight Vehicles project. At SoCalGas, we are conducting education and outreach to developers to help accelerate RNG projects in this and

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[6] SCAG. 2016 to 2040 RTP SCS - Transportation Goods Movement System Appendix, Adopted April 2016.

[7] Per 2016 to 2040 RTP SCS, approximately 35.5% (5-year average 2010 to 2014) of container volumes handled by the Ports of Los Angeles and Long Beach are transported by intermodal trains.

[8] It is assumed that the railroads would do a nearly complete fuel switch by major line to minimize duplicating fueling infrastructure.

[9] See AQMD Board Proposal: Recognize Revenue and Execute Contract for Development and Demonstration of Ultra-Low Emission Natural Gas Switcher Locomotive, available at http://srvwww.aqmd.gov/docs/default-source/Agendas/Governing-Board/2016/2016-jun3-002.pdf?sfvrsn=7

other sectors. SoCalGas has assisted project developers with assessing high-level costs and feasibility for projects like the Kern County Dairy Biogas Cluster, which would help advance the development of California's sustainable freight transportation system. This cluster of dairies could generate 1.5 to 2.5 million diesel-gallon equivalents per year using dairy waste, with each dairy also capable of generating renewable electricity on site with any excess biogas. It could be the first operating dairy biogas to pipeline interconnection project in California. SoCalGas and SDG&E believe that this project: achieves several key objectives, such as demonstrating measureable progress towards freight targets within a 2030 timeframe; has system transformation potential; presents opportunities for integrated State agency support; and has potential for scalability throughout the state, particularly in the Central Valley.

In addition, the project would directly benefit the economically disadvantaged communities adjacent to these dairies and transportation corridors traveled by trucks fueled with RNG by reducing SLCP emissions, improving air and water quality, and boosting economic growth. Extending natural gas infrastructure to these disadvantaged communities in conjunction with dairy-RNG pipeline interconnections could also present an opportunity to transition diesel and propane end-uses to cleaner burning natural gas appliances and vehicles, with the potential added benefit of NOx emission reduction.

It is essential to remember that this Dairy Biogas project relies on methane that would normally be released into our atmosphere and converts it into clean fuel for our freight vehicles. It is a double environmental win - California will reduce emissions from the agriculture sector while generating a renewable energy source for other applications.

II. Last Mile Delivery

The goal of last mile delivery is to ensure that consumer products are delivered to consumers who need them in a timely manner. ARB has added to this logistics goal by attempting to ensure that last mile delivery occurs in less polluting vehicles. The importance of last mile delivery is underscored as that last mile takes place in transportation environments where homes, schools and shopping centers are certain to be located, thereby risking emissions exposure from delivery trucks and vehicles of various sizes in highly populated areas.

Although still considered in the heavy-duty category, the vehicle engines targeted by ARB are smaller than those trucks utilized for commercial drayage. Specifically, in the Transportation Workshop Presentation, ARB references the inclusion of "zero emission class 3-7 trucks used for last mile delivery." (ARB Transportation Workshop Presentation slide 71.) Thus, trucks having a gross vehicle weight rating (GVWR) of 10,000 through 33,000 pounds are referenced in this slide. We believe natural gas engines, paired with the use of RNG and hybrid technology, can have a useful role in helping reduce emissions in this engine size category.

SoCalGas is working with funding and technology partners California Energy Commission (CEC), GreenKraft, CalSTART and Efficient Drivetrains to optimize and integrate existing compressed natural gas engines and plug-in hybrid electric vehicle powertrains into Class 4 medium duty trucks. The purpose of this truck operation is to conduct fleet ride and drive demonstrations and testing to gather field data to validate economy and emissions by regional fleet operators and 3rd party testing. Our overall goals are to demonstrate a 40% fuel economy improvement; establish the role of plug-in hybrid technology in CNG fleet operations; and benchmark the hybrid truck against a diesel or gasoline equivalent, hoping to specifically show a reduction in criteria pollutants over diesel. The project began in July 2014 and SoCalGas is hoping to share results of this pilot project by the end of this calendar year.

In the heavier truck category, SoCalGas is engaged in a natural gas/electric hybrid truck pilot for a Class 8 truck to help reduce NOx emissions below existing ARB standards. Collaborating with the CEC, UC Riverside, and US Hybrid, SoCalGas is testing a truck that combines Cummins Westport heavy duty liquefied natural gas engine with a 200 kW electric motor, optimizing battery storage and engine controls. Our goals in this pilot effort include exhibiting an ability to meet and exceed ARB emissions limits, and demonstrating improved fuel economy while reducing air emissions. This hybrid truck would achieve both particulate matter and NOx emissions lower than existing ARB regulations. Further, and most importantly for those concerned with pollution from ports and freight movement, this truck would eliminate frequent periods of idling typical at the Port facilities where drayage trucks often queue for long periods of time waiting for their cargo. This natural gas hybrid truck will operate in electric mode (EV mode) around 25% of time (30 miles) in charge depletion mode, then in hybrid mode with sustaining charge. The hybrid truck would have no limitation of the range and usage and will have higher number of operating hours than a diesel truck, resulting in a potentially dramatic reduction in port and in last mile delivery truck emissions.

SoCalGas is proactively working with a variety of funding and technology partners on a number of hybrid natural gas engines that will achieve the goal of lower GHG emissions in the last mile delivery of goods and consumer products. We will continue to work with ARB to share our findings from our demonstration and pilot vehicles, and hope for continued collaboration with staff on those findings as the Update and its implementation moves forward.

III. Advanced Clean Transit: Near-Zero Emission Bus Fleets

The Transportation Workshop proposed a zero-emission bus requirement under Advanced Clean Transit ("ACT") regulations. However, the results of a recent study[10] commissioned by Los Angeles County Metropolitan Transportation Authority ("LA Metro") found that the use of RNG and low-NOx CNG engines is currently more cost-effective at reducing GHGs than battery electric or fuel cell powered buses that are commercially available today. In addition, emission reductions of both GHG and NOx from low-NOx engines and RNG use are an order of magnitude more cost-effective than reductions from electric or fuel cell buses. Combined, these facts demonstrate the substantial benefits of allowing California transit agencies to use near-zero emission natural gas buses for the foreseeable future. Not only are there considerable NOx and GHG emission reductions, but the transit agency's duty-cycle needs can be met at considerably lower costs. Municipalities such as Santa Monica Big Blue Bus and San Diego Metropolitan Transit System have already made the move to RNG in their bus fleets. As low-NOx engines and low-carbon RNG are all available now to help accomplish California's goals in a timely manner, we urge ARB to specifically include them as part of a viable strategy in the next iteration of the Update.

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[10] Los Angeles Metro Technology Assessment, June 30 2016.

IV. Support for the Low Carbon Fuel Standard

Throughout our previous comments on the Update,[11] SoCalGas and SDG&E have continued to strongly support the LCFS. This program has been crucial in spurring the development of low-carbon fuels in California by providing clear market signals to producers that their investments in research and development will yield returns in the long-run. The LCFS has increased demand for alternative fuels, such as renewable natural gas, leading to new technologies to produce, deliver, and use that fuel. For example, in 2015, encouraged by the increasing availability and decreasing price of alternative fuels, Big Blue Bus, the transit agency of the City of Santa Monica, switched its bus fleet to 100% renewable natural gas, reducing its fleet's carbon footprint by an estimated 8,000 tons per year. It is innovations like this that will help California achieve its ambitious climate goals such as those set forth in the Update.

Further, the LCFS distinguishes RNG from existing organic sources, such as dairy waste, landfills, and waste water treatment as the lowest carbon intensity fuels available. In fact, the LCFS program recognizes that fueling vehicles with dairy manure-sourced RNG can provide approximately six times the GHG reduction benefits of utilizing zero tailpipe emissions technologies. A review of the LCFS reporting tool shows that RNG, as a percentage of total natural gas used in the transportation sector, has increased dramatically in the past two years, and currently makes up the majority of NGV fuel reported. We believe the LCFS will help the State meet its environmental and economic goals as it has been instrumental in creating price parity between alternative fuels and fossil fuels, such as gasoline and diesel, thereby helping spur the utilization of low-carbon fuels, such as RNG, in California that will yield substantial future GHG reduction benefits.

V. Biofuel Supply Module

SoCalGas and SDG&E support the further analysis of renewable fuel feedstock cost and availability through the development of the Biofuel Supply Module ("BFSM"). We believe it is an important step to begin incorporating supply and cost constraints for biofuels to more accurately inform strategies and sound policies to meet California's long-term GHG reduction goals. However, we seek clarification on several critical areas that are vague and should further be developed before the BFSM is utilized. Further, it is currently unclear whether the Module will solely be used to validate biofuels supply availability for the PATHWAYS model in relation to the United states Department of Energy's ("DOE's") Billion Ton Study ("BTS"), or if it might be used to compare and potentially prioritize biofuel pathways to direct policy goals and incentives that will shape California's transportation sector over the coming decades. SoCalGas believes it is critical that ARB's renewable fuel policies consider costs, "well-to-wheels" GHG benefits, and maximization of fuel production yields to prioritize the most cost-effective, sustainable and beneficial pathways to successfully meet California's goals. In reviewing the BFSM and the associated technical documentation, it remains uncertain whether this is a potential objective of the BFSM, or if a robust and equitable comparison of this nature will be achieved under the current model. SoCalGas and SDG&E believe that ARB should convene

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[11] SoCalGas Comments on Air Resources Board Scoping Plan Update Workshop, September 7 2016

working groups to actively solicit feedback and ensure these important environmental strategies are developed collaboratively, equitably, and transparently, and include the broadest and most inclusive range of solutions.

To this end, we believe several particular aspects of the module should be clarified especially as it relates to some critical nuanced aspects of biofuel carbon intensity metrics, supply and transportation.

A. Clarify links between BFSM and LCFS

Our understanding regarding the carbon intensity values reported in the BFSM is that they are derived from the CA-GREET model currently utilized in the LCFS program. However, the technical documentation does not specify any assumptions related to the CA-GREET model and in some cases does not seem to align with the parameters utilized. For example, there appear to discrepancies regarding some of the carbon intensity values associated with feedstock conversion. The carbon intensity value associated with biomethane produced from anaerobic digestion of dairy manure is significantly larger than that of biomethane produced from thermal gasification of cellulose and wood. Without clarifying the link between the BFSM and the LCFS, we cannot provide a more substantive commentary on the carbon intensity values presented.

B. Transportation of Finished Fuel

The technical documentation references a National Academy of Sciences study, and a single value for the transportation cost on a per 1,000-mile per gallon basis. It appears that this cost is some composite of the costs associated with transporting ethanol via rail, truck, and barge. However, the derivation is not included in the technical documentation. This singular value appears to be used for all biofuels in the model, including gaseous fuels. While the module outlines these four cost elements, it does not reveal them explicitly, which makes it difficult to provide substantive commentary on their accuracy or utility for the BFSM. What we do know is that the transportation costs for the finished fuel are likely under-estimated for many liquid fuels, and over-estimated for pipeline transported fuels.

For example, the access to and costs of transportation associated with pipeline transportation used for gaseous fuels differ considerably from those involved in the renewable diesel supply chain. We believe ARB needs to more fully examine the range of underlying transportation costs to obtain a better understanding of the different biofuel feedstocks. As a means to achieve this, we recommend ARB develop work groups across industry sectors to ensure the best available data is used to better inform the assumptions that are incorporated into the module. This engagement will allow a better view and more balanced approach so that ARB will not choose a biofuels pathway based on limited or inappropriate data comparisons.

