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HARNESSING THE UNTAPPED ENERGY POTENTIAL OF AMERICA'S HEARTLAND

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Surging global demand for lower-carbon marine fuels creates a golden opportunity for the United States to cement its leadership as the preeminent supplier of global liquefied natural gas — if it moves decisively now.

By Michael O'Laughlin

Michael O'Laughlin is the Chief Executive Officer of Vanguard Renewables. He leads the company's national expansion as the leader in domestic clean energy and environmental services, with over $2 billion planned capital deployment by 2029. Mr. O'Laughlin brings a combination of entrepreneurship and blue-chip experience to drive Vanguard Renewables' accelerated growth and operational excellence.

Vanguard Renewables is a leading U.S. environmental services company and producer of biomethane from organic waste. Headquartered in Weston, Massachusetts, the company builds, owns, and operates on-farm anaerobic digesters that convert food, beverage, and agricultural waste into pipeline-ready renewable natural gas. Vanguard Renewables is rapidly scaling its national footprint, with operational sites across the Northeast and new facilities under construction in the Midwest and South. By diverting organic waste streams from landfills, the company is reducing greenhouse gas emissions at scale while supporting critical domestic energy infrastructure and regenerative agriculture for America's farms. Vanguard Renewables is a portfolio company of Global Infrastructure Partners (GIP), part of BlackRock.

INTRODUCTION

Liquefied natural gas is a critical component of the U.S. strategy to achieve global energy dominance. Over the past decade, the U.S. has gone from selling scarcely any LNG to becoming the largest exporter in the world, hitting a record in 2025.[1]

As the U.S. looks to build on this momentum and serve additional markets, the maritime industry is emerging as one of the most significant future consumers of LNG. The global market for sustainable marine fuel is projected to grow from approximately $13 billion in 2024 to $836 billion by 2034.[2] For reference, the total global LNG export market was $105 billion in 2024.[3] By 2050, LNG could make up half of all maritime fuel, driven by global demand for reliable, lower-carbon alternatives.[4] However, LNG alone cannot satisfy long-term expectations for reduced emissions. Bio-LNG, a drop-in fuel derived from renewable natural gas, will be essential in making LNG the preferred fuel for the maritime industry. Blending bio-LNG with conventional LNG enables maritime operators to meet international requirements using a drop-in option that works with existing vessels and infrastructure.

America's heartland has a major role to play. New research into the production capacity of RNG has uncovered a previously untapped source, primarily in Midwestern states. Collectively, the region's economically viable agricultural waste (such as livestock manure and crop residues) and food waste provide enough feedstock to produce RNG equal to about 4.3% of U.S. natural gas consumption, or approximately 1,580 trillion Btu (British thermal units)—more than eight times the current RNG market (see sidebar, "About the research").[5, 6, 7]

Turning feedstock into RNG will require infrastructure investments that could unleash a wave of job creation in rural communities and enable farmers to generate $1.1 billion to $2 billion in additional revenues each year.[8] Farms ranging from small dairy operations to large producers could take advantage of this opportunity, drawing on a new revenue source to substantially bolster their financial resilience.

Capturing the full value at stake will require coordinated action from policymakers, farmers, agricultural associations, private investors, and local communities. A successful push will increase both production and export capacity — giving the U.S. another lucrative channel to extend its global LNG leadership.

