American Gas
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RENEWABLE SOURCES OF NATURAL GAS:

SUPPLY AND EMISSIONS REDUCTION ASSESSMENT

Executive Summary

An American Gas Foundation Study Prepared by:

ICF

Legal Notice

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Executive Summary

Renewable natural gas (RNG) is derived from biomass or other renewable resources, and is a pipeline-quality gas that is fully interchangeable with conventional natural gas. The American Gas Association (AGA) uses the following definition for RNG:

> Pipeline compatible gaseous fuel derived from biogenic or other renewable sources that has lower lifecycle carbon dioxide equivalent (CO2-eq) emissions than geological natural gas.

ICF conducted an assessment to outline the potential for RNG to contribute meaningfully and cost-effectively to greenhouse gas (GHG) emission reduction initiatives across the country. The report serves as an update and expansion to a 2011 report published by the American Gas Foundation (AGF) entitled *The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality*. Building upon the previous work, this report is focused on assessing a) the RNG production potential from various feedstocks, b) the corresponding GHG emission reduction potential, and c) the estimated costs of bringing RNG supply on to the system. ICF developed production potential estimates by incorporating a variety of constraints regarding accessibility to feedstocks, the time that it would take to deploy projects over the timeline of the study (out to 2040), the development of technology that would be required to achieve higher levels of RNG production, and consideration of likely project economics—with the assumption that the most economic projects will come online first.

ICF developed low and high resource potential scenarios by considering RNG production from nine (9) feedstocks and three production technologies. The feedstocks include landfill gas, animal manure, water resource recovery facilities (WRRFs), food waste, agricultural residues, forestry and forest product residues, energy crops, the use of renewable electricity, and the non-biogenic fraction of municipal solid waste (MSW).[1] These feedstocks were assumed to be processed using one of three technologies to produce RNG, including anaerobic digesters, thermal gasification systems, and power-to-gas (P2G) in combination with a methanation system. It is important to note that ICF's analysis is not meant to be prescriptive, rather illustrative in terms of how the market for RNG production potential might evolve given our understanding of the feedstocks that can be used and the current state of technology development. Consider for instance that many anaerobic digester projects use a combination of animal manure and agricultural residues as feedstocks—the analysis presented here only considers the anaerobic digestion of animal manure and the thermal gasification of agricultural residues. ICF recognizes that these type of multi-feedstock considerations will continue to exist in the market; however, we needed to make simplifying distinctions for the purposes of the resource assessment.

ICF estimated low and high resource potential scenarios by considering constraints unique to each potential RNG feedstock—these constraints were based on factors such as feedstock accessibility and the economics of RNG production using the feedstock. These constraints were then used to develop low and high utilization assumptions regarding each feedstock. The resource potential reported is also a function of the conversion efficiency of the production technology to which each feedstock is paired. ICF also presents a technical resource potential, which does not consider

[1] ICF notes that the non-biogenic fraction of MSW does not satisfy AGA's definition of RNG; however, this feedstock was included in the analysis. The results associated with RNG potential from this non-biogenic fraction of MSW are called out separately throughout the report for the sake of transparency.

accessibility or economic constraints. The resource assessment was conducted using a combination of national-, state-, and regional-level information regarding the availability of different feedstocks; and the information is presented using the nine (9) U.S. Census Regions.

In the **low resource potential scenario**, ICF estimates that about 1,660 trillion Btu (tBtu) of RNG can be produced annually for pipeline injection by 2040 (see Figure 1 below). That estimate increases to 1,910 tBtu per year when including the potential for the non-biogenic fraction of MSW. In the **high resource potential scenario**, ICF estimates that about 3,780 tBtu of RNG can be produced annually for pipeline injection by 2040 (see Figure 2 below). That estimate increases to 4,510 tBtu per year when including the potential for the non-biogenic fraction of MSW. For the sake of comparison, ICF notes that the 10-year average (2009 to 2018) for residential natural gas consumption nationwide is 4,846 tBtu; this is shown as the black-dotted line in Figure 1 and Figure 2 below. Ultimately, market conditions, technology development, and policy structures will determine the extent to which each of the feedstocks considered can be utilized. For the sake of reference, ICF also reports a technical resource potential scenario of nearly 13,960 tBtu—a production potential intended to reflect the RNG production potential without any technical or economic constraints.