C. Clarify supply data and ramp rates

We request that ARB clarify the supply data and ramp up rates detailed in the BFSM. It appears that the BFSM is based solely on feedstock supply estimates in 2030, as derived from DOE's BTS. However, the calculation of the feedstock supply is particularly confusing because the default value for the ramp rate, R, in the BFSM appears to be 100%. In other words, if left unchanged, the BFSM modeling results may show feedstock available in year 2020 equivalent to what the BTS indicates could be available in 2030. Utilizing this ramp rate relative to 2030 potential is confusing and can be improved by correlating the BFSM directly to the supply curves provided in the DOE's BTS on a discrete and annual basis. The current design might be due to preference of using a simpler approach due to computational limitations; however, this should be remedied to ensure that a scenario using the BFSM does not over-state the availability of a given feedstock.

Further, regarding biofuel supply chain practicality, the BFSM assumes that any finished biofuel produced in the United State is accessible to California. We know this to be an overly simplified and incorrect assumption. Even with a credit price of $200/ton, for instance, there are simply certain fuel production facilities that are not located in an advantageous position relative to transportation infrastructure that would enable delivery of finished fuel to California.

D. Assumed expansion of the biofuel industry

Pertaining to the expansion of the biofuel industry, the technical documentation indicates an assumed annual growth rate of 41%, derived by simply taking the average of the annual growth rate of a 15-year period for biodiesel (2001-2015; 60% average annual growth) and ethanol (1981-1996; 24% average annual growth). However, this assumption does not take into account the unique factors that propelled biofuel growth during those time periods.

The regulatory environment in the early 2000s, most notably incentives for biodiesel production, was far different than what exists for commercial facilities today. While the Renewable Fuel Standard 2 promotes the production of advanced biofuels, the tax incentives and production incentives that were provided to the emerging biodiesel industry in the early 2000s were extremely generous and had a marked impact on the rapid development of these fuels in this period. It is unrealistic to assume that these rates would be achieved in the absence of such aggressive policies. The table provided in Appendix A outlines a number of policies that influenced biodiesel production in this period.

VI. Conclusion

Again, SoCalGas and SDG&E appreciate the opportunity to comment on the Scoping Plan Update Workshop and we look forward discussing additional dialogue in the Update development process. Please contact me if you have any questions or concerns about these comments.

Sincerely,

Tim Carmichael

Tim Carmichael
Agency Relations Manager – Energy and Environmental Affairs
SoCalGas
and on behalf of SDG&E

Appendix A
Regulatory Drivers of Biofuel Growth in the 1908s to early 2000s

The Biofuel Supply Module technical documentation indicates an assumed annual growth rate of 41%, derived by simply taking the average of the annual growth rate of a 15-year period for biodiesel (2001-2015; 60% average annual growth) and ethanol (1981-1996; 24% average annual growth). However, this assumption is overly simplified and does not take into account the unique factors that propelled biofuel growth during those time periods.

The regulatory environment in the early 2000s, most notably incentives for biodiesel production, were far different than those that exist for commercial facilities today. While the RFS2 promotes the production of advanced biofuels, the tax incentives and production incentives that were provided to the emerging biodiesel industry in the early 2000s were extremely generous and had a marked impact on the rapid development of these fuels in this period. It is unrealistic to assume that these rates would be achieved in the absence of such aggressive policies. The table provided below outlines a number of policies that influenced biodiesel production in this period.

Year	Intervention / Policy	Description
1998	USDA's Commodity Credit Corporation's (CCC) Bioenergy Program	Provided payments to producers to encourage biodiesel production; plants with capacity <65 MGPY were reimbursed 1 bushel of feedstock for every 2.5 bushels used for increased production (facilities with over 65 million gallons production capacity were reimbursed 1 bushel for every 3.5 bushels used for increased production).
1998	Amendment to Energy Policy Act	The 1992 Energy Policy Act (EPAct) requires a portion of new vehicle purchases by federal and state government fleets be alternative fuel vehicles. Biodiesel was added to the list of eligible alternative fuels via an amendment in 1998, thereby setting up an increase in demand in the early 2000s.
2002	Farm Bill; extending CCC Program eligibility	Although initially only biodiesel made from oil crops was eligible for payments, the 2002 farm bill extended the list of allowed feedstocks to include animal by-products, fats, and recycled oils of an agricultural origin.
2004	American Jobs Creation Act	Biodiesel blenders can claim a $1.00 per gallon tax credit for biodiesel from virgin oils and $0.50 per gallon for recycled feedstocks.

In the case of ethanol, the following table presents a summary of the incentives over the period of 1981 to 1996.

Federal Policy	**Description**

Energy Tax Act of 1978	Exempted 10% ethanol/gasoline blends from the 4 cents/gal federal gasoline excise tax Provided 10% energy investment tax credit for biomass-ethanol conversion equipment (in addition to the 10% investment tax credit available)
Energy Security Act of 1980	Authorized loan guarantee program for ethanol production facilities
Crude Oil Windfall Profit Tax Act of 1980	Extended ethanol excise tax exemption through 1992 Established income tax credit (40 cents/gal) for ethanol fuel use
Omnibus Reconciliation Tax Act of 1980	Placed a tariff on imported ethanol fuel (currently 54 cents per gallon)
Gasohol Competition Act of 1980	Banned gasoline marketer practices that discouraged use of ethanol/gasoline blends
Surface Transportation Assistance Act of 1982	Raised gasoline excise tax to 9 cents/gal Increased excise tax exemption for 10% ethanol/gasoline blends to 5 cents/gal
Tax Reform Act of 1984	Raised the excise tax exemption for 10% ethanol/gasoline blends to 6 cents/gal and the ethanol income tax credit to 60 cents/gal
Alternative Motor Fuels Act of 1988	Enacted CAFE credits for alternative fuel vehicle production
Omnibus Budget Reconciliation Act of 1990	Raised the gasoline excise tax to 14.1 cents/gal Reduced the excise tax exemption for 10% ethanol/gasoline blends to 5.4 cents/gal and the ethanol income tax credit to 54 cents/gal Extended the ethanol fuel tax incentives through 2000 Established the small ethanol producers income tax credit of 10 cents/gal
Energy Policy Act of 1992	Extended ethanol excise tax exemption to 5.7 and 7.7 ethanol/gasoline blends (at proportionate rates) Established requirements for alternative fuel vehicle purchases by certain vehicle fleets
Omnibus Budget Reconciliation Act of 1993	Raised gasoline excise tax to 18.4 cents/gal

As outlined in the tables above, there were a confluence of factors that drove increases in biodiesel and ethanol production over the respective 15-year periods. It seems that further consideration of the policy environment today in comparison to the period used to estimate expansion rates for the BFSM modeling prior to adopting these assumptions.

Appendix B: Game Changer Technical White Paper Executive Summary

GAME CHANGER
TECHNICAL WHITE PAPER

EXECUTIVE SUMMARY

NEXT GENERATION HEAVY-DUTY NATURAL GAS ENGINES FUELED BY RENEWABLE NATURAL GAS

gna
GLADSTEIN,
NEANDROSS
& ASSOCIATES

PREPARED FOR

Agility fuel systems

AGA American Gas Association

California Natural Gas Vehicle Partnership

Clean Energy

PG&E

South Coast AQMD

SoCalGas
A Sempra Energy utility

GAME CHANGER:
Next Generation Heavy-Duty Natural Gas Engines Fueled by Renewable Natural Gas

Abstract and Executive Summary

April 2016

Authorship and Uses

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PREPARED BY

gna GLADSTEIN, NEANDROSS & ASSOCIATES

ABSTRACT

This White Paper explores the need—and leading approaches—to immediately start deploying zero-emission and near-zero-emission heavy-duty vehicle (HDV) technologies on a wide-scale basis in the United States. Expeditious action is needed to reduce smog-forming emissions from HDVs to restore healthful air quality—as is legally required under the federal Clean Air Act—for approximately 166 million Americans who reside in areas with exceedingly poor air quality. At the same time, to combat global climate change, the United States must aggressively reduce greenhouse gas (GHG) emissions from HDVs, which are the fastest growing segment of U.S. transportation for energy use and emissions.

In many regions of the U.S., these goals cannot be achieved without a systematic transformation of today's diesel-fueled HDVs—particularly high-fuel-use heavy-heavy-duty vehicles (HHDVs)—to zero- or near-zero-emission technologies operated on low-carbon fuels. Four unique fuel-technology combinations currently hold the most promise to successfully achieve this transformation. These are: 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). Over the long term (several decades), it is likely that all four of these HDV architectures will contribute to meeting air quality and climate change goals.

However, air quality regulators have recognized that meeting air quality goals will require the immediate deployment of zero- and/or near-zero-emission HDVs, especially in the most-impactful HHDV applications like on-road goods movement trucking. This White Paper documents that only one fuel-technology platform meets all the commercial feasibility and logistics tests to immediately begin this transformation: near-zero-emission heavy-duty NGVs fueled by increasing volumes of ultra-low-GHG renewable natural gas (RNG).

In 2015, Cummins Westport certified the world's first heavy-duty engine at near-zero-emission levels (90 percent below the existing federal standard). To complement the NOx reductions provided by this landmark engine, conventional (fossil) natural gas provides significant GHG-reduction benefits. However, RNG completes the game-changing proposition by providing the lowest carbon intensity of any heavy-duty transportation fuel available in the market today. RNG can immediately provide deep GHG emission reductions when used in either in-use or new heavy-duty NGVs. Expanded RNG production in America can offer an array of environmental and economic benefits; these include enhanced job creation, improved air quality, and a number of environmental waste stream management improvements that will accrue at local levels.

Near-zero-emission natural gas engines using RNG provide a commercially proven, broad-based and affordable strategy to immediately achieve major reductions in emissions of criteria pollutants, air toxins and GHGs from America's on-road HDV sector. The 9-liter near-zero-emission engine being deployed today offers broad, immediate applicability in several HDV sectors that power our freight and public transportation systems (transit buses, refuse haulers, and short-haul delivery trucks). By 2018, Cummins Westport will certify and commercialize a near-zero-emission version of its existing 12-liter natural gas engine designed for HHDV applications. This 12-liter engine provides diesel-like performance for tractor-trailer trucks hauling

> One fuel-technology platform meets all the commercial feasibility and logistics tests to immediately begin this transformation: near-zero-emission heavy-duty NGVs fueled by increasing volumes of ultra-low-GHG renewable natural gas.

80,000 pounds over long distances and up steep grades, as routinely needed for goods movement trucking throughout our nation's interstate highway system. Notably, when near-zero-emission HHDVs with this engine begin to roll out in 2018, some large operator fleets will already be using significant volumes of ultra-low-GHG RNG to supplement (or entirely replace) fossil gas use.

With nearly the full range of HDVs covered, the combination of new near-zero-emission natural gas engine technology and RNG provides the single best opportunity for America 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.

With nearly the full range of HDVs covered, the combination of new near-zero-emission natural gas engine technology and RNG provide the single best opportunity for America to achieve immediate and substantial NOx and GHG emission reductions in the on-road heavy-duty transportation sectors.

