Renewable Natural Gas Analysis

Final Report

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Executive Summary

Central Hudson Gas & Electric Corporation ("Central Hudson") is preparing to integrate renewable natural gas (RNG) or biomethane into its gas distribution system to support New York State's environmental and economic goals, as well as customer interest in RNG development using local feedstocks. Central Hudson engaged Guidehouse Inc. (Guidehouse) to assess RNG potential within the counties that overlap its territory from various feedstocks and estimate the greenhouse gas (GHG) emissions reduction potential from RNG development. This report serves as an update to an earlier analysis Guidehouse prepared for Central Hudson on RNG potential to include updated resource inputs, where available, and compares the findings to those from a 2022 report for the New York State Energy Research and Development Authority (NYSERDA).[1]

Guidehouse collected county-level data on feedstock availability supplemented by data provided by Central Hudson and estimated the biomethane energy potentials (dekatherms, DTh) using a series of conversion factors for RNG yield by feedstock. The analysis focuses on near-term resources within Central Hudson's gas service territory (Figure ES-1), including landfill gas, wastewater treatment (WWT), agricultural residues, animal wastes, and food wastes for anaerobic digestion (AD) facilities.

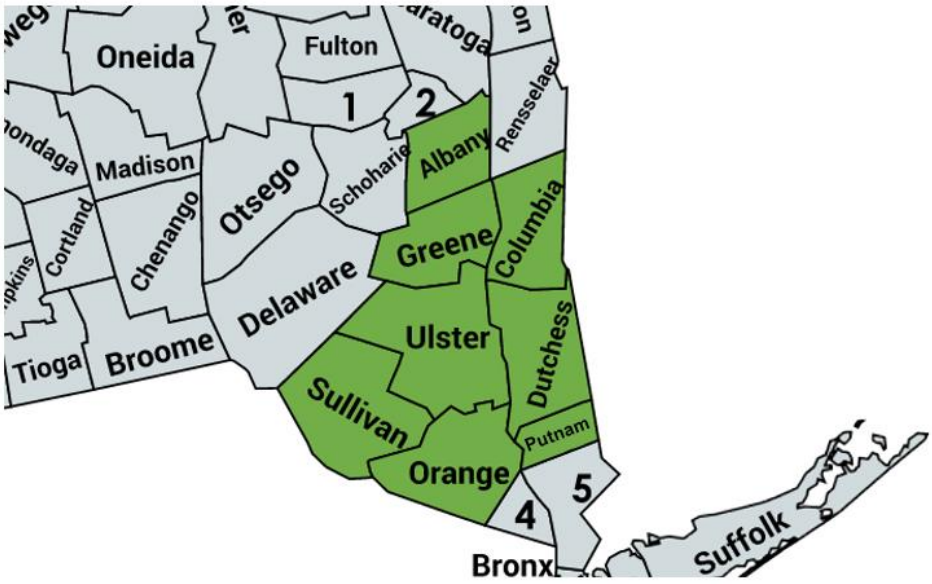

Figure ES-1 Geographic Regions Covered by Central Hudson RNG Analysis[2]

Table ES-1 summarizes the RNG production estimates for Central Hudson's gas service territory. The Maximum RNG Scenario estimates potentials without considering the technical and economic feasibility for specific projects. These estimates suggest RNG potential exists within Central Hudson's gas service territory (i.e., 3.3 million Dth per year, 8,926 Dth per day). The analysis found significant potential from agricultural residues (70%), animal wastes (10%),

[1] NYSERDA. "Potential of Renewable Natural Gas in New York State." April 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/files/EDPPP/Energy-Prices/Energy-Statistics/RNGPotentialStudyforCAC10421.pdf

[2] Underlying county map from Mapchart.net

and food wastes (13%) and limited potential from landfill and wastewater treatment facilities in the region.

Table ES-1 RNG Production Estimates for Central Hudson Gas Service Territory

Annual (MMDth)	Annual (Dth)	Daily (Dth)	Hourly (Dth)
3.3	3,258,160	8,926	372

RNG resources could support New York State (NYS) and customer GHG emissions reduction goals for use by building, transportation, industrial, or electric generation segments. Based on the RNG production potential identified in this study, Guidehouse estimated that RNG could offset 218,152 metric tons CO2e per year (100-year global warming potential [GWP])[3] if fully developed and directed towards Central Hudson customers, taking into consideration the emission from feedstock transportation. This estimate includes a weighted average of the carbon intensities (-16.3 kg CO2e / Dth) and expected emissions to transport the feedstocks to central RNG processing facilities located in Central Hudson service territory. Significant GHG emission reductions could be achieved because many of the available feedstocks are net carbon sinks (e.g., RNG produced from food and animal waste avoid methane emissions). Accurately estimating carbon intensities for prospective RNG supplies requires detailed analysis of each RNG production facility and its intended end-use.

In April 2022, ICF Resources, LLC prepared a report for NYSERDA titled "Potential of Renewable Natural Gas in New York State", which provided a statewide view of RNG potential from available feedstocks under different sets of assumptions. Although our report uses similar data inputs and overall methodology to the NYSERDA report, direct comparisons between the two reports are difficult given the differences in analysis scope and reporting granularity. Most notably, the NYSERDA report summarizes RNG potential in 2040 on a regional basis within NYS, rather than near-term potential at the county level as in this report.[4] While it is difficult to directly compare the results of the two analyses, the rough order of magnitude for the estimated RNG potential within and surrounding Central Hudson's service territory are similar for both studies. Guidehouse's estimate of 3.3 TBtu/yr (million DTh/yr) is in the same range as the NYSERDA estimates of 2.3 to 6.2 TBtu/yr under the Limited Adoption and Achievable Deployment scenarios for 2040 when assuming a similar set of feedstocks. The NYSERDA report also provides an Optimistic Growth scenario which shows 10.3 TBtu/yr. of regional RNG potential in 2040, when assuming greater utilization of lower density and/or higher cost feedstocks. Significant state and local policy support, market drivers, and technology development would likely be necessary to support cost-effective collection and processing for the higher RNG production scenarios.

[3] Guidehouse is not able to include the 20-year GWP emissions impacts as the necessary carbon intensity estimates for RNG feedstocks are generally not reported in industry literature on both a 100-year and 20-year GWP basis.

[4] Central Hudson's service territory covers only a share of two NYS regions reported in the NYSERDA report, with **BOLD** counties denoting those at least partially served by Central Hudson: Region 7 – Capital District: **Albany, Columbia**, **Greene,** Rensselaer, Saratoga, Schenectady, Warren, Washington; Region 8 – Hudson Valley: **Dutchess, Orange**, **Putnam**, Rockland, **Sullivan, Ulster,** Westchester

1. Approach to Scope of Work

1.1 Background

Central Hudson provides electricity and natural gas service in Albany, Columbia, Dutchess, Greene, Orange, Putnam, Sullivan, and Ulster Counties in New York State. Figure 1-1provides an overview of Central Hudson's service territory, including counties and towns that receive electricity and/or natural gas service.

