BATES WHITE
ECONOMIC CONSULTING

Renewable Natural Gas Supply and Demand for Transportation

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I. Executive Summary

The Renewable Natural Gas (RNG) industry has grown substantially over the past five years, largely in response to supportive policies like the Renewable Fuel Standard (RFS), which is administered by the Environmental Protection Agency (EPA) under the Clean Air Act. RNG availability has accelerated demand for natural gas use in transportation, enhanced the economic value associated with converting trucks and fleets from diesel, and promoted investments in CNG and LNG infrastructure. RNG production potential and the ability of the transportation market to absorb RNG are important factors for developers, investors, and regulators to consider as they make decisions about the future. While not all RNG will go to transportation fuel markets, EPA must weigh RNG demand, supply and other factors as part of its rulemaking responsibilities under the RFS. Accordingly, this report examines current conditions and various demand and supply projections for RNG as a transportation fuel in the U.S. The following is a summary of findings:

- RNG production from 2015 through 2018 has more than doubled, to **304 million ethanol gallons equivalent (EGE)** in 2018, with an average annual growth rate of 30 percent.

- RNG is completely interchangeable with conventional natural gas. RNG is a sustainable, drop-in fuel that may replace, or blend with, natural gas. RNG is distributed on existing natural gas pipelines and local distribution systems, allowing it to easily reach end-use customers.

- Natural gas use in transportation is growing because it is increasingly economic, especially for medium and heavy duty vehicles like refuse trucks, parcel carriers, transit buses, and long-haul trucks. The broad availability of RNG in combination with the RFS RIN credit value enhances the economic benefit of converting trucks, busses and fleets from diesel to natural gas.

- There is substantial scope for increased use of natural gas in transportation. In municipal transit alone, displacing just a quarter of diesel-fueled buses with natural gas vehicles would increase annual natural gas demand by **200 million EGE**.

- A key reference for estimated natural gas use in transportation, the Short-Term Energy Outlook (STEO) produced by the Energy Information Administration (EIA), reflects reporting data that do not fully capture current use, and the STEO consequently significantly understate demand.

- EIA's Annual Energy Outlook (AEO) estimates and projects natural gas use in transportation based on natural gas vehicle (NGV) counts and usage data. The AEO demand estimate for 2018 is **1,047 million EGE**, nearly twice the level of the STEO estimate for that year.

- Independent estimates of NGV demand approximate the AEO levels for current consumption levels, providing support for the conclusion that the AEO represents a more reliable estimate of aggregate demand for natural gas in transportation than levels reported in the STEO.

- The AEO projects U.S. NGV demand for natural gas at approximately **1,800 million EGE** in 2025. A 2017 report by the Fuels Institute projects U.S. NGV demand for natural gas in 2025 at approximately **2,500 million EGE**.

- There remains substantial technical potential for increased production of RNG. Technical potential from landfills exceeds **5,000 million EGE** annually. The EPA estimates annual production potential from dairy and swine farms corresponding to approximately **2,200 million EGE** of RNG. A report by the National Renewable Energy Laboratory (NREL) estimates *incremental* annual production potential (e.g., including only landfill sites with no current biogas projects) totaling approximately **4,800 million EGE** of RNG from landfills, agricultural waste, wastewater and other organic waste.

- The RNG industry has grown rapidly in a short period of time, with significant further growth anticipated in the near term. As of April 2019, there were **96** operating RNG projects and **61** RNG projects under construction or in advanced development. Since 2015, the number of companies developing RNG projects grew from **15** to more than **50**.

- RNG projects require substantial capital investment. Total capital costs for smaller landfill projects are in the range of **$5 million** to **$25 million**, and upwards of **$100 million** for larger projects, including agricultural and wastewater projects. Based on information provided by its member companies, the RNG Coalition estimates that the average RNG project requires **$17 million** of capital investment.

- The development of a new RNG facility creates significant employment, requiring design and engineering services, **20 to 40** local trade positions during construction, and typically **3 to 5** permanent employees for on-site operations. Employment is promoted more broadly through ongoing operating and maintenance expenditures.

- A study by ICF estimated that RNG production facilities generate **4.7 to 6.2** jobs per million EGE, indicating that each additional **100 million EGE** of RNG production would drive the creation of **470 to 620** jobs (approximately 550 additional jobs per 100 million EGE). Incremental jobs were estimated to provide income per worker of **$68,960**, more than twice the median income per individual in California (the focus of the study).

- Job impacts from RNG projects are generally concentrated in rural areas, where the effects are more likely to be significant relative to the size of the local economy and the availability of well-paying jobs.

- RNG provides substantial environmental benefits when used as a vehicle fuel. Direct tailpipe pollutant emissions from vehicle engines fueled by natural gas (both RNG and geologic) are very low, with emissions of CO2 **25 percent to 35 percent** lower for natural gas than for gasoline or diesel.

- RNG provides significantly enhanced emissions benefits, including an **85 percent** reduction of CO2 emissions relative to diesel fuel, according to analysis by

Argonne National Labs, considering RNG sourced from landfills only. Based on that estimate, the approximately **300 million EGE** of current annual RNG production reduces CO2 emissions by at least **1.04 million metric tonnes**.

- RNG projects linked to agricultural digesters have received significantly negative carbon intensity scores under the California Low Carbon Fuel Standard program, meaning that the projects produce a *net subtraction* of greenhouse gases in the atmosphere (on a CO2 equivalent basis).

- NGVs fueled with RNG out-perform electric vehicles in CO2 emissions reduction when accounting for emissions from electricity generation in the U.S.

II. Introduction and RNG Industry Overview

This report summarizes the review of the supply and demand of Renewable Natural Gas (RNG) in the U.S. performed by Bates White Economic Consulting. Bates White was engaged by the Coalition for Renewable Natural Gas (RNG Coalition) to conduct an assessment of historical and projected supply and demand of RNG for transportation use in the U.S., with reference to the ongoing support for RNG production and use from state and federal programs, particularly the Environmental Protection Agency's (EPA's) Renewable Fuel Standard (RFS) program.

RNG is derived from raw biogas captured at landfills, wastewater facilities and agricultural digesters and is processed to high energy content fuel that that is completely interchangeable with conventional natural gas. RNG production transforms discarded organic materials into productive fuel for transportation, heat and power. The development of high-Btu RNG projects began in the United States 1982, and has accelerated in recent years, largely in response to programs promoting the use of renewable and low carbon fuels in transportation.

Since 2010, RNG has qualified under the federal RFS program as an advanced biofuel. In 2014, EPA revised its pathways for biogas-derived fuels and recognized RNG as a cellulosic biofuel, which is assigned a RIN code of D3. Qualification for the D3 fuel category was based on feedstock analysis and greenhouse gas (GHG) reductions from RNG relative to petroleum fuels exceeding 60 percent. RNG currently constitutes approximately 98 percent of fuel in the D3 category.[1]

Individual state programs also promote the use of RNG in transportation. California's Low Carbon Fuel Standard (LCFS) establishes requirements to reduce the carbon intensity of transportation fuels. In 2018, the LCFS program was extended, with a carbon intensity reduction goal of 20 percent in 2030 relative to 2010. Oregon implemented a similar mechanism through its Clean Fuels Program in 2016, with a requirement to

[1] Based on RFS RIN generation data for 2017 and 2018.

reduce the carbon intensity of transportation fuels 10 percent by 2025 relative to 2015. Other state programs promote RNG through other mechanisms.