SIDEBAR

ABOUT THE RESEARCH

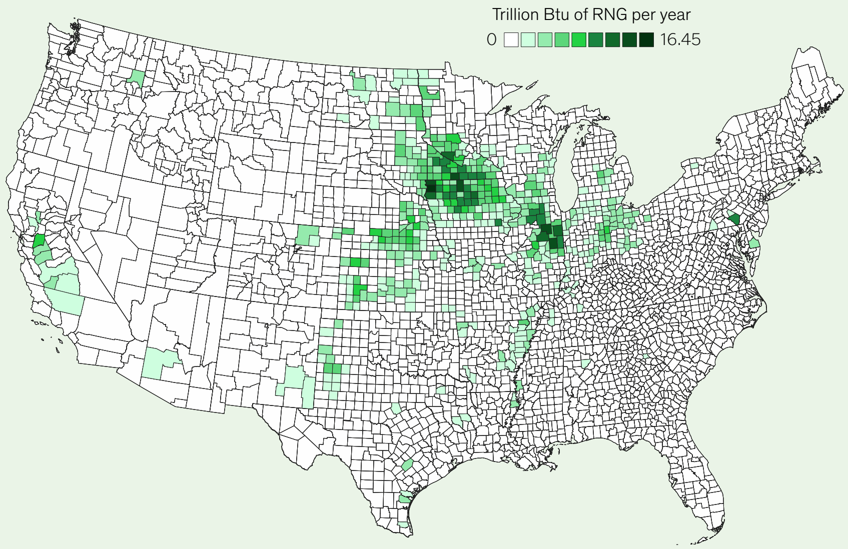
Producing renewable natural gas from agricultural or food waste is a growing option to offer markets a lower-carbon-intensity fuel compared to using landfill or wastewater sludge as feedstocks. To determine the size of the opportunity, we evaluated all available agricultural feedstocks (crop residues, dairy and swine manure, nondairy cattle manure, and poultry manure) and food waste.

Our analysis found that approximately two-thirds of U.S. counties have enough agricultural feedstocks to produce more than 10,000 MMBtu (million British thermal units) a year, with the greatest concentration of opportunity in the Midwest.[1] To assess only viable sources, we excluded feedstocks located more than 10 miles from an existing natural gas pipeline and volumes too small to support scale. This process quantified the economically viable potential of agricultural feedstocks to produce 1,444 trillion Btu across the United States (exhibit).[2]

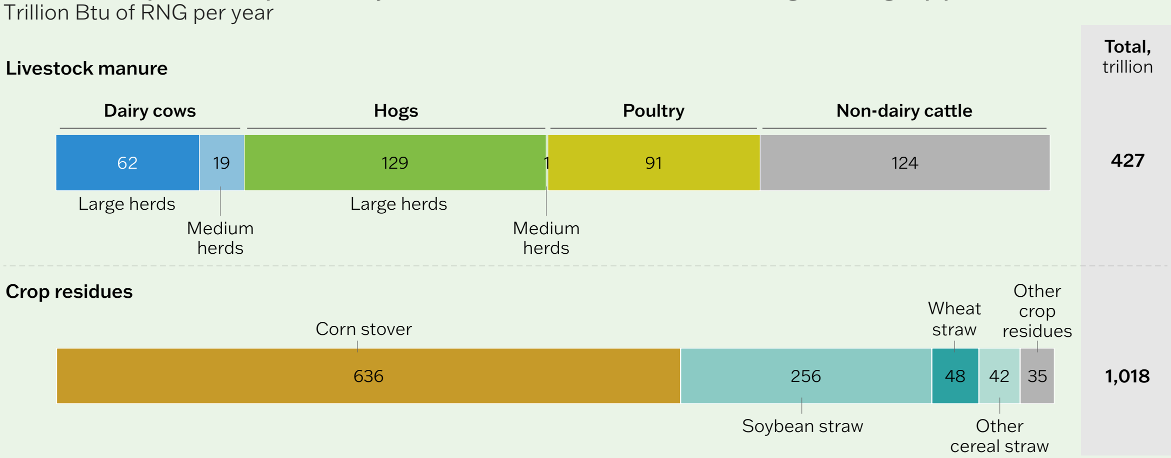
EXHIBIT

After strict filtering for project feasibility, there is still substantial RNG potential from ag waste.

