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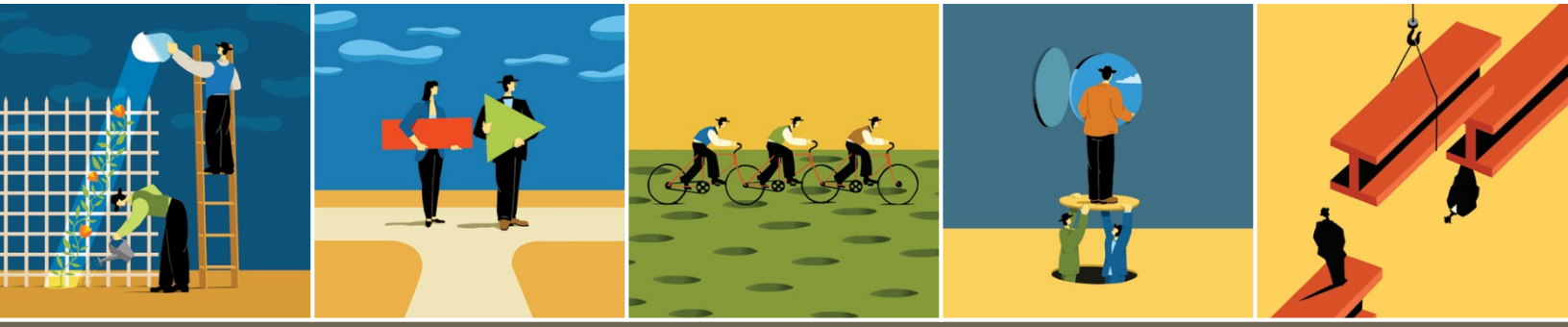

RESEARCH REPORT

Market Data: Renewable Natural Gas

Distributed Biogas Production, Upgrades, and Electricity Generation for Power and Transportation Applications

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Section 1
EXECUTIVE SUMMARY

1.1 Market Overview

Biogas for commercial use is a product of anaerobic digestion (AD), a method in which microorganisms break down organic matter in an oxygen-starved environment and one of the oldest processing technologies. It is captured in modern landfills (landfill gas-to-energy, or LFGTE) and biodigesters that treat a range of organic waste streams. While biogas is a combination of gases and other volatile impurities, its main component (50%–70%) is biomethane (CH_4), known in the energy market as natural gas (NG). As such, biogas can be combusted in NG turbines and by other prime mover technologies to produce electricity and heat. It can also be upgraded to pure biomethane or renewable natural gas (RNG) through the process of removing the impurities and other gases.

Biogas power generation is widely utilized for onsite generation by industrial-scale facilities and distributed customers alike. Offering reliable baseload power to the grid, biogas enjoys favorable regulatory support in many national markets and is expected to play a significant role in meeting expanding renewable energy targets.

Biogas feedstocks are available worldwide. However, logistical challenges associated with its collection, aggregation, transportation, and handling, coupled with poor energy density relative to fossil fuels, make power and fuel generation from biogas viable in only a narrow set of circumstances—where organic matter is available in large quantities and in continuous supply.

In addition, the levelized cost of energy (LCOE) for biogas projects can vary widely. Projects using gas recovered from landfills are the cheapest source of renewable energy currently available, but small-scale biogas projects based in rural locations need more aggressive incentives to be competitive with other sources of energy. For this reason, biogas remains a subsidy-dependent enterprise. In the short term, high growth will be limited to regions with policy support in place and where low-cost resources have not been tapped.

In the long term, higher growth in the biogas market will depend on a combination of technical improvements and the sector's ability to find and develop untapped opportunities. The latter is key, as the industry's natural fragmentation means that significant efforts are necessary for new markets—either regional or new end uses like transportation—to reach a point in which all stakeholders are aligned. On the technical side, breakthroughs in feedstock conversion rates and innovation around control systems are necessary to improve the competitiveness of biogas and unlock the potential of higher-cost resources.

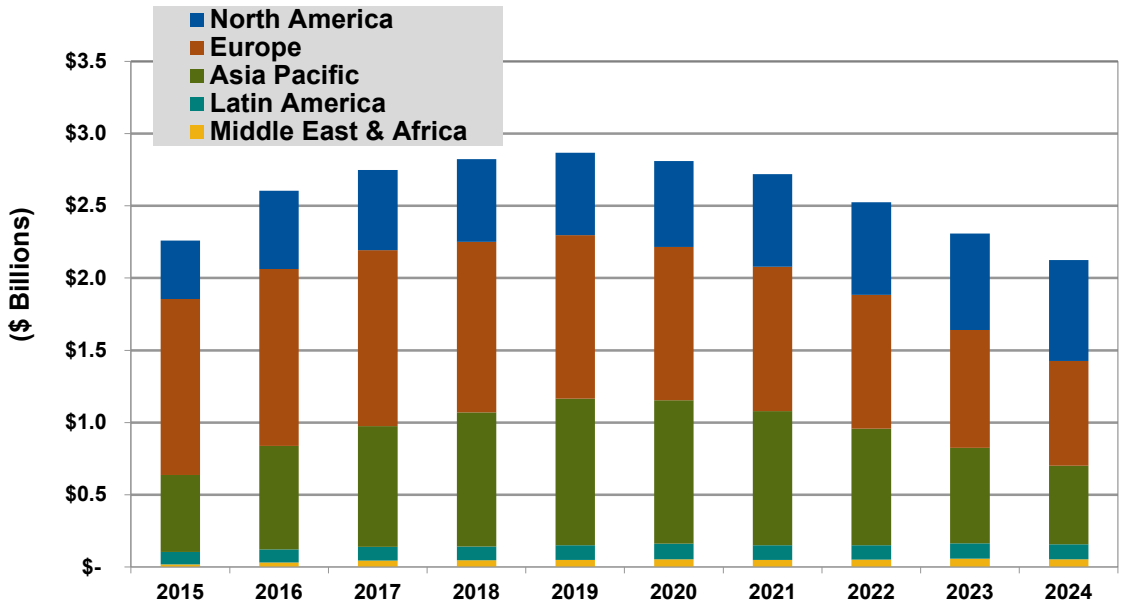
1.2 Market Forecasts

This report provides an update to Navigant Research's biogas forecast published in 2013, focusing on four feedstock sources within the global biogas market: waste, industrial, agricultural, and sewage. A key difference in this report from previous forecasts is the addition of a new market—the RNG market—including its use in the transport sector. Three end-use markets are covered in this report: electricity, RNG injection, and transport.

Global cumulative revenue from investment in biogas production capacity is expected to reach $25.8 billion between 2015 and 2024. Cumulative revenue from Europe is projected to take the largest share of the market, with $10.5 billion coming from this continent. Asia Pacific is expected come close, with $8.0 billion in cumulative revenue, and North America is forecast to follow with $5.9 billion. Latin America and the Middle East & Africa combined are expected to account for only $1.5 billion in cumulative revenue by 2024.

Annual biogas revenue from Europe is projected to drop from a peak of $1.2 billion in 2016 to just $0.7 billion in 2024 as countries reduce their incentive schemes. Asia Pacific is expected to follow a similar trend. Although its potential is huge, the current policies in place in Asia Pacific allow only landfill-based projects to be developed, limiting growth beyond 2020 as cheap resources become scarce. Revenue from North America is expected to increase slowly, from $0.4 billion in 2015 to $0.7 billion in 2024.

Chart 1.1 Annual Biogas Market Revenue by Region, World Markets: 2015-2024



(Source: Navigant Research)

Section 2
DATA ASSUMPTIONS

2.1 Background

As a stable and well-understood process, biogas industry scale-up will hinge on innovative applications and business models rather than breakthrough technologies.

2.2 Biogas Segmentation

The biological process to convert organic matter into biogas is the same in all instances. However, biogas project economics vary significantly depending on the type of project (which varies depending on the source of this organic matter). The four major sources and types of projects are described in Table 2.1.

Table 2.1 Biogas Market Segments by Source

Source	Description
Waste	Installations that utilize the gas capture in landfill recovery systems to provide an additional revenue stream.
Industrial	Digester installations that convert organic waste from industrial processing facilities into raw biogas in an oxygen-starved environment and use onsite prime mover technology to produce electricity or inject it into the natural gas (NG) grid.
Agriculture	Digester installations that convert agricultural products (residues or energy crops) and animal waste into raw biogas in an oxygen-starved environment and use onsite prime mover technology to produce electricity or inject it into the NG grid.
Sewage	Biogas collected from sewage treatment plants and used to produce electricity or inject it into the NG grid.

(Source: Navigant Research)

Another way to segment the industry is by the end use of biogas. Traditionally, biogas has been combusted onsite to produce electricity, but other uses have appeared over time. Table 2.2 lists the end uses of biogas.

Table 2.2 Biogas Market Segments by End Use

End Use	Description
Electricity	Installations that combust biogas on a dedicated basis through greenfield facilities to produce electricity.
Renewable Natural Gas (RNG) Injection	Installations that produce and upgrade biogas into pure biomethane (biogas contains between 50% and 70% biomethane when produced) on a dedicated basis through greenfield facilities and inject it into the NG grid.
Transport	This is a subsegment of RNG injection in which the RNG is used as a renewable transport fuel, replacing or combined with liquefied natural gas (LNG) or compressed natural gas (CNG). Governments often set specific incentives for the transport market.

(Source: Navigant Research)

2.3 Methodology

Navigant Research biogas forecasts are based on an analysis of industry momentum, regulatory support, production economics, and waste management practices across key markets. The forecast looks at the landfill gas-to-energy (LFGTE) and anaerobic digestion (AD) deployments across four key sources: waste, industrial processes (e.g. food processing, slaughterhouses, breweries, etc.), agriculture, and sewage treatment. Due to the distributed nature of AD and a lack of verifiable data across all segments, data is compiled from a combination of country-specific analysis, voluntary reporting, and estimates based on existing, publicly available data sets.

Although a business-as-usual growth model is assumed as a baseline for forecasting, a number of variables are assumed to affect the market to varying degrees:

- The development of waste management policies and infrastructure
- Availability of subsidies and other price support mechanisms
- Environmental and emissions regulations
- End-market opportunities and access
- NG price movements and market growth

The biogas production forecast is represented as annual installed raw biogas production capacity, installed power generation capacity, and biogas injection capacity. RNG projections are based on upgraded biogas (biomethane) projections. Market value projections are based on anticipated annual revenue across all installations. All projections are segmented by region, and in some cases, feedstock source and end use. In an attempt to standardize the energy content of biogas, all figures of raw capacity are accounted in billion cubic feet (Bcf) of NG.

