ISSUE BRIEF Transport

COUNCIL OF ENGINEERS FOR THE ENERGY TRANSITION
An independent advisory council to the United Nations Secretary-General

This is an advanced publication currently undergoing peer review

# Unlocking Low-Emission Energy from Waste: A Sustainable Solution for Shipping and Fisheries in Emerging Economies

## Key Messages

- Mismanaged municipal waste poses significant risks to public health, environmental pollution, and methane emissions. It can be transformed, however, into valuable clean fuel to advance sanitation and decarbonization. Waste management is underfunded in many regions, and projects may require a strong business case to prioritize waste treatment initiatives.

- Liquid biomethane (bio-LNG) which can be produced from waste, is a sustainable low-carbon alternative to fossil fuels for the maritime industry and a suitable bunker fuel for LNG-powered ships.

- Organic municipal waste offers a valuable feedstock for producing biomethane, a clean fuel with high decarbonization potential. Producing biomethane from waste is a proven technology widely used in Europe, Brazil, China, and the US. However, at present, it is more expensive to produce than fossil methane, and incentives are crucial for stimulating its production and use.

- A growing demand for bio-LNG in the shipping industry could foster regional cooperation around its manufacture and transport, encouraging the development of clean fuel supply chains in the Gulf of Guinea and beyond.

- Incentives and regulatory support are crucial to make biomethane production financially viable. The International Maritime Organization (IMO) is currently negotiating global rules to ensure the decarbonization of the shipping industry, including introducing a a GHG emissions pricing mechanism. This could make biomethane a competitive option for maritime fuel if the GHG price is high enough.

- Integrating waste management with renewable energy production promotes regional prosperity and addresses Sustainable Development Goals (SDGs), including Goal 1: No Poverty; Goal 3: Good Health and Well-being; Goal 6: Clean Water and Sanitation; Goal 11: Sustainable Cities and Communities; Goal 13: Climate Action; Goal 14: Life Below Water; and Goal 17: Partnerships for the Goals.

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NOV 2024

## Executive Summary

A unique opportunity is emerging for developing countries' port regions to advance climate action and sustainable development. These regions can simultaneously improve sanitation infrastructure and decarbonize the maritime sector through the production and use of biofuels. This brief proposes a systems approach whereby waste-to-energy technologies are used to treat municipal waste, including water sanitation and food waste, and convert it into biomethane — a clean, low-emission fuel suitable for shipping and fishing vessels. By leveraging waste-to-energy technologies, many cities can produce liquefied biomethane (bio-LNG) to replace conventional fossil fuels in maritime transport. This strategy aligns with the goal of the International Maritime Organization (IMO) to achieve net-zero greenhouse gas emissions from international shipping by 2050. It also addresses public health risks associated with inadequate waste management, such as the spread of infectious diseases and environmental pollution.

Drawing inspiration from successful projects in Brazil and Europe, this brief demonstrates how biogas production from waste can contribute to clean energy solutions and economic growth. It also highlights a proxy case study in Lagos, Nigeria, which demonstrates the potential of the Gulf of Guinea to produce significant amounts of biomethane by treating waste from just a portion of its urban populations.

The Council of Engineers for the Energy Transition (CEET) is currently collaborating with local authorities and stakeholders in the Gulf of Guinea to explore regulatory frameworks, technical solutions, and funding options for implementing such projects. The aim is to position the region as a key player in the global supply chain for clean maritime fuels, contributing to multiple Sustainable Development Goals (SDGs), including clean water and sanitation, climate action, good health, and sustainable cities.


# 1. INTRODUCTION

Climate change presents significant challenges that require urgent action across all sectors of the global economy. For emerging economies, these challenges are compounded by pressing development needs. However, combining climate action with sustainable development can create solutions that address multiple issues simultaneously. This brief proposes a systems approach that connects the decarbonization of maritime transport with the implementation of sanitation infrastructure in the Gulf of Guinea. The production and use of biofuels, supported by the implementation of cleaner energy standards for shipping and the improvement of public health infrastructure, could mitigate greenhouse gas emissions and enhance development in the region.

# 2. THE CHALLENGES

## 2.1. Reducing Emissions in Maritime Transport

Due to the rise in global trade, maritime fleets have expanded significantly over the past decades. In July 2023, the International Maritime Organization (IMO) adopted the "2023 IMO Strategy on Reduction of Greenhouse Gas (GHG) Emissions from Ships,"[1] which aims to reduce shipping carbon intensity by at least 40% by 2030 (compared to 2008 levels) and achieve net-zero GHG emissions from international shipping by 2050. To meet this goal, the plan outlines various strategies to improve energy efficiency and enact a phased transition from conventional fossil fuels — such as heavy fuel oil, marine diesel, and marine gas oil — to low-emission alternatives like biofuels, liquefied natural gas (LNG), and hydrogen-based fuels. The initial targets require replacing at least 5% (ideally 10%) of conventional fuels by 2030. By then, ships must refuel (i.e, "bunker") with low-emission alternatives at ports worldwide.

Achieving these targets requires replacing the fuels and upgrading port infrastructure to handle the storage, distribution, and bunkering of new fuel types. Additionally, ships may need retrofitting or new engines compatible with alternative fuels. While one large ship can burn between 10,000 and 40,000 tons of fuel annually, the global maritime industry as a whole currently consumes about 300 million tons of fossil fuel annually. Thus, substantial investment and coordinated efforts are necessary to meet the scale of the challenge, which includes attaining large production capacity of low-carbon fuels and ancillary infrastructure for storage and bunkering at ports worldwide.