The reported RNG resource potential estimates reported here are 90% and 180% increases from the comparable resource potential scenarios from 2011 AGF Study. These changes are largely attributable to improved access to data regarding potential feedstocks for RNG production and are generally not attributable to more aggressive assumptions regarding feedstock utilization or conversion efficiencies. Furthermore, the analysis presented here includes estimates for RNG production from P2G systems using dedicated renewable electricity. While there are multiple studies regarding P2G technology and its uses, we believe this is the first study to quantify RNG production potential nationwide from P2G.

A diverse array of resources can contribute to RNG production—there is a portfolio of potential feedstocks and technologies that are or will be commercialized in the near-term future that will help realize the potential of the RNG market. Figure 1 and Figure 2 below demonstrate the diversity of RNG resource potential as a GHG emission reduction strategy. On the technology side, most RNG continues to be produced using anaerobic digestion paired with conditioning and upgrading systems. The post-2025 outlook for RNG will increasingly rely on thermal gasification of sustainably harvested biomass, including agricultural residues, forestry and forest product residues, and energy crops. The long-term outlook for RNG growth will depend to some extent on technological advancements in power-to-gas systems.[2]

[2] The RNG potential for P2G/methanation is shown as a pattern fill in Figure 1 and Figure 2 because of the way ICF estimates likely project economics for P2G. In reality, however, the low and high resource potential for P2G using dedicated renewable electricity will be constrained by more factors that could be considered in this report; and it is conceivable that the RNG resource potential from P2G is considerably higher than considered here.

Figure 1. Estimated Annual RNG Production, Low Resource Potential Scenario, tBtu/y

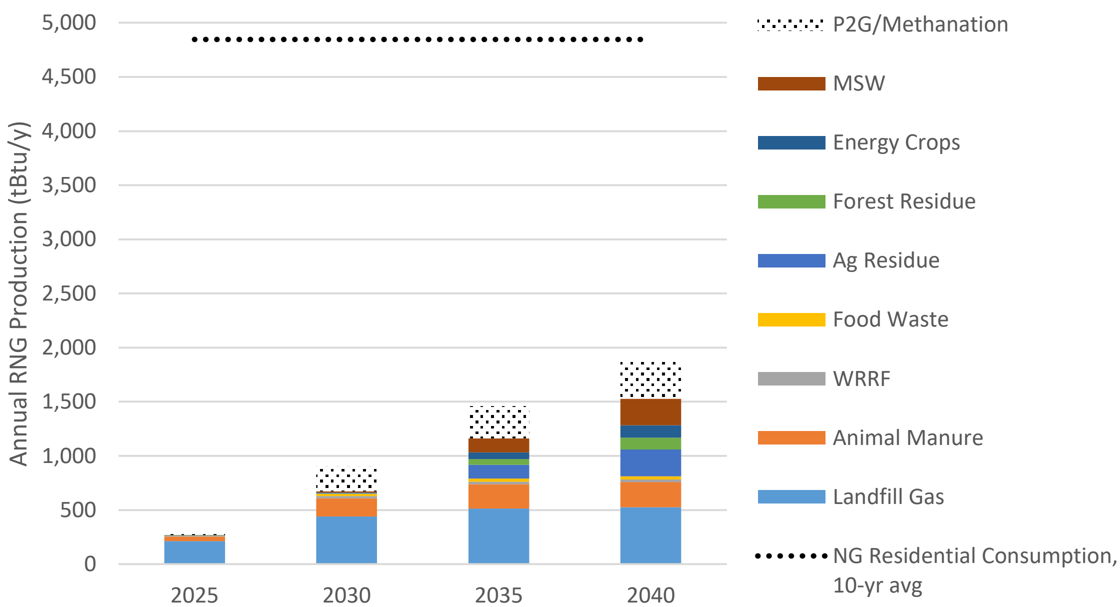
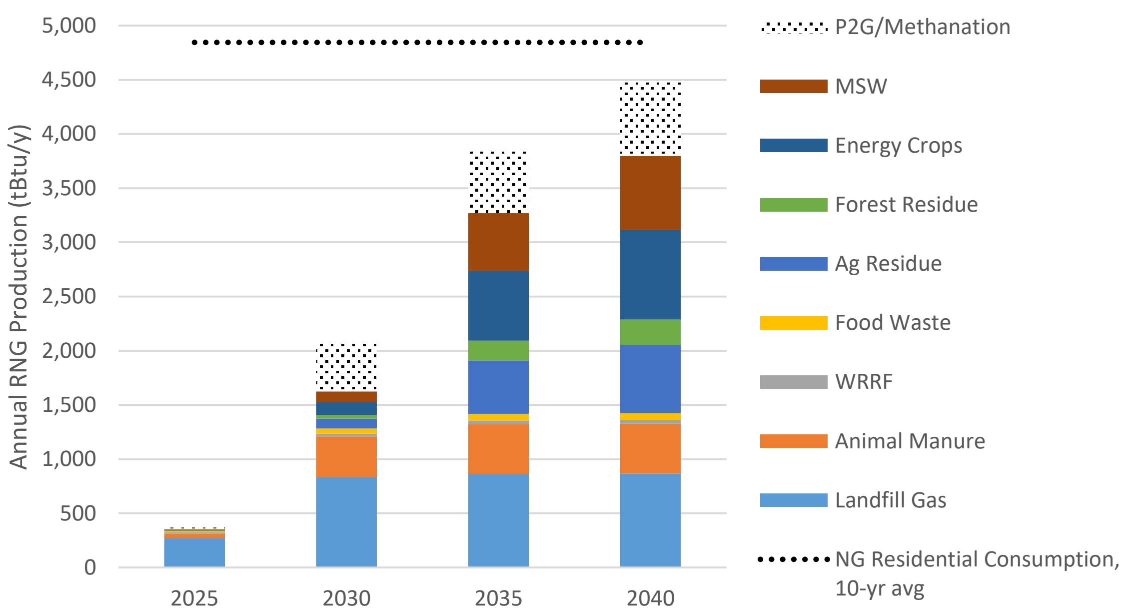