2.4 Policy Assumptions

Renewable energy targets set either aspirational or mandated goals for the integration of renewable energy in national electricity, thermal, and fuel production portfolios. These targets are an important mechanism to direct long-term policy and reduce market risk for investors and project developers. Navigant Research's forecast assumes that these policies remain in place through 2024 and are coordinated with incentives and policies that offer reasonable certainty and policy stability to drive investment in support of biogas projects. A sampling of international incentives across global biogas markets is outlined in Table 2.3.

Table 2.3 Biogas Power and RNG as Transport Fuel Policy Support Mechanisms, Selected Markets: 2015

Country	Biogas Power Incentives	RNG Injection Incentives	Biogas Transport Incentives
China	» China offers a ¥0.225/kWh ($0.035/kWh) premium over the cost of the provincial price of desulfured coal power. » Grid access limited to plants over 500 kW.	» None.	» The government has set a target of producing 300 million tons of cellulosic and non-grain-based fuels combined by 2020. » Cellulosic fuel's production receives a slightly higher subsidy of ¥800 per ton ($125/ton) of ethanol-equivalent fuel.
France	» Basic rate of between €0.1337/kWh ($0.146/kWh) to €0.1119/kWh ($0.13/kWh) depending on size. » €0.04/kWh ($0.044/kWh) energy efficiency premium. » €0.026/kWh ($0.028/kWh) mature premium.	» Rate of between €0.45/kWh ($0.50/kWh) to €0.95/kWh ($0.105/kWh) depending on size for landfills. » Basic rate of between €0.64/kWh ($0.70/kWh) to €0.95/kWh ($0.105/kWh) depending on size organic residues (non-landfill) plus a premium depending of the feedstock source.	» Incentivized through its renewable energy in transport mandate. France targets 7.7% of biofuels in diesel and gasoline. » Biogas is considered a double counting fuel, which is capped at 0.35% of the target. » In 2014, France did not use biogas in transport.

Country	Biogas Power Incentives	RNG Injection Incentives	Biogas Transport Incentives
Germany	» Biogas electricity from organic waste of less than 500 kW capacity: €0.152/kWh ($0.17/kWh) produced for 20 years. » Biogas electricity from organic waste of less than 20 MW capacity: €0.1366/kWh ($0.15/kWh). The rate for landfill biogas is €0.065/kWh ($0.07/kWh) up to 500 kW and €0.057/kWh ($0.06/kWh) for up to 5 MW. » Germany capped future growth of biomass-based electricity capacity to 100 MW per year.	» None; indirectly incentivized through the electricity and transport incentives.	» Incentivized through its carbon reduction in transport mandate, which calls for a 3% reduction in greenhouse gases from gasoline and diesel by 3% in 2015, 4.5% in 2017, and 7% in 2020 and onwards. » RNG was given a default 80%-86% reduction compared to gasoline. » Germany is actively using biogas in transport. In 2014, it consumed 1.8 Bcf.
India	» Set project by project by the Central Electricity regulatory Commission.	» None.	» None.
Italy	» Biogas electricity from organic waste of less than 300 kW capacity: €0.236/kWh ($0.26/kWh) produced for 20 years. » On the other end of the scale, projects of more than 5 MW of capacity using food or feed crops as feedstock would receive only €0.091/kWh ($0.10/kWh).	» Incentive scheme announced, but tariffs have not been set.	» Incentivized through its renewable energy in transport mandate, which calls for 1.2% of advanced biofuels (in which most of RNG falls) in 2018, 1.6% by 2020, and 2% by 2022. » RNG consumption generates twice the credits due to its low carbon footprint. » As of 2014, Italy had not used biogas as a fuel.

Country	Biogas Power Incentives	RNG Injection Incentives	Biogas Transport Incentives
United Kingdom	» £0.1013/kWh ($0.16/kWh) for plants with a capacity of less than 250 kW and down to £0.0868/kWh ($0.13 kWh) for plants between 500 kW and 5 MW. » The U.K. feed-in tariff (FIT) system has a degression system in place; the tariff drops by 10% if new capacity additions of under 500 kW pass 4.5 MW per year, and 20% if additions pass 9 MW. » For plants over 500 kW, the limits are 38.4 MW and 76.9 MW for the 10% and 20% tariff degressions.	» £0.075/kWh ($0.03/ cubic feet) for the first 40,000 MWh injected in the grid in a year, £0.044/kWh ($0.02/ cubic feet) for the next 40,000 MWh and £0.034/kWh ($0.015/ cubic feet) thereafter.	» Incentivized through its renewable energy mandate. The U.K. target is set at 3.9% (energy) for biodiesel and 4.6% (energy) for gasoline replacements. This rose to 4.75% in 2015.
United States	» Defined by local regulation.	» Defined by local regulation.	» Incentivized through its Renewables Fuel Standard program. » Classified as cellulosic fuel; obtains D3 RINs. » Low Carbon Fuel Standard (LCFS) credits (in California).

(Source: Navigant Research)

2.5 Key Inflection Points

Broadly speaking, there are three key drivers affecting the uptake of biogas that were taken into account in constructing market data forecasts for this report:

» **Policy support:** Biogas remains a subsidized market globally and any scaling back or increase in incentives can have a dramatic impact on the project financing and the rate of deployment. The main policies affecting biogas deployments are end-product incentives (FITs, green certificates, portfolio standards, etc.) and waste management standards. Biogas offers some strategic advantages over other renewable and non-renewable technologies. Unlike solar and wind energy, biogas can be stored and used at peak demand, therefore benefiting from higher prices. In addition, since biogas can be produced in any location where organic residues are available, it can contribute to any country's energy security strategy.

- **Regional price of NG:** Despite local incentives, the price of NG and electricity can make or break deployment in a specific region. Any increase in the price of fossil fuels or emissions regulations can help reduce the cost differential between the various fuels.
- **Efficiency of the conversion technology:** Digester technologies are well-understood; therefore, capital costs are not expected to fall significantly in the next 10 years. Operational costs can vary significantly from site to site depending on feedstock characteristics (percentage of digestible matter and accessibility of it) and the site's operational excellence. A drop in the overall levelized cost of energy (LCOE) is expected as technologies to improve feedstock conversion rates and reduce time in the fermentation tank, such as advanced enzymes and control automatization, hit the market.

Section 3
MARKET FORECASTS

3.1 Forecast Assumptions

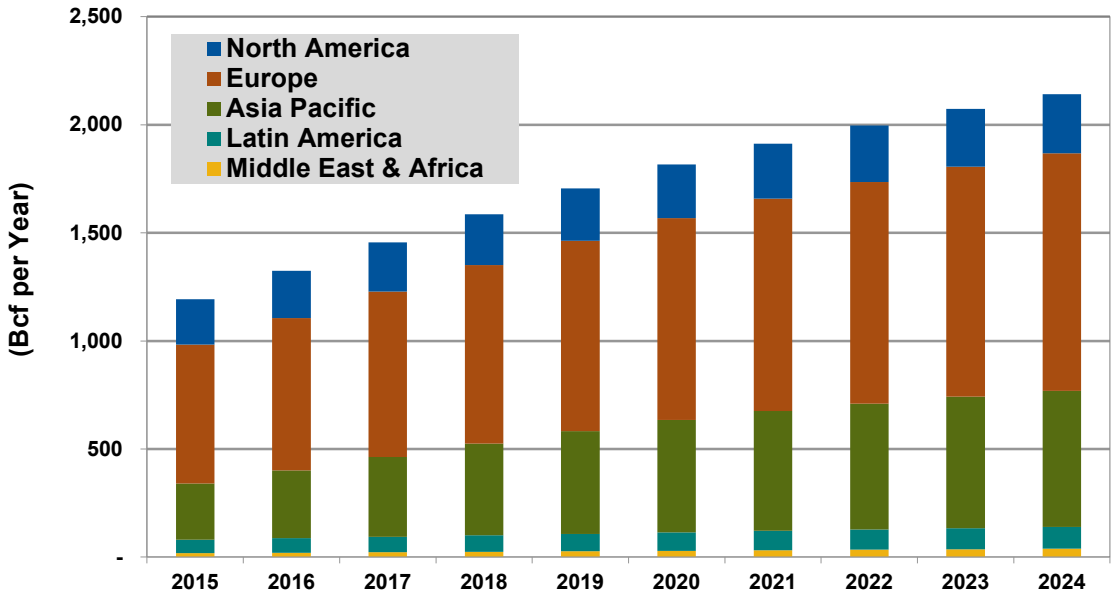
The market forecasts in this report assume that the following policy and market trends will continue or will materialize. These assumptions are based on industry interviews and internal expertise:

- **In the United States, landfilling remains a low-cost option:** Based on current observed trends, Navigant Research assumes landfill capacity will continue to increase as a low-cost solution for waste disposal. Owing to a growing emphasis on NG, AD is expected to struggle without direct support in the United States.
- **Opportunities in the transport market materialize:** The LCFS and the July 2014 U.S. Environmental Protection Agency (EPA) ruling promoting biogas as a cellulosic fuel provide the industry with a platform for expansion.
- **Europe leads, but growth falls as targets are achieved:** Navigant Research assumes that a rush to meet the European Union's (EU's) aggressive landfill directive targets for 2020 will support industry growth for the next 5 years. However, opportunities will decline once countries hit their targets.
- **Asia Pacific continues to stumble because it lacks clear policies supporting the industry:** Navigant Research assumes that Asia Pacific offers the best potential among all world regions for growth. However, its lack of support policies and unstructured waste management systems, particularly in the poorer countries like India, will keep the biogas industry from achieving high growth rates in this region.
- **NG slows near-term biogas progress, but lays foundation for long-term biogas growth:** Navigant Research's forecasts generally assume that recent NG discoveries in the United States and other key regions will depress market demand for biogas. Yet, a long-term buildout of NG infrastructure—pipelines, LNG export/import hubs, increased use of NG as a transportation fuel, etc.—could lay the foundation for long-term growth in the biogas industry if the cost equation works.

3.2 Biogas Forecasts by Region

Gross raw biogas production capacity worldwide is projected to reach 2.14 trillion cubic feet per year in 2024. This represents a 2 times increase over production capacity in 2014 and a 6.7% CAGR through 2024.