Feasible RNG production potential from agricultural residues within 10 miles of an existing natural gas pipeline (1,444 TBtu)



Feasible RNG production potential by feedstock, within 10 miles of an existing natural gas pipeline,
Trillion Btu of RNG per year



Note: RNG is renewable natural gas.
Source: USDA National Agricultural Statistics Service, MAPSPAM, FAOSTAT, FAO Gridded Livestock of the World, American Biogas Council, American Gas Association, Argonne National Lab, EPA AgSTAR, EIA, USDA Census, USDA ERS

The United States generates approximately 40.5 million tons of food waste annually. Food waste can be processed through co-digestion with manure, making small and midsize dairy operations ideal locations for siting RNG production. This feedstock is projected to contribute an additional 136.6 trillion Btu, bringing the total viable potential to approximately 1,580 trillion Btu.[3]

[1] See endnotes for analysis of feasible RNG potential from livestock manure and crop residues.

[2] National Agricultural Statistics Service, Quick Stats, 2022, https://quickstats.nass.usda.gov/; International Food Policy Research Institute, "Global Spatially-Disaggregated Crop Production Statistics Data for 2010 Version 2.0," Harvard Dataverse, 2019, https://doi.org/10.7910/DVN/PRFF8V; FAOSTAT, http://www.fao.org/faostat/en/; Tévécia Ronzon and Stephan Piotrowski, "Are Primary Agricultural Residues Promising Feedstock for the European Bioeconomy?," *Industrial Biotechnology* 13, no. 3 (2017): https://doi.org/10.1089/ind.2017.29078.tro; Vassilis Daioglou et al., "Projections of the availability and cost of residues from agriculture and forestry," *Global Change Biology Bioenergy* 8, no. 2 (2016): https://doi.org/10.1111/gcbb.12285; Economic Research Service, "Livestock and Meat Domestic Data," updated Sept. 30, 2025, https://www.ers.usda.gov/data-products/livestock-and-meat-domestic-data; Jessie Birman et al., *Geographical analysis of biomethane potential and costs in Europe in 2050*, ENGIE, May 2021; University of Minnesota Extension, "Crop residue management," 2021, https://extension.umn.edu/corn-harvest/crop-residue-management; M. Mintz and M. Lerner, *Database of Renewable Natural Gas (RNG) Projects: 2023 Update*, Argonne National Laboratory, July 2024, https://www.anl.gov/esia/reference/renewable-natural-gas-database; U.S. Environmental Protection Agency, LMOP Landfill and Project Database, September 2024, https://www.epa.gov/lmop/lmop-landfill-and-project-database; U.S. Environmental Protection Agency, Livestock Anaerobic Digester Database, June 2024, https://www.epa.gov/agstar/livestock-anaerobic-digester-database; American Biogas Council, "Biogas State Profiles," https://americanbiogascouncil.org/resources/state-profiles/; U.S. Energy Information Administration, Natural Gas Interstate and Intrastate Pipelines, 2024.

[3] See endnotes for analysis of feasible RNG potential from livestock manure and crop residues.

FACTORS DRIVING EXPORT DEMAND IN MARITIME

Today, the world's shipping fleet relies primarily on traditional fossil fuels, with LNG supplying only about 4% to 6% of the industry's total fuel consumption. As the maritime fuel market expands and diversifies, LNG and bio-LNG are expected to play a significantly larger role. Our analysis projects that LNG could supply 50% of the maritime fuel mix by 2050, with bio-LNG contributing an additional 13% (Exhibit 1).