The shipping and fishing industries differ significantly in

1 MPEC80, working paper, "2023 IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS" (International Maritime Organization, July 7, 2024), https://www.imo.org/en/MediaCentre/PressBriefings/pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted-.aspx.

size, capacity, and operational practices. The IMO regulates international shipping and oversees certain safety aspects of fishing activities, but the fishing sector is not included in the IMO's decarbonization strategy. The decarbonization of fishing vessels and fisheries will need separate decarbonization targets, R&D, and implementation guidelines. According to a 2024 UNCTAD report entitled "Energy Transition of Fishing Fleets," the fishing industry contributes about 0.5% of global $CO_2$ emissions, a small percentage compared to other sectors.[2] However, the sector supports 40 million fishers and provides 4% of the world's food production, making it vital for local economies and food security.

## 2.2. Improving Sanitation in Developing Countries' Cities

Developing sanitation infrastructure is critical to improving public health and promoting prosperity. However, a 2023 assessment of SDG 6 indicated that the world is not on track to achieve universal access to safe water and sanitation in 2030.[3] As of 2022, around 3.6 billion people still lack access to safely managed sanitation services, primarily in developing countries.[4] In many emerging economies, wastewater and other solid waste are often uncollected or improperly handled. This leads to severe public health risks, including the spread of infectious diseases, such as cholera, hepatitis, polio, and vector-borne illnesses like dengue fever and malaria. Recurrent infections can result in chronic malnutrition, while mismanaged waste contributes to environmental pollution through the leakage of ammonia, heavy metals (e.g., mercury), and toxic chemicals, leading to the eutrophication of water bodies and ocean contamination. The UN General Assembly has developed a comprehensive water and sanitation strategy emphasizing collective action to address these challenges, focusing on developing countries.[5]

Furthermore, poor sanitation contributes to climate change by releasing methane through the natural rotting of perishable waste, such as sanitation and food waste. Methane is a potent greenhouse gas that has contributed to roughly 30% of the average temperature increase experienced by the planet today.[6] Global methane emissions from the decomposition of perishable waste totaled more than 70 million tons in 2023,[7] with Nigeria alone accounting for roughly half a million tons.[8]

While mitigating methane emissions is one of the most cost-effective ways of reducing climate impacts,[9] waste valorization ventures are expensive. In developed countries, they are financed with taxpayer money, but the same may not be possible in emerging economies, where citizens tend to have low incomes and city administrators are faced with other urgent issues.

2 United Nations Conference on Trade and Development, Energy transition of fishing fleets opportunities and challenges for Developing Countries, UNCTAD.Org, Geneva, Switzerland: United Nations Publications, 2024. https://unctad.org/system/files/official-document/ditcted2023d5_en.pdf.

3 Charlotte MacAlister et al., Global Water Security 2023 Assessment, 2023.

4 "Progress on household drinking water, sanitation and hygiene 2000–2022: special focus on gender," New York: United Nations Children's Fund (UNICEF) and World Health Organization (WHO), 2023.

5 UN-Water, United Nations System-Wide Strategy for Water and Sanitation (UN-Water, July 2024), https://www.unwater.org/sites/default/files/2024-07/UN_System-wide_Strategy_for_Water_and_Sanitation_July2024_vs23July2024.pdf.

6 IEA (2024) "Global Methane Tracker 2024," IEA, Paris https://www.iea.org/reports/global-methane-tracker-2024, Licence: CC BY 4.0.

7 "Global Methane Tracker 2024."

8 RMI and Clean Air Task Force, "Map of Global Waste Methane Emissions: Nigeria," Wastemap.Earth, 2023, https://wastemap.earth/map?mode=country&country=NGA&city=&site=.

9 Future Earth, The Earth League, WCRP (2024), 10 New Insights in Climate Science 2024/2025. Stockholm. doi:10.5281/zenodo.13950099.

# 3. THE OPPORTUNITIES

## 3.1. Increasing Demand for Low-Carbon Fuels for Shipping

A unique opportunity is emerging for developing countries' port regions to advance climate action and sustainable development. The regulatory framework for sustainable maritime transport led by the IMO and the urgent need to improve sanitation in urban areas (aligned with SDG 6) are opening doors for innovative solutions. By leveraging expanding carbon markets and climate funds, these regions can develop local resources to replace fossil fuels in maritime transport. This approach reduces greenhouse gas emissions and drives sustainable development by improving public health, creating jobs, and fostering economic growth.

Today, ships primarily rely on liquid fossil fuels derived from petroleum refining, such as heavy fuel oil and marine diesel. These conventional fuels significantly contribute to greenhouse gas emissions, mainly CO2, which is now regulated, and black carbon, a potent pollutant that has yet to face comprehensive global regulations. To meet decarbonization goals, the shipping industry can adopt a dual approach: enhancing the energy efficiency of vessels and operations while transitioning to renewable propulsion technologies.

Innovations such as wind-assisted propulsion, including sails and rotor systems, offer immediate reductions in fuel consumption by harnessing wind power. These advancements contribute to reducing the industry's carbon footprint in alignment with global climate targets. While renewable propulsion technologies, like wind sails and rotors, can significantly reduce fuel consumption, they alone cannot decarbonize the entire global fleet. Estimates suggest that only 5-10% of the global shipping fleet could fully transition to wind-based propulsion, leaving most vessels reliant on liquid fuels. Most ships must therefore switch to alternative low-emission fuels to meet decarbonization targets. There are multiple options to consider:

- Biodiesels (fatty acid methyl esters from vegetable and waste oils): These can be blended with conventional marine fuels to lower emissions.

- Bio- and e-Methanol: Methanol is an attractive fuel for shipping and the number of methanol-powered ships on order is rapidly increasing.[10] However, using gray methanol (from coal or natural gas) causes greater well-to-wake emissions than conventional fuels, while bio and e-methanol are currently more pricey than alternative low-emissions fuels.