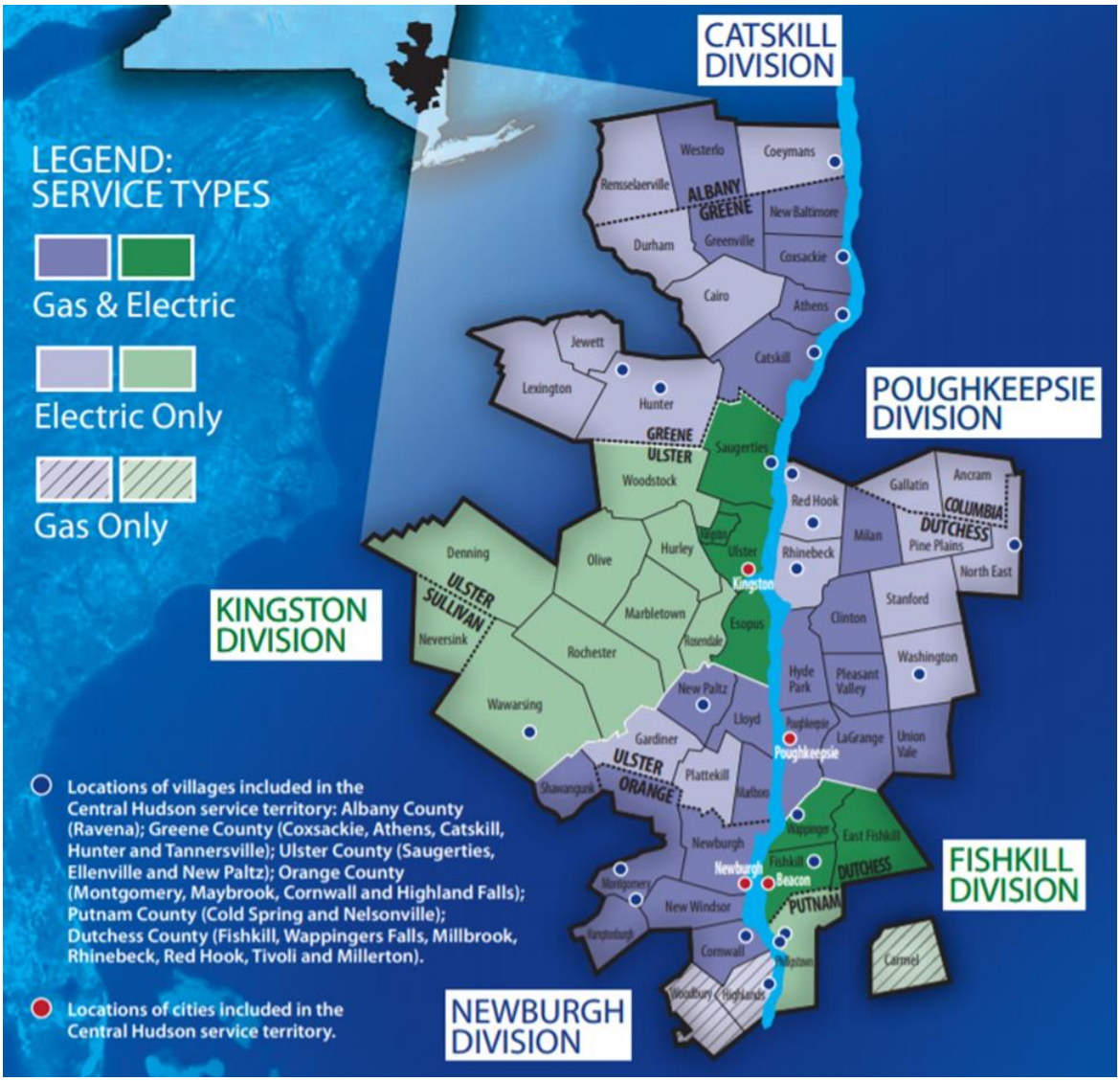

Figure 1-1 Central Hudson's Service Territory[5]

[5] Central Hudson, Service Territory map, Accessed December 2023. https://www.cenhud.com/about-us/our-service-territory/#:~:text=Central%20Hudson%20delivers%20natural%20gas,the%20Capital%20District%20at%20Albany.

Central Hudson is preparing to integrate RNG into its gas distribution system to support New York State's environmental goals to reduce greenhouse gas (GHG) emissions by 85% relative to 1990 levels by 2050. Central Hudson customers have also expressed interest in RNG development using local feedstocks. Currently, no RNG projects exist in Central Hudson's gas service territory that directly inject into Central Hudson's gas distribution system.

The RNG industry has grown significantly in recent years for landfill, agricultural, and other projects. Figure 1-2 shows that 34 new RNG facilities became operational throughout North America between 2022 and 2023. Historically, most RNG facilities were constructed at landfills. However, agricultural projects have made up a growing share of the total in recent years. The EPA estimates that agricultural projects made up nearly 60% of operational RNG projects in 2022, up from just 15% in 2012.[6]

Figure 1-2 also illustrates that more facilities are under development today, with over 400 facilities expected to be operating by the end of 2026, according to EPA data. The EPA data for future years only tracks landfill gas and agricultural projects currently under development for select years. EPA landfill gas data includes announced projects expected to begin operation through 2026, while agricultural project data only includes announced projects through 2023. New projects will likely be added to the database in future years.

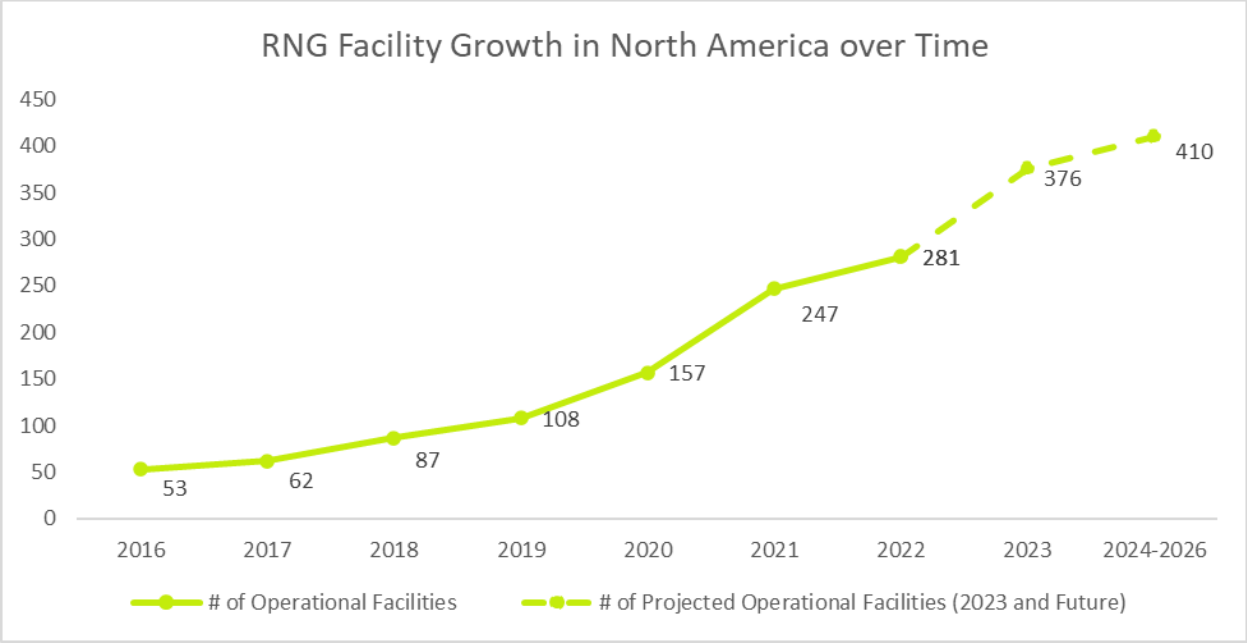

Figure 1-2 RNG Facility Growth in North America over Time[7] [8] [9]

[6] Environmental Protection Agency (EPA) Landfill Methane Outreach Program (LMOP). "Renewable Natural Gas." August 3, 2023. https://www.epa.gov/lmop/renewable-natural-gas

[7] RNG Coalition Infographic. "North American RNG Facility Growth." https://www.rngcoalition.com/infographic

[8] Environmental Protection Agency (EPA) Landfill Methane Outreach Program (LMOP). "Landfill Gas Energy Project Data." July 2023. https://www.epa.gov/lmop/landfill-gas-energy-project-data

[9] Environmental Protection Agency (EPA) AgSTAR. "Livestock Anaerobic Digester Database." January 2023. https://www.epa.gov/agstar/livestock-anaerobic-digester-database

Figure 1-3, produced by the RNG Coalition, shows that there are over 800 RNG facilities that are either operational, under construction, or planned in the U.S. and Canada. The quantity indicated by this figure is greater than that in Figure 1-2 because this figure has a broader scope than the previous one. Notably, New York has among the most projects of any state or province pictured, at 45 operational or planned projects.