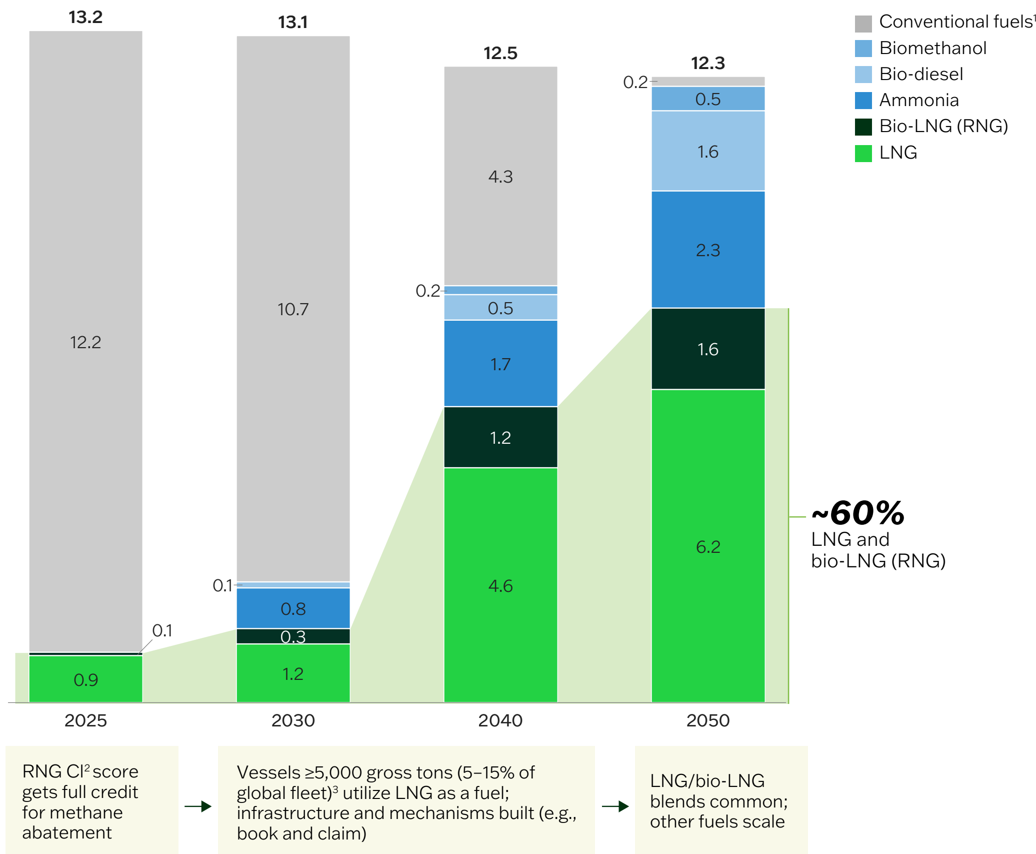
LNG is well positioned to become the fuel choice of maritime operators. Bio-LNG is essential to this trajectory because it allows LNG to maintain its competitiveness in a low-carbon market. Bio-LNG is fully compatible with existing LNG systems, and even modest blending helps shipping companies meet lower-carbon international requirements. This compatibility creates a high-value export product that strengthens the long-term outlook for U.S. LNG.

The United States is better positioned than any global competitor to support the massive growth opportunity ahead. The country produces only 5% of the world's supply of very low sulfur fuel oil diesel but already accounts for roughly 35% of global LNG production. As the maritime industry shifts from diesel to LNG, the U.S. can capture a significant share of the expanding fuel market. The existing network of approximately 3 million miles of natural gas pipelines and robust liquefaction capacity can support increased production to meet demand.

EXHIBIT 1

Bio-LNG and LNG could account for 60% of the global maritime shipping fuel mix — if bio-LNG receives credit for methane abatement.

Maritime shipping fuel mix, exajoules



[1]Low sulfur fuel oil, high sulfur fuel oil, marine gas oil, marine diesel oil. [2]Carbon intensity (CI) score (gCO e/MJ). [3]Uses emission generation concentration (~85% of emissions driven by ships 5,000 GT, ~47% of global fleet) to estimate the percent of ships in the global fleet that would need to use LNG. Uses potential fuel weighting to estimate range of fleet conversion need.
Source: Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, Lloyd's Register, SEA LNG

In fact, the U.S.'s swift ascent to LNG leadership clearly demonstrates that rapid scaling and the attendant benefits are well within reach. The country grew from a marginal LNG exporter in 2016 to the world's largest supplier in 2024, less than a decade later. By applying a similar playbook to RNG, the U.S. could secure new markets, extend its influence in global shipping, reduce foreign dependence, and solidify its energy leadership for decades to come.

The global maritime industry has implemented regulations for decarbonization that will create an enduring demand for biofuels, which can be used to offset carbon from shipping activities. The EU Emissions Trading System for shipping extends Europe's "cap and trade" system to include greenhouse gas emissions from vessels exceeding 5,000 gross tonnage that dock at EU or European Economic Area ports.[9] As a result, maritime operators have direct financial liability for emissions, creating incentives to reduce their carbon footprint.