- Ammonia: Due to its toxicity, this fuel requires specialized engines and robust safety systems. Although promising, it is not yet approved for maritime use.

- Other experimental drop-in fuels: These include pyrolysis oils, oils from hydrothermal liquefaction, and other emerging biofuels that are still being researched.

- Batteries: This could be a solution for short voyages.

- Hydrogen: Hydrogen is attractive to use in internal combustion engines or fuel cells, but has not yet had a breakthrough due to the high costs of storage (resulting from a combination of low energy density in compressed form, and very high costs of refrigeration for the liquid form).

10 Methanol as Fuel Heads for the Mainstream in Shipping," DNV Maritime Impact, April 20, 2023, https://www.dnv.com/expert-story/maritime-impact/Methanol-as-fuel-heads-for-the-mainstream-in-shipping/.

- LNG and bio-LNG: By the end of the decade, more than 1,000 ships will be powered by LNG.[11] While LNG is currently the most cost-effective option for reducing GHG emissions, its overall well-to-wake emissions reduction potential is limited, ranging from 1% to 16%.[12] This is partly due to LNG's fossil fuel origins, methane leakage during fuel production (well-to-tank),[13] and ship operation (tank-to-wake).[14] Losses from the engine greatly reduce LNG's potential as a decarbonization fuel. In contrast, bio-LNG is perfectly interchangeable with LNG and is approved for marine use. Bio-LNG is liquified biomethane produced from the anaerobic digestion of organic waste which, untreated, would emit methane into the atmosphere (e.g., sewage, municipal solid waste (MSW), or agricultural residues). See Section 4 for more information on Bio-LNG.

The IMO is still examining financial measures to encourage the industry's decarbonization. The so-called "Mid-Term Measures" (MTMs) consider various options, mostly including levies for non-compliance that would collect revenue. The IMO is also discussing ways by which collected revenue may not only facilitate industry decarbonization (in-sector), but also foster a just and equitable transition (out-of-sector). Waste valorization schemes like the one we are proposing might fit well into such efforts aimed at justice and equitability.

In addition, a new World Trade Organization (WTO) agreement is being developed to phase out fossil fuel subsidies for the fishing industry.[15] This could help align the sector with broader decarbonization efforts in maritime transport. The decarbonization of fishery fleets may also be achieved through national commitments and regional efforts. For instance, the European Union (EU) provides financial incentives through the European Maritime, Fisheries, and Aquaculture Fund (EMFAF) to encourage retrofitting fishing vessels with energy-efficient technologies. Although focused on broader shipping, Norway's Green Coastal Shipping Program has seen voluntary participation from the fishing sector in adopting LNG and battery-powered vessels. In Japan, voluntary fuel-efficiency guidelines encourage fishing companies to modernize their fleets. In contrast, Iceland's fishing industry has proactively adopted low-carbon technologies to support the nation's goal of carbon neutrality by 2040. These examples show how voluntary national and regional initiatives can drive meaningful progress in reducing fishing industry emissions, even without formal international regulation.

## 3.2. Transforming Waste to Energy in Major Port Cities

Major port cities in the Gulf of Guinea have an opportunity to improve sanitation by transforming waste into a renewable energy source that powers local economies and supports decarbonization efforts. Biogas produced from anaerobic digestion of sewage sludge may be further transformed into electrical power or biomethane (after purification of biogas). Either way, they can contribute to satisfy residential and industrial demand leveraging existing transmission networks. There are successful examples worldwide that can serve as models of inspiration.

In Europe, over 20,000 plants that transform waste into energy exist.[16] In Brazil, Sabesp, one of the largest water and sewage service providers globally, is pioneering sewage treatment efforts to produce biogas, which is then upgraded

11 Margarethe Anderson, "Maritime Decarbonization Efforts Propelled as Orders for Alternative-Fueled Vessels Grow," DNV, January 9, 2024, https://www.dnv.com/news/maritime-decarbonization-efforts-propelled-as-orders-for-alternative-fueled-vessels-grow-251921/#:~:text=The%20dominating%20segment%20for%20this,this%20trend%20continues%20into%202024.%E2%80%9D.

12 Well-to-Wake refers to the complete lifecycle emissions of fuel, covering both the production and extraction of the fuel (Well-to-Tank) and its final combustion in a ship's engine (Tank-to-Wake). It provides a holistic view of the total greenhouse gas emissions from the fuel's origin to its use in maritime transport. Specifically used in the maritime and aviation sectors.

13 Well-to-Tank represents the emissions generated during fuel extraction, production, processing, and transportation until ready for use in a ship's engine or other applications.

14 Tank-to-Wake measures the emissions produced during the actual use of the fuel in a ship's engine, from the fuel tank to the point where emissions are released into the atmosphere during the ship's operation.