Figure 2. Estimated Annual RNG Production, High Resource Potential Scenario, tBtu/y



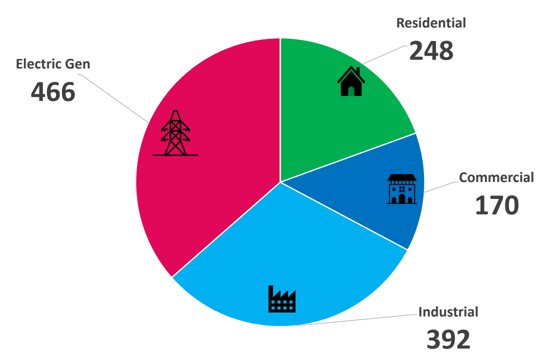
The potential for power-to-gas systems as a contributor to RNG production could be significant. Power-to-gas (P2G) is a form of energy technology that converts electricity to a gaseous fuel. Electricity is used to split water into hydrogen and oxygen, and the hydrogen can be further processed to produce methane when combined with a source of carbon dioxide. If the electricity is sourced from renewable resources, such as wind and solar, then the resulting fuels are carbon neutral. In this study, ICF made the simplifying assumption that all hydrogen produced via P2G would be methanated for pipeline injection. This assumption should not be viewed as a determination of the best use of hydrogen as an energy carrier in the future; rather, it was a simplifying assumption to compare more easily P2G to other potential RNG resources evaluated in this study.

ICF generally finds that the potential for RNG deployment could exceed the estimated high resource potential scenario because we opted to employ moderately conservative assumptions regarding the expected utilization of various feedstocks. These assumptions manifest themselves as constraints on the availability of supply for each feedstock, recognizing there will likely be competition for each feedstock. It is important to note that ICF did not make any assumptions regarding a specific policy or incentive framework that would favor RNG production over some other energy source (e.g., liquid biofuels).