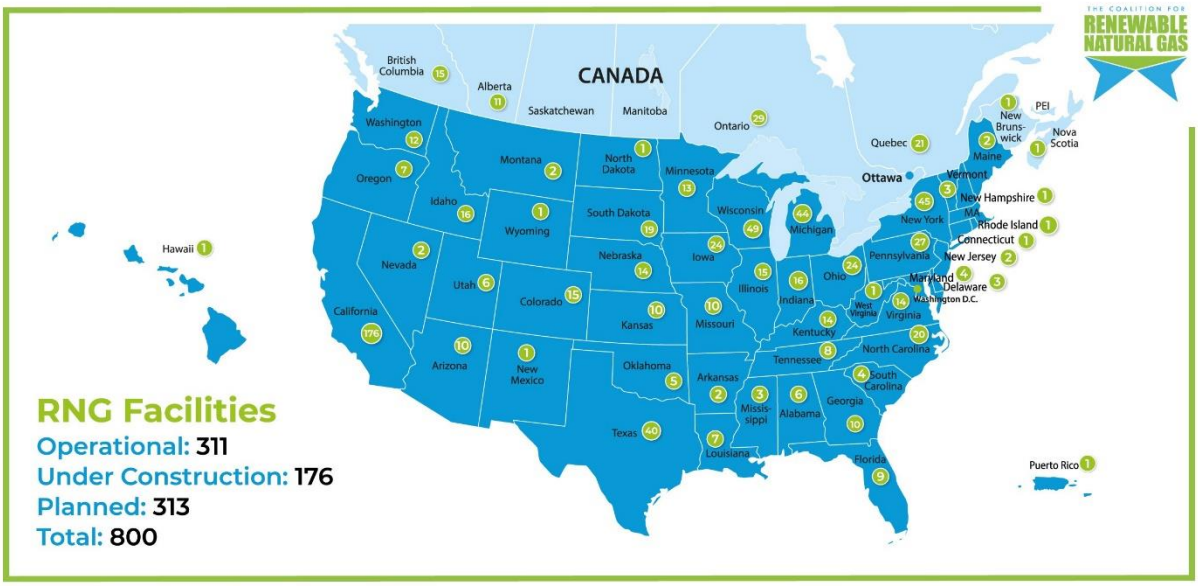

Figure 1-3 Operational, Under Construction, and Planned RNG Facilities in the U.S. and Canada[10]

The list below highlights recent RNG projects and initiatives by gas utilities, industrial facilities, and other RNG developers:

- **Beam Suntory (KY)**, maker of liquor brands such as Jim Beam and Maker's Mark, in 2022 announced their plan to build a $400 million anaerobic digester facility across the street from their Boston, KY distillery. The facility will convert the distillery's spent stillage to renewable natural gas for use on-site and is projected to reduce the distillery's emissions by 50%.[11]
- **PG&E (CA)** recently connected a large RNG facility to its gas pipeline network. The project will capture more than 1.6 million MMBtu of dairy methane per year that would otherwise be emitted into the atmosphere.[12] [13]

[10] RNG Coalition Infographic. "RNG Facilities in Canada and the U.S. as of November 14, 2023." https://www.rngcoalition.com/infographic

[11] Beam Suntory, "Beam Suntory Unveils Renewable Energy-Powered Jim Beam Expansion." September 14, 2022. https://www.beamsuntory.com/en/news/Renewable-Energy-Powered-Jim-Beam-Expansion

[12] PG&E Corporation. "PG&E Joins with Aemetis, Inc. to Officially Open New Renewable Natural Gas Interconnection." June 10th, 2022. https://investor.pgecorp.com/news-events/press-releases/press-release-details/2022/PGE-Joins-with-Aemetis-Inc.-to-Officially-Open-New-Renewable-Natural-Gas-Interconnection/default.aspx

[13] Aemetis. "Aemetis and PG&E Hold Ribbon Cutting Event for Centralized Biogas Cleanup and Renewable Natural Gas Interconnection with PG&E Pipeline." June 10th, 2022. https://www.aemetis.com/aemetis-and-pge-hold-ribbon-cutting-event-for-centralized-biogas-cleanup-and-renewable-natural-gas-interconnection-with-pge-pipeline/

- **Green Impact Partners (Can.)** was approved to build a $1.2 billion RNG facility outside of Calgary, Canada. The facility, called Future Energy Park, is projected to produce over 3.5 million MMBtu of RNG annually. RNG produced by the facility will be injected directly into the local natural gas distribution network.[14]
- **U.S. Energy (WI)** has partnered with Dallman East River Dairy to generate RNG from dairy cow waste. The onsite RNG production was previously used to generate electricity, but the project connected to the regional natural gas pipeline network in 2019.[15]
- **SoCalGas (CA)** announced in 2022 a target to deliver 20% RNG by 2030.[16]
- **Dominion (VA)** is undergoing a joint venture with Smithfield Foods called Align RNG to develop RNG resources at hog farms in VA, NC, and UT.[17] The first project was completed in June 2020 and produces about 236,000 Dth of RNG annually from 26 hog farms in UT.
- **NW Natural (OR)** developed a wastewater treatment plant (WWTP) to provide RNG to compressed natural gas (CNG) vehicles in Portland.[18] NW Natural also connected a Shell biogas facility with their gas network in 2021. In 2019, Oregon passed legislation that established state RNG procurement goals of 15% by 2030, 20% by 2035, and 30% by 2050.[19]

The U.S. RNG market will continue to evolve based upon federal, state, and local policy support, market drivers such as corporate and utility decarbonization goals, and further technology development for collection, production, and processing systems. Levelized RNG production costs ($/DTh) may decrease over time as technology advancements in RNG production equipment and plant designs could lead to lower cost and more efficient processes. Economies of scale could also be realized as the industry implements larger projects and develops mature local networks to collect and transport feedstocks. Nevertheless, RNG facility costs ($) and production costs ($/DTh) can vary significantly based on facility size, location, ease of interconnection, and the quality, concentration, and cost of feedstocks. The economic attractiveness and feasibility of any RNG project will need to be considered on a case-by-case basis. Generally, RNG projects with the lowest facility and feedstock costs (e.g., landfills) or those that have attractive emissions reduction potential under current policies (e.g., animal and food wastes) will be implemented first in a region since they will have the most attractive economics for producers.

1.2 Project Objectives

Gas utilities across New York State (NYS) are pursuing RNG developments to reduce carbon intensity of their fuel supplies, decrease fugitive GHG emissions from landfills and other sites in

[14] Green Impact Partners. “Green Impact Partners Achieves Major Milestone: Future Energy Park Receives Final Regulatory Approval to Construct and Operate the Facility.” December 11, 2023. https://www.greenipi.com/newsroom/green-impact-partners-achieves-major-milestone-future-energy-park-receives-final-regulatory-approval-to-construct-and-operate-the-facility/

[15] Markham, Lynn; Blaha, Karen; Michalesko, Ryan (2022). “Wisconsin Anaerobic Digester Operations: Agricultural Industry Case Studies.” November 2022. https://www3.uwsp.edu/cnr-ap/clue/Documents/Energy/WI%20Biogas%20Case%20Studies%20Report%2011-11-2022_WebR.pdf

[16] SoCalGas. Aspire 2045: Sustainability Strategy. June 2022. https://www.socalgas.com/sustainability/aspire2045

[17] Align Renewable Natural Gas. https://www.alignrng.com/?carousel=0

[18] NW Natural. “Renewable Natural Gas.” Accessed December 2023. https://www.nwnatural.com/about-us/environment/renewable-natural-gas#tab-2-focus

[19] NW Natural. “Renewable Natural Gas Bill Signed by Governor Kate Brown.” July 31, 2019. https://www.globenewswire.com/news-release/2019/07/31/1895023/0/en/Renewable-Natural-Gas-Bill-Signed-by-Governor-Kate-Brown.html

their service territories, and provide local supply resources to offset peak-day capacity concerns. In 2021, Central Hudson engaged Guidehouse Inc. (Guidehouse) to assess regional RNG potential from available feedstocks and estimate the GHG emissions reduction potential from RNG development. This report serves as an update to that report to include more recent resource data where available and compares the findings to those from a 2022 report for the New York State Energy Research and Development Authority (NYSERDA).[20] The analysis focuses on near-term resources within the Central Hudson gas service territory, including landfill gas, WWTP, agricultural residues, animal wastes, and food wastes for anaerobic digestion.