15 United Nations Conference on Trade and Development, 2024.

16 Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, "Biogas as a Source of Biofuels for Shipping: Insights into the Value Chain" (June 11, 2024), https://cms.zerocarbonshipping.com/media/uploads/documents/Biogas-as-a-Source-of-Biofuels-for-Shipping_1_Insights-into-the-Value-Chain.pdf.

to biomethane. Sabesp's wastewater treatment plants (WTPs) in the state of São Paulo, for example, in Barueri, São Miguel Paulista, and Franca, demonstrate how biogas from sewage can contribute to clean energy solutions. The Barueri WTP, the largest in Latin America, will have the capacity to produce 100,000 $Nm^3$ of biomethane per day, which can be commercialized, injected into the gas network, or used for energy cogeneration and sludge drying. Other international examples include the Point Loma WTP in San Diego, USA, which produces 22,000 $Nm^3$ of biomethane per day, and the Henriksdal WTP in Stockholm, Sweden, which fuels buses and cars with biomethane. Such waste valorization schemes significantly reduce greenhouse gas emissions by replacing non-renewable energy sources and preventing methane emissions from the natural decomposition of waste. The models described above can be replicated in other global contexts facing similar waste management challenges and the need for sustainable energy solutions. In addition to megacities in the Gulf of Guinea, other cities and ports that may find such scheme attractive include: (i) Jakarta's Port of Tanjung Priok, which handles over 7 million TEUs annually;[17] (ii) India's Jawaharlal Nehru Port Trust (JNPT), handling 5 million TEUs annually[18]; (iii) the Port of Manila in the Philippines; and (iv) the Port of Chattogram in Bangladesh; all of which are vital to their countries' economies.

## 4. THE POTENTIAL OF BIO-LNG

A systems approach is recommended to address the interconnected challenges of decarbonizing the maritime sector and improving urban sanitation — for example, in the Gulf of Guinea. By utilizing proven technologies and leveraging existing policy frameworks, efforts can be coordinated to deploy a systems-wide solution. Bio-LNG can be integrated into existing LNG infrastructure and engines, lowering emissions. Its lifecycle emissions may even be negative with improved waste management practices. Bio-LNG also contributes to a circular economy, since the digestate, the by-product resulting after digestion of the biomass, may be used as a fertilizer, thus returning macro- and micronutrients to the soil. This approach supports the transition away from fossil fuels and into low-emission maritime transport while helping major cities tackle pressing sanitation issues.

As of 2023, Europe leads in biogas production, with over 1,550 biomethane plants and more than 21,000 biogas plants across the continent.[19] These installations are spread unevenly across European countries, reflecting widespread technology acceptance. Biogas now accounts for approximately 5.5% of the EU's total gas consumption, showcasing its growing importance in the energy mix. The European experience demonstrates significant job creation in the sector. It highlights how biogas can tap into vast potential from waste sources such as sewage, agricultural residues, municipal food waste, industrial by-products from breweries, ethanol production, and vegetable oils. The EU's biogas market is bolstered by its well-developed natural gas network, which allows biomethane to be transported physically and traded virtually through systems like "guarantees of origin."

Biogas production has recently seen significant growth in the United States, with 96 new projects operational in 2023 alone.[20] While most biogas in Europe is generated from crop residues and animal manure, in the US, the primary feedstock is municipal solid waste. Though municipal wastewater is used to a lesser extent in the US and Europe, interest in this source is increasing due to its multiple benefits,[21] such as reduced emissions, energy generation, and potential cost

17 TEU (Twenty-foot Equivalent Unit) is a standard measurement used in the shipping industry to quantify cargo capacity. It refers to the volume of a 20-foot-long shipping container, which is 20 feet long, 8 feet wide, and 8.5 feet high. One TEU represents a single 20-foot container, while a 40-foot container equals 2 TEUs. This measurement is widely used to standardize and compare the capacity of container ships and port throughput.

18 "Container Traffic at JNPT Jumps 25.9% to 5.63 Million Teus in 2021," Business Standard, January 27, 2022, https://www.business-standard.com/article/economy-policy/container-traffic-at-jnpt-jumps-25-9-to-5-63-million-teus-in-2021-122012701737_1.html.

19 "European Biomethane Map 2024," European Biogas Association, July 5, 2024, https://www.europeanbiogas.eu/european-biomethane-map-2024/.

20 "Third Year of Record Growth for U.S. Biogas Industry; Expected to Continue in 2024," American Biogas Council, February 13, 2024, https://americanbiogascouncil.org/third-year-of-record-growth-for-u-s-biogas-industry-expected-to-continue-in-2024-2/#:~:text=In%202023%2C%2096%20new%20biogas,gasoline%20cars%20from%20the%20road.

21 "Outlook for biogas and biomethane: Prospects for organic growth," IEA, Paris https://www.iea.org/reports/outlook-for-biogas-and-biomethane-

savings. The growing attention to biogas from wastewater is driven by its ability to address waste management challenges, while contributing to energy resilience and environmental sustainability.

China and India have also been significant biogas producers and users, particularly for clean cooking in rural areas, where biogas has helped reduce reliance on traditional biomass, like wood and charcoal. The Chinese government offers incentives for the valorization of waste and the development of rural areas, which is attracting investments.[22] While the potential for the widespread adoption of biogas and biomethane technologies in emerging economies is huge, particularly for industrial and energy purposes, it is still in its early stages.

In recent years, more countries have recognized the untapped potential of biogas for sustainable energy generation. Brazil, for example, is rapidly expanding its biogas production capacity. Traditionally, Brazil's biogas has been primarily used to generate electricity, particularly in agricultural sectors that produce large amounts of organic waste, such as sugarcane and livestock farming. However, there has been a notable shift toward upgrading biogas into biomethane, which has broader applications for transport and industrial use. In 2022, 22% of Brazil's biogas production was upgraded to biomethane, supporting the country's strategy to decarbonize sectors like transportation and heavy industry.[23]

Brazil has also developed a robust ecosystem of stakeholders, including government agencies, private sector companies, and research institutions, to support the scaling of biogas and biomethane production.[24] This comprehensive strategy is supported by favorable policies, such as the RenovaBio program, which incentivizes biofuel production and consumption. According to McKinsey, the biomethane market in Brazil could reach a value of USD 15 billion by 2040,[25] driven by the country's vast organic waste resources and increasing investments in biogas infrastructure. Brazil's expansion of biogas and biomethane offers a blueprint for other emerging economies to follow, showcasing how renewable energy can be harnessed to help address waste management and drive economic growth.