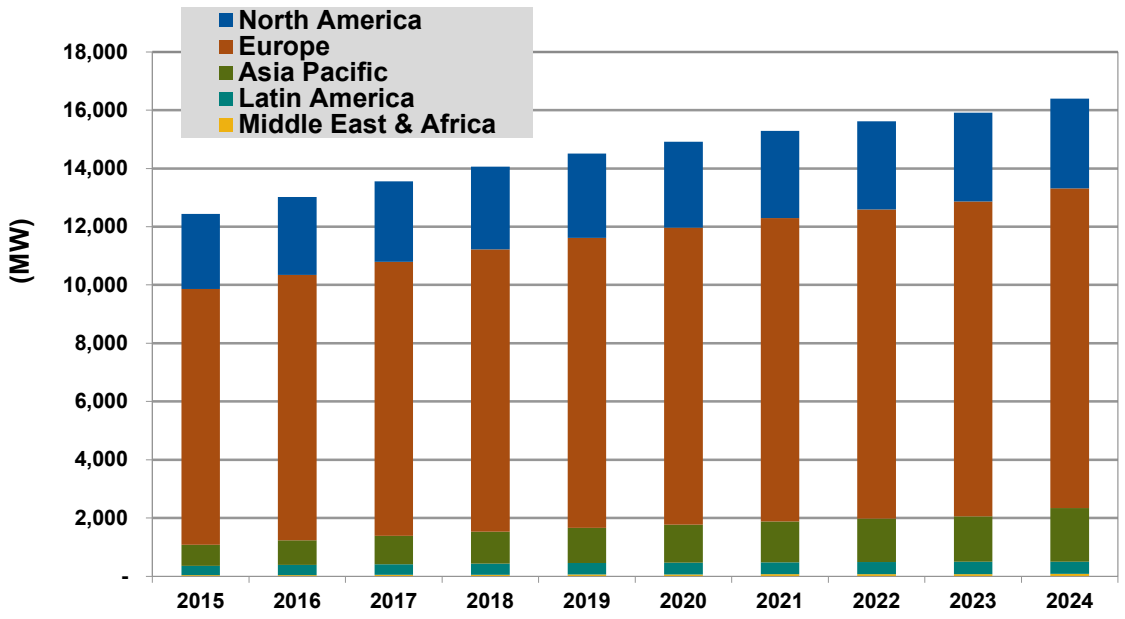
Chart 3.1 Annual Raw Biogas Production Capacity by Region, World Markets: 2015-2024



(Source: Navigant Research)

Europe leads in terms of electricity production from biogas. Europe currently accounts for 71% of all the generation capacity, North America accounts for 21%, and Asia Pacific 5.8%. By 2024, Europe's share is expected to fall to 67% and North America's to 19%. The big winner will be Asia Pacific, which will see its global share of biogas electricity generation capacity soar to 11%.

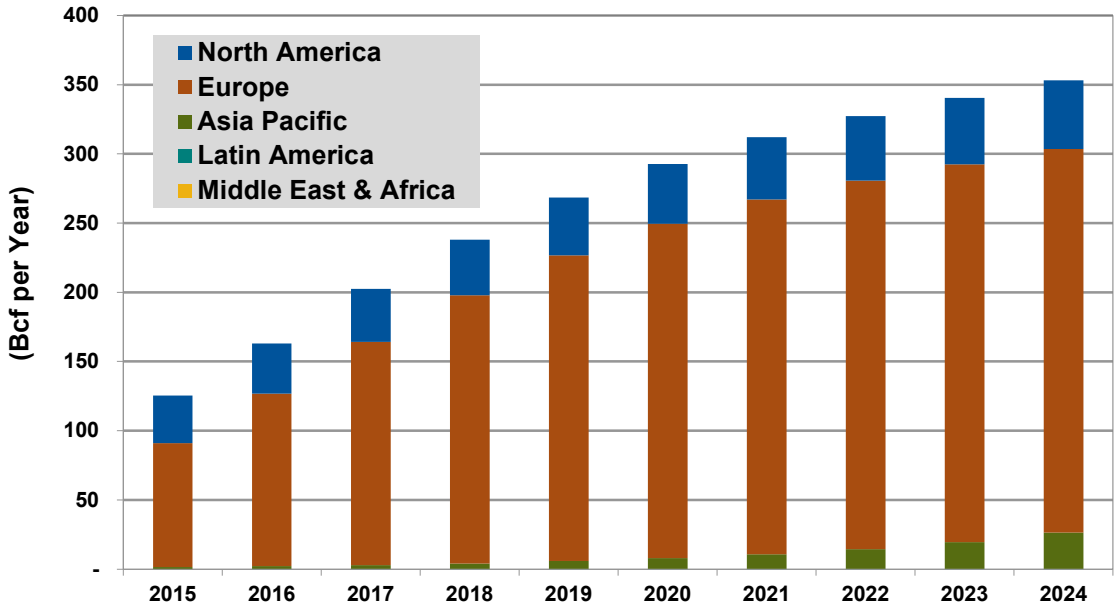
Chart 3.2 Installed Biogas Electricity Generation Capacity by Region, World Markets: 2015-2024



(Source: Navigant Research, International Renewable Energy Agency, U.S. Environmental Protection Agency)

Europe also leads in terms of RNG injection. In 2015, the continent's RNG production capacity has an estimated global share of 71%, North America's share is 27%, and Asia Pacific's is only 1%. Thanks to Germany's efforts to increase the amount of RNG in its pipelines to limit imports, Europe is projected to raise its share to 78% (69% of the global capacity will be installed in Germany) by 2024. Despite the increase in RNG in its transport system, North America is expected to see its share reduced by half to 14%. Finally, Asia Pacific will see its share increase to 7%.

Chart 3.3 Annual RNG Production Capacity by Region, World Markets: 2015-2024

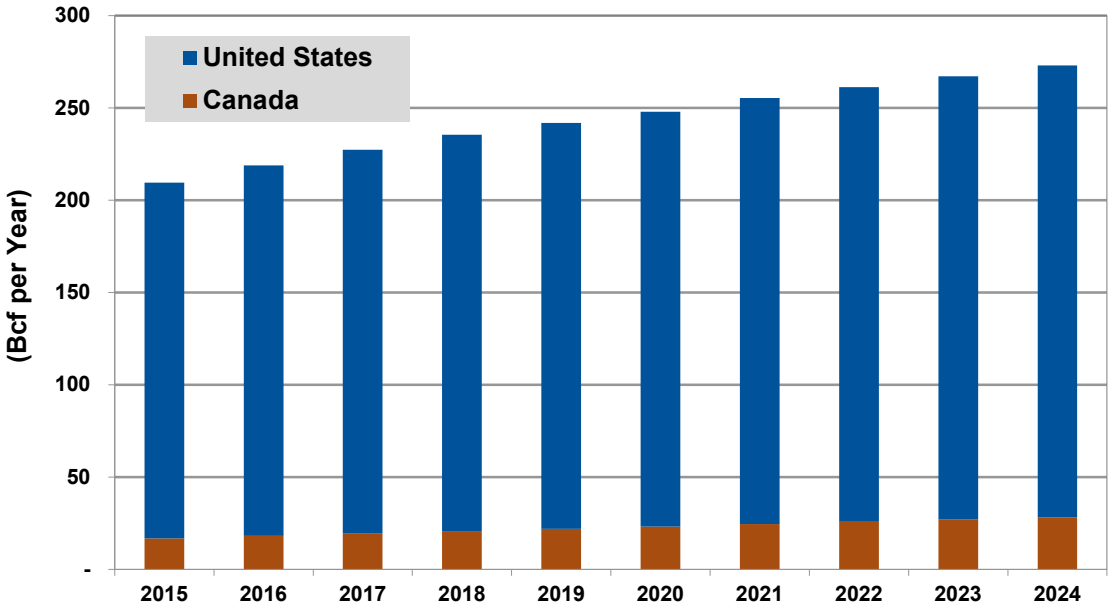


(Source: Navigant Research)

3.2.1 North America

North America produced 205 Bcf per year of biogas in 2014; 92% was produced in the United States and the remaining 8% in Canada. Overall, North American biogas production capacity is projected to reach 273 Bcf per year by 2024, representing a 3.0% 2015–2024 CAGR over the forecast period. Growth in North America is expected to be slowed by limited access to end markets due to low electricity prices and the availability of cheap sources of NG flooding the market. The North American biogas market will remain dependent on its patchy state-level support, resulting in a low CAGR for the region.

Chart 3.4 Annual Raw Biogas Production Capacity by Country, North America: 2015-2024



(Source: Navigant Research)

3.2.1.1 United States

The United States had an annual production capacity of 189 Bcf per year of biogas in 2014 and is expected to reach 245 Bcf per year by 2024 at a 2.7% CAGR between 2015 and 2024.

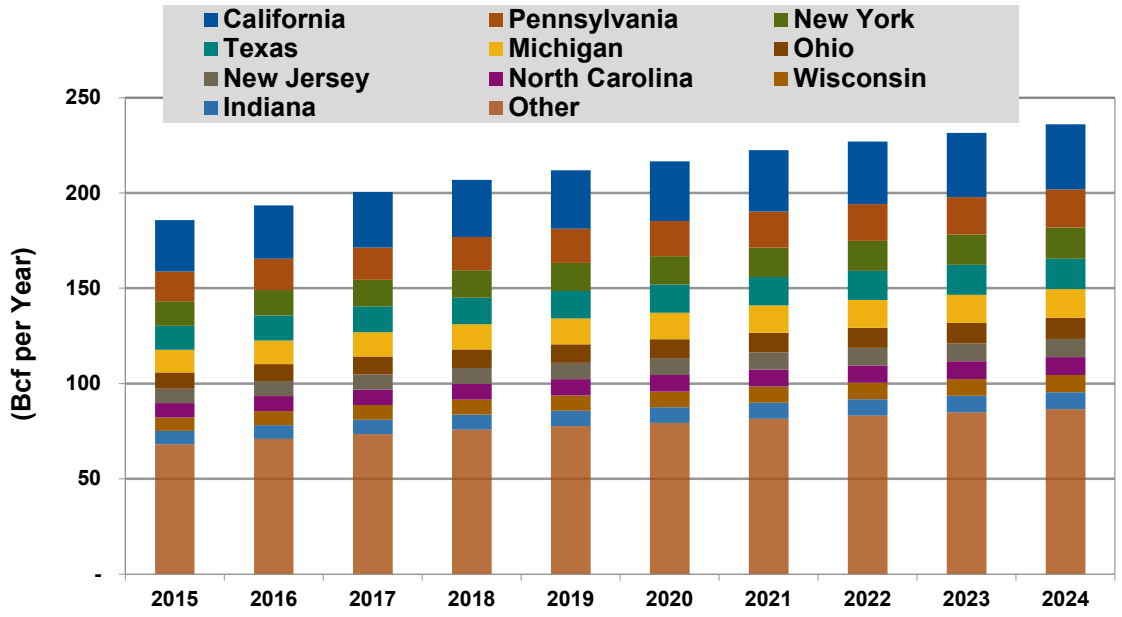
The U.S. biogas market is currently ruled by waste biogas capture, with LFGTE as the most prevalent biogas source. According to the EPA's Landfill Methane Outreach Program, there were an estimated 595 LFG capture projects in 2014. Similar data from the AgStar program showed that there were 247 on-farm digesters in the United States. LFGTE project development has slowed down since the country's most profitable sites have been developed and low NG and electricity prices offer diminishing revenue opportunities—even in areas with supporting regulations (Renewable Energy Certificates, carbon credits, etc.). Although potential for on-farm digesters and sewage biogas capture is high in the United States, the industrial segment is expected to realize the greatest growth as corporate entities look to improve their sustainability

profiles and increase onsite generation for operations. Food processers, in particular, have started to aggressively adopt AD technology.