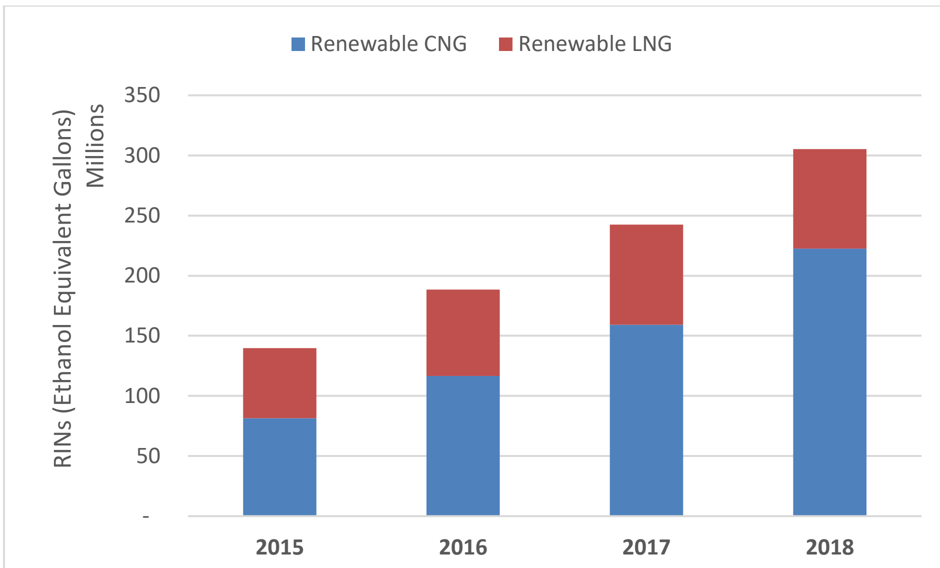
RNG reaches end users predominantly through injection into the interstate natural gas pipeline system. Processing biogas to the same quality as conventional natural gas makes RNG a completely interchangeable substitute in natural gas fueled vehicles (NGVs) – i.e., it is a so-called "drop in" fuel – and means that RNG producers can leverage existing distribution infrastructure. RNG can be injected directly into the common carrier pipeline system that serves public and dedicated fueling stations. Tracking procedures are used to demonstrate the correspondence between the quantity of RNG injected into a pipeline and the amount removed elsewhere on the system for fueling vehicles. Contracts between RNG producers or marketers and off-takers, such as private truck fleet operators and municipal transit systems, establish pricing for RNG that accounts for production and distribution costs and the value of RFS RINs and applicable state credits.

Most RNG is currently produced from landfill projects, accounting for approximately 95 percent of RNG volumes reported through the RFS program. The dominance of landfill gas projects is a function of the growing industry deploying capital where there are many cost-effective opportunities: landfills are numerous, many produce substantial quantities of processable gas, and the required technologies are relatively mature. Production of RNG from agricultural waste and municipal wastewater is in a comparatively early stage of development, but with significant future production potential, as discussed further in Section IV. Technology development and investment in these projects are increasing, with a number of agricultural waste-to-RNG and wastewater-to-RNG projects currently under construction or in advanced planning. These types of projects offer significant opportunities for increased RNG production, and in many cases greater GHG emission reduction per unit output.

Industry investment has accelerated to meet the demand for low carbon and renewable fuels and comply with the policies that govern them. Continued growth in investment, technology development and RNG output will be largely influenced by the annual volume requirements established by EPA under the RFS program, and the confidence of developers and investors that the program will provide support going forward.

RNG production from 2015 (the first full year of qualification as cellulosic biofuel under RFS) through 2018 has more than doubled, with an average annual growth rate of 30 percent. Figure 1 shows the RNG production growth based on RFS RIN generation data, which distinguishes renewable compressed natural gas (CNG) and renewable liquefied natural gas (LNG).

Figure 1: RNG Production Qualifying as Cellulosic (D3) or Advanced (D5) Biofuel Under RFS, 2015-2018[2]



[2] RIN generation data, updated March 2019. https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rins-generated-transactions.

III. RNG Demand

In this report, we examine RNG demand and supply in the U.S. transportation fuel market. It is important to emphasize that both demand and supply are determined in large part by the EPA's implementation of the federal RFS program. The federal RFS program provides critical support for the RNG industry by establishing renewable volume obligations (RVOs) for cellulosic biofuels. Transportation fuel demand for RNG is interrelated with the overall demand for natural gas for vehicles (i.e., including both RNG and geologic natural gas). Natural gas use in transportation is growing because it is increasingly economic, particularly for vehicles used intensively, such as refuse trucks, parcel carriers, transit buses, and long-haul trucks. Through supportive renewable fuel policies, RNG accelerates the overall demand for natural gas use in transportation by creating additional economic benefit for end-users. The availability of RNG enhances the economic value of converting trucking and municipal fleets from diesel to natural gas, which in turn supports investments in CNG and LNG supply infrastructure, boosting the value and viability of further conversions. Indeed, this reinforcement effect is a hallmark of the effectiveness of the RFS program.

The demand for RNG is captured retrospectively by the successful absorption of RNG by the natural gas transportation market and corresponds to the RNG production qualifying for D3 RINs, summarized in Figure 1, above. Potential future demand for RNG is determined by the capacity of the end-use markets to absorb RNG production.

Because RNG is recognized as fully-interchangeable with geologic natural gas, end-use markets for RNG are increasingly diverse – including electricity generation, industrial heating, hydrogen production, fuel cell supply, liquid fuel refining, plastics manufacturing, and for delivery directly to gas consumers. Increased awareness by customers, and the expansion of RNG marketing and contracting experience of producers as well as independent marketers, have broadened the market for RNG. In addition to direct support for RNG production, the RFS program has promoted the development of new marketing channels and expansion of the customer base for RNG. Sustaining and growing these nascent markets for domestically-produced RNG will depend significantly on the assurance that producers, consumers, and marketers have in continued RFS support.

While the total market for RNG is likely to be increasingly diverse going forward, we focus in this report on the anticipated demand for RNG as vehicle fuel (as both CNG and LNG). Below, we consider available data sources for natural gas transportation demand, and examine various drivers of increasing natural gas use.

A. EIA Short-term Energy Outlook

The U.S. Energy Information Administration (EIA) reports historical data and near-term projections for natural gas use in transportation through its Short-Term Energy Outlook (STEO), which is released on a monthly basis. We understand that this is a key reference for EPA in assessing the potential consumption of RNG when it sets the D3 RVO. The STEO for February 2019 indicates consumption of natural gas (RNG and geologic natural gas combined) in vehicles in 2018 equivalent to 533 million gallons of ethanol (in this report, we present volumes of natural gas, including RNG, in terms of ethanol gallons equivalent (EGE) to maintain consistency with RFS reporting of RINs).[3] The STEO projects NGV consumption of 547 million EGE in 2019, an increase of 2.5 percent from the prior year, and consumption of 562 million EGE in 2020, a further annual increase of 2.7 percent.

EPA recently established the 2019 RVO for cellulosic biofuel at 418 EGE. As discussed in the next section of this report, EPA's methodology for determining the RVO focuses on supply data based on reported RIN generation. At first glance, it appears that the RVO represents a large portion – 76 percent (=418mEGE/547mEGE) – of projected 2019 vehicle demand for natural gas. *This is misleading, however, because the STEO data substantially understates both historical and projected NGV usage volumes.*

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[3] The December 2018 STEO generally reports historical values for each month through November 2018, and projected values from December 2018 through December 2019. Reported monthly values for NGV consumption are constant for September through December. The annual NGV consumption value for 2018 consequently reflects a projection for part of the year.

Data on NGV fuel use for California, available through reporting from the LCFS program, provide a reliable measure of demand for that state, because LCFS tracks credits for both RNG and geologic natural gas used in NGVs. The California data indicate current total NGV fuel use of approximately 278 million EGE on an annual basis,[4] which is 52 percent of the amount the STEO indicates for total U.S. usage in 2018 (533 million EGE). While NGV fuel use in California is significant, the state accounts for less than 20 percent of U.S. fueling stations (both public and private) providing CNG/LNG (NGV fueling infrastructure is discussed further in section III.E.2, below). The implied residual volume of 255 million EGE (533mEGE less 278mEGE) of NGV fuel use for the remainder of the country, as implied by the STEO data, appears unrealistically low.