While the opportunity and potential benefits to widely deploy near-zero-emission heavy-duty NGVs are quite large, significant challenges must be systematically and expediently addressed. This White Paper describes recommended actions for government and industry stakeholders that will help meet these challenges and immediately begin broad deployments of near-zero-emission heavy-duty NGVs, using progressively greater volumes of ultra-low-GHG RNG. First and foremost, national, state and local incentive funding programs should be established or strengthened that 1) subsidize the higher costs to produce and deploy these new-generation heavy-duty NGVs, and 2) help produce and transport RNG, where the economics and logistics are most conducive. Recommendations are provided about how to allocate available incentive funds toward deployments that can immediately and cost effectively achieve large reductions for key pollutants.

EXECUTIVE SUMMARY

America's Immediate Need for Zero- and Near-Zero Emission Heavy-Duty Vehicles

Nationwide, on-road heavy-duty vehicles (HDVs) contribute approximately 50 percent of America's smog-precursor emissions and 20 percent of our transportation-related greenhouse gas (GHG) emissions. Heavy-duty trucks—primarily used to transport freight and goods—are the second largest and fastest-growing segment of the U.S. transportation system for both energy use and emissions of harmful pollutants. Despite significant progress to gradually move towards cleaner alternative fuels such as natural gas, propane, hydrogen, and electricity, America's transportation sector continues to rely heavily on combusting two fossil petroleum fuels: gasoline and diesel. Only a very small, albeit growing, percentage of energy consumed in the U.S. transportation sector comes from alternative or renewable sources.

The dominance by fossil petroleum fuel in America's transportation sector—particularly the near-total use of diesel fuel by the largest heavy-heavy duty vehicles (HHDVs)—has many major adverse environmental consequences, with high corresponding economic costs. HHDVs emit disproportionately high levels of smog-causing pollutants that cause millions of Americans to regularly breathe unhealthful air. They emit high levels of toxic air contaminants (TACs) such as cancer-causing diesel particulate matter (DPM); this disproportionately impacts minority populations living in economically disadvantaged communities, which are often located adjacent to freeways or within areas of high diesel engine activity. Finally, HHDVs are also major emitters of greenhouse gases (GHGs), which cause global climate change.

The dominance by fossil petroleum fuel in America's transportation sector–particularly the near-total use of diesel fuel by the largest "heavy-heavy duty vehicles" (HHDVs)–has many major adverse environmental consequences, with high corresponding economic costs.

Under the federal Clean Air Act, air quality officials in areas that don't meet health-based National Ambient Air Quality Standards (NAAQS) must develop and implement emissions-reduction strategies that demonstrate how attainment will be achieved according to set time lines, most of which are in the next 5 to 10 years. The greatest ongoing air quality challenge is to attain NAAQS for ozone and fine particulate matter ("PM2.5") in our nation's most-polluted air sheds; these include California's South Coast and Central Valley air basins, the greater Houston area, Phoenix and much of the Boston-Washington corridor. The key to achieve NAAQS for both ozone and PM2.5 is to aggressively control oxides of nitrogen ("NOx") emissions from HHDVs. This must be done while also controlling other key pollutants, including GHGs and TACs.

Over the last two decades, America has made major advancements to reduce on-road HDV emissions of NOx, DPM, other TACs, and GHGs. Solid progress has been made to phase in lower emission diesel trucks and cleaner, alternative fuels to power a wide array of HDV types. In particular, today *approximately 65,000 heavy-duty natural gas vehicles (NGVs*) are being operated throughout the U.S., *avoiding combustion of an estimated 400 million diesel gallons annually.* While this represents less than one percent of the nation's in-use HDV fleet, the market accelerated in the last five to 10 years as Waste Management, Frito Lay, UPS, Anheuser-Busch, Procter & Gamble and many other large national corporations have made considerable commitments to the adoption of heavy-duty natural gas vehicle trucks and/or renewable natural gas fuel. In some cases, large heavy-duty fleets have achieved 100 percent conversion to NGV operations (e.g., the Los Angeles County Metropolitan Transit Authority, with approximately 2,300 CNG transit buses in operation). Heavy-duty natural gas truck sales have represented approximately 2 to 3 percent of total market volume in recent years, while annual NGV sales in the refuse and transit sectors have been 60 and 30 percent respectively.

Despite these important advancements, faster and far-greater progress is required. To meet health and environmental goals, America's heavy-duty transportation system needs a full transformation to the cleanest-available HDV technologies and fuels, as soon as they are developed and commercialized. In areas with the most severe air quality problems—such as southern and central California, Phoenix and the greater Houston area—restoration of healthful air quality will require immediate, systematic phase in of HDVs that provide *zero-emission or near-zero-emission levels of NOx.*

To meet health and environmental goals, America's heavy-duty transportation system needs a full transformation to the cleanest-available HDV technologies and fuels, as soon as they are developed and commercialized.

Key Related Policy Goals Involving Heavy-Duty Vehicles

Consumption of energy, creation of local air pollution, and emissions of GHGs that exacerbate global climate change are all closely related in today's U.S. HDV sector. There are many federal, state and local policies converging in this nexus that are collectively helping to drive America's gradual transition towards advanced, clean HDV technology. Examples of key interrelated objectives involving the HDV transportation sector include the following:

- Reduce regulated pollutants (e.g. NOx) to attain National Ambient Air Quality Standards
- Reduce usage of petroleum-based diesel fuel
- Increase production and use of low-carbon renewable fuels
- Increase fuel economy of heavy-duty NGVs while reducing GHG emissions
- Reduce upstream leakage of emissions of methane (a GHG and Short-Lived Climate Pollutant)
- Reduce emissions of black carbon (a Short-Lived Climate Pollutant)
- Replace, retrofit or repower in-use HDVs that pre-date state-of-the-art emission controls

California has the nation's most-aggressive goals to address these types of energy and environmental policy issues. The California Air Resources Board (CARB) and other state and local transportation authorities have clearly laid out the state's need for early, wide-scale deployment of zero- and near-zero-emissions HDVs, especially in the most-impactful HHDV applications like on-road goods movement trucking.

Four Leading Fuel-Technology Pathways

Four unique fuel-technology combinations currently hold the most promise to successfully transform America's HDV transportation sector to zero and near-zero emissions using low-carbon non-petroleum fuels. These are: two types of low-emission internal combustion engines (fueled by renewable natural gas or renewable diesel); and two types of electric-drive systems (powered by batteries or hydrogen fuel cells). Each of these HDV pathways offers unique opportunity and challenges regarding their potential to help transform America's on-road HDV fleet. Over the long term (several decades), it is likely that all four of these HDV architectures will contribute to meeting air quality and climate change goals.

The essential need is for zero- and/or near-zero-emission technologies and fuels to deeply penetrate into the urban HDV and on-road transportation sector in less than 10 years.

However, the actual role that each will ultimately play largely depends on how soon and to what degree they can be commercially deployed on a wide-scale, especially in high-impact HHDV applications. The essential need is for zero- and/or near-zero-emission technologies and fuels to deeply penetrate into the urban HDV and on-road transportation sector in less than 10 years. As air quality regulators have widely recognized, early deployment is needed for hundreds of thousands of HDVs (especially HHDVs) using the cleanest available fuel-technology platforms. Lesser deployments will be insufficient in many U.S. cities to achieve health-based NAAQS, or drive down GHG emissions from the transportation sector as needed to mitigate global climate change.

The table below briefly describes each of the four leading HDV fuel-technology pathways, differentiated by their technology and fuel type, emissions profiles, and estimated timeline for initial commercial deployment to power significant numbers of on-road HDVs. As summarized below (and further documented in this White Paper), only one fuel-technology pathway and strategy provides the ability to immediately begin broadly providing extremely low NOx and GHG emissions in high-impact HDV sectors. This pathway involves early deployment of commercially available near-zero-emission heavy-duty NGVs using progressively higher blends of renewable natural gas (RNG), as highlighted by the green dotted lines.

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

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

Game Changer: Commercially Mature Near-Zero-Emission Heavy-Duty NGVs

Near-zero-emission heavy-duty NGVs provide a game-changing proposition because they can immediately begin transforming America's diesel-dominated freight movement system. In September 2015, CWI's 8.9 liter ISL G NZ engine became 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. This "next-generation" heavy-duty natural gas engine is now commercially available in a broad range of HDV sectors that power our freight and public transportation systems (transit buses, refuse haulers, and short-haul delivery trucks). In 2017 CWI is expected to also certify with CARB and EPA a near-zero-emission version of its 11.9 liter ISX12 G engine, with commercial product to be available immediately after certification is achieved. This will expand on-road applications of near-zero emissions HDVs into HHDTs used in high-fuel-use goods movement applications, including for-hire long-haul trucking. CWI is also expected to certify its 6.7-liter ISB6.7 G engine to CARB's 50 percent optional low-NOx level (0.1 gbhp-hr), and make it commercially available in limited applications by 2017. (Note: other heavy-duty engine manufacturers are also working to certify and commercialize near-zero-emission heavy-duty gaseous fuel engines.)

The figure below summarizes the important low-NOx credentials of these three CWI engines, and their immediate-to-near-term timeframes for commercial rollout.

These three CWI low-NOx engines can collectively power a full range of on-road HDV applications where heavy-duty natural gas engines are already available across a wide range of leading OEM truck chassis product offerings.