At the state level, the distribution of biogas capacity closely follows each state's population and population density. This is expected, given that the U.S. biogas production capacity is heavily tilted toward LFGTE—which relies on waste generated in urban centers.

From the top 10 list, Indiana and Wisconsin are the only outliers. Wisconsin is only the 20th largest state by population but it is the leading in biogas production from its agricultural sector (dairy). The state's large dairy sector and early introduction of a renewable portfolio standard supporting AD have made this possible.

Chart 3.5 Annual Raw Biogas Production Capacity by State, United States: 2015-2024



(Source: Navigant Research)

3.2.1.1.1. *Electricity*

After strong growth between 2005 and 2012, when the industry grew at a 13% CAGR, a pipeline analysis of the EPA project database shows that the industry decelerated to 6% CAGR in the last 2 years. A further drop to a 2.1% CAGR is expected for the period between 2015 and 2024. The United States had an installed capacity of 2,350 MW at the end of 2014 and is expected to reach 2,969 MW by 2024 at a 2015–2024 CAGR of 2.1%.

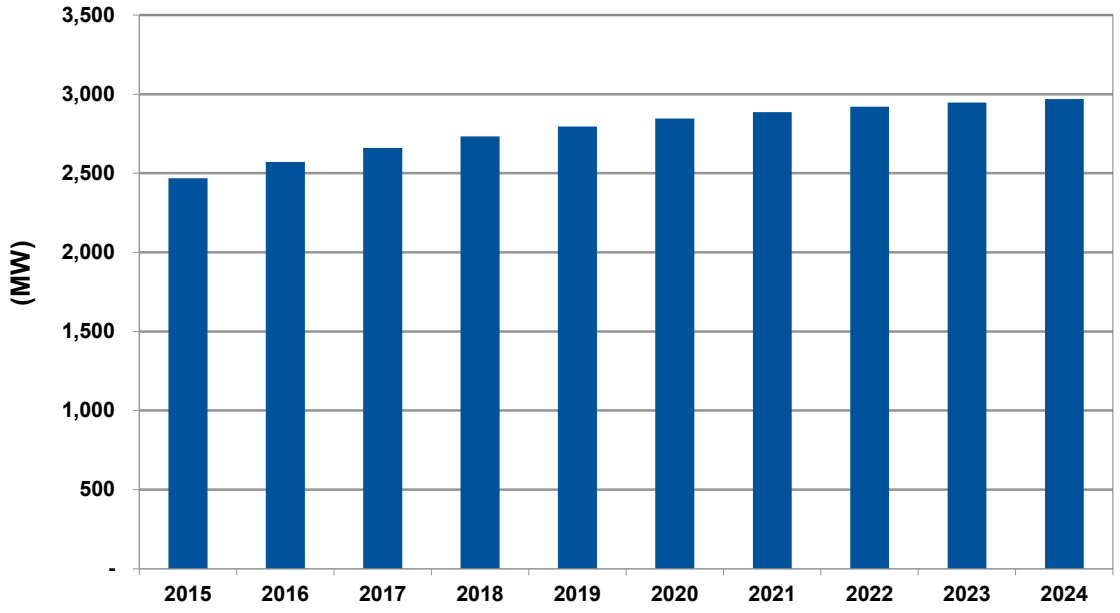
Most of the growth in installed electricity capacity in the past has been driven by the U.S. Clean Air Act of 1996. This act requires that large landfills install gas collection and control systems, which means that (at the very least) the facilities must collect and flare the gas. However, instead of flaring, most landfill owners have installed infrastructure to produce electricity. As

mentioned before, most facilities have been developed and therefore growth in LFGTE is now constrained to growth in the waste industry. For this reason, the majority of future growth in electricity production is expected to come from AD systems on farms.

Electricity production from livestock farms—mainly swine and dairy operations—has been growing significantly in the last 10 years, albeit from a very low starting base. The installed capacity at the end of 2014 was 120 MW. Opportunities in this area are still many. The EPA estimates a potential of 1,667 MW of capacity if all the farms that could use biogas recovery systems install it (this includes farms with more than 500 dairy cows or more than 2,000 swine heads).

In June 2013, President Barack Obama instructed his administration to develop a strategy to reduce methane emissions and promote technologies that help farmers, energy companies, and communities convert methane into a renewable energy source via the Climate Action Plan. When fully implemented, this plan should give the biogas sector room to grow, as the infrastructure needed to reduce emissions is the base for biogas production.

Chart 3.6 Installed Biogas Electricity Generation Capacity, United States: 2015-2024



(Sources: Navigant Research, International Renewable Energy Agency, U.S. Environmental Protection Agency)

3.2.1.1.2. RNG

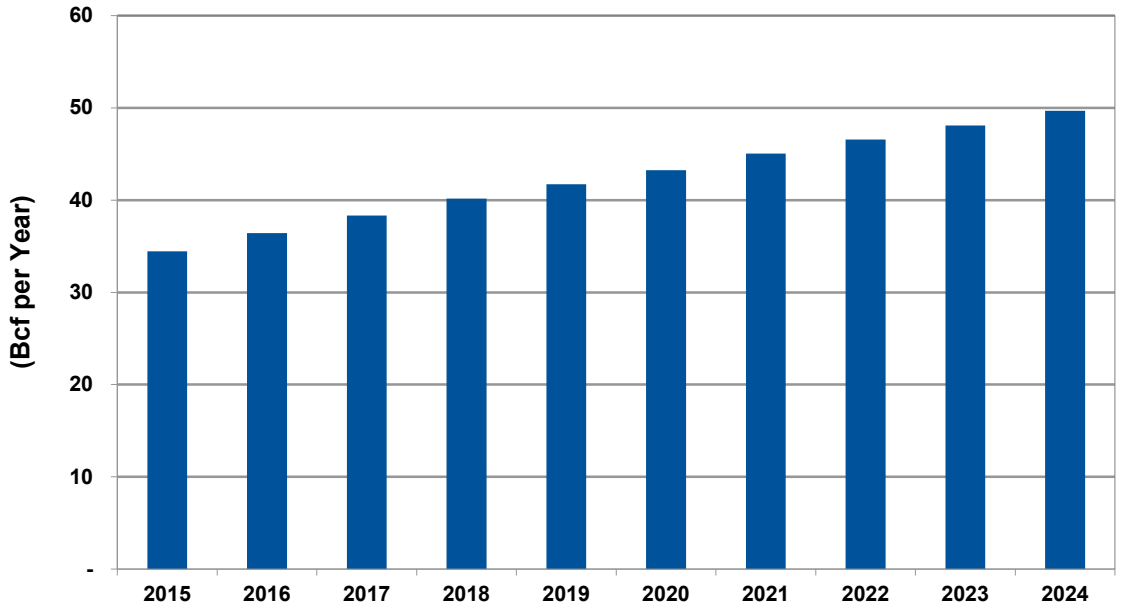
The United States had a production capacity of 33.8 Bcf per year of pipeline-grade RNG at the end of 2014, of which only a fraction (2.2 Bcf per year) was used in transport, while the rest was simply sold and fed into the NG grid. Production of RNG is expected to reach 49.7 Bcf per

year by 2024 at a 2015–2024 CAGR of 4.2%, mostly driven by the growth in the transport market.

The use of purified biogas (RNG) in the U.S. transport market is a new development. A combination of two factors—policy changes and the increased use of non-renewable NG as a transport fuel—has made RNG a feasible transport fuel option.

According to Navigant Research's *Natural Gas Vehicles* report, consumption of NG in the U.S. transport sector will grow at a 13% CAGR between the end of 2014 and 2024, reaching 221 Bcf per year at the end of this period. This growth will be driven by a 125% expansion in the NG vehicle fleet in the country. Although NG and RNG compete for the same fuel market, using RNG would not be possible without the infrastructure for NG.

Chart 3.7 Annual RNG Production Capacity, United States: 2015-2024



(Source: Navigant Research)

On the policy side, the change that has had the strongest impact was the reclassification the EPA did of biogas within its Renewable Fuel Standard program (RFS2). Until July 2014, if biogas was used as transport fuel, it generated an advanced biofuel credit (known as D5 RIN). However, on July 2, 2014, the EPA approved RNG (either in its compressed or liquefied form) from landfill, municipal wastewater treatment facilities (sewage), or independent ADs using agricultural residues or other organic waste as a cellulosic fuel within the RFS2. Therefore, RNG generates a cellulosic biofuel credit (known as D3 RIN).

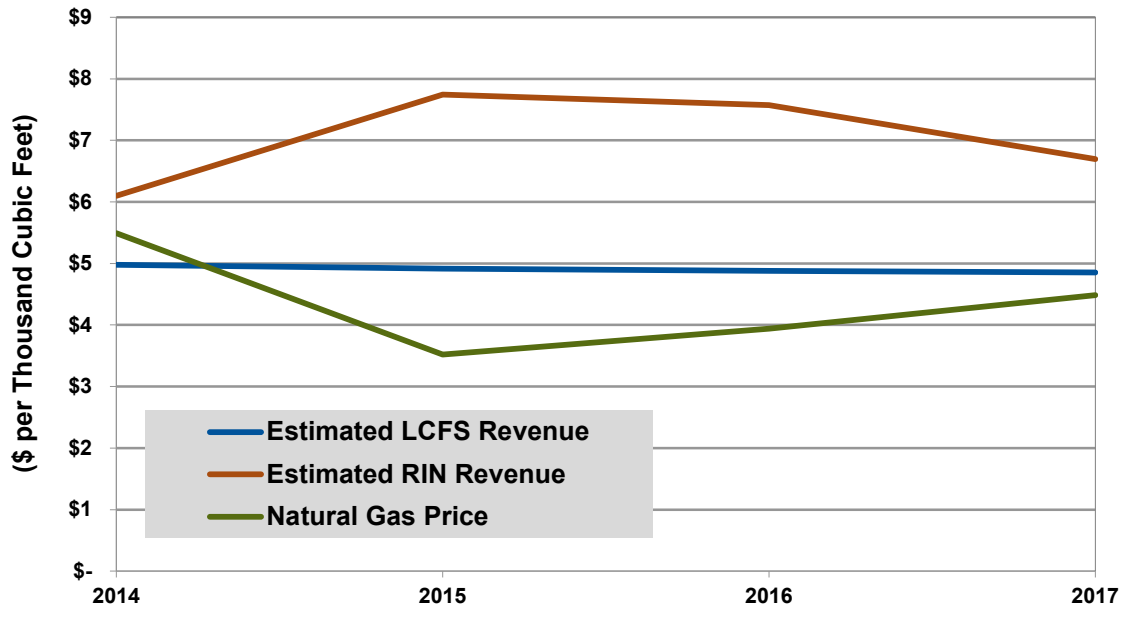
D5 RINs can be generated using several pathways, and there is a sufficient amount of them in the market. In contrast, D3 RINs are scarce and, until that moment (July 2014), were only generated from fuels coming from pilot facilities; thus, D3 RINs are the most expensive RIN

certificates. Since this change took place, consumption of RNG in the transport segment has soared. According to the EPA, in 2013, the United States generated 25.9 million D3 RINs from biogas (the equivalent of 2.2 Bcf), while in 2014, it generated 32.5 million D5 RINS (2.9 Bcf)—all between July and December. In the first 7 months of 2015, this figure has already passed 61 million D5 RINs (5.4 Bcf). The EPA targets for 2015 and 2016 are 106 million D3 RINS (9.4 Bcf) and 206 million D3 RINs (18.3 Bcf). These targets offer the industry an opportunity to grow in the short term, but uncertainty around the continuation of the RFS2 program clouds its long-term prospects.