The STEO data for NGV fuel use are not necessarily faulty, but it is important to put them in appropriate context. Simply, those entities required to report on Form EIA-176 and Form EIA-886 do not have the data or are not required to report the appropriate data in order to conclude the actual volume of natural gas fuel use in vehicles. The reporting does not capture LNG sales that occur outside of natural gas utility distribution systems. The historical values reported in the STEO (and, by extension, the near-term projections) are derived from reporting for Form EIA-176, which gathers data from natural gas pipeline companies, distributors and other entities delivering natural gas, and Form EIA-886, which gathers data from entities supplying or using alternative fuel vehicles.[5] While both forms entail mandatory reporting of actual data, the sources produce very different values. For example, for 2016, the latest reporting year for which comparable values are available from EIA, Form EIA-176 data indicate approximately 523 million EGE of CNG/LNG use, while Form EIA-886 data indicate approximately 207 million EGE of use. The value reported in the STEO for 2016 corresponds to 517 million EGE.

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4 Data for the latest four quarters, through Q3 2018, from the 'LCFS Quarterly Data Spreadsheet', updated January 31, 2019; accessed at: https://www.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm; EGE volumes converted from reported diesel gallon equivalents using a diesel energy content of 129,000 Btu/gallon, and ethanol energy content of 77,000 Btu/gallon (lower heating values).

5 Form EIA-176, "Annual Report of Natural and Supplemental Gas Supply and Disposition"; Form EIA-886, "Annual Survey of Alternative Fueled Vehicles". See, https://www.eia.gov/Survey/.

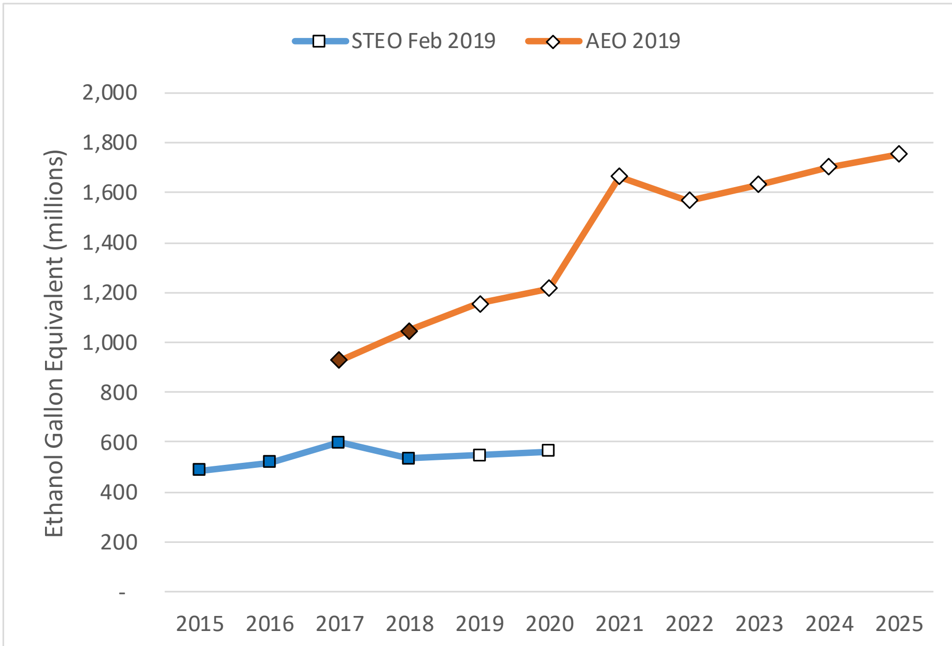
Form EIA-176 has more comprehensive coverage of relevant entities that are required to report than does Form EIA-886. Nonetheless, there are gaps in its ability to capture a complete picture of NGV fuel use. One illustration of this is that a natural gas distributor may classify certain sales as being to a commercial or industrial end-use customer and be unaware that the customer uses some of the delivered gas to fuel a vehicle fleet. The STEO would not capture such volumes as fuel for transportation. Reporting used in the STEO estimates also excludes natural gas used in rail transportation, which qualifies for RINs under RFS. EIA recognizes the limitations of the reported data underlying the STEO as a measure of aggregate natural gas use in transportation.

B. EIA Annual Energy Outlook

EIA produces a separate estimate of natural gas fuel use in transportation for its long-term Annual Energy Outlook (AEO) data series and forecast. At a high level, the AEO fuel volume estimation methodology uses a buildup of data for vehicle counts, vehicle miles traveled, and fuel economy to estimate fuel demand. The AEO also accounts for rail use of natural gas, which the STEO does not. Forecasted fuel use, extending out twenty years, is estimated using dynamic projections of each factor, including engine economics, relative fuel prices, technology adoption, macroeconomic growth, and a variety of other variables. Figure 2 compares the respective STEO and AEO series for natural gas use in transportation; historical data points are shown with solid fill, and projected data points without fill. (We note that the modest spike in demand for 2021 in the AEO projection, which stands out from the trend shown in the figure, corresponds to a projected drop in natural gas prices in that year).[6]

6 The underlying National Energy Modeling System (NEMS) used by EIA to develop the AEO projections is a dynamic model of the entire U.S. energy system, representing supply, demand and prices, across energy sources and end-use sectors, and which is also linked to a macroeconomic model.

Figure 2: STEO and AEO Historical and Projected NGV Fuel Use



Source: EIA

Comparing the latest common year reported as historical, 2018, the AEO estimate of NGV fuel use (1,047 million EGE) is nearly twice the magnitude of the STEO estimate (533 million EGE). As noted above, the markets covered by the two series are not identical. In particular, the AEO includes natural gas for freight rail use, while the STEO does not. The AEO projects substantial growth of natural gas use for rail, driven by conversions of freight rail locomotives from diesel to natural gas based on favorable economics.

Returning to the California reference level of 300 million EGE of current annual NGV fuel use, the AEO estimate of 1,047 million EGE nationally would imply 747 million EGE of use in the rest of the country, or approximately 71 percent of the total. This NGV fuel volume split between California and the rest of the U.S. of 29% / 71% corresponds more plausibly to the relative shares of fueling stations that provide CNG/LNG of 20% / 80% (see further discussion of fueling infrastructure in section III.E.2, below).

C. Independent Demand Estimate

Demand for natural gas in transportation is of central concern for developers of RNG projects, and investors, because the ability to translate RFS eligibility into supporting revenue requires the fuel to be tracked through to actual qualified use. This is typically done through contracting arrangements between RNG sellers and end-users that include information reporting requirements. Confidence in the prospective level of demand from off-takers is an important element in justifying near-term and longer-term business plans. Overall demand for natural gas for transportation is also important for RNG market participants that are also fuel distributors – i.e., that transact and distribute conventional natural gas as well as RNG.

Bates White conducted interviews with a number of RNG market participants regarding their views of natural gas demand for transportation, and reviewed a detailed model provided by Amp Americas, a company involved in CNG distribution and RNG project development. Bates White evaluated the model methodology and recreated a modified version of the model to estimate NGV fuel demand. The approach is similar to that used for the AEO data series, in that it relies on data for NGV counts, annual vehicle miles and fuel mileage by vehicle category. Table 1 summarizes the basic model construct, with data and results for 2016.