1.3 Approach

The following list summarizes our analysis approach in this project:

- Collected county-level data on feedstock availability for agricultural products, animal wastes, food wastes, landfills, and wastewater treatment plants from studies conducted at the national and state levels.
- Estimated the biomethane volume production potential using a series of conversion factors developed for AD facilities in Europe.
- Summarized the biomethane energy potentials (in dekatherms) by feedstock, county, and region.
- Evaluated potential GHG emissions impacts under different carbon intensity assumptions.

[20] NYSERDA. "Potential of Renewable Natural Gas in New York State." April 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/files/EDPPP/Energy-Prices/Energy-Statistics/RNGPotentialStudyforCAC10421.pdf

2. RNG Feedstock & Production Potential

This section provides an overview of available RNG feedstocks in Central Hudson's gas service territory and estimates RNG production potential by feedstock and county.[21]

2.1 Feedstock Availability in Central Hudson's Gas Service Territory

2.1.1 Focused Counties in Central Hudson's Gas Service Territory

This analysis considers RNG feedstocks that are available within Central Hudson's gas service territory. Agricultural residues, food wastes, and other resources are commonly transported to buyers, composters, landfills, and other destinations. These feedstocks could similarly be transported to an RNG production facility within Central Hudson's gas service territory that could connect with Central Hudson's gas pipeline network. As shown in Figure 2-1, Guidehouse covers the counties that overlap with the service territory in this study: Albany, Columbia, Dutchess, Greene, Orange, Putnam, Sullivan and Ulster.

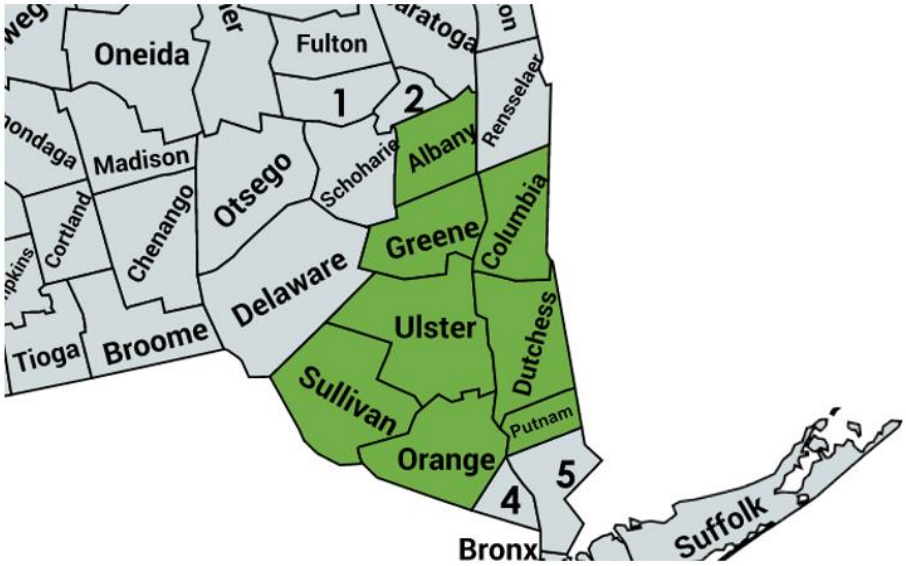

Figure 2-1 Geographic Regions Covered by Central Hudson RNG Analysis[22]

2.1.2 RNG Production Technologies

RNG can be supplied from a variety of feedstocks and production technologies, as shown in Figure 2-2. Historically, landfill projects used captured landfill gas to generate electricity for sale to local utilities, but a number of landfills are now producing renewable compressed natural gas (CNG) for on-site and off-site vehicle use. AD systems transform food, agricultural, and other

[21] Our estimation does not consider the Taylor Biomass facility in Orange County
[22] Underlying county map from Mapchart.net

waste streams into biogas, which can be cleaned and upgraded to pipeline quality biomethane. Besides landfill gas, virtually all RNG projects in North America use AD systems.

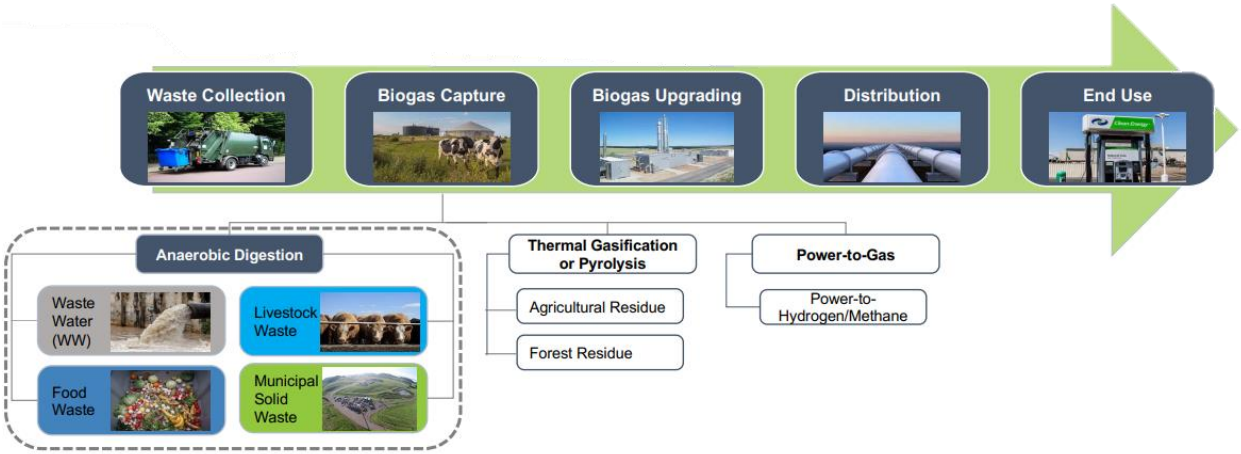

Figure 2-2 RNG Feedstocks and Production Technologies[23]

The analysis focuses on near-term resources (5-10 year time horizon) within counties that include Central Hudson gas franchises, including landfill gas, wastewater treatment, agricultural residues, animal wastes, and food wastes for anaerobic digestion.[24] Technologies such as thermal gasification and power-to-gas could provide additional RNG potential but will likely not have wide availability in the U.S. over the near-term timeframe of this analysis.

- **Thermal Gasification** systems transform woody biomass and wastes into clean, high quality biomethane, and are beginning commercialization in Europe. Additional opportunities exist to convert biogas into bio-LNG that can be injected into the nearest gas pipeline or used in a nearby vehicle fueling station.
- **Power-to-Gas** systems using excess or dedicated renewable electricity would offer another potential low carbon gas resource. Various organizations in the U.S., Europe, and other markets are conducting research today to explore the possibility of these technologies for future gas network decarbonization.

2.1.3 Available RNG Feedstocks and Key Assumptions

Table 2-1 outlines key RNG feedstock categories and data resources. Guidehouse collected county-level estimates for all AD feedstocks with near-term potential within the Central Hudson gas service territory. Multiple renewable feedstocks in Central Hudson's gas service territory have at least some availability with the exception of landfill gas projects. EPA's Landfill Methane Outreach Program (LMOP) database indicates there are no candidates for landfill gas

[23] RNG Coalition. "Economic Analysis of the US Renewable Natural Gas Industry." December 2021. https://static1.squarespace.com/static/53a09c47e4b050b5ad5bf4f5/t/61ba25c889b4fb7566404e6c/1639589328432/RNG+Jobs+Study.pdf

[24] Many agricultural residues resources can be used for either thermal gasification or anaerobic digestion facilities. For anaerobic digestion facilities, agricultural residues will generally be blended with animal, food, and other waste streams rather than as a single feedstock for the RNG facility. Given the near-term outlook for this analysis, we assume that agricultural residues would be blended for anaerobic digestion facilities rather than use in thermal gasification facilities.

development in the region.[25] Nearby landfill facilities are either closed, too old to be developed, or currently producing RNG for on-site electric generation. For example, the municipal landfills in Albany and Colonie capture RNG today to generate electricity on-site using reciprocating engines and have experienced several upgrades since the initial RNG projects over the last 25 years.