Another policy, the California LCFS, also promotes the use of RNG as transport fuel. The LCFS aims to reduce the carbon intensity (CI) of transport fuels used in California. CI values are assigned to fuels based on the life-cycle analysis of its production pathway. Like in the RFS2, obligated parties can either use low carbon fuels to achieve their target or buy credits to meet their requirements.

Some examples of CI values for biogas are 11.26 gCO2e/MJ for landfill compressed RNG produced in California and 13.45 gCO_2e/MJ for AD biogas also produced in this state—this compares favorably with the 67.7 gCO_2e/MJ CI of CNG. Chart 3.8 shows the cumulative effect of RINs and LCFS certificates on the price paid for biogas in California. The LCFS is attracting RNG (and investment in production capacity) into the state and regions with pipeline connectivity with California.

Chart 3.8 Annual Revenue from RNG as Transport Fuel, California: 2014-2017



(Source: Navigant Research)

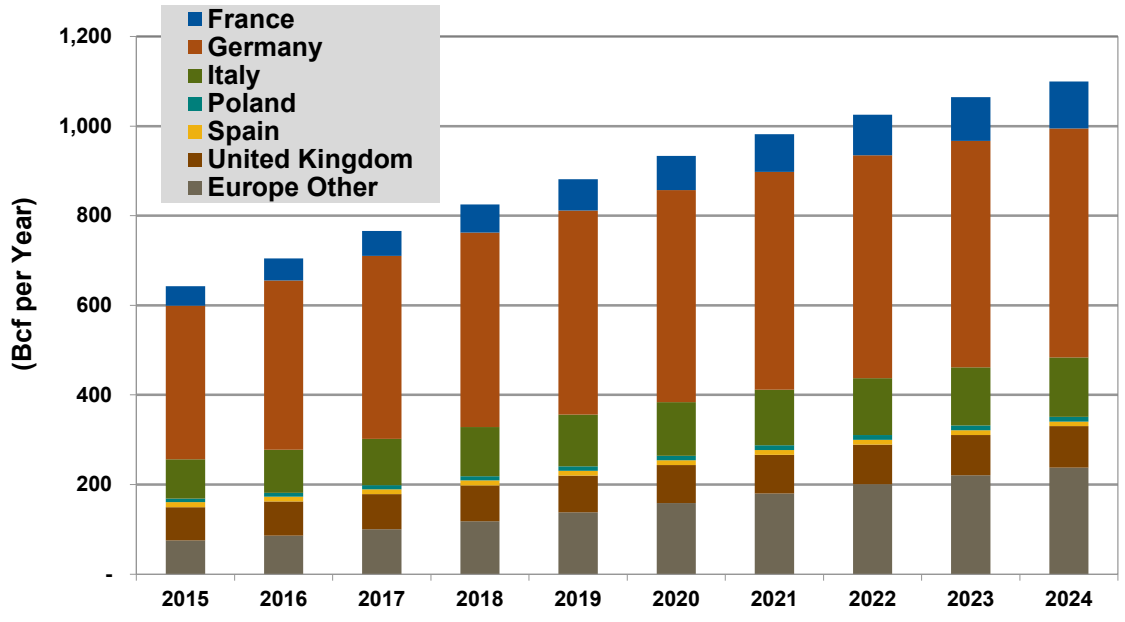
3.2.2 Europe

Driven by strong waste management and renewables integration policies, Europe is expected to hold its position as the leading region worldwide, with Germany as the epicenter of global biogas production. The European share of global raw biogas production capacity is expected to fall slightly from 54% in 2014 to 51% in 2024 as other markets develop faster. Most of Europe's growth (64%) is projected happen in the 5 years to 2020, with the remaining occurring in the second part of the decade.

The European biogas market is currently led by on-farm digesters, with Germany accounting for 52% of total biogas production capacity. Germany's share of production is expected to decrease to 46% by 2024 as growth in other EU countries accelerates.

The agriculture segment is expected to drive biogas growth across the region, but capacity additions will drop significantly as countries reduce or phase out incentives. Growth in the European industrial segment (21.8% 2015–2024 CAGR) is expected to lead all regions throughout the continent as strong zero waste policies hit food producers, processors, and retailers in European countries. Overall, European biogas production capacity is projected to reach 1,099 Bcf per year by 2024, representing a 6.1% CAGR between 2015 and 2024. Europe's agriculture segment leads all industries worldwide with 849 Bcf of annual biogas production capacity installed by 2024.

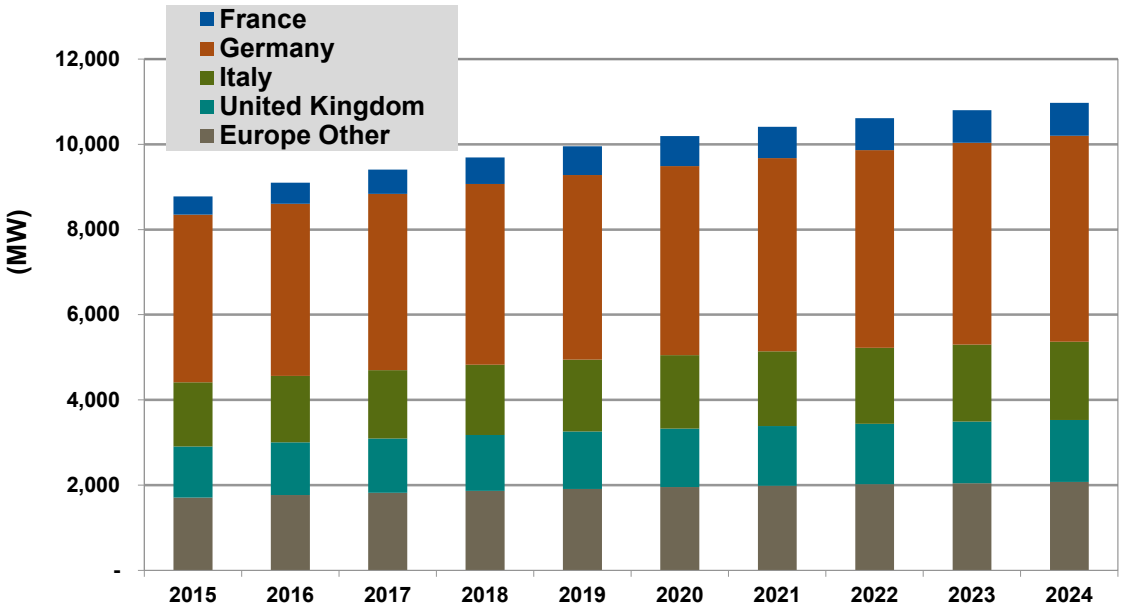
Chart 3.9 Annual Raw Biogas Production Capacity by Country, Europe: 2015-2024



(Source: Navigant Research)

The installed biogas electricity generation capacity in Europe is expected to reach 11 GW by 2024, up 30% from installed capacity in 2014, or a 2015–2024 CAGR of 2.5%.

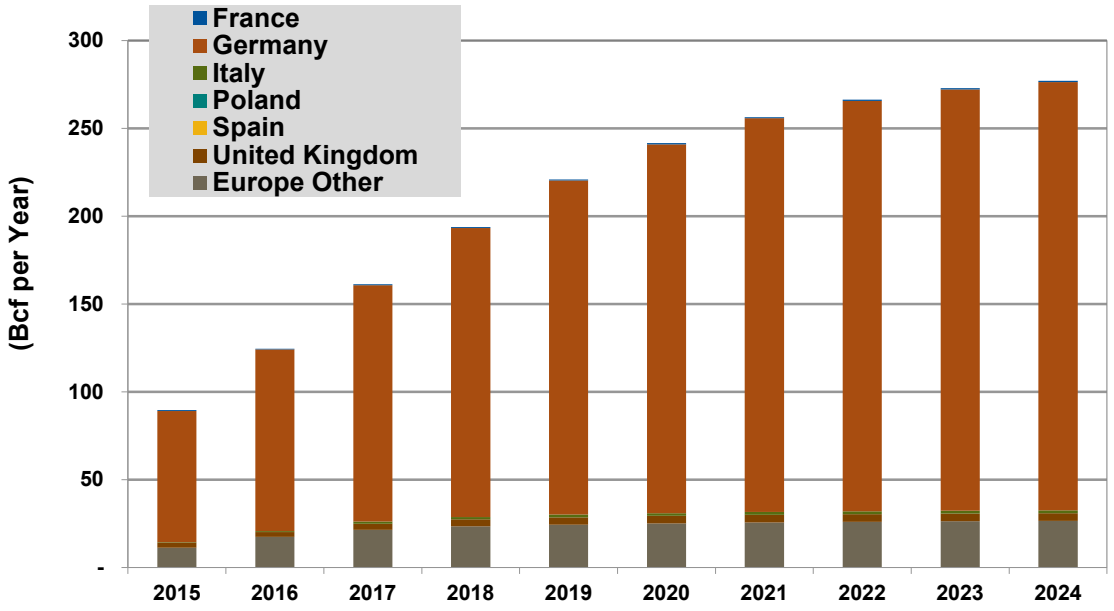
Chart 3.10 Installed Biogas Electricity Generation Capacity by Country, Europe: 2015-2024



(Sources: Navigant Research, International Renewable Energy Agency, U.S. Environmental Protection Agency)

The European RNG production capacity was 51 Bcf per year in 2014. Capacity is expected to reach 277 Bcf per year by the end of the forecast period at a 13.4% CAGR between 2015 and 2024.