In addition, the FuelEU Maritime Regulation, which went into effect on Jan. 1, 2025, mandates the gradual uptake of renewable and low-carbon fuels and the use of onshore power supply in ports starting in 2030, in part by providing credit for the carbon abatement of renewable fuels.[10, 11] This regulation has the effect of discouraging shippers from refueling in the United States because doing so does not result in carbon-abatement credit.

SIZING THE OPPORTUNITY FOR AMERICA'S HEARTLAND

If the United States were to harness the potential of agricultural and food waste for RNG production, meeting increased demand from the maritime industry could generate substantial national and local economic benefits.

Agricultural and food waste is converted into renewable natural gas through anaerobic digestion. Organic materials such as livestock manure, crop residues, and food waste are placed in sealed tanks, where they are broken down by microbes to produce biogas. That biogas is then upgraded into pipeline-quality RNG, while the remaining material can be used as nutrient-rich fertilizer replacement.

This pathway allows farmers and food producers to turn organic-waste streams into energy while reducing methane emissions and creating new revenue and economic development opportunities.

SIGNIFICANT NEW REVENUE FOR FARMERS

Producing RNG from agricultural waste could provide a critical new revenue source for farmers: between $1.1 billion and $2 billion in additional annual revenue, or a total of $105 billion to $185 billion through 2050 (Exhibit 2).[12]

Farmers could increase revenues by supplying crop waste to RNG facilities; in 2025, a challenging year, Midwestern row crop farmers could have reduced losses by nearly one-third by using this strategy.[13] For example, after accounting for potential cost savings from displacement of synthetic nitrogen fertilizers, a corn or soy operation hosting an RNG project could approach breakeven, even in a subpar year.

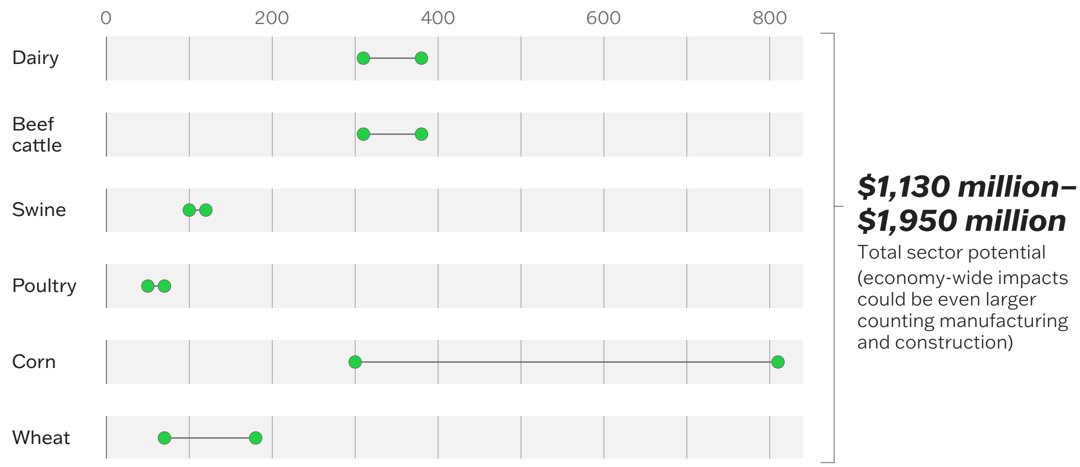
Exploring RNG potential at the state level: Ohio deep dive. Our research analyzed individual Midwestern states to quantify the opportunity. Ohio provides a useful example, as it has already established a robust foundation for RNG production. The state currently produces 10.3 trillion Btu of RNG annually with feedstocks consisting entirely of food waste, landfill gas, and wastewater.[14] By drawing on abundant crop residues and livestock manure, Ohio could produce 74.5 trillion Btu of RNG annually — a sevenfold increase over its current production.[15]

Existing facilities could add agricultural residues into their feedstock mix, using co-digestion, to expand production while diversifying the feedstock base. A shift toward agricultural feedstocks would help diversify Ohio's RNG feedstock portfolio while significantly reducing methane emissions from manure, crop waste, and local food waste streams.