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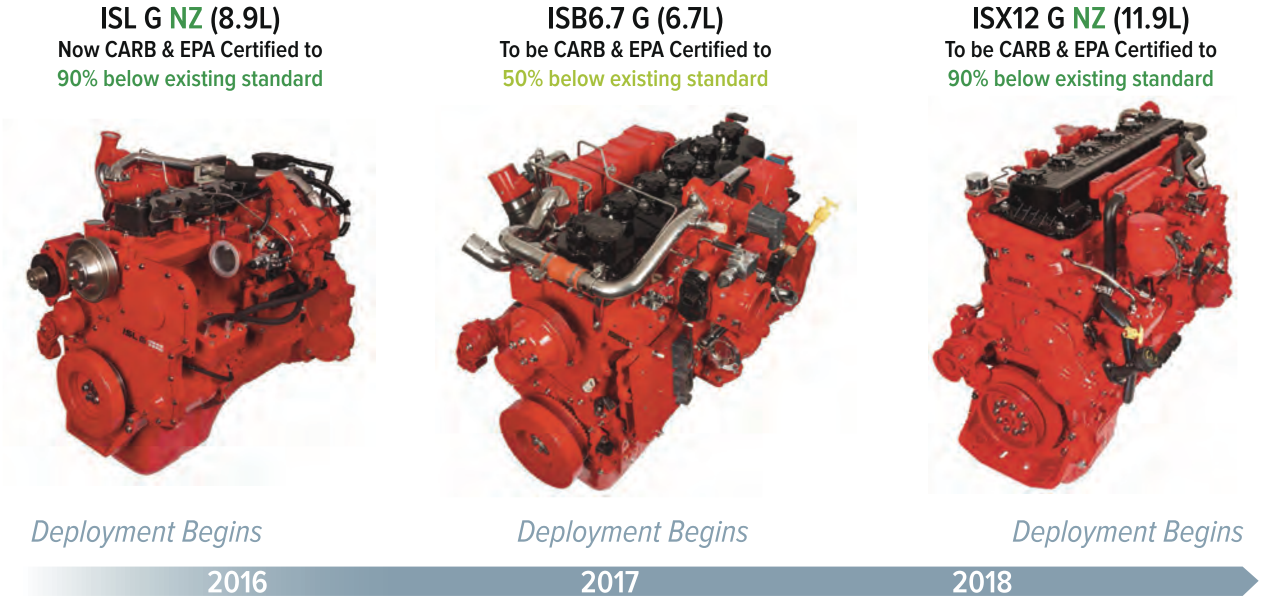
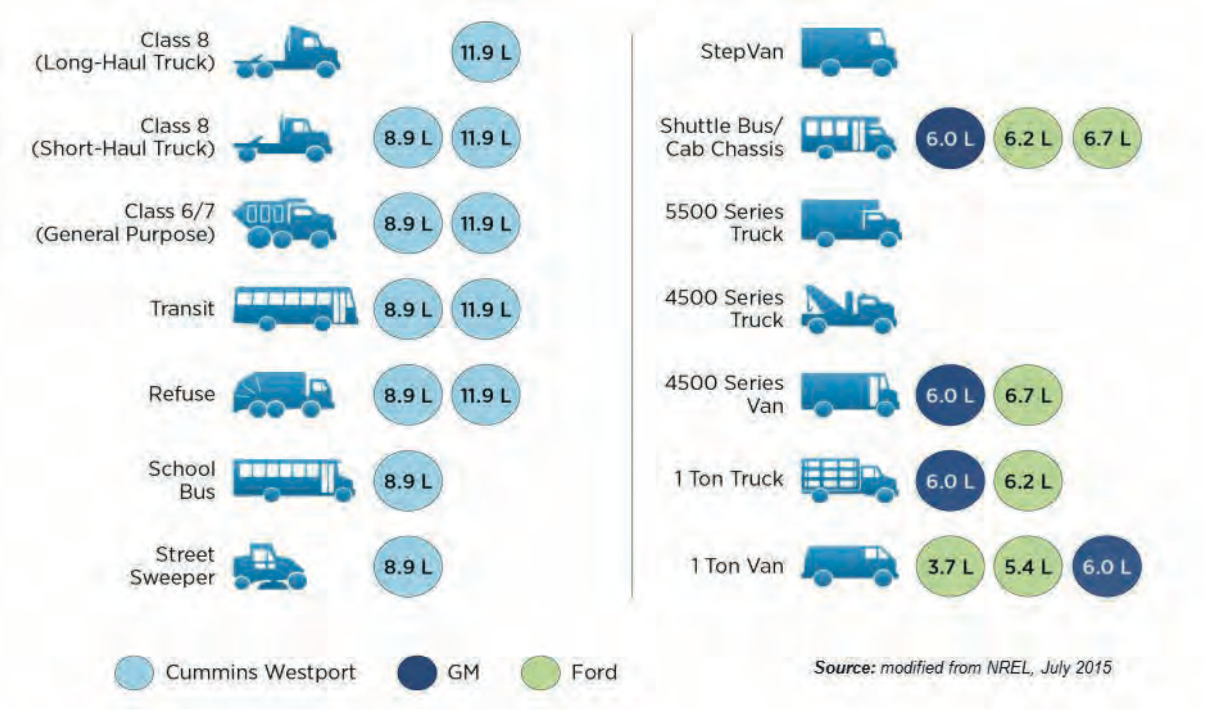


Figure 1: CWI heavy-duty ultra-low-NOx engines: anticipated timeline for certification and deployment



Source: *modified from NREL, July 2015*

Figure 2: Existing HDV applications and engine sizes that can utilize CWI's ultra-low-NOx engines

As shown in the left side of the figure above, CWI's 8.9-liter and 11.9-liter natural gas engines are now offered in many types of HDVs. Its 6.7-liter natural gas engine will work in many smaller trucking applications that currently offer natural gas models (right side). Collectively, these three heavy-duty natural gas engines can deliver up to 90 percent NOx reductions in virtually every on-road HDV application by 2018, beginning with immediate deployments of the 8.9-liter engine.

Designation of CWI's NZ engine technology as being "near-zero-emission" may significantly undervalue its relative importance as a long-term, sustainable ultra-low-emission option for America's HDV transportation sector.

Equivalent NOx Emissions as Low as Heavy-Duty Battery Electric Vehicles

Designation of CWI's NZ engine technology as being "near-zero-emission" may significantly undervalue its relative importance as a long-term, sustainable ultra-low-emission option for America's HDV transportation sector. Based on an analysis further described in this White Paper, HDVs powered by engines certified to 0.02 g/bhp-hr emit smog-forming NOx at levels as low as, or lower than, NOx emissions associated with generating the electricity used to charge heavy-duty battery-electric vehicles (BEVs). This is due to the relatively high NOx emissions rates from today's power plants—particularly in regions that rely heavily on coal-based generation. However, even in states like California, Oregon and Washington—where the average "grid mix" is fairly clean due to higher reliance on clean renewable energy sources and natural gas power generation—HDV engines emitting at 0.02 g/bhp-hr NOx compare very favorably to heavy-duty BEVs for extremely low NOx emissions.

Market Momentum Achieved Over Decades

This game-changing proposition for clean HDV transportation did not emerge suddenly, or in a vacuum. As described in this White Paper, NGV stakeholders, OEMs, end users and government agencies have made very large investments over the last two decades to make natural gas a mainstream transportation fuel. A wide array of public and private heavy-duty fleet operators and NGV industry stakeholders have spent *tens of billions of dollars* to purchase NGVs, build fueling infrastructure, upgrade maintenance facilities, train personnel and otherwise work to expand this still-developing market. Notably, invested public funds such as those that help end users "buy down" the incremental costs of NGVs often contribute to local and regional economies.

Today, an estimated 65,000 heavy-duty NGVs are displacing diesel fuel on America's roadways. This accomplishment is unique in America's HDV transportation sector for any low-emission alternative fuel.

Today, many different manufacturers collectively produce a wide array of NGV and/or engine models for U.S. markets. In the HDV sector, nearly 20 U.S. truck and bus OEMs have allocated a significant amount of human and financial capital and other company resources to develop and offer NGV products on a national commercial scale. With continued market growth, leading heavy-duty truck OEMs have begun to enter into Tier 1 supplier arrangements and long-term partnerships with key component suppliers. In some cases, leading OEMs have made direct equity investment in component supplier businesses, thus indicating an expected growth of the market in forward years. These partnerships and collaborations are focused on improving the utility and lifecycle economics of heavy-duty NGVs by driving down costs; increasing on-board fuel storage capacities; shortening production and delivery timelines; and improving vehicle performance, operational reliability, maintenance and service, parts availability, and overall up-time and efficiency. The development of Tier 1 supplier arrangements - which require several years of consistent market growth - is a clear sign of a maturing marketplace for heavy-duty NGVs.

In aggregate, the alignment taking place in the sector points to a very strong, robust and increasingly integrated market for NGV technologies. It is important to recognize that it took two full decades of major ongoing efforts by a spectrum of stakeholders—combined with about five years of a very compelling fuel price spread benefitting end users—to achieve this unprecedented level of commercialization for a clean alternative fuel HDV technology. The result is that heavy-duty NGVs have emerged as a proven mainstream alternative to conventional diesel HDVs.

Today, on-road heavy-duty NGVs in the truck, transit and refuse sectors are fully commercialized, successful technologies. They have displaced very significant volumes of diesel. Commercial offerings have been growing, in response to the compelling price advantage natural gas has offered over diesel, combined with government incentives offered in states like Pennsylvania, Texas, California, Colorado and others. This has resulted in high demand for these products from heavy-duty fleet owners. An estimated 65,000 heavy-duty NGVs are now displacing diesel fuel on America's roadways every day. Despite relatively high capital and market entry expenses, end users have been able to achieve compelling life-cycle cost savings that provide attractive payback on investments.

This accomplishment is unique in America's HDV transportation sector for any low--emission alternative fuel. Only natural gas has reached—or even come close to reaching—this "critical mass" of investments, product offerings from mainstream OEMs, fueling station networks, training programs, incentive offerings, stakeholders, and vehicle deployments. Notably, no mainstream heavy-duty OEMs have announced plans to commercialize any other type of heavy-duty alternative fuel vehicle (AFV) technology. No other type of alternative fueling stations exist that are specifically designed to accommodate HDVs, with the exception of proof-of-concept systems for a few select transit applications.

Corporate Sustainability as a Driver for Heavy-Duty NGVs

Beginning in late 2014, the price of diesel has dropped from record levels, thereby narrowing the price spread between it and compressed natural gas (CNG) and liquefied natural gas (LNG). Thus, life-cycle economics have not been a strong driver for fleet managers to switch their heavy-duty diesel vehicles over to NGVs. However, growing confidence in the major environmental benefits of commercially proven heavy-duty NGVs is providing an impetus for fleets to continue to make this transition. This is exemplified by the many major American corporations—both shippers and carriers—now investing in heavy-duty natural gas trucks as foundations of their sustainability policies, and in the interest of long-term fuel diversity and price stability. For example, UPS has already built 23 LNG and CNG fueling operations across 10 states. UPS's March 2016 announcement indicates it will soon build another 12 CNG stations. Increasingly, the company is investigating and using RNG to displace fossil natural gas at these stations. In Memphis and Jackson (Mississippi), UPS will use an estimated 1.5 million DGEs per year of LNG made from landfill gas to fuel up to 140 of its HDVs. Many other similar examples are described in this White Paper.

Renewable Natural Gas: the Second Element for Transforming HDV Transportation

RNG is the second element of this game-changing fuel-technology pathway. RNG is a gaseous mixture of methane and other compounds that is produced from renewable sources, using either biological or chemical processes. Producing RNG is a highly sustainable process from multiple pathways. 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 wildfire, and improvements to agricultural processes and yields. Moreover, RNG production facilities can help create local jobs and economic development in virtually any community across America.

RNG is the second element of this game-changing fuel-technology pathway.

The most important benefits of RNG relate to its potential use to fuel hundreds of thousands of near-zero-emission heavy-duty NGVs. Used together to replace conventional diesel HDVs, this fuel and engine technology can immediately and uniquely begin delivering 90 percent (or greater) reductions in NOx emissions for the large U.S. fleet of on-road HDVs. Simultaneously, RNG will provide deep GHG reductions (80 percent or greater), due to the very low (and in some cases negative) carbon intensity values of various production pathways. This is clearly illustrated in the figure below, which compares preliminary "carbon intensity" (CI) values (in grams per mega joule of "CO_2 equivalent" GHGs) for eight different heavy-duty transportation fuel pathways.

RNG will provide deep GHG reductions (80 percent or greater), due to the very low (and in some cases negative) carbon intensity values of various production pathways.