Chart 3.11 Annual RNG Production Capacity by Country, Europe: 2015-2024



(Source: Navigant Research)

3.2.2.1 Italy

Gross raw biogas production capacity in Italy is projected to reach 132 Bcf per year in 2024. This represents a 67% increase over production capacity in 2014 and a 4.7% CAGR between 2015 and 2024. Italy will remain Europe's second-largest biogas market through the forecast period.

3.2.2.1.1. Electricity

Italy, along with Germany, was one of the countries within Europe with a strong support mechanism for biogas-based electricity production. The installed capacity in Italy grew from 480 MW in 2010 to 1,388 MW in 2013 (42.5% CAGR), totaling 1,611 plants. To try to limit industry growth, the Italian government reduced the FIT in 2014 by between 10% and 30% and set a limit of 160 MW per year for biomass-based projects, including biogas projects within this limit. Italy's scheme, in place since January 2013, favors biogas electricity from organic waste of less than 300 kW capacity. These projects receive €0.236/kWh ($0.26/kWh) produced for 20 years. At the other end of the scale, a project using crops of more than 5 MW of capacity receive only €0.091/kWh ($0.10/kWh).

Due to the new policy scheme, it is expected that growth between 2015 and 2024 will slow to a CAGR of only 2.2% to installed capacity of 1,831 MW.

3.2.2.1.2. RNG

No one was producing pipeline-grade RNG in Italy in 2014. However, the government set the first stepping stones in December 2013, when it authorized its use as a transport fuel and introduced an RNG price formula to incentivize its consumption. RNG from organic waste counts twice toward Italy's renewable energy in transport target of 10%. With the largest natural gas vehicle (NGV) fleet in Europe—Navigant Research expects Italy's NGV sales to reach 93,000 by the end of 2015—RNG could make quick gains in Italy's transport fuel market.

Driven by the country's relatively new RNG policy, production capacity in Italy is expected to reach 2 Bcf per year in 2024.

3.2.2.2 Germany

Gross raw biogas production capacity in Germany is projected to reach 511 Bcf per year in 2024. This represents a 68% increase over production capacity in 2014 and a 4.5% CAGR between 2015 and 2024. Despite a decreasing growth rate, Germany will remain Europe's largest biogas market through the forecast period.

3.2.2.2.1. Electricity

Germany currently has the largest base of electricity generation using biogas in the world. In 2014, the country had 3,840 MW of installed capacity. In its 2013 energy reform, Germany capped future growth of biogas electricity generation capacity to 100 MW per year and reduced its FITs significantly, curtailing the growth in the industry. Biogas electricity generation capacity in Germany is expected to grow at a 2.3% CAGR through 2024, ending with 4,840 MW. Although currently small with only 15,000 vehicles projected to be sold in 2015, German NGV sales are expected to be 5 times larger by the end of 2024.

3.2.2.2.2. RNG

Most of the hopes within the German biogas industry are set on its growing transport market. In 2015, Germany moved away from transport policy using renewable fuel blending quotas based on their energy content to one based on their CI. Although is too early to see the results of the policy change, it is likely that RNG will benefit, as it has one of the lowest carbon footprints of the available options (an 80%–86% reduction compared to gasoline—almost twice that rapeseed-based biodiesel, the most common renewable fuel used in the country). RNG production in Germany is expected to grow at a 14.0% CAGR between 2015 and 2024, ending this period with 244 Bcf per year.

3.2.2.3 France

Gross raw biogas production capacity in France is projected to reach 105 Bcf per year in 2024. This represents a 173% increase over production capacity in 2014 and a 10.2% CAGR between 2015 and 2024. France is expected to be the fastest-growing market in Europe, though its

current low base of just 38 Bcf will not allow the country to surpass Italy's cumulative installed capacity before the end of 2024.

3.2.2.3.1. *Electricity*

France's energy strategy is beginning a transition period in which the government plans to reduce the country's reliance on nuclear energy. Unlike Germany, France has been slow in adopting renewable energy technologies. Due to its large installed nuclear power capacity, the country has a low carbon footprint and therefore has not been as affected as other European countries by the introduction of carbon reduction targets. However, in July 2015, France announced a plan to reduce its dependence on nuclear energy from 75% of its electricity mix to 50% while keeping its carbon footprint in check. Soon afterwards, an increase of between 10% and 20% in the FIT rate for biogas electricity was announced.

As a result of the new support, biogas electricity generation capacity in France is expected to grow at a 6.8% CAGR between 2015 and 2024 to 776 MW.

3.2.2.3.2. *RNG*

The RNG market in France is underdeveloped and, unless policy supporting it within the transport sector changes, it is unlikely to develop. The current RNG production capacity is 0.4 Bcf per year and is expected to reach 0.7 Bcf per year at the end of 2024 at a 4.3% 2015–2024 CAGR.

3.2.2.4 United Kingdom

Gross raw biogas production capacity in the United Kingdom is projected to reach 92 Bcf per year in 2024. This represents a 27% increase over production capacity in 2014 and a 2.4% CAGR between 2015 and 2024. The U.K. government is currently reassessing all of its FITs. If a significant shift happens, the biogas industry outlook in the country could change drastically.

3.2.2.4.1. *Electricity*

The United Kingdom had an installed capacity of 1,155 MW at the end of 2014, and it is expected to grow at a 2.2% CAGR between 2015 and 2024 to 1,458 MW.

The U.K. government supports biogas electricity generation with a FIT, which is currently set at between £0.1013/kWh ($0.16/kWh) for plants with a capacity of less than 250 kW and down to £0.0868/kWh ($0.13/kWh) for plants between 500 kW and 5 MW. The U.K. FIT system has a degression system in place; the tariff drops by 10% if new capacity additions of under 500 kW pass 4.5 MW per year, and 20% if additions pass 9 MW. For plants over 500 kW, the limits are 38.4 MW and 76.9 MW for the 10% and 20% tariff degressions. This system limits future biogas growth significantly.

3.2.2.4.2. RNG

The United Kingdom had an RNG production capacity of 3 Bcf per year in 2014 and is expected to reach 4 Bcf per year in 2024 at a 5.4% CAGR between 2015 and 2024.

Most of the RNG is injected into the grid and used as a heat source under the Renewable Heat Initiative. Within this scheme, the government pays £0.075/kWh ($0.03/cubic feet) for the first 40,000 MWh injected in the grid in a year, £0.044/kWh ($0.02/ cubic feet) for the next 40,000 MWh, and £0.034/kWh ($0.015/ cubic feet) thereafter.

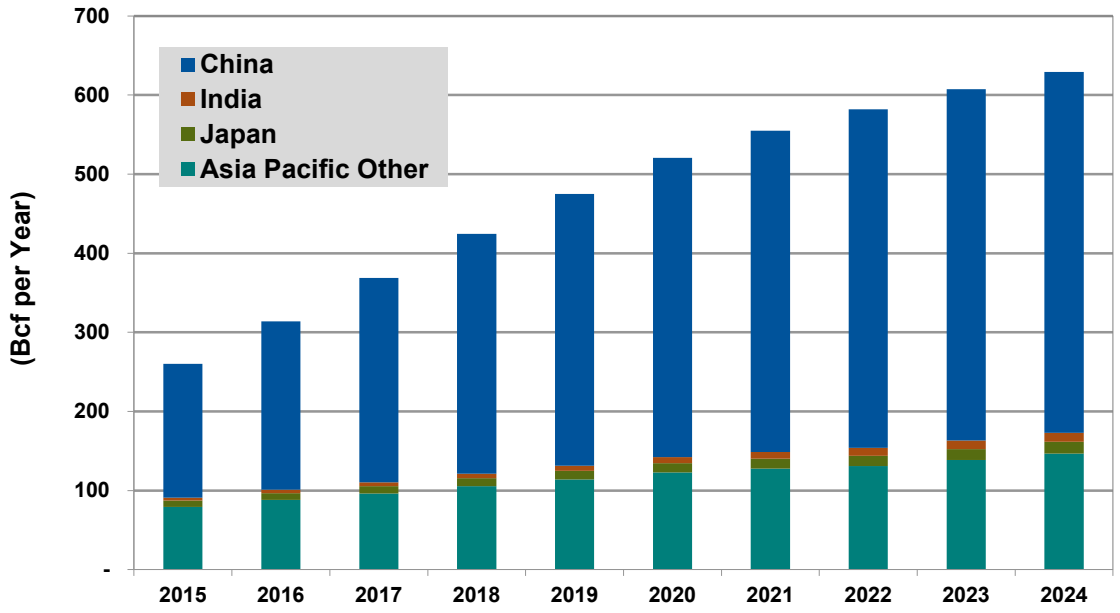
3.2.3 Asia Pacific

Asia Pacific production capacity is expected to reach 629 Bcf per year by 2024 as improved urban waste management and wastewater treatment facilities come online. Although leading global growth in biogas production capacity, biogas industry expansion in China and India (as well as other developing countries) is expected to be tempered by a lack of infrastructure and not enough financing to keep pace with rapid urbanization. Asia Pacific biogas production capacity surpassed North America in 2014 when it produced 212 Bcf per year, giving it the second-largest share of the global biogas market.

Among all regions, Asia Pacific's biogas production capacity growth remains the biggest wild card. With rapid urbanization, growing demand for sanitation infrastructure, and 44% of the global urban population, the region is sitting on the greatest potential for biogas capture worldwide. Currently, the commercial (medium- and large-scale) AD and LFGTE markets are underdeveloped, while small-scale residential digesters used for cooking and home heating are widely deployed throughout China and India. With improved waste management policies, infrastructure, and increased investment, biogas growth in Asia Pacific has the potential to dwarf growth in all other regions over the next decade.

Across the region, all industry segments are expected to see some growth over the forecast period as waste management and sanitation infrastructure gradually improve. The waste industry segment is projected to represent 50% of biogas production capacity in Asia Pacific during 2024, 29% is expected to come from agricultural residues, and 19% from sewage. Overall, Asia Pacific biogas production capacity is expected to account for 29% of total installed production capacity worldwide by 2024.