It is important to note that while biogas is familiar to African countries, most past projects have been small-scale, focusing on household or community-level applications. The results have been mixed with infrastructure, financing, and maintenance challenges. The potential for large-scale biogas production in Africa remains to be explored.[26] The first large-scale biogas plant in West Africa was established in Burkina Faso in 2017, running on brewery and slaughterhouse waste as its primary feedstock.[27]

As global interest in renewable energy grows, the time is ripe for African countries to explore their substantial biogas potential. Tapping into this resource could open new opportunities, particularly in sectors like maritime transport, leveraging on decarbonization and climate finance. Biogas offers a sustainable alternative to fossil fuels, and with suitable

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prospects-for-organic-growth, Licence: CC BY 4.0.

22 "Air Liquide Launches Its Biomethane Activity in China," Air Liquide, July 12, 2022, Air Liquide, https://www.airliquide.com/sites/airliquide.com/files/2023-02/air-liquide-launches-its-biomethane-activity-china_63f4c28cf3117.pdf.

23 BiogasWorld, "Brazilian Biogas: A Growing Market," BiogasWorld, February 6, 2024, https://www.biogasworld.com/news/brazilian-biogas-a-growing-market/.

24 Felipe Souza Marques, "The Brazilian Biomethane Industry: Challenges and Opportunities," Biogas World, February 12, 2024, https://www.biogasworld.com/news/the-brazilian-biomethane-industry-challenges-and-opportunities/#:~:text=The%20Brazilian%20Biomethane%20Industry%3A%20Challenges%20and%20Opportunities,-Share&text=Data%20from%20December%202022%20(Brazilian,growth%20as%20compared%20to%202021.

25 Alexandre Sawaya et al., "The Green Hidden Gem – Brazil's Opportunity to Become a Sustainability Powerhouse: Brazil," McKinsey & Company, November 4, 2022, https://www.mckinsey.com/br/en/our-insights/all-insights/the-green-hidden-gem-brazils-opportunity-to-become-a-sustainability-powerhouse.

26 Kalina, Mar., Ogwang, Jonathan Òlal, & Tilley, Elizabeth, "From potential to practice: rethinking Africa's biogas revolution," Humanit Soc Sci Commun 9, 374 (2022), https://doi.org/10.1057/s41599-022-01396-x.

27 Dinesh Surroop, Zumar M.A. Bundhoo, and Pravesh Raghoo, "Waste to Energy through Biogas to Improve Energy Security and to Transform Africa's Energy Landscape," Current Opinion in Green and Sustainable Chemistry 18 (August 2019): 79–83, https://doi.org/10.1016/j.cogsc.2019.02.010.

investments and policy support, African nations could become leaders in renewable energy production. Globally, biogas is now recognized as a mature, ready-to-use technology and a valuable domestic energy source.

## 5. A CASE STUDY PROXY: The Gulf of Guinea

A short assessment of the opportunity to implement the integrated approach proposed in this brief is provided below, with a focus on the Gulf of Guinea, and more specifically, Lagos.

Why the Gulf of Guinea?

For this exercise, we have selected the Gulf of Guinea, and in particular, the city of Lagos for the following reasons:

1. Lagos is a megacity with an urban population of nearly 22 million inhabitants, which is rapidly growing (2-3% per year). The metropolitan area covers approximately 3,500 km2.

2. Only 5% of the city (urban and metropolitan) is served by a sewage system. Most wastewater is collected in septic tanks and only 5-10% of the city's total sewage waste is properly managed.

3. Another organic waste produced by the city is food waste, with the Nigerian average being roughly 190 kg per person per year.[28] Food waste is not managed properly and often ends up dumped.

4. The large amount of unmanaged organic waste within the city perimeter is a huge hazard to public health and the environment. However, from the point of view of bioenergy production costs, this is a "bonanza," since biomass aggregation is an important driver of bioenergy production cost.

5. As an oil and gas producer, Nigeria has the infrastructure and expertise needed to handle methane.

6. Lagos can serve as a model for other countries of the Gulf of Guinea (Ghana, Togo, Benin, Cameroon, the Ivory Coast), which might find it attractive to tap into this value proposition to ensure proper treatment of their waste, while earning on sales of bioenergy.

7. The development of countries surrounding the Gulf of Guinea is strengthened by the African Continental Free Trade Zone (AfCFTA), which increases shipping activities in the region, with international shipping giants frequently using Nigerian ports.

### 5.1. Reference Case: European Cost of Manufacturing and Sales Prices of Bio-LNG

If the biogas supply chain can be optimized so that liquefied biomethane (bio-LNG) achieves a profoundly negative GHG emissions intensity (also referred to as a "Carbon Intensity (CI)[29] score") of -100 $gCO_2eq/MJ$, sales prices could reach

28 Kolawole, I.D., Kolawole, G.O., Sanni-manuel, B.A. et al, "Economic impact of waste from food, water, and agriculture in Nigeria: challenges, implications, and applications—a review," Discov Environ 2, 51 (2024), https://doi.org/10.1007/s44274-024-00086-6.