Excluding cost considerations, the deployment of P2G systems for RNG production requires assumptions across a variety of factors, including but not limited to access to renewable electricity, the corresponding capacity factor of the system given the intermittency of renewable electricity generation from some sources (e.g., solar and wind), co-location with (presumably affordable) access to carbon dioxide for methanation, and reasonable proximity to a natural gas pipeline for injection. ICF's analysis did not seek to address all of these project development considerations; rather, we sought to understand the potential for P2G systems assuming access to dedicated renewable electricity production, meaning that these are purpose-built renewable electricity generation systems that are meant to provide dedicated power to P2G systems. ICF did not explicitly consider renewable electricity that could be curtailed from over-supply of renewable electricity as a result of compliance with Renewable Portfolio Standards (RPS). Ultimately, the issue of curtailment is a complicated one, and exploring it in detail was beyond the scope of this analysis. However, ICF's initial assessment indicates that P2G systems running on curtailed renewable electricity will play an important transitional role in helping to deploy the technology and achieve the long-term price reductions that are required to improve the viability of P2G as a cost-effective pathway for RNG production. Despite the importance of curtailed renewable electricity as part of the transition towards more cost-effective P2G systems, ICF's analysis does focus more on the opportunity for, and associated costs of RNG production using P2G systems with dedicated renewable electricity generation. It is important that this assumption by ICF is recognized as a limitation of our analysis, rather than a commentary on how the market will ultimately develop for P2G systems.

ICF estimates that RNG deployment could achieve 101 to 235 million metric tons (MMT) of GHG emission reductions by 2040. The GHG emission reductions were calculated using IPCC guidelines stating that emissions from biogenic fuel sources should not be included when accounting for emissions in combustion. This accounting approach is employed to avoid any upstream "double counting" of emissions that occur in the agricultural or land-use sectors per IPCC guidance. Generally speaking, biogenic carbon in combustion is excluded from carbon accounting methodologies because it is assumed that the carbon sequestered by the biomass during its lifetime offsets emissions that occur during combustion. Figure 3 shows the 10-year average (2009-2018) of carbon dioxide (CO_2) emissions from natural gas consumption across multiple sectors; and most notably that the residential energy

Figure 3. Average Annual CO_2 Emissions (in MMT) from Natural Gas Consumption, 2009-2018



sector on average emitted about 248 MMT of CO_2 emissions nationwide over the 10-years considered.

GHG emission reductions attributable to RNG can be a complicated issue driven by different accounting systems. Although we focus on the GHG emission reductions potential using IPCC guidelines in this report, many stakeholders are likely familiar with the lifecycle accounting approach for GHG emissions that is used by California's Low Carbon Fuel Standard (LCFS) program. In that accounting system, the GHG emissions from production and processing to combustion are accounted for—and fuels like RNG sourced from animal manure generally have a negative emissions factor, which reflects the upstream "crediting" of capturing methane that would have otherwise been vented to the atmosphere. ICF addresses these various accounting systems, and reviews the GHG emission reductions under a lifecycle accounting framework in an appendix.

ICF estimates that the majority of the RNG produced in the high resource potential scenario is available in the range of $7-$20/MMBtu, which results in a cost of GHG emission reductions between $55/ton to $300/ton in 2040. ICF evaluated the potential costs associated with the deployment of each feedstock and technology pairing, and made assumptions about the sizing of systems that would need to be deployed to achieve the RNG production potential outlined in the low and high resource potential scenarios. ICF reports that RNG will be available from various feedstocks in the range of $7/MMBtu to $45/MMBtu. These costs are dependent on a variety of assumptions, including feedstock costs, the revenue that might be generated via byproducts or other avoided costs, and the expected rate of return on capital investments. ICF finds that there is potential for cost reductions as the RNG for pipeline injection market matures, production volumes increase, and the underlying structure of the market evolves.

As noted previously, the opportunity of RNG from P2G systems (and paired with methanation units) warrants further consideration; however, ICF's analysis demonstrates that the combination of production potential and potential cost reductions for P2G systems is promising. With respect to RNG from P2G, the three main drivers for the production costs include: a) the electrolyzer, b) the cost of renewable electricity, and c) the cost of methanation. ICF finds that there is significant cost reduction potential in the P2G market, as the installed capacity (measured in GW, for instance) for electrolyzers increases over the next 10-15 years. ICF assumed that dedicated renewable electricity systems, co-located with P2G systems, could provide electricity at a levelized cost in the range of $10 to $55 per MWh. Lastly, there is significant cost reduction potential for methanation paired with P2G systems.