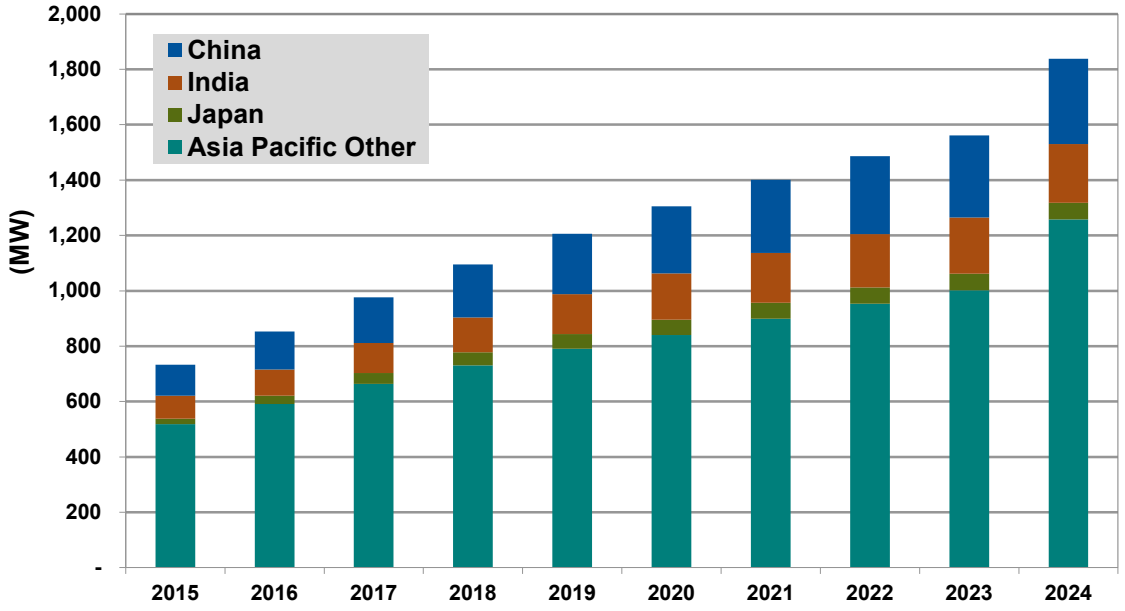
Chart 3.12 Annual Raw Biogas Production Capacity by Country, Asia Pacific: 2015-2024



(Source: Navigant Research)

The installed biogas electricity generation capacity in Asia Pacific is expected to reach nearly 2 GW by 2024, up 165% from installed capacity in 2014, or a 10.8% CAGR between 2015 and 2024.

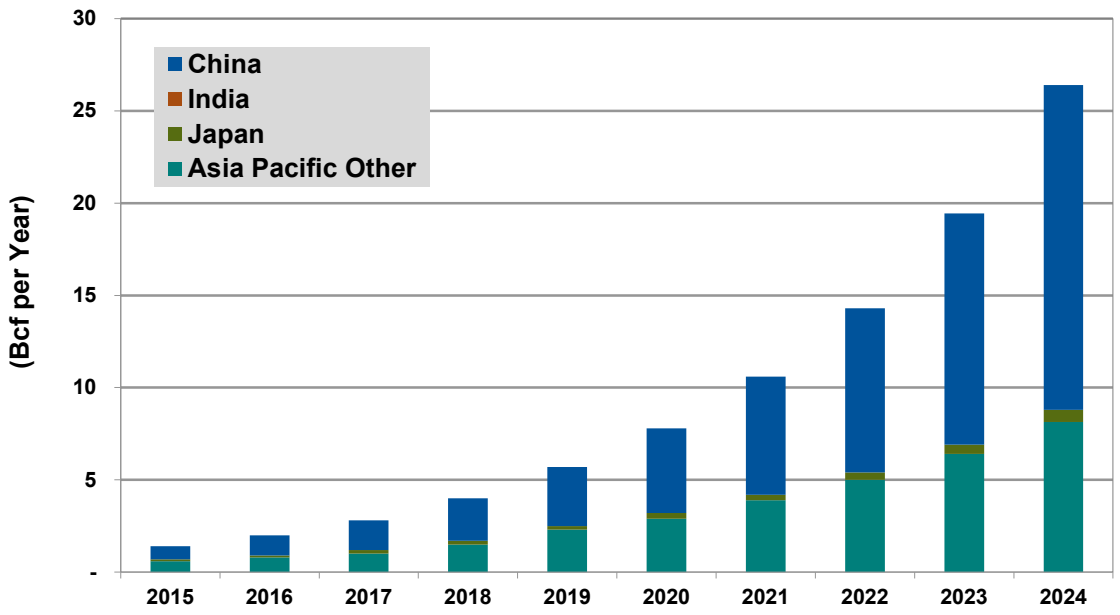
Chart 3.13 Installed Biogas Electricity Generation Capacity by Country, Asia Pacific: 2015-2024



(Sources: Navigant Research, International Renewable Energy Agency, U.S. Environmental Protection Agency)

The RNG production capacity in Asia Pacific was 1 Bcf per year in 2014. Capacity is expected to reach 26 Bcf per year by the end of the forecast period at a 38.6% 2015–2024 CAGR.

Chart 3.14 Annual RNG Production Capacity by Country, Asia Pacific: 2015-2024



(Source: Navigant Research)

3.2.3.1 China

Gross raw biogas production capacity in China is projected to reach 456 Bcf per year in 2024. This represents a 250% increase over production capacity in 2014 and an 11.7% CAGR between 2015 and 2024.

3.2.3.1.1. Electricity

China had an installed capacity of 89 MW at the end of 2014, a figure that is expected to grow at an 11.9% CAGR between 2015 and 2024 to 308 MW.

Although China has a long-established program to promote digesters in rural households, commercial-sized projects are mainly demonstration projects developed under the United Nations Framework Convention on Climate Change Clean Development Mechanism (UNFCC CDM). The potential for AD in the agricultural value chain is huge, but it has been limited by a poorly implemented incentive scheme. China offers a ¥0.225/kWh ($0.04/kWh) premium over the cost of the provincial price of desulfured coal power, but grid companies are only obliged to connect projects over 500 kW, limiting potential biogas projects significantly.

China's biogas to electricity is dominated by LFGTE projects. The Standard for Pollution Control on the Landfill Site of Municipal Solid Waste (GB16889-2008) states that LFG recovery facilities and flare systems have to be installed when the landfill design capacity are more than

2.5 million tons and the landfill body depth is more than 20 meters. For small-scale landfill, the flare or other measures to reduce methane emissions should be also used. LFGTE gives landfill managers an option to profit from the systems they have to install.

3.2.3.1.2. RNG

China had an RNG production capacity of 0.5 Bcf per year in 2014 and is expected to reach 17.6 Bcf per year in 2024, at a 43.1% 2015–2024 CAGR.

China does not have a specific target for RNG injection nor policies supporting RNG in transport. Yet, some growth is expected because the country has one of the largest NGV fleets in the world and the refilling infrastructure in place, making it an ideal place for RNG in transport. Sales of more than 6 million NGVs are expected in China by 2024.

3.2.3.2 India

Gross raw biogas production capacity in India is projected to reach 11.4 Bcf per year in 2024. This represents a 280% increase over production capacity in 2014 and a 13.4% CAGR between 2015 and 2024. This is the highest CAGR for biogas production capacity in any country, although it starts from a very low base.

3.2.3.2.1. Electricity

India had an installed capacity of 72 MW at the end of 2014, and it is expected to grow at an 11.1% CAGR between 2015 and 2024 to 212 MW.

As in China, LFGTE dominates biogas electricity generation capacity. Incentives for LFGTE are set project by project based on the guidelines set by the Central Electricity Regulatory Commission. The country is targeting 350 MW by the end of 2017, but at the current growth rate, it is unlikely India will achieve this goal.

3.2.3.2.2. RNG

India does not have any policy supporting RNG for either heat or transport; therefore, this sector is not expected to develop before 2024.

3.3 Conclusions and Recommendations

The biogas market is moving away from its traditional markets—LFGTE globally and agricultural and industrial AD in Europe—as the best sites are developed and European countries reduce their industry incentives. This industry has attempted to move into other regions that offer good potential, like North America and Asia Pacific, but the lack of supporting policies and general public awareness is slowing down development. Other regions, like Latin America and the Middle East & Africa, are not at a point where they could offer significant growth.

The biogas industry is also looking at new markets that could offer some potential. Two markets in which RNG could have an impact are transport and domestic heating. The transportation market is looking for ways to reduce its environmental impact as current solutions, such as

biofuels and electric vehicles (EVs), are neither optimal (in the case of biofuels) nor at the necessary scale to make a difference in the short to medium term (in the case of EVs). RNG—piggybacking the NG infrastructure—can at least be used as a transitional fuel.

In the long term, higher growth in the biogas market will depend on a combination of technical improvements and the sector's ability to find and develop untapped opportunities. The latter is key, as the industry's natural fragmentation means that significant efforts are necessary for new markets—either regional or new end uses like transportation—to reach a point in which all stakeholders are aligned. Farmers must be comfortable with the technology, developers must understand the available technologies and farmers' needs, investors must understand specific sector risks such as feedstock and offtake risks, and structures must be set in place to ensure the project's bankability so investment can take place. On the technical side, breakthroughs in feedstock conversion rates, especially for feedstock with high cellulose content, and innovation around control systems are necessary to improve the competitiveness of biogas and unlock the potential of higher-cost resources.

3.4 Biogas Forecasts by Segment

Navigant Research forecasts deployments across four key sources or segments: waste (landfills), industrial processes (e.g. food processing, slaughterhouses, breweries, etc.), agriculture (residues and crops), and sewage treatment. Production capacities are an estimate of nameplate capacity that a developer or plant owner would report. Nameplate capacity projections usually assume that plants operate 8,760 hours per year, which is unlikely. Plant operation rates vary significantly depending on technology reliability and operation expertise, feedstock availability, and end-product demand.

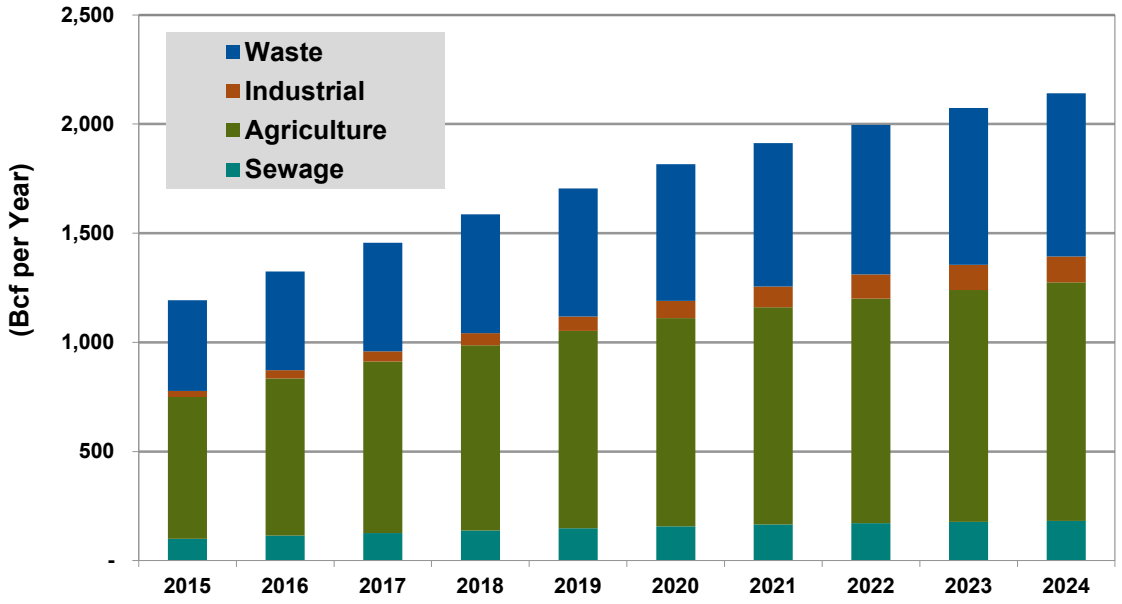
It is expected that the biogas industry will double in size during the next 10 years. Global capacity is estimated at 1,194 Bcf per year in 2015—NG equivalent—and it is expected to grow to 2,142 Bcf per year by 2024 at a compound annual growth rate (CAGR) of 6.7%. To put it in perspective, according to the U.S. Energy Information Administration, the world consumed 119,697 Bcf per year in 2012 (biogas could represent 1.8% of the NG market in 2024 if demand remained at the same level—which is unlikely).