29 The CI score of a fuel is determined by evaluating its entire lifecycle — starting from the collection of raw materials (such as sewage or organic waste) to the processing, purification, and eventual combustion of the fuel. Negative CI scores are achieved when the fuel avoids emitting GHGs and actively reduces them; Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, "Biogas as a Source of Biofuels for Shipping: Well-to-Wake Greenhouse Gas Emissions" (June 11, 2024), https://cms.zerocarbonshipping.com/media/uploads/documents/Biogas-as-a-Source-of-Biofuels-for-Shipping_4_Well-to-Wake-Greenhouse-Gas-Emissions-from-Biogas-Based-Bio-methane-and-Bio-methanol.pdf.

as high as 200 EUR per megawatt-hour (MWh).[30] The CI score measures the GHG emissions of a fuel across its entire lifecycle (from production to consumption), with negative scores indicating that the fuel displaces more emissions than it produces. This sales price is significantly higher than the current European production cost of biomethane, which is around 80 EUR/MWh.[31] Under this favorable scenario, the revenue generated from biomethane sales would not only cover the operational costs of collecting and treating sanitation waste, but also turn a profit, making it a commercially viable venture.

Assuming the production cost per MWh of biomethane is 80 EUR, and the sales price can be driven up to 200 EUR/MWh with a negative CI score, the margin per MWh would be 120 EUR. An estimated 1200 GWh/year production would generate approximately 230 million EUR/year in gross profit.

However, if the CI score is high—around 20-30 $gCO_2eq/MJ$, approaching the upper limit set by the EU Renewable Energy Directive (RED)—the achievable sales price would drop significantly.[32] S&P reports a sales price of around 70 EUR/MWh for bio-LNG with 89% savings.[33] In this less favorable scenario, the revenue from biomethane sales would only partially cover the waste collection and treatment costs. For instance, with a production cost of 80 EUR/MWh and a sales price of 70 EUR/MWh, there would be a 10 EUR/MWh loss, requiring additional financing or subsidies to make the project financially viable.

Bio-LNG sales prices are subject to high variability depending upon demand/supply dynamics, LNG prices, ability to pool and bank emissions credits, among other factors.

## 5.2. Required Infrastructure in the Gulf of Guinea

In realistic terms, setting up the infrastructure for large-scale biomethane production in the Gulf of Guinea would involve significant capital investment. The costs would vary depending on the project scale, the technology used, and the region's existing infrastructure. The rough estimate of the capital cost involved in constructing a world-scale biogas plant based on organic waste from a city of 7 million inhabitants, like the WTP in Barueri, Brazil, is around 20 to 30 million EUR for a production of 100,000 $Nm^3$/day biogas. This includes the cost of anaerobic digesters, gas purification units, liquefaction technology, and storage facilities. Additional costs will consist of establishing a distribution network if none exists. In Europe, such a plant could cost more than double. It is therefore important to understand the specific context of the country involved.

Regarding the region's existing gas supply chain, more biomethane infrastructure is needed, as many ports and cities in the Gulf of Guinea lack robust natural gas networks. However, conventional gas infrastructure in some countries, such as Nigeria, could provide a foundation for scaling up biomethane distribution. Tapping into existing pipelines or developing small-scale distribution networks within port cities could accelerate the adoption of biogas as a clean maritime fuel. Also, electricity may locally be a problem. The demand of electrical power for a bio-LNG supply chain is roughly 10% of the energy produced (i.e., for a production of 1200 GWh/year, the supply chain needs 120 GWh/year, see Table 1). This

30 Aly Blakeway et al., "Feature: Bio-LNG to Follow LNG Path to Europe's Net-Zero Future," ed. Benjamin Morse, S&P Global Commodity Insights, July 3, 2024, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/lng/070324-bio-lng-to-follow-lng-path-to-europes-net-zero-future.

31 Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, "Biogas as a Source of Biofuels for Shipping: Well-to-Wake Greenhouse Gas Emissions" (June 11, 2024).

32 "DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources." Official Journal of the European Union 61, no. L328 (December 21, 2018): 82–209. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001.

33 Blakeway et al.

may be an issue in Lagos and such a project would have to foresee independent power generation.

It is essential to recognize that this assessment is based on European and Brazilian price structures. A more precise evaluation incorporating local costs and sales prices will be necessary to accurately assess the business opportunity in the Gulf of Guinea and determine the need for external financing.

## 5.3. Proxy Parameters for Lagos, Nigeria

Lagos, Nigeria, with an urban population of approximately 21 million, is one of Africa's largest and fastest-growing cities. As in many urban centers, Lagos faces significant sanitation and waste management challenges. For this proxy case study, the proposed waste collection and biogas production system is designed to serve the urban population with 3 biogas-producing facilities serving around 7 million people each. This system would convert sewage and organic municipal solid waste into biomethane, a clean energy solution. The coverage of 7 million people per production facility is dictated by the size of the plant. To our knowledge, this capacity for an individual wastewater treatment plant is the current world scale. To serve the needs of a city as large as Lagos, we assume that multiple plants of that size would have to be built.

Table 1. Lagos, Nigeria Proxy Case Study

| Parameter | Value |
|---|---|
| Population Served | 21 million in 3 plants (covering 7 million each) |
| Suitable Waste | Sanitation waste and organic fraction of municipal solid waste |
| Expected Production of Biomethane | Approximately 120 million $Nm^3$/year, equivalent to 85,000 t/year bioLNG (101,000 Tons of Oil Equivalent (TOE)/year or 1,200 GWh/year) |
| Electricity Demand | 120 GWh/year |
| Digestate Disposal | Used as fertilizer |
| Anticipated Cost of Production | 80 EUR/MWh (1,100 EUR/t bio-LNG or 880 EUR/TOE; based on European costs for anaerobic digestion, upgrading and liquefaction; no wastewater treatment) |
| Bio-LNG: "Typical" Well-to-Tank (WtT) CI score | 13 gCO2e/MJ (based on 86% GHG emissions savings and biomethane for transport based on biowaste, closed digestate, off-gas combustion in RED II[34]) |
| Bio-LNG: WtT CI score "with credits" for improved waste management (if permitted) | -100 gCO2e/MJ (based on 206% GHG emissions savings and biomethane for transport based on wet manure, closed digestate, off-gas combustion in RED II[35]) |
| Emissions from 1 reference ship (consuming 20,000 t/y HFO) | 78,000 t CO2e /year<br>Target saving in 2030: 5% = 3,900 t CO2e |
| Biomethane needed to ensure compliance for 1 reference ship in 2030 | "Typical" CI Score: 1,000 t/year bio-LNG<br>"With credits" CI Score: 400 t/year bio-LNG |
| # of ships consuming 20,000 tons HFO/y that can comply with a 5% emissions savings target | "Typical" CI Score: 85 ships<br>"With credits" CI Score: 210 ships |