Table 2-1 Key RNG Feedstocks and Data Sources

Feedstock Type	Brief Description	Sources for Feedstock Data for 2021 Report	Updates Available in 2023
Agricultural Residues			
Corn stover	Leaves, stalks, and cobs of corn plants left in a field after harvest	2016 DOE Billion Ton Report	No, 2016 is the latest update
Soybeans straw and pods	Straw and casings remaining after soybeans are harvested		
Winter and spring wheat	Byproducts remaining after harvest		
Biodegradable Waste			
Animal waste	Manure from cattle, sheep, and hogs[26]	2017 USDA Annual Reports[27]	No, this is the latest report. The 2022 Census of Agriculture will be released in early 2024.
Food waste	Leftover food from larger commercial food generators (no feasible residential sources found in area studied)	2017 NYSERDA Food Waste Report[28]	No, 2017 is the latest report
WWTP sludge	A byproduct during sewage treatment of industrial or municipal wastewater[29]	2019 NYS Dept. of Energy Conservation[30]	Yes, updated dataset from February 2023

[25] U.S. Environmental Protection Agency. Landfill Methane Outreach Program (LMOP), Updated July 2023. https://www.epa.gov/lmop

[26] Cattle, sheep, and hogs are the most prevalent types of animals in the area

[27] U.S. Department of Agriculture. National Agricultural Statistics Service. 2017 Census of Agriculture. https://www.nass.usda.gov/Quick_Stats/CDQT/chapter/2/table/11/state/NY/county/087

[28] Industrial Economics. "Benefit-Cost Analysis of Potential Food Waste Diversion Legislation." Prepared for NYSERDA. March 2017. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Research/Environmental/Benefit-Cost-Analysis-of-Potential-Food-Waste-Diversion-Legislation.pdf

[29] Stehouwer, Richard. "What is sewage sludge and what can be done with it?". September 15, 2010 https://extension.psu.edu/what-is-sewage-sludge-and-what-can-be-done-with-it

[30] New York State Department of Environmental Conservation. Wastewater Treatment Plants database. February 15, 2023. https://data.ny.gov/Energy-Environment/Wastewater-Treatment-Plants/2v6p-juki/about_data

Table 2-2 summarizes biomethane potential estimates and expected biogas yields for key RNG feedstocks. Guidehouse applied the following assumptions for resource potential during this analysis to provide a realistic estimate for RNG potential in the region. Even if resources are available, technical, economic, and other challenges may prevent the development of RNG resources and facilities. As discussed later in this report, there are also several market and policy trends that may reduce feedstock availability for RNG production, or direct RNG resources to specific end-uses.

- Biogas yield estimates are based on Guidehouse estimates developed in Europe for the European Biogas Association[31] and EU ARGO Biogas online feedstock Atlas[32]. Guidehouse assumed biomethane is 60% of biogas volume with 1,036 Btu/CF. Actual values will vary by facility design and feedstock mix.
- For agricultural residues, this report used data from the U.S. Department of Energy's 2016 Billion Ton Report. This report and online database provide estimates of biomass supply down to the county level. Guidehouse used the "base case scenario" and a conservative price / production forecast for each feedstock to avoid double counting of available acreage and showing unlikely RNG potential.[33]
- For animal wastes, this report used data from the U.S. Department of Agriculture's 2017 Census of Agriculture. This online database provides estimates on livestock inventory down to the county level. Guidehouse used data for cattle, sheep, and hogs because they comprised the majority of regional livestock population. Guidehouse assumed there was no minimum threshold of number of animals per farm to be included in our analysis. The 2022 Census of Agriculture is expected for release in early 2024.
- For food waste, this report used data from the 2017 NYSERDA Food Waste Report which estimates weekly food waste produced by institutional, retail, service, and hospitality facilities in each county.[34]
- For wastewater treatment plant resources, this report used data from the 2023 New York State Department of Environmental Conservation database which characterizes the daily effluent for each facility in the state by county. Only wastewater treatment plants with a minimum threshold of 17 million gallons per day (MGD) were included.[35]

[31] Terlouw et al. 2019. "Gas for Climate. The Optimal Role for Gas in a Net-Zero Emissions Energy System." Guidehouse Netherlands B.V. March 2019. Available at: https://www.europeanbiogas.eu/wp-content/uploads/2019/11/GfC-study-The-optimal-role-for-gas-in-a-net-zero-emissions-energy-system.pdf

[32] EU ARGO Biogas online feedstock Atlas. https://daten.ktbl.de/euagrobiogasbasis/startSeite.do. Description of the database is found here: https://ieo.pl/dokumenty/projekty/agrobiogaz/project_results.pdf

[34] In addition, the New York State Pollution Prevention Institute maintains a mapping tool for large food waste generators in the state. https://www.rit.edu/affiliate/nysp2i/organic-resource-locator

[35] New York State Department of Environmental Conservation. Wastewater Treatment Plants database. February 15, 2023. https://data.ny.gov/Energy-Environment/Wastewater-Treatment-Plants/2v6p-juki/about_data

Table 2-2 RNG Feedstock Characteristics

Feedstock Type	Share of Resource Potential for Biomethane Production	Biogas Yield (ft^3/kg dry matter)
Agricultural Residues		
Corn stover **Soybeans straw and pods** **Winter and spring wheat**	10 to 100%, varies by feedstock	10.6 to 31.1, varies by feedstock
Biodegradable Waste		
Animal waste	100%	12.9
Food waste	100%	28.6
WWTP sludge	100%	n/a, 7.9 Dth per million gallons treated

For the estimate, Guidehouse assumed biomethane is 60% of biogas volume with 1036 Btu/CF. Actual values will vary by facility design and feedstock mix.

2.2 RNG Resource Potential in Central Hudson's Gas Service Territory

Guidehouse calculated the RNG resource potential for each county and feedstock using the collected feedstock data and methodology described above. Table 2-3 summarizes the RNG production estimates for Central Hudson's gas service territory. Based on this analysis, Guidehouse estimated that 3.3 million Dth per yr (8,926 Dth per day) of RNG potential exists within Central Hudson's gas service territory. However, this estimate does not consider technical or economic feasibility. Section 4 compares these estimates to 2040 RNG resource potentials developed in a 2022 NYSERDA report[36].

Table 2-3 RNG Production Estimates for Central Hudson Gas Service Territory

Annual (MMDth)	Annual (Dth)	Daily (Dth)	Hourly (Dth)
3.3	3,258,160	8,926	372

Table 2-4 summarizes the estimated RNG production potential by feedstock. The largest RNG feedstocks across the region are corn stover (69%), food waste (13%), and animal waste (10%). Each of the major feedstocks has at least some resource potential in the area, with the largest resources from agricultural byproducts in Columbia County. Animal farms in the area assessed are relatively small compared to farms farther upstate or west in New York State. Food wastes and wastewater treatment feedstocks are also available and more concentrated in urban and suburban areas. Only two regional WWTPs located in Albany County (Albany County Water Purification District, North Plant and South Plant) have sufficient capacity for an on-site RNG project (combined 64 million gallon/day, 23,360 million gallon/year of wastewater sludge

[36] NYSERDA. "Potential of Renewable Natural Gas in New York State." April 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/files/EDPPP/Energy-Prices/Energy-Statistics/RNGPotentialStudyforCAC10421.pdf

production).[37] The food waste RNG potential includes organic wastes collected from retail, service, hospitality, and institutional sectors. Guidehouse did not identify local requirements in the analysis region requiring separate collection of residential organic wastes, which could present another feedstock to increase local RNG production potential.[38]

Table 2-4 RNG Production Estimates by Feedstock

Feedstock category	Agricultural residues					Biodegradable wet waste		
Feedstock type	Corn stover	Soybeans straw	Soybeans pods	Winter wheat	Spring wheat	Animal waste	Food waste	WWTP sludge
Dth/yr.	2,239,990	95,574	170	19,033	14,545	341,254	436,868	110,726
Percentage	69%	3%	0%	1%	0%	10%	13%	3%

[37] Several other WWTPs located within the analysis region (e.g., Poughkeepsie, Newburgh, Kingston, Beacon) had daily effluent between 5-10 MGD, which is below the 17 MGD threshold for on-site AD facilities.