Table 1: Independent Demand Model of NGV Fuel Use

Vehicle category	2016 NGV Count	Average Annual Miles Traveled	Fuel Efficiency (miles/GGE)	Fuel Demand (mmGGE/year)	Fuel Demand (mmEGE/year)
	(1)	(2)	(3)	(4)=(1)x(2)/(3)/1000000	(5)=(4)x1.48
Over the road	14,000	68,155	4.59	208	308
Refuse	17,000	25,000	2.48	171	253
Transit	11,000	34,053	2.68	140	207
LNG	5,000	68,155	4.59	74	110
School Buses	5,500	12,000	5.44	12	18
Total	**52,500**	**41,153**	**3.60**	**605**	**896**

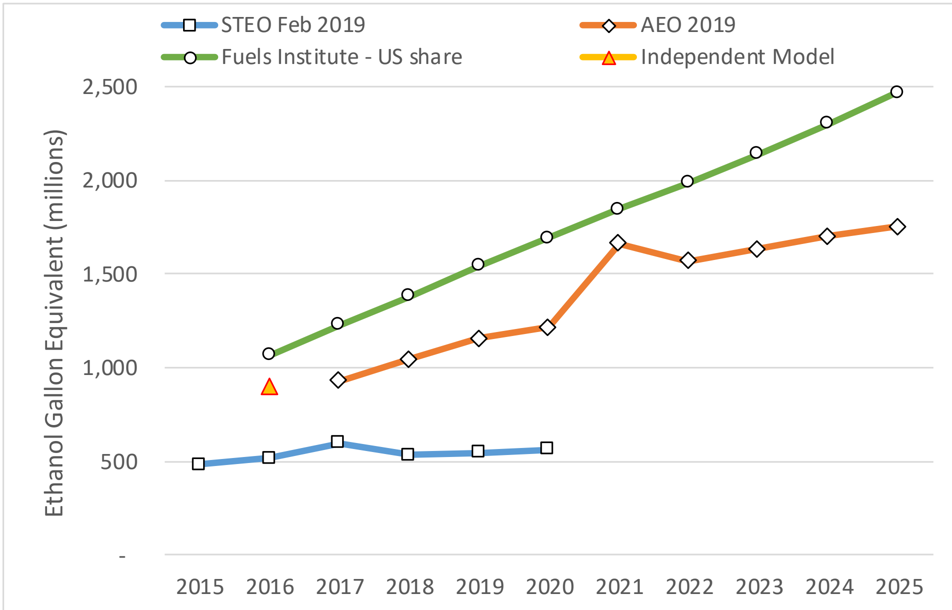
(1) 2016 Vehicle count from 2014 NGV America study plus projections of new natural gas vehicles in 2014, 2015, and 2016 ACT Research
(2) Average annual miles traveled from the Alternative Fuels Data Center
(3) Transit, refuse, and school bus fuel economy from 2010 National Renewable Energy Laboratory (NREL) technical report. Freight truck fuel economy from 2003 NREL report. LNG vehicles assumed to be primarily over-the-road trucks and are assigned the same fuel efficiency.

The result of this estimation methodology, of 896 million EGE of natural gas fuel consumption in 2016, is similar in magnitude to the reported AEO historical value for 2017 of 929 million EGE. The result provides confidence in the AEO values as a reasonable reflection of NGV fuel demand, and also offers a basis for considering how NGV fuel use is likely to grow. Fundamentally, demand will follow the number of natural gas fueled vehicles in operation. While the scope of this report did not allow for development of projected NGV counts and corresponding fuel demand, we address specific drivers of the likely growth in NGVs in subsection E, below. We first consider another projection of NGV fuel demand.

D. Fuels Institute Projected NGV Fuel Consumption

A report issued in 2017 by the Fuels Institute, “Tomorrow’s Vehicles: An Overview of Vehicle Sales and Fuel Consumption Through 2025,” presents projections developed by Navigant Research of road vehicle counts and fuel use, including a range of alternative fuel technologies, for North America. Multiple, integrated forecast models incorporate information on vehicle costs, efficiency, fuel prices, infrastructure and projections of commercial truck and bus counts. Bates White was not able to review the detailed model assumptions or the breakout for separate North American markets. Based on communication with representatives at the Fuels Institute, we understand that the U.S. share of projected vehicle sales and fuel consumption represents roughly 80 percent of the total. If that share is applied across the forecast, it results in a value for NGV fuel use in 2016 of 1,065 million EGE, within 11 percent of the AEO value for 2017 of 929 million EGE. Figure 3 shows the 80 percent US share of the NGV fuel use projection reported by the Fuels Institute compared to the STEO and AEO series, and also marks the 2016 demand estimate from the independent model discussed above.

Figure 3: Forecast Comparison Including Fuels Institute



The Fuels Institute projection of natural gas use in NGVs has a significantly higher growth rate (9.8 percent compound annual from 2016 to 2025) compared to the AEO (5.8 percent CAGR), though it does not account for freight rail use as the AEO does. Bates White has insufficient information regarding the details of the respective models to evaluate the reasonableness of the longer-term projections. Nonetheless, we find that the rough comparability of near-term estimates from the AEO, the Fuels Institute, and the independent methodology discussed above reinforces the reasonableness of the results and the conclusion that the STEO estimate is not established to determine current consumption levels and therefore significantly understates those levels.

The NGV market is still at a relatively early stage of development, which means that historical data provide a limited guide to future growth. Below we consider the underlying factors that are driving growth in in the NGV market.

E. NGV Demand Drivers

Growth of natural gas use in medium- and heavy-duty vehicles has been driven both by economics and by the environmental benefits provided by natural gas compared to diesel fuel. The rapid drop in natural gas commodity prices following the shale revolution has played a significant role in driving demand for natural gas in transportation, particularly as prices have remained within a relatively narrow range since 2009. High and volatile diesel fuel prices also encouraged conversions to natural gas. Figure 4 compares the average monthly wholesale spot price of natural gas and low-sulfur diesel fuel, in comparable energy terms – dollars per million Btu.[7] Diesel prices are tightly correlated with movements in world oil prices (the plateau in diesel prices seen in the figure for 2011-2014 corresponds to oil prices around $100/barrel; the lower level in 2017 reflects oil prices around $50/barrel). Low natural gas prices over the past decade have been driven by rapid growth in production from shale resources, even as demand for natural gas has increased. U.S. dry shale gas production grew more than six-fold in the ten years through 2018.[8]

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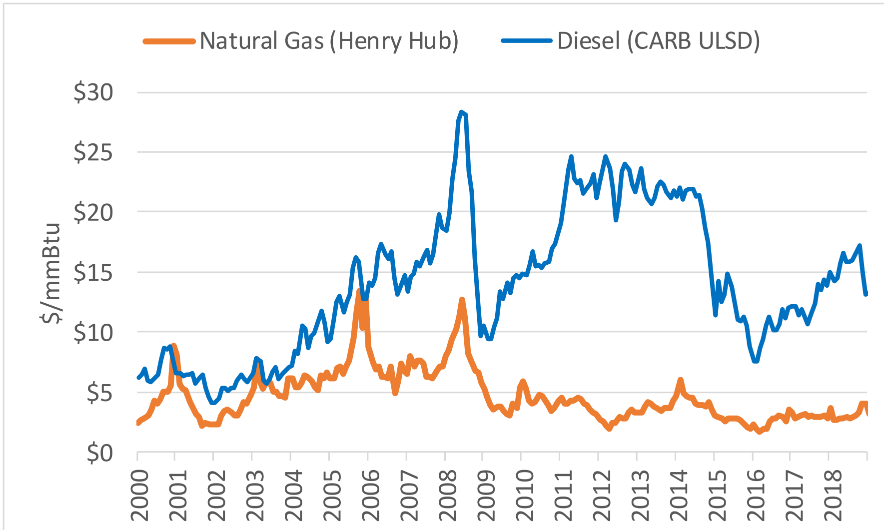
7 Natural gas commodity prices are generally reported in $/mmBtu, while diesel (or distillate) fuel prices are typically reported in $/gallon. The diesel prices in Figure 4 were derived from values in $/gallon using a conversion factor of 0.1375 mmBtu per gallon, based on data from EIA. For example, the diesel average wholesale spot price of $1.81 in December 2018 translates to $13.14/mmBtu (=$1.81/0.1375).