Other WTPs worldwide have demonstrated how biogas generation from sewage can be upgraded to biomethane, which can be injected into gas networks, used for electrical power cogeneration, compressed and liquefied to serve as a road or maritime fuel, etc. Implementing such a system in Lagos would tackle pressing waste management issues and transform sanitation infrastructure into a renewable energy source, supporting local economies, and contributing to decarbonization.

34 "DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources."

35 "DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources."

The projected biomethane production for Lagos, serving approximately 21 million people, is around 120 million $Nm^3$/year, equivalent to 85,000 t/y bio-LNG (101,000 TOE/year (tons of oil equivalent) or approximately 1,200 GWh/year of energy. This biomethane could be used as clean maritime fuel for shipping operations, enabling compliance with the 5% emissions reduction 2030 target for 85 ships (if credits for improved waste management may not be counted) or 210 ships (if credits may be counted). By supplying ships with low-carbon fuel, Lagos would help reduce greenhouse gas emissions from shipping, a critical sector for global climate action. Additionally, the digestate produced from the anaerobic digestion process could be used as fertilizer, further supporting agricultural sustainability in the region and the circularity of macro and micronutrients in soils.

With its large population and pressing sanitation issues, Lagos presents a compelling case for implementing biogas production as a sustainable energy solution. This proxy case study offers a realistic framework for analyzing such a project's potential costs, benefits, and environmental impacts. By adjusting the figures to reflect local conditions—such as waste availability, energy demand, and infrastructure—the project can be designed to deliver both economic and environmental benefits. Achieving a low CI score will be crucial for ensuring financial viability, while the local assessment will help determine the project's precise scale and financing needs. With coordinated efforts from government, private investors, and international organizations, Lagos could become a model city for integrating biogas into its energy and waste management systems.

## 5.4. VISION FOR THE FUTURE: THE GULF OF GUINEA AS A MAJOR PRODUCER OF CLEAN MARITIME FUELS

The Council of Engineers for the Energy Transition (CEET) is supporting efforts to transform the Gulf of Guinea into a strategic hub for clean maritime fuels, positioning the region as a key player in the decarbonization of the global maritime sector. The objective is to identify bankable projects that can produce substantial amounts of low-carbon maritime fuel in the short and medium term, using local waste streams such as sanitation and food waste to generate biomethane.

A dialogue has been established with local authorities and other stakeholders to examine regulatory frameworks, identify the best technical solutions for the local context, and explore business models and funding options. This dialogue is crucial for ensuring that the projects are technically sound and financially viable for national and international investors. A techno-economic analysis is underway to assess how the region can lead in the advanced supply chain for clean maritime fuels, thus contributing to regional development.

The CEET is also actively collaborating with authorities and policymakers in the Gulf of Guinea to raise awareness of the opportunity. Bringing this opportunity to the forefront of decision-making is essential, as the region has the potential to contribute significantly to global climate action and regional prosperity. The ambition is to establish cooperation models that leverage this convergence of favorable factors into real-world projects that can address climate change, while fostering economic growth and sustainability in the region.

The technical analysis will also consider the logistics of sanitation services, the capacity of waste treatment facilities, and the optimization of waste-to-energy processes. This will help define cost structures, risks, and revenue streams, ensuring that the proposed projects are financially attractive and can be supported by national and international investors. UN organizations and international experts will play a key role in facilitating this dialogue and analysis, supporting the successful launch of clean-fuel projects in the Gulf of Guinea.

# BIBLIOGRAPHY

"Air Liquide Launches Its Biomethane Activity in China." Air Liquide, July 12, 2022. Air Liquide. https://www.airliquide.com/sites/airliquide.com/files/2023-02/air-liquide-launches-its-biomethane-activity-china_63f4c28cf3117.pdf.

Anderson, Margarethe. "Maritime Decarbonization Efforts Propelled as Orders for Alternative-Fueled Vessels Grow." DNV, January 9, 2024. https://www.dnv.com/news/maritime-decarbonization-efforts-propelled-as-orders-for-alternative-fueled-vessels-grow-251921/#:~:text=The%20dominating%20segment%20for%20this,this%20trend%20continues%20into%20 2024.%E2%80%9D.

BiogasWorld. "Brazilian Biogas: A Growing Market." BiogasWorld, February 6, 2024. https://www.biogasworld.com/news/brazilian-biogas-a-growing-market/.

Blakeway, Aly, Megan Gildea, Hassan Butt, Harry Clyne, and Clio Ho. "Feature: Bio-LNG to Follow LNG Path to Europe's Net-Zero Future." Edited by Benjamin Morse. S&P Global Commodity Insights, July 3, 2024. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/lng/070324-bio-lng-to-follow-lng-path-to-europes-net-zero-future.

"Container Traffic at JNPT Jumps 25.9% to 5.63 Million TEUs in 2021." Business Standard, January 27, 2022. https://www.business-standard.com/article/economy-policy/container-traffic-at-jnpt-jumps-25-9-to-5-63-million-teus-in-2021-122012701737_1.html.

"DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources ." Official Journal of the European Union 61, no. L328 (December 21, 2018): 82–209. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001.

"European Biomethane Map 2024." European Biogas Association, July 5, 2024. https://www.europeanbiogas.eu/european-biomethane-map-2024/.

Future Earth, The Earth League, WCRP (2024). 10 New Insights in Climate Science 2024/2025. Stockholm. doi:10.5281/zenodo.1395009.

IEA (2024), "Global Methane Tracker 2024." IEA, Paris https://www.iea.org/reports/global-methane-tracker-2024, Licence: CC BY 4.0.

IEA (2020), "Outlook for biogas and biomethane: Prospects for organic growth." IEA, Paris https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth, Licence: CC BY 4.0.

Kalina, M., Ogwang, J.Ò. & Tilley, E. From potential to practice: rethinking Africa's biogas revolution. Humanit Soc Sci Commun 9, 374 (2022). https://doi.org/10.1057/s41599-022-01396-x.

Kolawole, I.D., Kolawole, G.O., Sanni-manuel, B.A. et al. Economic impact of waste from food, water, and agriculture in Nigeria: challenges, implications, and applications—a review. Discov Environ 2, 51 (2024). https://doi.org/10.1007/s44274-024-00086-6

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. "Biogas as a Source of Biofuels for Shipping: Insights into the Value Chain." (June 11, 2024). https://cms.zerocarbonshipping.com/media/uploads/documents/Biogas-as-a-Source-of-Biofuels-for-Shipping_1_Insights-into-the-Value-Chain.pdf.

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. "Biogas as a Source of Biofuels for Shipping: Well-to-Wake Greenhouse Gas Emissions." (June 11, 2024). https://cms.zerocarbonshipping.com/media/uploads/documents/Biogas-as-a-Source-of-Biofuels-for-Shipping_5_Techno-Economic-Trends.pdf.

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. "Biogas as a Source of Biofuels for Shipping: Well-to-Wake Greenhouse Gas Emission.s" (June 11, 2024). https://cms.zerocarbonshipping.com/media/uploads/documents/Biogas-as-a-Source-of-Biofuels-for-Shipping_4_Well-to-Wake-Greenhouse-Gas-Emissions-from-Biogas-Based-Bio-methane-and-Bio-methanol.pdf.

MacAlister, Charlotte, Guillaume Baggio, Duminda Perera, et. al. Global Water Security 2023 Assessment, Nov 4, 2024.

"Methanol as Fuel Heads for the Mainstream in Shipping." DNV Maritime Impact, April 20, 2023. https://www.dnv.com/expert-story/maritime-impact/Methanol-as-fuel-heads-for-the-mainstream-in-shipping/.

MPEC80. Working paper. "2023 IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS." International Maritime Organization, July 7, 2024. https://www.imo.org/en/MediaCentre/PressBriefings/pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted-.aspx.

RMI and Clean Air Task Force, "Map of Global Waste Methane Emissions: Nigeria," Wastemap.Earth, 2023, https://wastemap.earth/map?mode=country&country=NGA&city=&site=.

Sawaya, Alexandre, Nelson Ferreira, Reinaldo Fiorini, Roberto Fantoni, Wieland Gurlit, Marcelo Aude, Gustavo Taylor, et al. "The Green Hidden Gem – Brazil's Opportunity to Become a Sustainability Powerhouse: Brazil." McKinsey & Company, November 4, 2022. https://www.mckinsey.com/br/en/our-insights/all-insights/the-green-hidden-gem-brazils-opportunity-to-become-a-sustainability-powerhouse.

Souza Marques, Felipe. "The Brazilian Biomethane Industry: Challenges and Opportunities." Biogas World, February 12, 2024. https://www.biogasworld.com/news/the-brazilian-biomethane-industry-challenges-and-opportunities/#:~:text=The%20Brazilian%20Biomethane%20Industry%3A%20Challenges%20and%20Opportunities,-Share&text=Data%20from%20December%202022%20(Brazilian,growth%20as%20compared%20to%202021.

Surroop, Dinesh, Zumar M.A. Bundhoo, and Pravesh Raghoo. "Waste to Energy through Biogas to Improve Energy Security and to Transform Africa's Energy Landscape." Current Opinion in Green and Sustainable Chemistry 18 (August 2019): 79–83. https://doi.org/10.1016/j.cogsc.2019.02.010.

"Third Year of Record Growth for U.S. Biogas Industry; Expected to Continue in 2024." American Biogas Council, February 13, 2024. https://americanbiogascouncil.org/third-year-of-record-growth-for-u-s-biogas-industry-expected-to-continue-in-2024-2/#:~:text=In%202023%2C%2096%20new%20biogas,gasoline%20cars%20from%20the%20road.

"Progress on household drinking water, sanitation and hygiene 2000–2022: special focus on gender." New York: United Nations Children's Fund (UNICEF) and World Health Organization (WHO), 2023.

UN-Water, United Nations System-Wide Strategy for Water and Sanitation (UN-Water, July 2024), https://www.unwater.org/sites/default/files/2024-07/UN_System-wide_Strategy_for_Water_and_Sanitation_July2024_vs23July2024.pdf.

United Nations Conference on Trade and Development. Energy transition of fishing fleets opportunities and challenges for Developing Countries. UNCTAD.Org. Geneva, Switzerland: United Nations Publications, 2024. https://unctad.org/system/files/official-document/ditcted2023d5_en.pdf.

Veracity. Accessed November 5, 2024. https://afi.dnv.com/statistics/f12b0923-2a88-4278-8b18-1858d569cf4d.

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