[38] County-level estimates for residential food waste were not identified for the analysis region. Nevertheless, previous analysis by Natural Resources Defense Council for food waste sources in 3 cities found residential food wastes account for 33-54% of all food wastes, with restaurant, retail, institutional, processing, and other commercial sites contributing to the remainder. This suggests that should communities in Central Hudson's service territory adopt residential food waste collection programs, the estimated RNG potential from food waste could increase considerably. This residential contribution would likely be on the order of 50-100% of the current potential calculated for commercial food wastes (i.e., an additional 200,000-400,000 Dth/yr). Hoover and Moreno. 2017. "Estimating Quantities and Types of Food Waste at the City Level"
https://www.nrdc.org/sites/default/files/food-waste-city-level-report.pdf

Table 2-5 summarizes the RNG production estimates by county. Our findings suggest that Central Hudson could consider biodegradable waste feedstocks as well as agricultural residues within its gas service territory. Central Hudson could work with developers to site one or more RNG facilities near the borders of Orange and Dutchess Counties that could connect with the wider Central Hudson gas network and minimize transportation costs and emissions.

Table 2-5 RNG Production Estimates by County as Share of Total Potential[39]

County	Dth/yr.	% of Total
Albany	505,349	16%
Columbia	1,019,763	31%
Dutchess	672,361	21%
Greene	103,190	3%
Orange	562,021	17%
Putnam	15,595	0%
Sullivan	126,684	4%
Ulster	253,198	8%
Total	**3,258,160**	**100%**

2.2.1 Feasibility Considerations for RNG Facilities and Feedstocks

The RNG production estimates detailed in this section represent a maximum potential for Central Hudson's gas service territory assuming a near-term time horizon and typical project feasibility constraints. Table **2-6** details several historical feasibility thresholds for major RNG feedstocks. While our analysis identified that resources exist regionally to develop RNG resources, site-specific technical, economic, and logistical considerations would reduce the feasibility of RNG development below these estimates. In actuality, the achievable potential would depend on a variety of factors including facility siting, local permitting, proximity to pipelines[40], access to feedstocks, and transportation feasibility. Beyond these factors, RNG development will also be impacted by competing uses for feedstocks (e.g., fertilizer, animal bedding, composting, solar PV facilities) and policy drivers for renewable fuels (e.g., RNG for emissions reduction in transportation vs. building sectors).

[39] Feedstock potential data is on a county level, not including the total number of sources for feedstock.
[40] The two sites selected are within 2000 feet to existing pipeline.

Table 2-6 Feasibility Thresholds for RNG Feedstocks

Feedstock type	RNG Threshold	Notes
Animal Wastes	• >500 cattle per farm for on-site AD facility • Lightly processed biogas could be piped to nearby central RNG facility (hub and spoke design) • Wastes could be transported off-site	2018 EPA AgSTAR report[41]
WWT Facilities	• 17 million gallons per day (MGD) for on-site AD facility • Sludge could be transported offsite	2011 AGF report[42] based on EPA and other resources
Landfill Gas	• > 1 million tons of waste in place, and either currently accepting waste or closed within last 5 years	EPA LMOP program[43]
Food Wastes	• < 25-50 miles from waste generation facility (institutional, retail, hospitality)	New York State law requires food waste recycling if within 25 miles of AD or compost facility[44]
Agricultural Residues	• < 25-50 miles from farm	Guidehouse estimate based on USDA biomass report[45] and New York State food waste laws

Figure 2-3 provides an overview of competing uses for RNG feedstocks and supplies, which may reduce the potential feedstock supply available for RNG production. RNG agricultural residues account for over 70% of Central Hudson's RNG potential and could decrease with solar PV farm conversions. New York State has an aggressive clean electricity target with 100% zero-carbon electricity by 2040. Substantial renewable electricity growth is needed to reach targets of 70% in 2030 and 100% in 2040.[46] As a result, there is a growing trend for NYS farmland to be converted to solar PV developments or real estate projects, which may decrease the resource potential for agricultural residues as an RNG feedstock.

[41] U.S. Environmental Protection Agency. Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities. June 2018. https://www.epa.gov/sites/production/files/2018-06/documents/epa430r18006agstarmarketreport2018.pdf

[42] Gas Technology Institute. The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality. Prepared for American Gas Foundation. 2011. https://www.eesi.org/files/agf-renewable-gas-assessment-report-110901.pdf

[43] U.S. Environmental Protection Agency. Landfill Methane Outreach Program (LMOP). Updated July 2023. https://www.epa.gov/lmop/landfill-technical-data

[44] Waste360. New York State Budget Includes Food Waste Mandate. April 5, 2019. https://www.waste360.com/food-waste/new-york-state-budget-includes-food-waste-mandate

[45] Gallagher, Paul. Biomass Supply from Corn Residues: Estimates and Critical Review of Procedures. Prepared for U.S. Department of Agriculture. November 2012. https://ageconsearch.umn.edu/record/308488/?ln=en

[46] New York State Governor Press Office. "Governor Cuomo Executes the Nation's Largest Offshore Wind Agreement and Signs Historic Climate Leadership and Community Protection Act." July 18, 2019. https://www.suny.edu/suny-news/press-releases/7-19/7-18-19-offshore-wind/governor-offshore-wind-agreement.html

There is also competition for food waste. New York State follows the EPA food hierarchy, which prioritizes feeding people and animals above industrial uses.[47] In addition, composting is a widely used process to convert food waste, yard waste, and wood waste to soil and mulch.

Lastly, as evidenced by the two local landfill projects, RNG produced from landfills has often been used for on-site electricity generation and combined heat and power (CHP) plants.

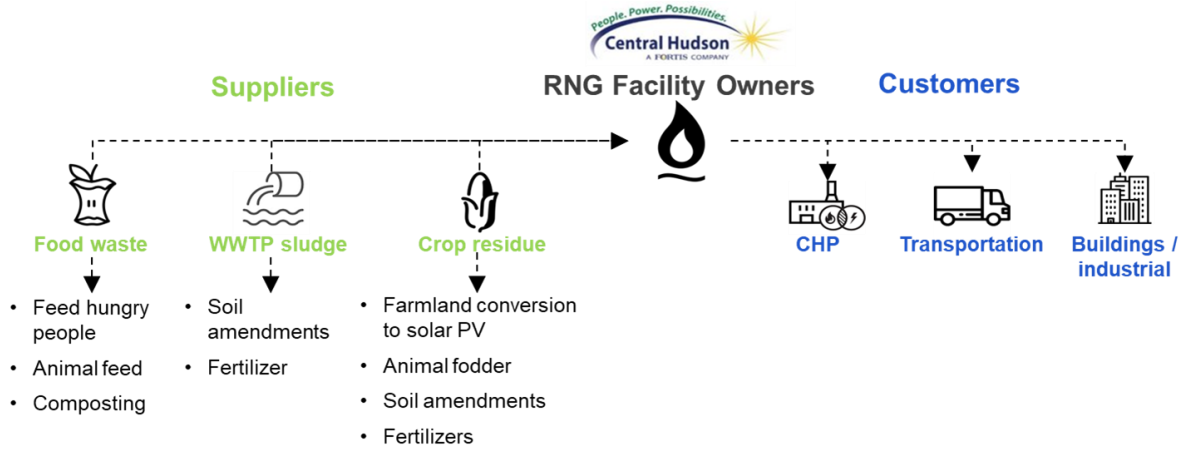

Figure 2-3 Competing Uses of RNG Feedstocks and Supplies

[47] U.S. Environmental Protection Agency. Food Recovery Hierarchy. Accessed December 2023. https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy

3. GHG Emissions Reductions from RNG Supplies

This section summarizes the GHG emissions reduction potential from available RNG supplies for Central Hudson's gas service territory.