EXHIBIT 2

If fully developed, the US ag sector could add approximately $1.1 billion to $2 billion to farm revenue per annum.

Annual sector potential range by livestock category, $ million per year



Drivers of variation

Within livestock categories, variability in stipend per head (or per ton of manure) drives range. Market rates have fluctuated especially with RINs/LCFS credit prices.

Within crop categories, variability/uncertainty of fraction of residues that can be sustainably removed from croplands drives range.

Between categories, differences stem from scale of economically feasible potential and the chemical potential associated with the feedstock.

Food waste as an economic engine for small to midsize dairy farms. Farmers also have the opportunity to host anaerobic digesters that process food waste. The United States produces roughly 40.5 million tons of food waste annually, representing approximately 24% of the municipal solid waste that ends up in landfills.[16] This food waste further contributes 58% of methane emissions from landfills. Co-digestion with dairy manure represents a better way to repurpose food waste, and ample siting opportunities exist.[17]

More than 90% of the approximately 36,000 dairy farms in the U.S. have 500 or fewer dairy cattle. Together, these smaller farms account for about one-quarter of total dairy farm value.[18] Extending the RNG opportunity to this segment through access to anaerobic digesters would enable more farmers to participate in RNG markets.

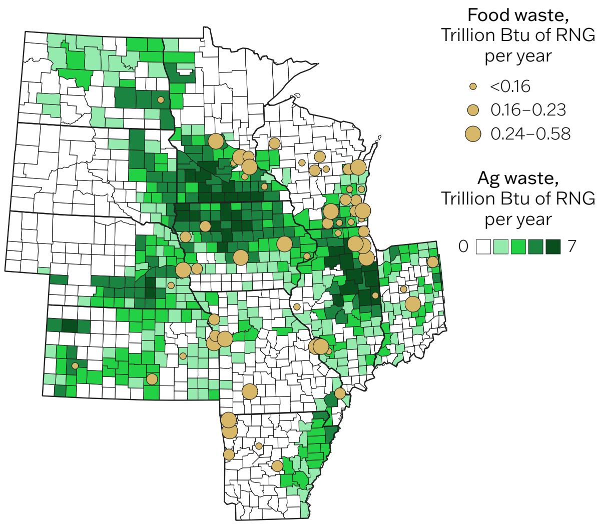
Jordan Dairy Farms in Rutland, Massachusetts, illustrates the benefits. With 800 head of cattle and 700 turkeys, the farm produces more than 9,000 pounds of manure each year, which it combines with 20,000 pounds of food and beverage waste from food processors. Biodigesters on the farm process these materials into 8,000 megawatt-hours of renewable energy annually while abating methane emissions through landfill diversion.[19] The example reinforces both how food waste offers a reliable feedstock source and how smaller dairy farmers can form long-term partnerships to host RNG production.

The Midwest as a hotbed of RNG production. Our analysis identified 10 counties with co-incidence of both food waste and agricultural waste RNG potential. Most are located in the

EXHIBIT 3

The Midwest shows high synergy potential for co-digestion of food and agricultural waste.

Feasible RNG production potential from food waste[1] and ag waste,[2] Trillion Btu of RNG per year



Top 10 Midwest counties by RNG production potential from food waste[1] and ag waste,[2] Trillion Btu of RNG per year

Total U.S. food waste amounts to 40.5 million tons annually, translating to ~136.6 TBtu of RNG potential

Industrial sources account for 32 million tons (~79%) of total food waste, with retail contributing 8.5 million tons (~21%)

The top 10 counties with the highest overlap of food and agricultural waste represent 1% of the national potential

- 22% of RNG potential in these counties comes from food waste
- 90% of food waste in these counties originates from industrial sources

[1]Includes ag-waste potential from mid-sized dairy farms, mid-sized swine farms, and crop residues. [2]Includes counties where total food waste is between 100 and 500 tons per day.