According to this illustrative data from CARB, when fossil CNG or LNG are combusted in currently available spark-ignited heavy-duty engines, they provide CI reductions of approximately 15 and 9 percent, respectively (relative to the baseline diesel pathway). The CI values of CNG and LNG are decreased substantially when RNG replaces fossil natural gas as the feedstock. As the last four bars of the graph show, numerous RNG pathways provide very significant CI reductions relative to the diesel baseline. These range from a 75 percent reduction for "Renewable LNG: Landfill Gas,"[1] to a 125 percent reduction for "Renewable CNG: High Solids Anaerobic Digestion." Moreover, an additional CI benefit (approximately 4 gCO_2e/MJ) is achieved for each of these RNG types when combusted in CWI's near-zero-emission engine. This is attributable to the engine's closed crankcase ventilation system, which reduces "downstream" methane emissions by 70 percent. All four RNG pathways in CARB's illustrative data have lower CI values than the "Average California Electricity" pathway (CI value of 31.0 gCO_2e/MJ) assumed to recharge heavy-duty BEVs, and the "Gaseous Hydrogen

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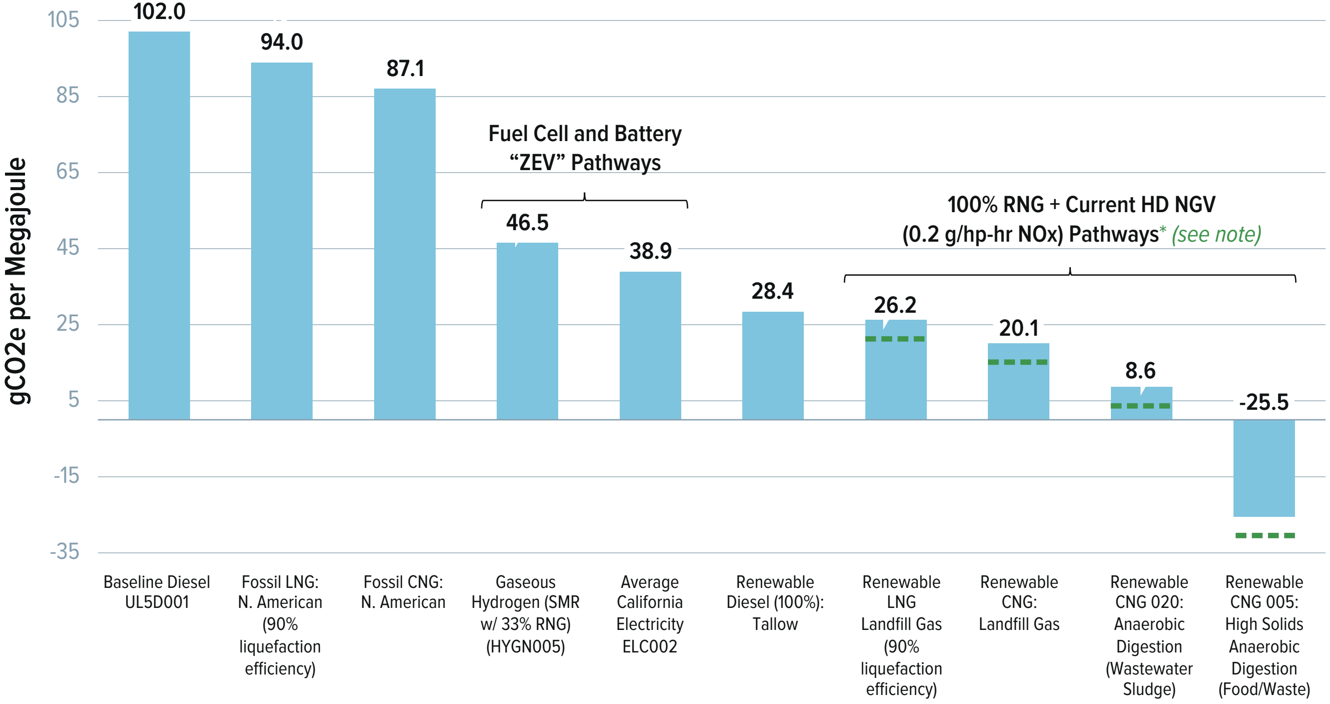
[1] This reflects the relative CI advantage in the LCFS today for fossil CNG and LNG compared to baseline diesel. This is likely to change over time, based on LCFS credit generation and other factors.

Carbon Intensity Scores for Heavy-Duty Truck Pathways
Final California Low-Carbon Fuel Standard, 2015
CA-GREET 2.0, EER-Adjusted



- - - - * **Note:** using the new "NZ" NG engine (0.02 g/hp-hr) **will further reduce the CI scores of these RNG pathways by about 4 gCO_2e/MJ** (closed crankcase ventilation reduces methane by 70%).

Source: California Air Resources Board, "LCFS Illustrative Fuel Pathway Carbon Intensity Determined using CA-GREET2.0,"discussion presented by staff on 9/17/15 and/or CARB LCFS Final Regulation Order, Table 6; note that *HSAD pathway is EER-adjusted by the CARB formula (-22.93 base CI divided by EER of .9), even though this improves its CI score.

Figure 3: Comparative carbon intensity (CI) scores for heavy-duty truck pathways (CARB, 2015)

(SMR with 33% RNG)" pathway (CI value of 46.5 gCO$_2$e/MJ). Future changes to the grid mix and/or hydrogen-production processes will likely result in lower CI values for these two ZEV pathways.

CARB has noted that it is technically and economically feasible to deploy approximately 400,000 near-zero-emission HDVs by 2030, and this "large-scale deployment" of low-NOx, very-low-PM goods movement trucks "will provide the largest health benefit of any single new strategy" under consideration by California.

The middle bar of this figure shows that a "Renewable Diesel (100%) – Tallow" pathway can also provide low-CI transportation fuel. Renewable diesel (which is chemically different than "biodiesel") is a "drop-in" replacement for conventional diesel. Growing numbers of HDVs in California and other regions are now using this renewable diesel fuel as a substitute for conventional diesel. It can provide compelling GHG reductions and modest criteria pollutant benefits in today's diesel engines. To date, however, no heavy-duty diesel engine (using conventional or renewable diesel) has been certified below the existing NOx standard of 0.2 g/bhp-hr. Engine manufactures have detailed challenging "NOx-GHG" tradeoff issues that must be resolved before heavy-duty diesel engines can be certified to the 0.02 g/bhp-hr NOx level, which as noted has already been achieved by CWI's ISL G NZ natural gas engine. Heavy-duty diesel engines certified to 0.02 g/bhp-hr NOx are not expected to be developed and available until at least the mid-2020 timeframe. This assumes that challenging NOx-GHG tradeoff issues can be resolved, as necessary for low-NOx diesel engines to also comply with tightening federal fuel efficiency / GHG standards.

Heavy-duty natural gas engines appear to offer another important advantage over diesel engines: their ability to maintain low NOx emissions during in-use operation. Based on a body of test data, CARB has found that 2010-compliant heavy-duty diesel engines with advanced emissions controls can exhibit NOx "control challenges" during in-use operation in low temperature, low speed duty cycles. To date, in-use heavy-duty NGVs have not exhibited this problem with their emissions control technology, which is generally less complex than diesel technology. This has helped CWI achieve very-low NOx certification levels that still offer good margin, to meet very challenging requirements from CARB / EPA to maintain low NOx emissions throughout the useful life of the engine.

Concurrence from Air Quality Regulators

Concluding that "combustion technology will continue to dominate" the on-road HDV sector over the next 15 years, CARB has found that low-NOx trucks are "the most viable approach" to meet California's mid- and longer-term goals to attain NAAQS for NOx and PM2.5. CARB has noted that it is technically and economically feasible to deploy approximately 400,000 near-zero-emission HDVs by 2030, and this "large-scale deployment" of low-NOx, very-low-PM goods movement trucks "will provide the largest health benefit of any single new strategy" under consideration by California. To simultaneously meet GHG and petroleum-use-reduction targets, CARB will target approximately 55 percent of fuel demand for these trucks to be met with renewable fuel. As noted, only heavy-duty natural gas engine technology has been certified (by either CARB or EPA) for commercial sale at the near-zero-emission level, starting with CWI's ISL G NZ engine. In CARB's own words, "these advanced natural gas vehicles are expected to deliver near term opportunities to reduce NOX emissions, and with the use of renewable natural gas, could also deliver deep GHG emission reductions." CARB concludes that "deployment of 350,000 electric trucks over the next 15 years would require technology development and cost that are well beyond what will be needed to deploy low-NOx trucks."

CARB's plans to deploy large numbers of near-zero-emission HDVs in California are urgently geared towards attaining the ozone NAAQS by 2023 in the South Coast and Central (San Joaquin) Valley areas, which both face extremely tough challenges to drastically reduce ozone. Over just seven years, these air basins require very large NOx reductions from high-impact heavy-heavy-duty goods movement trucks and other HHDVs. At the same time, state and local goals for GHG reductions must also be met. The major tool that air quality regulators have in these two areas is to maximize government incentives towards immediate replacement of in-use diesel HHDVs with commercially available near-zero-emission heavy-duty NGVs using RNG.

The opportunity to rapidly achieve large-scale gains from commercially available heavy-duty NGVs using RNG does not diminish the important need for, and/or potentials of, heavy-duty ZEV technologies such as battery-electric and fuel vehicle vehicles. In certain MHDV and bus applications, there is good potential within the next decade to deploy increased numbers of heavy-duty ZEVs to meaningfully reduce NOx and GHG emissions.

The Need to Deploy All Feasible Zero-Emission and Near-Zero-Emission HDV Options

The opportunity to rapidly achieve large-scale gains from commercially available heavy-duty NGVs using RNG does not diminish the important need for, and/or potentials of, heavy-duty ZEV technologies such as battery-electric and fuel vehicle vehicles. In certain MHDV and bus applications, there is good potential within the next decade to deploy increased numbers of heavy-duty ZEVs to meaningfully reduce NOx and GHG emissions. Based on broad consensus about current heavy-duty ZEV technology, these are medium-fuel-use, return-to-base applications having daily range requirements less than about 100 miles. This has been widely acknowledged by air quality regulators at the Federal, state, and local levels. For example, to the greatest extent feasible, California's South Coast Air Quality Management District seeks to immediately deploy battery-electric and plug-in hybrid trucks, which can help provide valuable NOx, GHG and TAC reductions in short-range, medium-heavy-duty goods movement applications.

It is clear that America must continue to push for the cleanest on-road HDV fuel and technology pathways. All four heavy-duty ZEV and NZEV fuel-technology pathways described in this White Paper are needed for our nation to meet daunting energy and environmental challenges, while continuing to transport freight efficiently and competitively. It will be essential to avoid over-reliance on any single fuel-technology combination, or "picking winners" in unsure markets.

Renewable Natural Gas: Opportunity and Challenges

This White Paper provides further discussion and specific recommendations about how to unlock our nation's major resources to produce RNG as a transportation fuel. Key areas of importance include the need to better recognize and monetize the diverse societal benefits that can be gained through management of environmental waste streams to produce RNG and use it as a substitute fuel for HDVs. The implications go well beyond transforming America's heavy-duty transportation sector. Expanded production and use of RNG for HDVs can be important catalysts for building our nation's overall markets for sustainable, environmentally benign renewable fuels (such as renewable hydrogen and electricity).

Due to the availability of federal and state monetary incentives, RNG is an affordable and increasingly important ultra-clean fuel for the HDV transportation sector.

Producing RNG is significantly more expensive than conventional (fossil) natural gas. However, transportation is a high-value use for RNG, due to the availability of federal and state monetary incentives (as described in this White Paper). The net result is that currently, RNG is an affordable and increasingly important ultra-clean fuel for the HDV transportation sector. In 2015, approximately 80 million DGEs of RNG were consumed by heavy-duty NGVs in California and across the U.S. Some companies are producing RNG onsite at landfill or dairy operations, and using it to power their own large fleets of heavy-duty NGVs. Because there is no "blend wall" for RNG; it can be used as a drop-in fuel in today's existing heavy-duty natural gas engines at any mixture with conventional natural gas, up to 100 percent RNG. That means an estimated 65,000 in-use medium- and heavy-duty NGVs that are currently moving goods and people on America's highways could potentially start using RNG, where locally available and price competitive. In areas across the U.S. where affordable RNG is not yet available—or as RNG is gradually blended into the natural gas mix—heavy-duty NGVs using fossil natural gas will still provide very important GHG-reduction benefits compared to conventional diesel HDVs.