Governments, utilities, fleet operators, and other stakeholders are pursuing RNG as a low carbon alternative to conventional fossil fuels. RNG produced from AD and biomethane capture reduce systemwide GHG emissions by avoiding the release of methane into the atmosphere. As shown in Figure 3-1, RNG can provide emissions reductions relative to baseline scenarios where the natural breakdown of organic materials would otherwise emit methane and carbon dioxide into the atmosphere. Methane combusts into water and carbon dioxide when it is burned as fuel. Carbon dioxide's global warming potential (GWP) is 1, while methane has a GWP of approximately 28 on a 100-year GWP basis and 81-83 on a 20-year GWP basis.[48] For RNG projects, eliminating methane emissions provides the majority of avoided GHG emissions. The specific carbon intensity of RNG is a complex calculation that depends on feedstock, production technology, location, and other factors. Key variables that affect the GHG reduction or avoidance potential of RNG include:

- Methane emissions potential of the feedstock (i.e., how methane would be produced if the feedstock was not used for RNG).
- Capture rate for methane emissions (i.e., how much of the methane emission rate is being avoided by the RNG production process).
- Collection and transportation emissions (i.e., fuel use by machinery and vehicles necessary to collect and transport the feedstocks to RNG production facilities).
- RNG processing inputs and efficiency (i.e., the energy consumption and fugitive emissions to transform feedstocks to RNG for on-site use or pipeline injection).

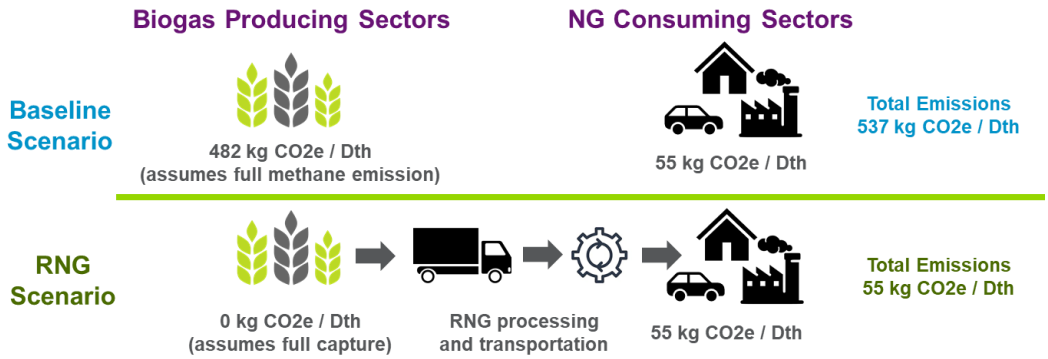

Figure 3-1 Schematic of RNG GHG Emissions Reductions

Upper limit example based on Figure 6-12 on 2019 EFI Report
"Optionality, Flexibility & Innovation: Pathways for Deep Decarbonization in California."[49]

[48] Environmental Protection Agency. "Understanding Global Warming Potentials." April 18, 2023. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[49] Energy Futures Initiative. Pathways for Deep Decarbonization in California. May 2019. https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5ced6fc515fcc0b190b60cd2/1559064542876/EFI_CA_Decarbonization_Full.pdf

Table 3-1 provides the estimated carbon intensities for RNG produced by various feedstocks analyzed in this report, before taking into consideration the emission from feedstock transportation. The carbon intensity of RNG feedstocks ranges from slightly below that of fossil natural gas (e.g., landfill gas that would normally be collected and flared) to significantly below zero (e.g., dairy waste from open ponds), indicating that the RNG feedstock diverts a high rate of upstream methane emissions. Estimating the exact carbon intensities for RNG feedstocks within a region is difficult without detailed analysis of each RNG production facility. Thus, Figure 3-2 provides more general ranges along with an estimated average for carbon intensity from each feedstock. These ranges are based on current pathways in the California Air Resources Board's (CARB) Low Carbon Fuels Standard (LCFS). The carbon intensities and emissions reduction estimates are based on industry lifecycle assessments for different RNG feedstocks using 100-year GWP values. GHG emissions reductions from RNG production would likely be larger if using 20-year GWP values in the calculation. Guidehouse is not able to include the 20-year GWP emissions impacts as the necessary carbon intensity estimates are generally not reported in industry literature on both a 100-year and 20-year GWP basis.

Table 3-1 Estimated Carbon Intensity and Emissions Reductions for RNG Feedstocks

Fuel	Carbon Intensity (kgCO2e/Dth)	Carbon Reduction (kgCO2e/Dth)	% of RNG Potential for CH	Emissions Reductions (metric ton CO2e)
Natural Gas	52.9	NA	NA	NA
Landfill RNG	36.8	16.1	0%	0
Corn Stover RNG	23.1	29.8	73%	70,570
WWT RNG	8.2	44.7	3%	4,949
Food Waste RNG	-24.2	77.1	13%	33,683
Animal Waste RNG	-288.2	341.1	10%	116,402
Weighted Average for Central Hudson Service Territory*	**-16.3**	**NA**	**100%**	**225,604**

* This table presents values before taking into consideration the emission from feedstock transportation, which are discussed later in this section. These values represent GHG emissions on a 100-year GWP basis.

Natural gas carbon intensity is based on end-use combustion.
Carbon intensity for RNG vehicle use based on CARB estimates in 2018 UC Riverside study,[50] except for corn stover which is based on 2012 ANL study,[51] Corn stover represents all agricultural residues.

Detailed RNG project analyses, such as those for state and federal renewable fuel programs, rely on Argonne National Laboratory's GREET Model[52] and estimates from the California Air

[50] Raju et al. Optimal Pathways to Achieve Climate Goals – Inclusion of a Renewable Gas Standard. University of California, Riverside. Center for Renewable Natural Gas. September 24, 2018. https://www.cert.ucr.edu/sites/g/files/rcwecm1251/files/2019-01/Optimal_Pathways_Report.pdf

[51] Wang et al. Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane, and cellulosic biomass for US use. Argonne National Laboratory. Environmental Research Letters. Volume 7. December 2012. https://iopscience.iop.org/article/10.1088/1748-9326/7/4/045905/pdf

[52] Argonne National Laboratory. GREET Model. https://greet.es.anl.gov/

Resources Board (CARB). These well-to-wheel estimates account for full lifecycle emissions for vehicle fuels based on a database of RNG production facilities, including lifecycle energy consumption and emissions associated with production, processing, compression, leakage, and end-use consumption. The estimates are a good indicator for specific feedstocks, but additional research is needed to determine appropriate factors for gas utility and other non-vehicle uses.

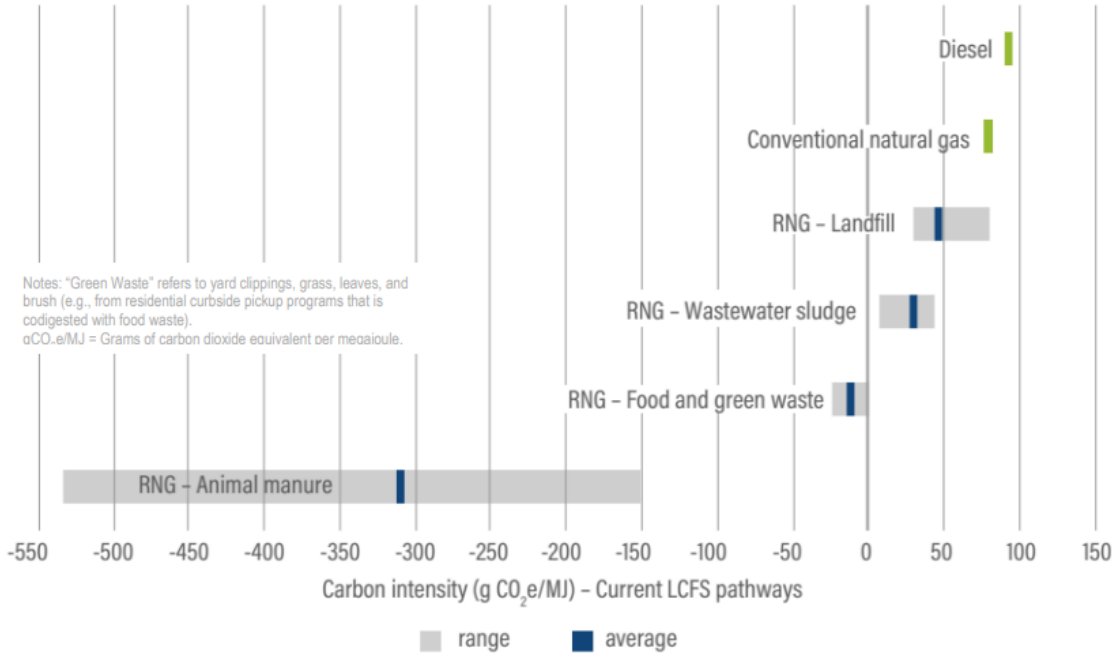

Figure 3-2 RNG Feedstock Carbon Intensity Ranges Based on Current Low Carbon Fuels Standards (LCFS) Pathways[53]

Based on the RNG production potential identified in this study, Guidehouse estimated that RNG could offset 218,152 metric tons CO2e per year if fully developed and directed towards Central Hudson customers, taking into consideration the emission from feedstock transportation. This estimate includes a weighted average of the carbon intensities in Table 3-1 (-16.3 kg CO2e / Dth) and expected emissions to transport the feedstocks to central RNG processing facilities located in Central Hudson service territory.