Midwest (Exhibit 3).[20] A look at Stearns County, Minnesota, the top-ranked county in the United States for availability of both food waste and agricultural waste to fuel RNG production, reinforces the potentially far-reaching benefits.[21] Food waste accounts for the majority of the county's 3.77 trillion Btu in potential RNG production.[22] In 2022, the county had nearly 2,700 farms in operation, with about 70% focused on livestock, poultry, and products.[23] Since 95% of these farms are operated by families, additional revenue from RNG production could not only contribute to their bottom line but also stimulate economic activity in the surrounding community.

JOB CREATION ACROSS MARKETS

Expanding RNG production to meet maritime demand would substantially increase job growth across the entire natural gas value chain. Investments could create new jobs in farming communities, energy infrastructure, and transportation, and these new projects would mobilize construction crews, engineers, and heavy equipment operators across the country (Exhibit 4).[24] By 2050, this economic activity could create 390,000 to 680,000 jobs across the sectors supporting the build-out, including 230,000 to 405,000 jobs to build and operate fuel production facilities and 35,000 to 60,000 from maritime ports and terminals.[25]

EXHIBIT 4

Meeting the demand for biofuels could boost US GDP by a cumulative $2 trillion–$3 trillion and create 390,000–680,000 jobs by 2050.

Low estimate / High estimate

Industry	Cumulative GDP impact by 2050, $ billion	Average annualized GDP impact, $ billion	GDP uplift,[1] %	Workforce impact, thousand
Fuel production	1,000–1,765	53	2.7	230–405
Ports and terminals	200–315	12	0.4	35–60
Ship building	10–20	1	2.1	2–3
Power generation	305–520	7	3.9	55–95
Hydrogen production	300–480	16	2.8	60–100
Agriculture	105–185	6	0.4	0
Rail	30–55	2	1.7	10–20
Total	1,950–3,340	97	0.3	390–680

[1]Calculated as average annualized GDP impact divided by 2024 GDP in each sector.
Source: Calculations based on estimated investment in U.S. infrastructure and U.S. Bureau of Economic Analysis, "Input–Output Accounts Data," Industry Economic Accounts, accessed August 22, 2025, https://www.bea.gov/data/industries/input-output-accounts-data

COORDINATED ACTION IS NEEDED TO ADVANCE US ENERGY DOMINANCE AND SUPPORT AMERICAN FARMERS

Expanded production and export of biofuels could generate $2 trillion to $3 trillion in cumulative GDP by 2050, creating a powerful source of economic growth.[26] Unlocking the full potential of renewable fuels for the maritime industry will require coordinated action across several fronts.

PASS LEGISLATION TO LEVEL THE PLAYING FIELD

A critical gap in current U.S. policy is the exclusion of ocean-going vessels from the Renewable Fuel Standard program. This omission forces refiners to retire valuable renewable identification number credits when biofuels such as RNG are used in maritime applications. This places the United States at a competitive disadvantage in global shipping markets.

The bipartisan Renewable Fuel for Ocean-Going Vessels Act, introduced by U.S. Sens. Pete Ricketts, R-Neb., and Amy Klobuchar, D-Minn., would address this gap by recognizing ocean-going vessels in the RFS. The resulting market expansion would strengthen U.S.

energy dominance, improve long-term competitiveness, and expand markets for farmers and renewable fuel producers. A companion bill in the House of Representatives, introduced by Rep. Mariannette Miller-Meeks, R-Iowa, had 20 bipartisan cosponsors as of November 2025,[27] reflecting broad support for expanding domestic energy production.

The legislation would allow biofuels used for ocean-going vessels to qualify under the RFS. This simple adoption would expand market access for American farmers, enhance American energy security, and create parity for maritime fuels with over-the-road and aviation fuel types in the Renewable Fuel Standard.

These actions are critical to leveling the playing field with FuelEU maritime regulations. Once shippers can refuel in the United States and receive credit for carbon abatement, it will open several new markets for U.S. LNG and bio-LNG producers.