RNG is widely available in California, and it currently fuels more than half of the state's NGVs. However, RNG production specifically for the purpose of fueling heavy-duty NGVs is relatively limited in America. Several barriers and challenges remain before national production on a large scale will occur. However, with concentrated focus and strong development efforts, the potential to greatly expand RNG production in the U.S. is significant. Studies from a range of sources (including the U.S. government) estimate that there are sufficient technically recoverable feedstocks in the U.S. to produce enough RNG to displace tens of billions of diesel gallons. This is enough RNG to fuel large portions of America's heavy-duty on-road goods movement sector.

Importance of Proportional Incentives for Immediately Deployable Heavy-Duty NZEVs

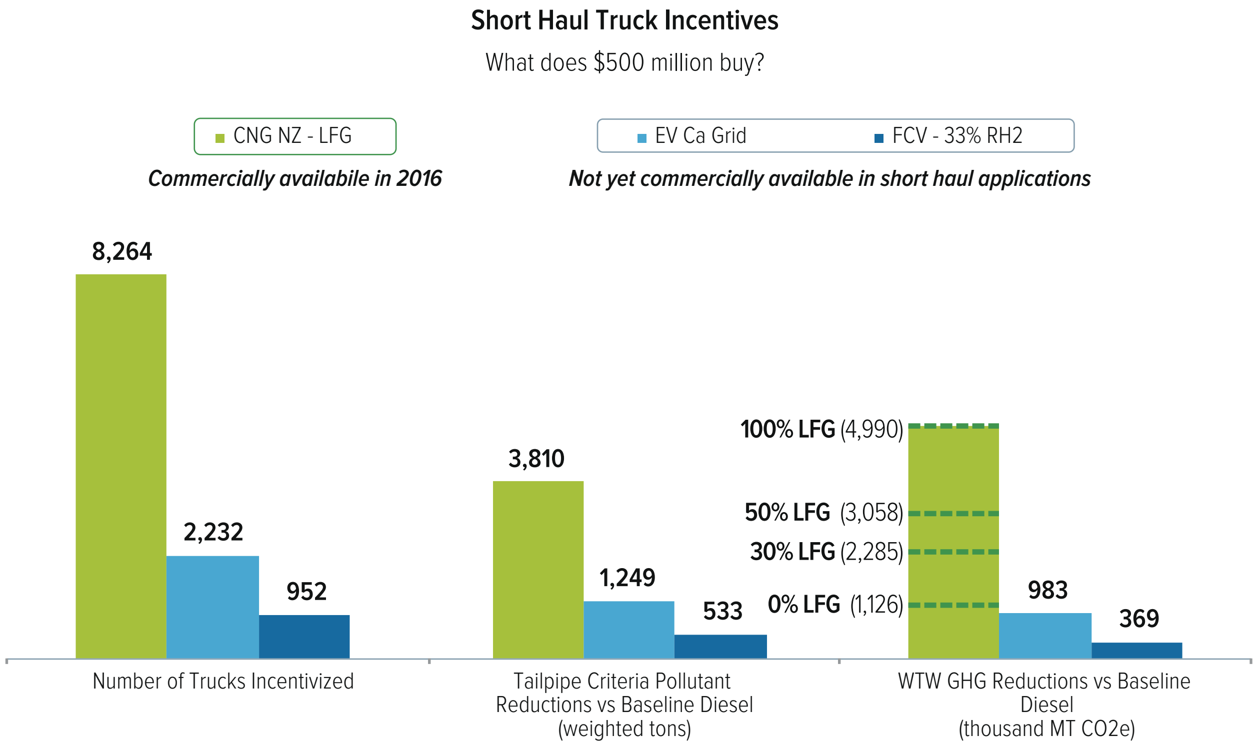
The use of economic incentives by government agencies has long been an important tool to control environmental pollution and drive the use of energy alternatives to petroleum. Incentive funds have been extremely important in accelerating commercialization of alternative fuel HDVs, and their replacement of older in-use diesel vehicles. Notably, government agencies that allocate public funds to incentivize low-emission HDV purchases as an air quality improvement strategy must carefully consider the magnitude, type and timeline of air quality benefits that can be achieved. The associated emissions reductions must be real, quantifiable, enforceable, and surplus. In addition, incentive allocations must meet standardized criteria for cost effectiveness. Finally, to achieve the fastest results, they should be focused on HDV technologies and fuels that are fully commercialized and immediately ready for wide scale deployment.

To provide a tangible example of the effectiveness of public investments in near-zero emission heavy-duty NGVs and RNG, this White Paper provides an analysis that compares the relative costs and air quality benefits of spending $500 million to help purchase three different HDV options.

The combination of near-zero-emission heavy-duty NGVs and increasing volumes of ultra-low-GHG RNG fuel provides an extremely cost effective option for immediately achieving major NOx and GHG reductions from America's on-road HDV sector.

As the figure below demonstrates, a $500 million investment would help deploy roughly 4X more near-zero-emission CNG trucks than battery-electric trucks, and 9X more compared to fuel cell trucks. As a result, roughly 3X and 8X more tailpipe criteria pollutants would be reduced respectively. And finally, using the $500 million to buy down near-zero-emission CNG trucks that operate on 100 percent RNG from landfill gas (CNG NZ - LFG) would provide roughly 5X and 14X GHG reductions, respectively, compared to the battery-electric truck (EV CA Grid) and the fuel cell truck (FCV 33% RH2). Even at a 0 percent LFG blend (i.e.,100 percent fossil CNG), purchasing heavy-duty NGVs still achieves the highest level of well-to-wheels (WTW) GHG reductions due to the greater numbers of low-GHG natural gas trucks that can be purchased for the same amount of money.

As this analysis demonstrates, the combination of near-zero-emission heavy-duty NGVs and increasing volumes of ultra-low-GHG RNG fuel provides an extremely cost effective option for immediately achieving major NOx and GHG reductions from America's on-road HDV sector. Therefore, the best application of public incentive dollars for reducing mobile source air pollution is to maximize allocations towards immediate deployments, which can begin with return-to-base trucks, transit buses and refuse haulers. Within two years, deployments can begin in high-impact HHDV applications like regional and long-haul trucking. Focused investment in ultra-low NOx natural gas trucks and RNG to fuel those trucks will achieve the


Short Haul Truck Incentives

What does $500 million buy?

Incentive amounts based on incremental purchase cost of advanced heavy-duty short haul trucks over baseline diesel truck
Based on emissions and vehicle activity data from CARB EMFAC 2014
Weighted emissions = NOx + 20*PM10 + ROG
GHG emissions based on illustrative fuel pathways calculated by ARB Staff using CA-GREET 2.0
Cost effectiveness uses Moyer program capital recover factors based on typical retention period of first owner

Figure 4: Hypothetical comparison of trucks and benefits and benefits based upon a $500 million investment

greatest volumes of key pollutant reductions at the lowest cost, in the fastest timeframe possible, and in the neighborhoods most in need of relief from diesel engine emissions.

The best application of public incentive dollars for reducing mobile source air pollution is to maximize allocations towards immediate deployments of heavy-duty near-zero-emission NGVs, which can begin with return-to-base trucks, transit buses and refuse haulers.

The importance of robust public incentives to help rapidly deploy near-zero-emissions HDVs cannot be overstated. It does not appear that there will be any regulatory mechanism to mandate deployment of near-zero-emissions HDVs in California, or nationally, prior to 2024. Incentives are the only mechanism to spur early deployments, which CARB and other regulators have clearly emphasized to be essential for goal attainment over the next decade. Further, in the absence of EPA action, it will possibly take much longer for states not adopting CARB's standards to begin deployment of near-zero-emission NGVs. Finally, current low diesel prices—combined with the newly commercialized engine's incremental cost—make it harder for HDV diesel fleets to switch to heavy-duty near-zero-emissions NGVs.

Government agencies such as CARB and EPA have made tangible progress to ensure that their incentive funds for clean HDV technologies account for the emergence of this fuel-technology combination. Notable efforts are being made to ensure that such awards focus as much as possible on near-term, large NOx and GHG reductions. However, increased stakeholder awareness and actions are needed to help ensure that even greater amounts of incentive funds are allocated for large-scale deployment of commercially ready near-zero-emission heavy-duty NGVs. It is the high-impact HHDV applications—where there are no foreseeable commercial pathways to achieve zero emissions for one to two decades—that most need incentive funds to immediately deploy large numbers of heavy-duty NGVs.

Large-scale NOx reductions, as needed for NAAQS attainment in many American cities, cannot be achieved without such deployments. Heavy-duty NGVs, which already provide significant GHG reductions when using fossil natural gas, can achieve deep GHG reductions by using RNG, where available. Thus, incentives are also needed to increase RNG production, distribution and end use. This will take time on a national scale, but fossil natural gas will continue to offer important GHG reductions relative to diesel, as RNG is increasingly blended into the natural gas fuel mix and further drives down GHG emissions from the HDV transportation sector.

WHITE PAPER RECOMMENDATIONS

This White Paper provides an overview of major opportunities in America for wide-scale use of near-zero-emission heavy-duty NGVs fueled increasingly by RNG. To fully realize such potential, there are opportunities that should be pursued, and challenges that need to be addressed, in two key areas: 1) heavy-duty near-zero-emission natural gas engines and vehicles, and 2) RNG production and end use. The White Paper recommendations for both areas are summarized below.

Recommendations for Heavy-Duty Near-Zero-Emission Natural Gas Engines and Vehicles

1. All stakeholders should work together to develop and implement new strategies to educate potential HDV fleet buyers on important emerging information about near-zero-emission heavy-duty NGVs (commercialized make/models, benefits, costs, performance, availability of incentive programs, etc.).
2. CARB, EPA, interested local air districts and industry stakeholders should join together to conduct a rigorous, peer-reviewed comparative analysis on the full-fuel-cycle emissions of existing heavy-duty ZEV and NZEV technologies.
3. All stakeholders in areas with unhealthful air quality should encourage EPA to adopt national optional low-NOx standards for heavy-duty engines that are harmonized with those adopted by CARB.
4. EPA should establish a national template for HDV incentive programs that “leapfrog” to deployment of HDVs meeting (or beating) the near-zero-emission level of 0.02 g/bhp-hr NOx. Using this template, key national agencies (DOE, EPA, NHSTA) should join together to implement new clean HDV incentive programs in populated areas of the U.S. with high on-road diesel engine activity.
5. Key government agencies (federal, state and local) should continue and expand funding to manufacturers for advanced natural gas engines, HDVs and on-board fuel systems
6. CARB, the California Energy Commission (CEC) and other California agencies should review policies for HDV incentive programs to determine if adjustments can expedite awards and help ensure that they are proportional to the magnitude and expediency of NOx-reduction benefits. They should work together to devise and implement a multifaceted strategy in California that allows pooling of different incentive programs to provide major annual funding for rapid deployments.

Recommendations for RNG Production and End Use

7. Appropriate national, state and local agencies should join with the biofuels industry to develop and implement focused outreach and education efforts that provide important emerging information about the production of RNG and its use in heavy-duty near-zero-emission NGVs.
8. CARB and CEC should further study the potential future dynamics between the supply and demand for RNG as a transportation fuel in California.
9. Relevant federal and state agencies (especially in California) should work together to establish new policies and programs that specifically support the production of RNG as a transportation fuel.