8 EIA data for shale gas production show 3.4 trillion cubic feet (tcf) in 2008 and 21.5 tcf in 2018; see 'Dry shale gas production estimates by play', https://www.eia.gov/naturalgas/data.php#production).

Figure 4: Natural Gas and Diesel Average Monthly Spot Prices, 2000-2018



Source: EIA

While diesel fuel has advantages such as high energy density (i.e., a given amount of energy content takes up less space) and ubiquitous availability, the lower price of natural gas price per unit of energy provides economic benefits, especially for truck fleets with certain operational characteristics. Trucks that are used intensively – in miles or operational time – and that return to a central location every day, are prime candidates for exploiting the benefits of natural gas fuel use. Fleets of such trucks can take maximal advantage of low incremental fuel costs and reliance on central, dedicated fueling facilities.

Argonne National Labs maintains a cost assessment tool – the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool – that allows comparison of the overall costs of owning and operating different vehicle types running on traditional and alternative fuels.[9] For combination long-haul trucks (i.e. tractor trailers), the default inputs for the purchase cost of a new truck (tractor only) are:

9 Available at: https://greet.es.anl.gov/afleet_tool.

$100,000 for a diesel-fueled vehicle, and $165,000 for a CNG-fueled vehicle.[10] The default assumption for annual long-haul truck miles used in the model is 170,000 miles. Using national average retail fuel prices for 2018 reported for diesel and CNG by the U.S. Department of Energy's Alternative Fuels Data Center (AFDC) of approximately $3.20 per gallon for diesel fuel, and $2.50 for CNG on a diesel gallon equivalent basis, a CNG-fueled truck would offer fuel savings of more than $10,000 per year.[11]

Based on these and other inputs, the AFLEET tool calculates a simple payback period of 6.3 years for the purchase of a CNG-fueled truck rather than a diesel-fueled truck.[12] There are several factors that suggest a lower payback period would apply for more current data. For example, newer natural gas engines have improved efficiency,[13] and private fueling facilities for CNG or LNG can provide greater cost savings for truck fleets. The AFLEET model assumes that private fueling provides approximately a 20 percent cost advantage relative to public retail pricing for CNG, while the assumed cost advantage for private versus public retail fueling of diesel fuel is only 10 percent. The AFLEET analysis also does not consider the economics of engine conversion (as opposed to new vehicle purchase), which may offer more economic opportunities for switching to natural gas vehicle fuel.

For municipal transit bus fleets, natural gas fueled buses can offer cost advantages relative to diesel comparable to those for heavy-duty trucks. The comparative case with respect to electric buses depends on the relative cost of CNG/LNG and electricity for the given jurisdiction, and also on the usage patterns for the vehicles. A study performed by

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[10] The data populating the model include annotations that these costs are based on references from 2012 and 2013.

[11] The AFLEET model reflects assumed fuel efficiencies of 7.3 miles per gallon for diesel-fueled long-haul trucks, and 6.6 miles per gallon (on a diesel gallon equivalent basis) for CNG. The annual fuel cost savings for a CNG-fueled truck is then: (170,000mi / 6.6mpg)x$2.50/gal <u>less</u> (170,000mi / 7.3mpg)x$3.20/gal = $10,124.

[12] Fuel price data are based on averages of the national values reported in the four AFDC fuel price reports for 2018, translated to a common diesel-equivalent gallon basis; data accessed at: https://afdc.energy.gov/fuels/prices.html.

[13] For example, Cummins Westport has introduced a 12 liter, dedicated natural gas engine for heavy-duty trucks and buses, the ISX12N.

the National Renewable Energy Laboratory (NREL) of a pilot transit demonstration in southern California reported total operating costs of 46¢ per mile for CNG-fueled buses compared to 62¢ per mile for the battery electric buses being evaluated.[14] The study estimated that the CNG bus costs would have been higher on the shorter, lower-speed routes on which the electric buses were used, demonstrating that usage patterns play a significant role in determining cost effectiveness. An additional factor not addressed in the NREL study is that the use of RNG in natural-gas fueled vehicles can provide significantly greater CO2 emissions reduction compared to that from electric vehicles (see discussion in Section VI, below).

Municipal bus systems remain a significant potential source of growth for NGVs. As of 2015, diesel buses made up 65 percent of U.S. transit bus fleets, totaling just over 41,000 vehicles.[15] CNG-fueled buses made up 18 percent of the total (11,447 vehicles), with the remaining 17 percent consisting of diesel-electric hybrids (7,303), gasoline-fueled buses (2,172) and a relatively small number of other fuel types, including LNG (580) and electric battery (114). Displacing roughly a quarter of diesel-fueled vehicles would double the number of CNG-fueled transit buses, and would increase natural gas transportation demand by approximately 200 million EGE annually.

Refuse hauling fleets represent the second largest category of NGV fuel consumption. As indicated in Table 1, refuse fleets represent an estimated 253 million EGE of natural gas use, or about 28 percent of the total volume from that demand estimation methodology. Refuse trucks have high energy use, because of many stops and starts and additional energy used for compacting. They return to a depot each day, typically located in a metropolitan area with ready access to the gas distribution system. Additionally, offering reduced emissions (and reduced noise) within urban areas through the use of natural gas-fueled vehicles offers environmental and quality-of-life benefits to municipal clients of

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14 Foothill Transit Battery Electric Bus Demonstration Results: Second Report (June 2017), accessed at: https://www.nrel.gov/docs/fy17osti/67698.pdf.

15 American Public Transportation Association, "Clean Propulsion Resource Guide." (Rev. July 2017); accessed at: https://www.apta.com/resources/reportsandpublications/Documents/2017%20APTA%20Clean%20Propulsion%20Resource%20Guide_20170710.pdf

hauling services. Major haulers Waste Management, Inc., and Republic Services, Inc., have converted significant portions of their truck fleets to natural gas, and already use RNG to meet the majority of their CNG demand, with plans to expand the use of RNG going forward.

UPS has also significantly expanded natural gas use in its truck fleets. UPS began converting in 2012, when diesel prices were trending near $4.00/gallon (nearly $30/mmBtu) and natural gas prices were at historic lows. UPS has focused on moving to natural gas use in locations with a large number of high-mileage vehicles. As with waste hauling vehicles, UPS trucks tend to return to a central location daily, and often operate in areas with available natural gas distribution systems. UPS also operates its long-distance services on a hub system that allows trucks to return to the same location daily, again facilitating the use of dedicated natural gas fueling facilities.

RNG projects at landfills operated by Waste Management and Republic Services also represent a substantial share of total RNG production. These companies thus encompass both the supply side and demand side effects of support from the RFS program. Investment interest, development capabilities and advances in technology and production efficiency in supply are promoted on the one hand, while expanded RNG use and NGV conversions are promoted on the other. These are mutually reinforcing effects that point toward a maturing market. At the same time, maintaining the value that has been built in this market to date, and promoting further economic investment in production, distribution and in demand (e.g., truck and bus conversions), will depend on continued RFS support going forward. In particular, confidence in a multi-year commitment of RFS support will promote investments with a longer payback period that are currently foregone opportunities.