[53] RNG Coalition. "Using RNG To Meet Voluntary GHG Targets." May 2023. https://guidehouse.com/-/media/new-library/industries/esi/documents/2023/rng-coalition-draft-report_final_updated.ashx

Figure 3-3 provides potential GHG emissions reductions for Central Hudson by RNG feedstock. While agricultural residues account for the largest RNG resource, animal waste takes up the most significant portion of GHG emissions reductions. Food and animal wastes have significantly higher carbon reduction potential per Dth since these feedstocks would have higher methane emission rates if not collected for RNG development.

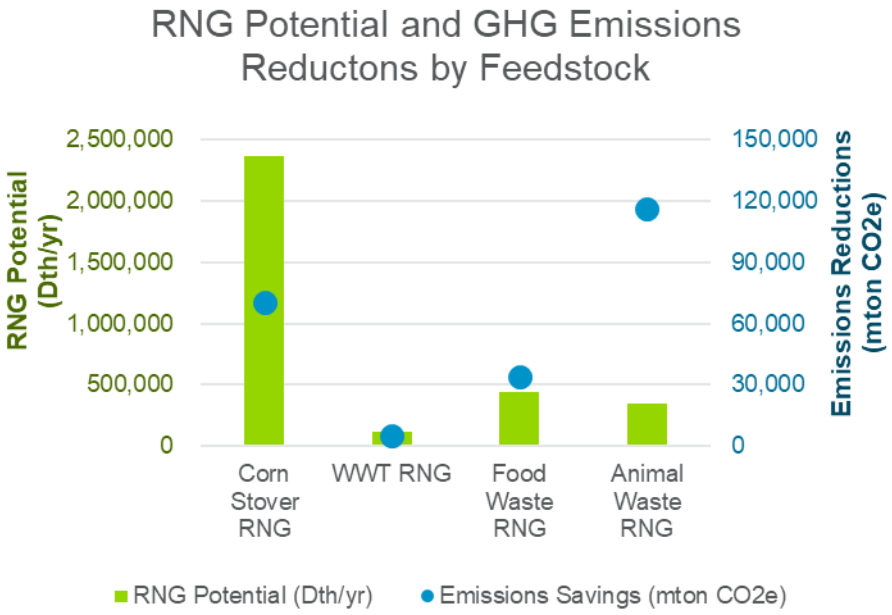

Figure 3-3 RNG Potential and GHG Emissions Reductions by Feedstock

4. Comparison with NYSERDA RNG Potential Report

Discussed in Section 1, Guidehouse prepared an original report for Central Hudson in 2021 on RNG potential for its service territory. In April 2022, ICF Resources, LLC prepared a report for NYSERDA titled "Potential of Renewable Natural Gas in New York State",[54] which provided a statewide view of RNG potential from available feedstocks under different sets of assumptions. The study's RNG production scenarios (i.e., Limited Adoption, Achievable Deployment, and Optimistic Growth, Maximum Potential) vary the share of feedstocks used for RNG production and growth rate of RNG development in NYS through 2040.

This section compares the findings of the NYSERDA report with the estimates contained in this report for Central Hudson's service territory. Although both reports use similar data inputs and overall methodology, direct comparisons between the two reports are difficult given the differences in analysis scope and reporting granularity. For example, the NYSERDA report provides RNG annual production potential regionally in 2040 whereas this analysis focuses on 5-10 year time horizon. More critically, the NYSERDA report summarizes RNG potential on a regional basis within NYS, as shown in Figure 4-1, rather than the county level as in this report. Central Hudson's service territory covers only a share of two NYS regions reported in the NYSERDA report, with **BOLD** counties denoting those at least partially served by Central Hudson (Figure 1-1):

- Region 7 – Capital District: **Albany, Columbia**, **Greene,** Rensselaer, Saratoga, Schenectady, Warren, Washington

- Region 8 – Hudson Valley: **Dutchess, Orange**, **Putnam**, Rockland, **Sullivan, Ulster,** Westchester

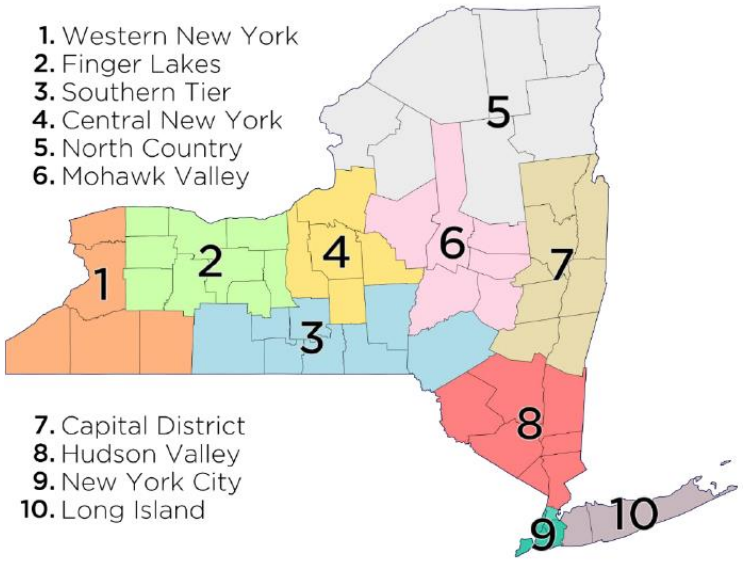

Figure 4-1 NYS Regions Analyzed in 2022 NYSERDA Report

[54] NYSERDA. "Potential of Renewable Natural Gas in New York State." April 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/files/EDPPP/Energy-Prices/Energy-Statistics/RNGPotentialStudyforCAC10421.pdf

While it is difficult to directly compare the results of the two analyses, the rough order of magnitude for the estimated RNG potential within and surrounding Central Hudson's service territory are similar for both studies. Table 4-1 highlights the estimated 2040 RNG potential for Region 7 and 8 in the NYSERDA report assuming a similar list of feedstocks analyzed in this report (e.g., agricultural residues, energy crops, animal waste, food waste, and WTTP sludge). Guidehouse's estimate of 3.3 TBtu/yr (equivalent to million DTh/yr) is in the same range as the NYSERDA estimates of 2.3 to 6.2 TBtu/yr under the Limited Adoption and Achievable Deployment scenarios for 2040.

Table 4-1 Comparison of Estimated Central Hudson RNG Potential to 2022 NYSERDA Report Assuming Similar List of Feedstocks (TBtu/yr.)

Region	Limited Adoption Scenario	Achievable Deployment Scenario	Guidehouse Estimate for Central Hudson
7 - Capital District	1.6	4.3	-
8 - Hudson Valley	0.8	1.8	-
Total	**2.3**	**6.2**	**3.3**

Data from Appendix A of 2022 NYSERDA Report[55] for agricultural residues, energy crops, animal waste, food waste, and WTTP sludge feedstocks.

The NYSERDA report also provides an Optimistic Growth scenario with greater utilization of local feedstocks through 2040, which shows a combined 10.3 TBtu/yr. of annual RNG potential for Regions 7 and 8 assuming similar feedstocks to this report.[56] This scenario assumes greater utilization of lower density and/or higher cost feedstocks and would likely require significant state and local policy support, market drivers, and technology development to support cost-effective collection and processing.

[55] NYSERDA. "Potential of Renewable Natural Gas in New York State." April 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/files/EDPPP/Energy-Prices/Energy-Statistics/RNGPotentialStudyforCAC10421.pdf

[56] The report provides a Maximum Potential scenario on a statewide basis (272 TBtu/yr. across all feedstocks), but does not provide a county or regional breakdown.

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