10. Air quality and energy regulatory agencies should continue to recognize and support fossil natural gas as a lower-carbon-intensity transportation fuel.
11. Key federal and California agencies, utilities, and other stakeholders should immediately work together to identify and discuss remaining obstacles to injecting RNG into common carrier natural gas pipelines.
12. EPA and other federal agencies should take action to increase volume obligations for Advanced Cellulosic Fuels under the federal RFS.

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& HEALTH

MEMORANDUM

To: Jennifer Morris, Southern California Gas Company

From: Julia Lester, Ramboll Environ

Subject: **Emission Benefits of Use of Liquefied Natural Gas in Ocean Going Vessels and Line-Haul Locomotives**

Date May 25, 2016

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INTRODUCTION

Southern California Gas requested Ramboll Environ to estimate the potential emission reductions expected from use of liquefied natural gas (LNG) in place of diesel fuel in ocean-going vessels and line-haul locomotives. This analysis uses an example route of a container ship making a one-way trip from Los Angeles to Shanghai, and a line-haul locomotive on a one-way trip from Los Angeles to Chicago.

RESULTS

Ocean-Going Vessel (OGV)

Emission estimates for an IMO Tier III diesel fueled 8,000 twenty-foot equivalent (TEU) OGV and a similar LNG OGV travelling from Los Angeles to Shanghai are shown in Table 1. Two different estimates are made for the diesel OGV one before 2020 and the other for 2020 and beyond to capture the change in emissions resulting from the switch in fuel oil sulfur content to 0.5% required by IMO Regulation 14. The results show a reduction of 92% in PM_{10}, 85% in NO_X, >99% in SO_X, and 39% in black carbon prior to 2020. For calendar year 2020 and beyond we see a reduction smaller reduction in PM_{10} of 69% due to the use of lower sulfur fuel oil; however reductions in black carbon emissions increase from 230 pounds per one-way trip (or 39%) to 330 pounds per one-way trip (or 49%).

To understand the potential impact of such a fuel switch, consider a scenario of LNG OGVs increasingly replacing diesel OGVs for container cargo transport between Southern California and Asia. Southern California Association of Governments' (SCAG's) 2016-2040 Reginal Transportation Plan/Sustainable Communities Strategy (RTP/SCS) estimates that the Ports of Los Angles and Long Beach will handle around 36 million TEUs in 2035.[1] More than 90% of this cargo

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[1] SCAG. 2016 to 2040 RTP SCS - Transportation Goods Movement System Appendix, Adopted April 2016. Available at http://scagrtpscs.net/Documents/2016/final/f2016RTPSCS_GoodsMovement.pdf. Accessed: May 2016.

(around 32.4 million TEUs) would be traffic to/from Asia.[2] If LNG OGVs started replacing diesel OGVs in 2020 and carried half of projected 2035 Asian cargo, black carbon emissions from OGVs would be reduced every year after introduction up to approximately 340 tons/year by 2035.

Line-Haul Locomotive

Emission estimates for a 100 rail car double-stacked intermodal container train powered by three Tier 4 diesel locomotives and a similar train powered by three LNG locomotives travelling from Los Angeles to Chicago are provided in Table 2. Both locomotives (diesel and LNG) meet the USEPA Tier 4 standard; as a result, there are no reductions in PM_{10} or NO_X for the LNG locomotives as compared to the diesel locomotive. We do, however, see a 13-pound per one-way trip or 87% reduction in black carbon emissions with the use of LNG in place of diesel.

Consider a scenario of LNG replacing diesel for freight trains from Southern California to and from the Midwest (e.g., Chicago). Historically, about 40% of the intermodal container cargo coming into the Ports of Los Angeles and Long Beach goes to the Midwest/Chicago by rail. These ports are projected to handle container volumes of around 36 million TEUs in 2035[3] of which around 12.8 million TEUs are estimated to be transported by on-dock and off-dock intermodal trains.[4] If we assume that 40% of these TEUs travel to Chicago/Mid-West region and a 100% of these trains are LNG fueled,[5] black carbon emissions would be reduced every year after the fuel switch up to approximately 85 tons/year by 2035.

ANALYSIS APPROACH

Ocean-Going Vessel (OGV)

OGV container ships usually use slow speed diesel engines for the main propulsion. Auxiliary power for the OGV's electrical needs are supplied either by auxiliary engines or a shaft generator connected to the main propulsion engine. In order to simplify this analysis, Ramboll Environ assumed that the auxiliary power would be supplied by the main propulsion engine.

The equation used to estimate the emissions of an OGV travelling from Los Angeles to Shanghai is provided below:

$$\textbf{OGV Emissions (tons/trip)} = \textbf{Engine Load (kW)} \times \textbf{Transit Time (hr/trip)} \times \textbf{Emission Factor (g/kW-hr)} \div \textbf{907,184.7 (g/ton)}$$

Emission factors used in this analysis are provided in Table 3. From January 1, 2016, OGVs are required to meet the International Maritime Organization (IMO) Tier III oxides of nitrogen (NO_X) standard of 3.4 g/kW-hr while operating within the North American Emission Control Area (ECA). Once outside the ECA, the OGV can operate at the Tier II NO_X standard of 14.4 g/kW-hr. For purposes of this analysis, Ramboll

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[2] Fact sheets for Ports of Los Angeles and Long Beach. Available at: https://www.portoflosangeles.org/pdf/POLA_Facts_and_Figures_Card.pdf and http://www.polb.com/about/facts.asp. Accessed: May 2016.

[3] SCAG. 2016 to 2040 RTP SCS - Transportation Goods Movement System Appendix, Adopted April 2016.

[4] Per 2016 to 2040 RTP SCS, approximately 35.5% (5-year average 2010 to 2014) of container volumes handled by the Ports of Los Angeles and Long Beach are transported by intermodal trains.

[5] It is assumed that the railroads would do a nearly complete fuel switch by major line to minimize duplicating fueling infrastructure.

Environ has assumed that the propulsion engine will operate a NO_X control technology like selective catalytic reduction to achieve the IMO Tier III standard while operating within the North American ECA.

Based on IMO Regulation 14, the sulfur content of fuel oils used on OGVs are required to be below 0.1% while operating inside the North America ECA. While operating in open sea (outside ECA), fuel oil sulfur content has to be maintained below 3.5%. Ramboll Environ has assumed a fuel oil sulfur content of 2.5% for this analysis. After 2020, OGVs will be required to use fuel oils with a sulfur content below 0.5%. Emission factors for particulate matter less than 10 microns (PM_{10}) and oxides of sulfur (SO_X) were obtained from California Air Resources Board's (CARB's) reference document titled "Emissions Estimation Methodology for Ocean-Going Vessels."[6]

Criteria air pollutant (PM_{10}, NO_X, and SO_X) emission factors for liquefied natural gas (LNG) OGVs were obtained from a scientific report published by the Norwegian Institute of Air Research.[7]

Emission factors for black carbon were estimated as the elemental carbon factor of PM_{10}. CARB[8] and United Stated Environmental Agency (USEPA)[9] speciation factors were used to estimate black carbon emission factors for various fuel types.

Emission estimates for an OGV travelling from Los Angeles to Shanghai were made for an 8,000 twenty-foot equivalent (TEU) OGV traveling at a speed of 25 knots. Transit time for the one-way trip was estimated based on vessel speed and total trip distance[10] of 5,708 nautical miles (nm). Trip distance within the North America ECA is around 200 nm.

Line-Haul Locomotive

Line-haul locomotives are used to move containers and bulk freight cross-country. Emissions from line-haul locomotives depend on the fuel efficiency, gross weight of the train, and mileage. The following equations were used to estimate the emissions from a line haul travelling from Los Angeles to Chicago:

$$\textbf{Locomotive Emissions (tons/trip)} = \textbf{Energy Consumption (bhp-hr/trip)} \times \textbf{Emission Factor (g/bhp-hr)} \div \textbf{907,184.7 (g/ton)}$$

$$\textbf{Energy Consumption (bhp-hr/trip)} = \textbf{Gross Weight of Train (gross ton)} \times \textbf{Track Mileage (miles/trip)} \div \textbf{Fuel Productivity Factor (gross ton-mile/diesel gallon)} \times \textbf{20.8 (bhp-hr/diesel gallon)}$$

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[6] Available at: http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf. Accessed: May 2016.

[7] Norwegian Institute of Air Research. Pollutant emissions from LNG fueled ships. Available at: https://brage.bibsys.no/xmlui//bitstream/id/378709/17-2015-sla-Deliverable_Emission_Factors_LNGships_v2.pdf. Accessed: May 2016.

[8] CARB's speciation profiles for PM4251, PM1191, and PM4252 OGVs are used to estimate black carbon emission factors for IMO Tier III slow speed engine operating on 0.1%, 2.5%, and 0.5% sulfur fuel oils respectively. Available at: http://www.arb.ca.gov/ei/speciate/speciate.htm. Accessed: May 2016.

[9] USEPA's speciation profiles for CNG buses is used to estimate black carbon emission factors for the LNG engine. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

[10] Transit distance estimates were obtained from http://www.sea-distances.org/. Accessed: May 2016.

USEPA Tier 4 emission standards for locomotives went into effect in calendar year 2015. As a result, this analysis compares the emissions from a Tier 4 locomotive with LNG locomotive. There is very limited data available for emission factors from diesel Tier 4 (one General Electric [GE] Tier 4 engine model certification data) and LNG locomotives (one GE LNG locomotive engine model). These are presented in Table 4. Both locomotives meet USEPA Tier 4 standard, however the LNG locomotive has slightly higher NO_X emissions as compared to the diesel locomotive. USEPA[11] speciation factors were used to estimate black carbon emission factor, which are assumed to be the elemental carbon fraction of PM_{10}.

A train's gross tonnage depends upon the number of rail cars, mass of freight carried, and the number of locomotives. The type of freight train chosen for this analysis is a 100 rail car double-stacked intermodal container train powered by three locomotives. Gross weight for this train was estimated to be 5,979 tons (Table 2). The track mileage along the BNSF route from Los Angeles to Chicago was estimated using BNSF's Division Maps[12] with detailed mile posts. CARB's estimates for fuel productivity factor[13] for line-haul locomotive travelling in California of 640 gross ton- miles per diesel gallon were used to estimate the energy consumption for the trip.

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[11] USEPA's speciation profiles for heavy-heavy duty diesel trucks without diesel particulate filter and CNG buses were used to estimate black carbon emission factors for the diesel and LNG locomotives. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

[12] Available at: http://www.bnsf.com/customers/where-can-i-ship/maps/. Accessed: May 2016.

[13] CARB. 2014. Locomotive Inventory Update. November 7. Available at: http://www.arb.ca.gov/msei/goods_movement_emission_inventory_line_haul_octworkshop_v3.pdf. Accessed: May 2016.

ATTACHMENT A
TABLES

Table 1. Emission Estimates for an Ocean Going Vessel Travelling from Los Angeles to Shanghai

Southern California Gas Company
Los Angeles, California

Propulsion Engine	Operating Year	Mass Emissions[1] (tons/trip)			
		PM_{10}	NO_X	SO_X	Black Carbon
IMO Tier III Slow Speed Engine	2016 to 2019	21.9	211.2	152.9	0.29
	2020 and beyond	5.7	211.2	27.8	0.34
LNG Engine	2016 and beyond	1.7	32.4	0.008	0.18

Operating Year	Emission Benefits of Using an LNG Engine[2] (% Reduction)			
	PM_{10}	NO_X	SO_X	Black Carbon
2016 to 2019	92%	85%	99.99%	39%
2020 and beyond	69%	85%	99.97%	49%

Notes:

[1] Mass emissions are estimated using the maximum continuous rating of a 8,000 TEU ocean going vessel (OGV) operating at 25 knots, the transit time for a one-way trip from Los Angeles to Shanghai, and the emission factors shown in Table 3.