1. Evolution of CNG Fuel Systems and Engines

Prior to about 2012, most of the natural gas demand for on-road transportation was from heavy-duty vehicles fueled with LNG. LNG's high energy density allowed long-distance truck routes (e.g., greater than 500 miles), and high-mileage vehicles were able to benefit from lower fuel costs while accommodating the additional weight, size and cost of LNG fueling systems. Since 2012, there has been a rapid expansion in the use of CNG for transportation, driven significantly by advances in vehicle fueling systems. Several companies have developed CNG fuel systems with increased capacity and reduced weight, extending the travel range for long-haul trucking beyond 500 miles on a single fueling. CNG offers additional flexibility for users, because the ability to rely on existing natural gas distribution infrastructure allows for wider availability of fueling stations. While LNG remains economic for certain applications, including long-haul trucking, technological innovations in CNG fuel systems and engines have facilitated the rapid growth in transportation demand for natural gas.

2. Expansion of NG Supply Infrastructure

Technical advances in on-vehicle fueling systems and natural gas engines have been accompanied by expanded availability of natural gas fueling stations. The increase in fueling stations enhances the value of moving to natural gas vehicles, and demonstrates that infrastructure is expanding in step with the growth in NGVs. The value of CNG-fueled vehicles has been reinforced by the fact that CNG does not require the specialized liquefaction, transportation and storage facilities needed for LNG. CNG fueling stations can be supplied directly from the existing natural gas distribution system, which allows for ready expansion of supply infrastructure.

The Department of Energy's Alternative Fuels Data Center (AFDC) tracks the number of fueling stations that provide CNG/LNG by state. As of the March 2019 update, the AFDC database identified CNG/LNG fueling stations in all fifty states. More than half of states have at least 20 such stations, with California, Texas, Oklahoma, Pennsylvania and New York ranking as the top five states by station count.[16]

[16] It is notable that all these states contain or overlap shale basins, though the Monterey basin in California is not one of the major natural gas production sources.

Table 2: Fueling Stations Providing CNG/LNG (as of March 2019)[17, 18]

Status	Public	Private	Total
Available	979	734	**1,713**
Temporarily Unavailable	20	8	**28**
Planned	65	15	**80**
Total	**1,064**	**757**	**1,821**

Of the current fueling stations providing CNG/LNG, 67 percent (1,141) opened in the eight years from 2011 through 2018. Data for planned facilities are mostly very near term – for example, 77 of the 80 planned facilities included in the database are expected to go into service in 2019 – and these figures are likely to be understated because they are based partly on voluntary self-reporting by fuel providers and other private entities. Nonetheless, the 77 facilities planned to go into service in 2019, plus 5 others that have already entered service in the first quarter of 2019, represent significant annual growth: 4.7 percent relative to the combined total for available and temporarily unavailable service stations.

F. Additional Drivers of Demand for RNG

The RFS program creates a mechanism to allow RNG producers to access the transportation fuels market. The D3 RVO effectively establishes the required volume of RNG for each compliance year, and tradable RIN credits encourage efficient production

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17 Data from AFDC Alternative Fuels Station Locator, https://afdc.energy.gov/stations/#/analyze, as of March 17, 2019.

18 The category 'temporarily unavailable' reflects "stations that are temporarily out of service or offline with plans to open again in the future."

and distribution, while providing a source of value to both producers and end-users.[19] RFS enhances the economic benefit of using RNG as a transportation fuel, encouraging switching/conversions to NGVs, and thereby boosting demand as well as production of RNG. For entities that operate on both the demand and supply sides – e.g., operating truck fleets and landfills – there are particular opportunities to benefit from self-supply of RNG, which explains why refuse haulers are a large and growing source of NGV fuel demand, as discussed above.

More generally, the RFS program facilitates the choice by private fleet operators and municipalities to use NGVs by promoting production of RNG and the economic and environmental benefits it provides. Companies and cities are able to advance their sustainability goals more economically by switching to NGVs. Expanded NGV and RNG use has also provided companies competitive benefits in meeting investor expectations, delivering service improvements for customers and communities, and in some cases by differentiating their service so that they are more competitive in securing business. These effects on business opportunities and behavior are a key effect of the RFS program.

[19] The value of D3 RINs is linked to the value of the cellulosic waiver credit (CWC) and the value of the D5 RIN. EPA is required to make CWCs available in years when it waives some portion of the statutory volume for cellulosic biofuel, which it has done each year of the RFS program. Obligated parties can meet their cellulosic biofuel requirement by retiring a D3 RIN or, alternatively, by purchasing a cellulosic waiver credit and retiring a D5 RIN. The CWC is set at the greater of $0.25 or $3.00 less the wholesale price of gasoline (EPA has set the CWC for 2019 at $1.77). The level of the CWC has generally resulted in D3 RINs being priced approximately equal to the CWC plus the D5 RIN price.

IV. RNG Supply

A. RNG Production Potential

1. Landfills

As noted above, RNG is currently produced predominantly from landfill gas. Table 3 summarizes D3 RIN generation data from the EPA Moderated Transaction System (EMTS).

Table 3: D3 RIN Generation from RNG by Feedstock[20]

	Landfills	Municipal Wastewater	Other Feedstocks	Total
2014	32,405,500	312	182,071	**32,587,883**
2015	138,230,443	171,158	1,457,544	**139,859,145**
2016	184,210,806	350,983	3,994,760	**188,556,549**
2017	232,850,074	4,489,026	3,238,339	**240,577,439**
2018	293,597,758	7,283,999	3,289,471	**304,171,228**
Total	**881,294,581**	**12,295,478**	**12,162,185**	**905,752,244**

Landfills represent the dominant source of RNG and also a significant remaining potential for increased RNG production going forward. RNG projects require substantial investment, and the larger landfills offer development opportunities because of the large volume of biogas that they typically generate and the experience of landfill operators in collecting gas for other purposes, such as generating electricity.

[20] EPA EMTS database, https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rins-generated-transactions, accessed March 17, 2019.

To estimate RNG production potential from landfills, Bates White created a model based on data from EPA's Landfill Methane Outreach Program (LMOP) database, which catalogs information on landfills nationwide. While the LMOP database remains a key information source on prospective project sites, several project developers interviewed by Bates White indicated that the LMOP database does not reflect the latest available information on the status of all projects. In particular, it is likely that some newer RNG projects already in operation are not reflected in the database. Consequently, we did not attempt to isolate incremental RNG production potential, but estimated aggregate RNG production potential, which includes existing RNG production.

Landfills with threshold potential for RNG projects were screened based on a minimum generation of 1,000 standard cubic feet per minute (scfm) of landfill gas. The methane content of landfill gas for each project was based on reported values, where available, or taken as the average for available data, which is approximately 50 percent of the collected biogas. The RNG production potential was then calculated based on bringing the concentration of methane to 100 percent. For example, a project collecting 1,000 million cubic feet of landfill gas annually with a methane content of 50 percent would be able to produce 500 million cubic feet of RNG per year. We further applied a factor of 85 percent to account for maintenance outages and parasitic energy use in processing. The results of the model are summarized in Table 4, below, which distinguishes several status categories identified in the LMOP database. Landfills with at least one existing operational LFG project have the potential to produce approximately 4,358 million EGE of RNG. Landfills with projects under construction or planned add approximately 184 million EGE of potential output, and "candidate" landfills, as defined by EPA, add a further 860 million EGE of RNG production potential.[21]

[21] According to the LMOP web site, "LMOP defines a candidate landfill as one that is accepting waste or has been closed for five years or less, has at least one million tons of waste, and does not have an operational, under-construction, or planned project; candidate landfills can also be designated based on actual interest by the site." Designation as a candidate site does not take into account factors that may make a site more or less desirable to develop for RNG, like proximity to a pipeline.