Although biogas capture from waste (landfill gas, or LFG, recovery projects and anaerobic treatment of organic municipal solid waste) has historically accounted for the greatest raw biogas production capacity globally, an acceleration of on-farm AD installations in recent years resulted in agriculture biogas accounting for the greatest share of raw biogas production among all industries in 2014. Growth in agriculture waste biogas production was encouraged by a supportive policy environment in Germany and Italy that has been curtailed. Together, LFG and agriculture accounted for 90% of all the biogas production in 2014, but they are expected to grow the least compared to other sources in the next 10 years. The 2015–2024 production capacity CAGR is expected to be 6.7% for the waste segment and 6.0% for the agriculture segment.

The sewage segment, like the waste and agriculture segments, is relatively mature, and the majority of opportunities in the countries analyzed have been tapped. Most opportunities in this segment will come from developing countries, particularly in the Asia Pacific region, which represented about 66% of the market in 2014.

Based on projections, growth in biogas production from industrial organic waste is expected to lead all industries with a 17.5% CAGR, reaching 119 Bcf per year in 2024. This will represent 6% of production across all industries in 2024, up from 2% in 2014. The industrial segment will benefit from the shift in consumer behavior in developed countries to food products and production methods with a low environmental impact. Worldwide, the food industry is diverting its waste stream away from disposal and into onsite utilization.

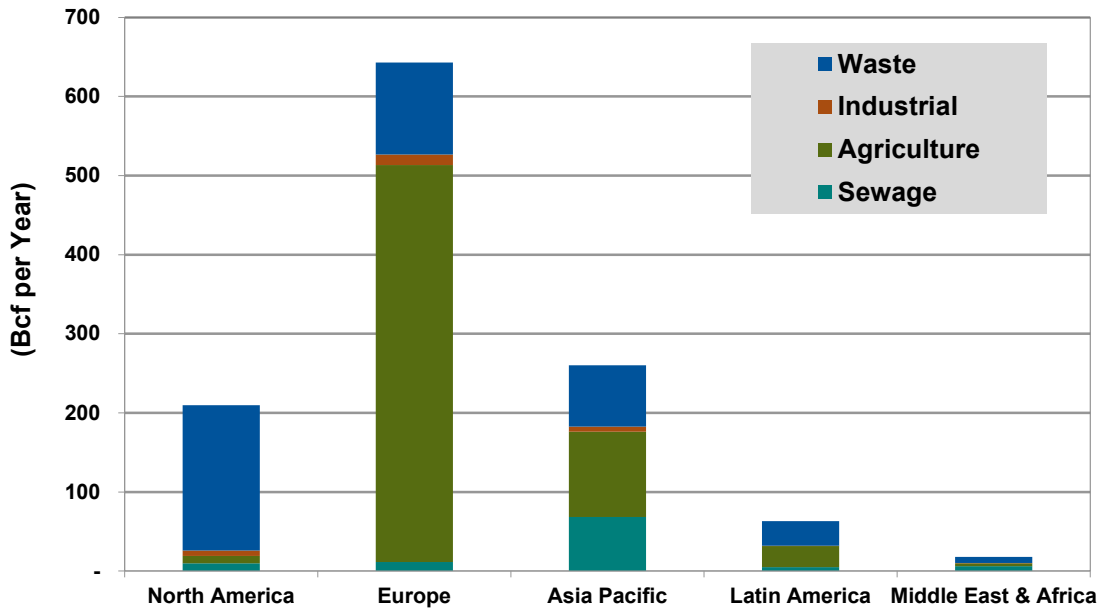
Chart 3.15 Annual Raw Biogas Production Capacity by Segment, World Markets: 2015-2024



(Source: Navigant Research)

All regions remain primarily focused on agriculture and waste applications. Biogas production in North America is skewed toward waste, relying on its policy mandating gas recovery systems in landfills. On the other side of the scale, Europe's production is based mainly on agricultural products. This situation is unique, as the use of grains and silage is not allowed in most countries. However, Germany's and Italy's decision to incentivize the production of biogas from energy crops (including grains and silage) helped to develop the agriculture segment in the region.

Chart 3.16 Annual Raw Biogas Production Capacity by Region and Segment, World Markets: 2015

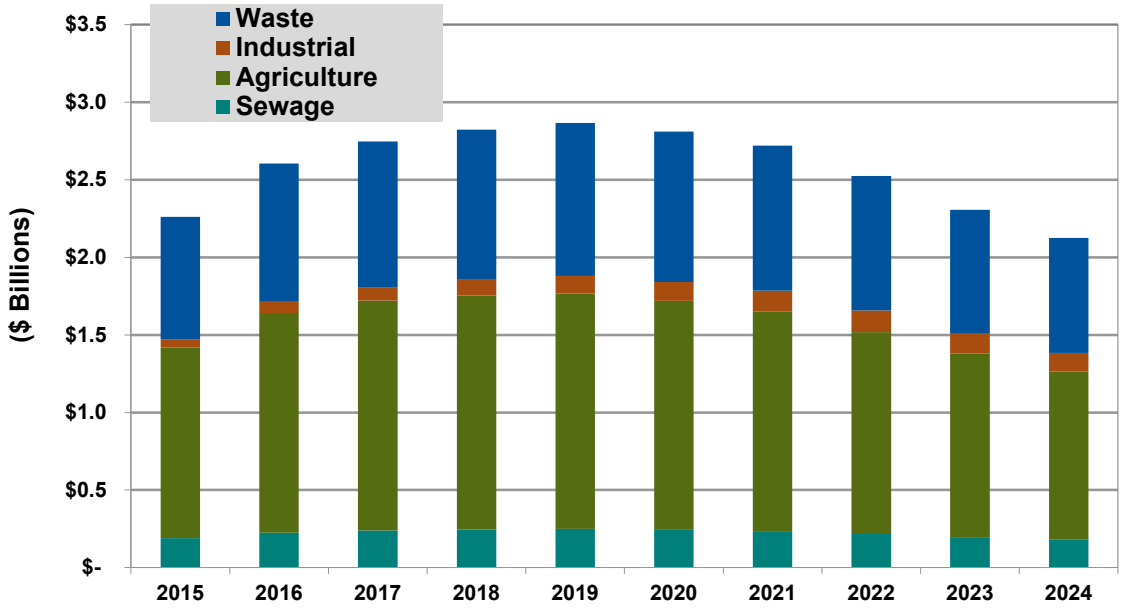


(Source: Navigant Research)

Global cumulative revenue generated by investment in biogas production infrastructure—excluding electricity generators, gas upgrading equipment, and its associated infrastructure—is projected to total $25.8 billion in the 10 years between 2015 and 2024. Most of the revenue is expected to come from the agriculture ($13.7 billion) and waste ($8.9 billion) segments.

Global annual revenue will average $2.6 billion, peaking at $2.9 billion in 2019 before dropping to $2.1 billion in 2024. Opportunities in the waste and agricultural sectors are expected to become scarcer and policy support will gradually be reduced.

Chart 3.17 Annual Biogas Market Revenue by Segment, World Markets: 2015-2024



(Source: Navigant Research)

Section 4

ACRONYM AND ABBREVIATION LIST

AD	Anaerobic Digester/Digestion
Bcf	Billion Cubic Feet
CAGR	Compound Annual Growth Rate
CDM	Clean Development Mechanism
CH_4	Methane
CI	Carbon Intensity
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
D3 RIN	Cellulosic Biofuel Credit
D5 RIN	Advanced Biofuel Credit
EPA	Environmental Protection Agency (United States)
EU	European Union
EV	Electric Vehicle
FIT	Feed-In Tariff
gCO_2e/MJ	Grams of Carbon Dioxide Equivalent per Megajoule
GW	Gigawatt
IEA	International Energy Agency
kW	Kilowatt
kW	Kilowatt
kWh	Kilowatt-Hour
kWh	Kilowatt-Hour
LCFS	Low Carbon Fuel Standard
LCOE	Levelized Cost of Energy

LFG	Landfill Gas
LFGTE	Landfill Gas-to-Energy
LNG	Liquefied Natural Gas
MW	Megawatt
MWh	Megawatt-Hour
NG	Natural Gas
NGV	Natural Gas Vehicle
RFS2	Renewable Fuel Standard
RIN	Renewable Identification Number
RNG	Renewable Natural Gas
U.K.	United Kingdom
U.S.	United States
UNFCC	United Nations Framework Convention on Climate Change

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SCOPE OF STUDY

Navigant Research has prepared this report to provide participants within the power generation and NG markets—including biogas producers, feedstock suppliers, equipment manufacturers, service providers, researchers, and investors—with market forecasts of raw biogas capacity from landfills, industrial, agricultural, and sewage facilities. The study's primary objective is to assess the market size and anticipated growth of electricity generated from biogas and RNG production for power and transportation applications. All major global regions are included, and the forecast period extends through 2024.

SOURCES AND METHODOLOGY

Navigant Research's industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Navigant Research's analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Navigant Research's analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Navigant Research's reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

Navigant Research is a market research group whose goal is to present an objective, unbiased view of market opportunities within its coverage areas. Navigant Research is not beholden to any special interests and is thus able to offer clear, actionable advice to help clients succeed in the industry, unfettered by technology hype, political agendas, or emotional factors that are inherent in cleantech markets.

NOTES

CAGR refers to compound average annual growth rate, using the formula:

CAGR = (End Year Value ÷ Start Year Value)$^{(1/steps)}$ – 1.

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenues, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2015 U.S. dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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