[2] Emission benefits are estimated as a percentage difference between the LNG engine mass emissions and the IMO Tier III slow speed engine mass emissions.

[3] Maximum continuous rating of a 8,000 TEU ocean going vessel (OGV) operating at 25 knots was obtained from the document titled "Propulsion of 8,000-10,000 teu Container Vessel" published by MAN Diesel & Turbo. Available at: http://marine.man.eu/docs/librariesprovider6/technical-papers/propulsion-of-8-000-10-000-teu-container-vessel.pdf?sfvrsn=10. Accessed: May 2016.

[4] Transit distance estimates were obtained from http://www.sea-distances.org/. Accessed: May 2016.

[5] Transit time was estimated using transit distance and OGV travel speed.

Constants:

Maximum Continuous Rating at 25 knots[3]	59,880	kW
OGV Travel Speed	25	knots
Transit Distance[4]	5,708	nm
Within North American ECA	200	nm
Outside North American ECA	5,508	nm
Transit Time[5]	228.32	hr
Within North American ECA	8	hr
Outside North American ECA	220.32	hr

Conversion Factor:

907184.7 g/ton

Abbreviations:

% - percentage
ECA - Emission Control Areas
g - grams
hr - hour
IMO - International Maritime Organization
knot - nautical miles per hour
kW - kilowatt
LNG - liquefied natural gas
nm - nautical miles
NO_X - oxides of nitrogen
OGV - ocean going vessels
PM_{10} - particulate matter less than 10 microns in diameter
SO_X - oxides of sulfur
TEU - twenty foot equivalent

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Table 2. Emission Estimates for a Train Traveling from Los Angeles to Chicago

Southern California Gas Company
Los Angeles, California

	Mass Emissions[1] (tons/trip)		
Engine	**PM_{10}**	**NO_X**	**Black Carbon**
Tier 4 Diesel Locomotive	0.0096	0.48	0.008
LNG Locomotive	0.0096	0.58	0.001

Emission Benefits of Using an LNG Engine[2] (% Reduction)		
PM_{10}	**NO_X**	**Black Carbon**
0%	-20%	87%

Notes:

[1] Mass emissions are estimated using energy consumption for a one-way trip (shown under sub-heading "constants" below) from Los Angeles to Chicago and emission factors shown in Table 4.

[2] Emission benefits are estimated as a percentage difference between the LNG locomotive engines mass emissions and diesel Tier 4 locomotive engines mass emissions.

[3] Train gross weight is estimated for a 100 stack car train carrying double-stacked forty foot equivalent containers on each stack car, powered by three locomotives.

[4] The weight for a locomotive was obtained from the product specification sheet for the GE Evolution Series Tier 4 Locomotive. Available at: http://media.getransportation.com/sites/default/files/3%20EvoSeries%20Tier%204_locomotives.pdf . Accessed: May 2016.

[5] Mass of a stack car was obtained from the BNSF Glossary of Railroad Terminology and Jargon. Available at: https://www.bnsf.com/customers/pdf/glossary.pdf. Accessed: May, 2016.

[6] Average weight for a forty foot equivalent container (empty and full) was estimated based on the 2015 container statistics from Port of Oakland. Available at: http://www.portofoakland.com/port/seaport/facts-and-figures/. Accessed: May 2016

[7] Diesel fuel productivity factor for California was obtained from ARB's Locomotive Inventory Update dated November 7, 2014. Available at: http://www.arb.ca.gov/msei/goods_movement_emission_inventory_line_haul_octworkshop_v3.pdf. Accessed: May 2016.

[8] Track mileage was estimated based on the track mileage along the BNSF route from Los Angeles to Chicago using BNSF's Division Maps with detailed mile posts. Available at: http://www.bnsf.com/customers/where-can-i-ship/maps/. Accessed: May 2016.

[9] Diesel fuel consumption was estimated using the gross weight of the train, fuel productivity factor, and track mileage.

[10] Energy consumption for a one-way trip from Los Angeles to Chicago was estimated by converting the diesel fuel consumption with the USEPA's conversion factor of 20.8 bhp-hr/gal diesel for large line-haul locomotives. USEPA's conversion factor is available at: https://www3.epa.gov/nonroad/locomotv/420f09025.pdf. Accessed: May 2016.

Train Gross Weight Estimate[3]:

Train Component	**Number of Components**	**Mass of Each Component (ton)**
Locomotive[4]	3	213
Train Car[5]	100	27.2
Forty Foot Equivalent Containers[6]	200	13.1
Gross Weight of the Train		**5,979**

Constants:

Diesel Fuel Productivity Factor[7]	640	gross ton-miles/diesel gal
Track Mileage[8]	2247.5	miles
Diesel Fuel Consumption[9]	20,997	diesel gal
Energy Consumption[10]	436,729	bhp-hr

Conversion Factors:

907184.7	g/ton
20.8	bhp-hr/diesel gal

Abbreviations:

% - percentage
bhp - brake horse power
g - grams
gal - gallon
hp - horsepower
hr - hour
LNG - liquefied natural gas
NO_X - oxides of nitrogen
PM_{10} - particulate matter less than 10 microns in diameter
USEPA - United States Environmental Protection Agency

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Table 3. Ocean Going Vessel Emission Factors

Southern California Gas Company
Los Angeles, California

Propulsion Engine Type	Operating Details	Fuel Type	Emission Factors (g/kW-hr)			
			PM$_{10}$ [1,2]	NO$_X$ [3,2]	SO$_X$ [1,2]	Black Carbon [4,5]
IMO Tier III Slow Speed Engine	Within North American Emission Control Area (ECA)	Marine Distillate 0.1% Sulfur[6]	0.25	3.4	0.36	0.013
	Outside ECA before January 1, 2020	Heavy Fuel Oil 2.5% Sulfur[7]	1.50	14.4	10.50	0.020
	Outside ECA after January 1, 2020	Marine Distillate 0.5% Sulfur[8]	0.38	14.4	1.90	0.023
LNG Engine	All operation	LNG	0.115	2.15	0.00051	0.012

Notes:

[1] PM$_{10}$ and SO$_X$ emission factors for the IMO Tier III Slow Speed Engine were obtained from California Air Resources Board's May 2011 reference document titled "Emissions Estimation Methodology for Ocean-Going Vessels." Available at: http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf. Accessed: May 2016.

[2] PM$_{10}$, NO$_x$, and SO$_X$ emission factors for the LNG engine were obtained from the scientific report, "Pollutant emissions from LNG fuelled ships" published by the Norwegian Institute of Air Research. Available at: https://brage.bibsys.no/xmlui//bitstream/id/378709/17-2015-sla-Deliverable_Emission_Factors_LNGships_v2.pdf. Accessed: May 2016.

[3] NO$_x$ emission factors for the IMO Tier III Slow Speed Engine are assumed to be equal to the IMO Regulation 13 Tier III standard of 3.4 g/kW-hr while operating within the North American ECA and IMO Regulation 13 Tier II standard of 14.4 g/kW-hr while operating outside ECA. Note, ocean going vessels (OGVs) are required to meet the Tier III standard only while operating inside the ECA. For purposes of this analyses Ramboll Environ has assumed that the slow speed engine will have a NO$_X$ control technology like an selective catalytic reduction (SCR) unit that operates only when the OGV is within the ECA.

[4] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. CARB's speciation profiles for PM4251, PM1191, and PM4252 OGVs are used to estimate black carbon emission factors for IMO Tier III slow speed engine operating on 0.1%, 2.5%, and 0.5% sulfur fuel oils respectively. Available at: http://www.arb.ca.gov/ei/speciate/speciate.htm. Accessed: May 2016.

[5] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. EPA's speciation profiles for CNG buses is used to estimate black carbon emission factors for the LNG engine. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

[6] IMO Regulation 14 requires OGVs to use fuel oils with a sulfur content ≤0.10% mass by mass (m/m) while operating within the North American Emission Control Areas (ECA), nominally 200 nautical miles out from the USA and Canadian west coast.

[7] IMO Regulation 14 requires OGVs to operate on fuel oils with a sulfur content ≤3.50% m/m while operating outside ECA. For purposes of this analyses Ramboll Environ has assumed the use of heavy fuel oil with a nominal sulfur content of 2.5% while operating outside ECA.

[8] IMO Regulation 14 requires OGVs to operate on fuel oils with a sulfur content ≤0.50% m/m while operating outside ECA on and after January 1, 2020. Depending on the outcome of a review as to the availability of the required fuel oil, this date could be deferred to 1 January 2025.

Black Carbon Speciation Factors:

Fuel	Speciation Profile	Elemental Carbon/PM$_{10}$
Marine Distillate 0.1% Sulfur	CARB PM4251[4]	0.052
Heavy Fuel Oil 2.5% Sulfur	CARB PM1191[4]	0.013
Marine Distillate 0.5% Sulfur	CARB PM4252[4]	0.061
LNG	Average of EPA Profiles 95220 and 95219[5]	0.102

Abbreviations:

% - percentage
ECA - Emission Control Areas
g - grams
hr - hour
IMO - International Maritime Organization
kW - kilowatt

LNG - liquefied natural gas
NO$_X$ - oxides of nitrogen
OGV - ocean going vessels
PM$_{10}$ - particulate matter less than 10 microns in diameter
SO$_X$ - oxides of sulfur

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Table 4. Locomotive Emission Factors
Southern California Gas Company
Los Angeles, California

Engine Type	Fuel Type	Emission Factors (g/hp-hr)		
		PM_{10} [1,2]	NO_X [1,2]	Black Carbon [3,4]
Tier 4 Diesel	Diesel	0.02	1.0	0.016
LNG Engine	LNG	0.02	1.2	0.002

Notes:

[1] PM_{10} and NO_X emission factors for the locomotive were obtained from USEPA engine certification 2015 data for a Tier 4 locomotive (engine family FGETK0958T3A, model ET44AC/C4). Available at: https://www3.epa.gov/otaq/certdata.htm#locomotive. Accessed: May 2016.

[2] PM_{10}, and NO_x emission factors for the LNG engine were obtained from the GE NextFuel^{TM} presentation slides, "NextFuelTM Natural Gas" published by the GE on September 3, 2014.

[3] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. EPA's speciation profiles for diesel heavy-heavy-duty truck without diesel particulate filter is used to estimate black carbon emission factors for the locomotives. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

[4] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. EPA's speciation profiles for CNG buses is used to estimate black carbon emission factors for the LNG engine. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

Black Carbon Speciation Factors:

Fuel	Speciation Profile	Elemental Carbon/PM_{10}
Diesel	EPA Profile 8995	0.7897
LNG	Average of EPA Profiles 95220 and 95219[4]	0.102

Abbreviations:

% - percentage	LNG - liquefied natural gas
ECA - Emission Control Areas	NO_X - oxides of nitrogen
g - grams	OGV - ocean going vessels
hr - hour	PM_{10} - particulate matter less than 10 microns in diameter
IMO - International Maritime Organization	SO_X - oxides of sulfur
kW - kilowatt	

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