Table 4: Total Annual RNG Production Potential from Landfills (millions of EGE)[22]

Landfill Categories	Potential Annual RNG Production (million EGE)
With at least one operational LFG project	4,358
Plus under construction/planned LFG projects	4,543
Plus "candidate" landfills defined by EPA	5,403

Other site-specific attributes – in particular, the proximity of a pipeline – will determine what proportion of the landfill sites with appropriate scale have the potential to host a viable RNG project. Such site-specific details are not identified in the LMOP database, and are not incorporated in the model. Incorporating other site-specific factors would likely reduce the estimates of potential RNG production presented in Table 4. However, the selected scale cutoff of 1,000 scfm is somewhat conservative (i.e., high) relative to the smallest projects currently being developed. Growth in investment activity, and continued process and efficiency improvements will likely reduce the threshold size of landfills considered as development prospects. We also note that our model does not reflect potential output from landfills designated in the LMOP database as "Low Potential" or "Future Potential" (the latter category corresponds to newer landfills for which there is insufficient data to estimate potential LFG generation volumes).

2. Livestock Waste

Agricultural projects represent a smaller volume of potential RNG production but, as noted in Section VI, below, with substantial GHG emission reduction effect. EPA's AgSTAR database lists 280 agricultural projects with waste digesters in operation or

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22 Modeled using data accessed as of March 18, 2019, identified on the LMOP web site as updated in February 2019; https://www.epa.gov/lmop/landfill-technical-data.

under construction. Most of these projects currently produce biogas for electricity generation or cogeneration.

Dairy farms represent the main potential for agricultural RNG project development because of the volume (and concentration) of waste produced. Several thousand cows are typically needed for an RNG project to be considered potentially viable, though not necessarily at a single farm. It may be economic for an RNG project to be linked to multiple smaller farms where manure can be piped or trucked to central digesters. EPA's AgSTAR database identifies 280 agricultural digester projects. More than three quarters of these are linked to dairy farms, with 42 (15 percent) linked to swine farms. The roughly 500,000 dairy cattle with associated digester projects have the potential to generate approximately 136 million EGE of RNG per year, assuming methane output at 20 mmBtu per year, per cow. However, this constitutes only a small portion of potential output from agricultural projects. EPA has identified more than 8,000 candidate dairy and swine operations that could support biogas recovery.

Table 5 summarizes the EPA's estimates of potential biogas recovery by farm type, and translates the energy volume into an RNG equivalent. While it is not likely that all candidate sites would be able to support RNG production, the volumes demonstrate the large technical potential for RNG production from agricultural waste. The estimates also exclude potential biogas recovery from chicken and beef cattle operations.

Table 5: Biogas / RNG Potential from Swine and Dairy Farms[23]

Animal Sector	Candidate Farms	Potential biogas mmBtu/year	RNG potential, millions EGE
Swine	5,409	71,484,000	928
Dairy	2,704	100,124,000	1,300
Total	**8,113**	**171,608,000**	**2,229**

3. NREL Estimates of Production Potential

A 2013 report by the National Renewable Energy Laboratory (NREL), "Biogas Potential in the United States," estimates methane generation potential from different biogas sources in the United States. For landfills, this volume corresponds to 1,498 million EGE per year, reflecting only "candidate" landfills as defined by EPA. This excludes potential conversion of existing biogas projects to RNG production, which is captured in the Bates White estimates above. At the same time, the NREL estimate reflects a larger volume of potential production from candidate sites than in the Bates White estimates, likely because previously-identified candidate sites have been developed over the past 5 years.

NREL estimates potential RNG production from municipal wastewater treatment facilities equivalent to 1,427 million EGE annually. The estimated potential production of RNG from animal manure corresponds to 1,162 million EGE per year. Finally, NREL estimated the potential RNG production from industrial, institutional, and commercial organic waste at the equivalent of 706 million EGE annually. These values are summarized in Table 6, which shows the combined total potential across the four feedstock categories equivalent to 4,794 EGE per year.

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[23] U.S. EPA, "Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities." (June 2018), derived from Table 1, page 4. Accessed at: https://www.epa.gov/sites/production/files/2018-06/documents/epa430r18006agstarmarketreport2018.pdf.

Table 6: NREL Estimated U.S. Potential RNG Production by Source[24]

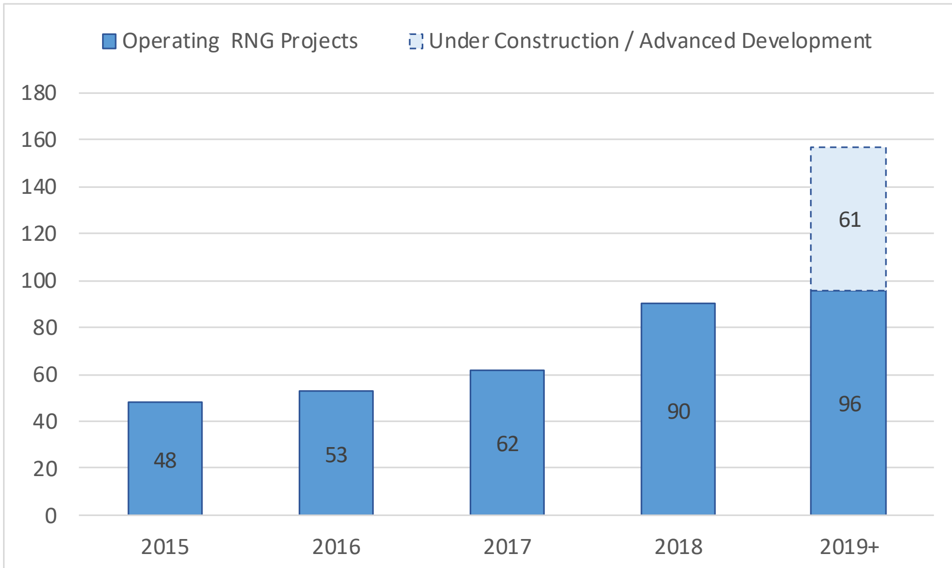
Source	RNG Potential, millions of EGE per year
Landfills	1,498
Wastewater	1,427
Animal manure	1,162
Other organic waste	706
Total	**4,794**

V. Investment and Economic Impact

The RNG industry has grown rapidly in a short period of time, with significant further growth anticipated in the near term. Figure 5 shows the number of RNG projects in operation each year since 2015, and the projects currently under construction or in an advanced state of development. Of the 96 RNG projects operating as of April 2019, 77 are producing RNG for transportation, and 19 produce RNG for electricity generation or residential/commercial heating. Over the period, the number of companies developing RNG projects grew from 15 to more than 50.

[24] National Renewable Energy Laboratory, "Biogas Potential in the United States," (2013); accessed at https://www.nrel.gov/docs/fy14osti/60178.pdf; data values converted from metric tonnes.

Figure 5: RNG Projects in Operation and Under Construction / Advanced Development



Source: RNG Coalition

RNG projects require substantial capital investment. Equipment and infrastructure include the following:

- Biogas collection system at landfills, and collection system upgrades;
- Anaerobic digesters for livestock or wastewater facilities;
- Conditioning equipment for cleaning and upgrading raw biogas to RNG;
- Compressors and pipeline infrastructure for delivering RNG to an interconnection with the natural gas pipeline system;
- Storage facilities and trucks for delivering RNG in the absence of an economic pipeline interconnection.

Total capital costs for smaller landfill projects are in the range of $5 million to $25 million, and upwards of $100 million for larger projects, including agricultural and wastewater projects. Based on information provided by member companies, the RNG Coalition estimates that the average RNG project requires $17 million of capital investment. The required cost for individual projects varies significantly, and depends on the type of feedstock, site specifics, including the cost of construction and right-of-way for a pipeline to interconnect with the common carrier system, and also reflects different cost structures of developers. Some entities self-finance; some pursue partnerships with utilities or other well-capitalized companies; some pursue bank financing for a portion of costs.

The development of a new RNG facility creates significant employment, requiring design and engineering services, 20 to 40 local trade positions during construction, and typically 3 to 5 permanent employees for on-site operations. Employment is promoted more broadly through ongoing operating and maintenance expenditures.