> "At its core, the Renewable Fuel Standard supports American agriculture. **It directly impacts what farmers receive for what they grow.** However, because the RFS excludes ocean-going vessels, the shipping industry is missing out on a proven cleaner fuel."
>
> **—Sen. Pete Ricketts,** Nebraska

To ensure that American farmers can fully capitalize on the economic opportunities for bio-LNG for maritime shipping, the federal government should explore both legislative and regulatory incentives to treat food waste as an eligible feedstock.

ENCOURAGE PUBLIC-PRIVATE PARTNERSHIPS FOR INFRASTRUCTURE INVESTMENT

Meeting maritime fuel demand would require $120 billion to $220 billion of investment in production capacity and delivery infrastructure for U.S. RNG and other advanced fuels.[28] Up to $175 billion would support construction of advanced fuel production facilities, storage tanks, and pipelines, while $25 billion to $45 billion would expand bunkering, terminal, and barging capacity.[29]

This level of investment is ambitious but achievable. In 2024 alone, public and private entities committed a record $265 billion to U.S. clean energy technologies and infrastructure.[30]

Currently, infrastructure investment for the maritime industry is difficult to justify because FuelEU penalizes shippers for refueling in the United States. Establishing a more favorable policy environment would unlock significant spending and position the United States as a critical fueling hub for global shipping. Financing at this scale would require coordination among government, private investors, and the agriculture sector.

EDUCATE STAKEHOLDERS ON THE OPPORTUNITY

Despite the massive potential for RNG to support expanded LNG production and meet rising international demand, many of the stakeholders that stand to benefit most are still unaware of the opportunity. The far-reaching impact of scaled-up production would extend well beyond individual farmers, bringing broader economic benefits to rural communities. Elected officials and policymakers at both the federal and state levels will also need clarity on how RNG can advance national priorities around energy dominance and long-term economic growth. Updating the RFS to counter the impacts of FuelEU and create a more favorable pricing environment would support the significant scale-up of bio-LNG and RNG through farm-based solutions.

Leveraging RNG to expand LNG supply presents a clear triple win — it strengthens U.S. energy leadership in global markets, generates new revenues for farmers and the agriculture sector across the Midwest, and drives sustained investment and job creation in rural communities.

The U.S. already has the components required to capture this opportunity: abundant feedstock, available land, farmers seeking new revenue streams, and private developers and investors ready to scale production. Demand from maritime operators is surging, and the nation's LNG infrastructure is mature and proven. What remains is targeted policy action to update policy frameworks and align incentives.

With timely action, the United States can accelerate deployment, unlock additional export capacity, and reinforce American energy dominance for decades to come.

ENDNOTES

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TECHNICAL APPENDIX

The analytical figures in this paper were generated by conducting geospatial analytics on a variety of publicly available data sources. The following steps outline our approach:

1. Compile a county-level understanding of agricultural activity in the United States, sourcing primarily from the U.S. Department of Agriculture's 2022 census of agriculture.

2. Convert agricultural activity (e.g., head of dairy cattle) into feedstock production (e.g., tons of manure per day) using established rules of thumb published by organizations such as land-grant universities and state-level extension agencies.

3. Convert feedstock volumes into renewable natural gas potential using conversion factors published by organizations such as national laboratories and the Environmental Protection Agency.

4. Subtract the feedstock used for existing RNG projects (sourced from industry associations such as the American Biogas Council and national laboratories) from the total potential.

5. Filter the remaining feedstock potential based on proximity to existing natural gas pipelines and collection feasibility considerations, such as minimum herd size for livestock operations or density of row crop operations.

6. On top of "untapped feasible RNG potential," overlay data on food waste availability adapted from a variety of sources, including EPA and ReFED, refined based on commercial experience.

7. Combine this total potential with per-unit/per-farm economics, estimated by using state-specific crop and livestock budgets from land-grant universities and extension offices to construct bottom-up profit-and-loss statements. This generates an understanding of total economic potential associated with RNG projects.

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