A study by ICF of economic impacts from potential expanded production of RNG and deployment of low NOx natural gas trucks in California applied a cost analysis reflecting average capital expenditures by RNG project type shown in Table 7.[25]

Table 7: Average Capital Expenditure by RNG Project Type – ICF Study[26]

Project Type	Average Capex per project, $mm
Landfill	$12.5
Wastewater	$24.4
Dairies	$45.3

[25] ICF, "Economic Impacts of Deploying Low NOx Trucks fueled by Renewable Natural Gas" (May 2017)

[26] Values are derived from the total capital expenditures assumptions (reported in Table 6 of the ICF report) for an illustrative case with 50 landfill, 100 wastewater and 200 dairy projects.

The ICF study estimated an output multiplier for RNG production investment of 1.83, meaning that each million dollars invested translates to a total increase in value to the economy of $1.83 million.

The study estimated aggregate employment effects considering additional associated investments in low NOx trucks and fueling infrastructure. To put the economic impact into context with effects from the production of other transportation fuels, the study estimates jobs created per volume of fuel production, finding that RNG production facilities generate 4.7 to 6.2 jobs per million EGE (converted from reported values per million diesel gallon equivalent). Applying the midpoint of the range, each additional 100 million EGE of RNG production would drive the creation of 550 additional jobs. In the California study, incremental jobs were estimated to provide income per worker of $68,960, more than twice the median income per individual in the state.

Although not addressed explicitly in the ICF study, job impacts from RNG projects are generally concentrated in rural areas, where the effects are more likely to be significant relative to the size of the local economy and the availability of well-paying jobs.

VI. Environmental Benefits

RNG provides substantial environmental benefits when used as a vehicle fuel. Direct tailpipe pollutant emissions from vehicle engines fueled by natural gas (both RNG and geologic) are very low. In particular, emissions of CO2 are approximately 27 percent lower for natural gas than for gasoline or diesel.[27] Natural gas also outperforms petroleum fuels in emissions of carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM), though fuel and engine emissions standards in the U.S. have substantially reduced the emissions of these pollutants from petroleum fuels. Natural gas-fueled engines nonetheless have the benefit of requiring less emission control equipment to achieve (and exceed) the regulatory standards.

[27] https://www.eia.gov/environment/emissions/co2_vol_mass.php

RNG provides significantly greater emissions benefits when evaluated using lifecycle analysis, which considers impacts not only from direct tailpipe emissions, but all effects from production to use – also referred to as "well to wheel" (WTW) assessment.

Argonne National Labs developed and maintains the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model, a lifecycle analysis tool that evaluates the energy and environmental effects of a range of end-use fuels, feedstock pathways and vehicle technologies. Table 8 summarizes the lifecycle CO2-equivalent (CO2e) emissions determined by the GREET model for a range of fuels, evaluated on an equal energy basis corresponding to a gallon of conventional gasoline.

Table 8: Lifecycle Emissions of CO2e per Gasoline Gallon Equivalent[28]

Fuel	CO2 Equivalent g/GGE
RNG (landfill)	1,637
Biodiesel (soybean)	4,193
Corn Ethanol	6,578
CNG (geologic)	8,767
Gasoline (E10)	10,785
Low-sulfur diesel	10,951
Electricity (U.S. avg)	16,604

Source: GREET model

RNG provides a significant reduction in CO2e emissions relative to the other listed fuels, including an 85 percent reduction relative to diesel fuel, which is most commonly displaced by the switch or conversion to NGV trucks and buses. RNG performs significantly better than geologic natural gas, because the GREET model assesses effects of geologic gas escaping to the atmosphere during extraction, transportation and distribution. Methane in the atmosphere has approximately 30 times the heat-trapping

[28] Argonne National Labs, GREET model, October 2018 release, using the WTW Calculator, available at https://greet.es.anl.gov/index.php

effect as CO2, so accounting for leaks of gas has a significant impact on the lifecycle emissions result.

The GREET model breaks out the WTW emissions effects into two components, “well to pump” (WTP) and “pump to wheel” (PTW). RNG from landfills has negative WTP emissions for GHG, reflecting the fact that if the biogas not been transformed into RNG for transportation use, the gas would otherwise have been released to the atmosphere, or flared, or burned for another purpose. RNG’s positive PTW emissions offset the negative WTP emissions, resulting in a small positive net WTW result.

The GREET model does not provide an option to assess RNG from sources other than landfills, but it is worth noting that California’s LCFS program has assessed RNG produced from two agricultural projects as having an overall negative carbon intensity – meaning that the projects do not simply result in a relative reduction of GHG emissions, but produce a net subtraction of GHG (on a CO2e basis) in the atmosphere. This reflects the fact that RNG from such projects reduce methane entering the atmosphere, which would have had a greater GHG effect than the CO2 that is eventually produced when the RNG is burned. As a result, RNG from such projects would appear in Table 8 with a negative lifecycle emission value.

Another notable result from the GREET model is that while electricity used as transportation energy has zero direct pollutant emissions, it generally scores poorly relative to other fuels on a lifecycle basis. This is because a significant portion of electricity generation in the U.S. continues to be from coal-fired power plants. The CO2e value for electricity in Table 8 reflects the overall energy mix in the U.S. in the 2018 time frame. Different generation mixes or sources produce different results. For example, it is likely that electric vehicles would achieve significantly better lifecycle emissions results in regions with substantial wind and solar generation. The GREET model analysis nonetheless highlights the importance of evaluating transportation energy sources on a lifecycle basis.

The overall GHG emission reduction effect of RNG is significant. According to the GREET model, RNG provides an 85 percent reduction of GHG relative to displaced diesel fuel on a lifecycle basis. Based on that estimate, the approximately 300 million

EGE of current annual RNG production reduces CO2 emissions by 1.04 million metric tonnes. A more detailed assessment might determine that the fuel displaced by RNG is not entirely diesel, which would reduce the estimated CO2 emissions reduction effect. At the same time, a full analysis would also need to extend the assessment of RNG beyond that from landfill sources. Such refinements would have offsetting effects on the emissions reduction estimate, with an uncertain net effect. The rough estimate nonetheless indicates the substantial GHG reduction from RNG use in transportation.

VII. Conclusion

Recent substantial growth of RNG production has been encouraged by policies supporting the use of renewable fuels for transportation uses, and specifically by qualification of RNG as a cellulosic biofuel under EPA's RFS program. Such support has enhanced the economic value of using natural gas as vehicle fuel, promoting the switch and/or conversion of trucking and municipal transit fleets to natural gas-fueled vehicles. The growth of the NGV market has been accompanied by substantial expansion of fueling infrastructure nationwide. The fact that RNG is completely interchangeable with conventional natural gas means that RNG producers can inject RNG into the existing natural gas pipeline and distribution system to reach end-users. The growing availability and accessibility of RNG enhances the economic value of expanding NGV fleets, further driving demand growth. These reinforcing effects provide assurance that the transportation market has the capacity to accommodate further growth in RNG volumes under RFS.

RNG production from 2015 through 2018 has more than doubled to an annual output above 300 million EGE, with an average annual growth rate of 30 percent. Substantial further production potential exists both from landfill sources, which represent the large majority of current output, as well as from agricultural waste and municipal wastewater sources. Assessments of feedstock availability indicate the technical potential to produce RNG on a scale of 5 billion EGE annually or greater. The continued development of industry expertise, process and technological advances, and expanded marketing channels are likely to expand the pool of economically viable projects going forward.

The RFS program has promoted both RNG production and expansion of end-use markets. Sustaining and growing these nascent markets for domestically-produced RNG will depend significantly on the assurance that producers, consumers, and marketers have in continued RFS support.