Biogas for Clean Cooking

ISSUE BRIEF

SMALL-SCALE BIOGAS FOR CLEAN COOKING—A COST-EFFECTIVE TECHNOLOGY TO TACKLE CLIMATE CHANGE AND ACHIEVE SDGS

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KEY MESSAGES

The Context

Across the world, 2.3 billion people rely on inefficient stoves and dirty fuels for cooking, resulting in negative effects on the environment and public health. Traditional cooking fuels like firewood, charcoal, and dung cause negative environmental and health impacts, particularly affecting women and children. Biogas solutions are readily available and can be implemented at household and community levels, bringing clean fuel for cooking, lighting, and organic fertilizers to rural communities.

The Opportunity

Small-scale biogas can serve as a multifaceted solution to the clean cooking challenge, helping reduce poverty, improve agriculture, and address energy and climate justice. Instead of focusing solely on cooking equipment to address the clean cooking issue, technological improvement can work in tandem with livelihoods and opportunities for income generation particularly connected to the development of agriculture and food supply chains. With integrated approaches focused on improving livelihoods, the deployment of clean cooking fuels will address various SDGs and mitigate climate change.

The Costs

Biogas digesters and stoves have a high installation price, but over time, it is by far the cheapest option to provide clean cooking. The annual operating cost of a biogas cooking stove is less than one-fourth of the annual operating cost of an LPG stove or less than one-fifth of a traditional charcoal stove. The IEA estimates that US$8 billion of investments are required to address the upfront costs, affordability, and scalability of clean cooking, as well as to provide universal access.

The Technology

Biogas is a mature technology that can be implemented at household and community levels. Biogas is a versatile fuel produced through anaerobic digestion of organic matter: food residues, domestic organic waste, and agricultural or animal waste, all of which are largely available, can be used to produce energy for cooking, heating, lighting, and power generation. No major technical challenges are associated with biogas production, but deployment must consider local conditions such as feedstock and water availability.

The Road Ahead

Biogas for clean cooking could serve 200 million people by 2040, half of them in Africa, according to the IEA. To realize this potential, a rural biogas strategy needs to overcome affordability, as well as institutional and local know-how barriers. This brief includes a 10-step recommendation package to help develop small-scale biogas for clean cooking.

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EXECUTIVE SUMMARY

Access to clean cooking is essential for achieving the goals of the Paris Agreement and various Sustainable Development Goals (SDGs). This is a major challenge in developing countries where 2.3 billion people still rely on traditional fuels such as firewood, charcoal, and dung – which cause deforestation, indoor air pollution, and greenhouse gas emissions. Without proper and accelerated action, 1.9 billion people will still be using polluting cooking fuels by 2030, most of them in Sub-Saharan Africa. This would be a failure of one of the key targets of SDG 7 and a missed opportunity to reduce greenhouse gas emissions, improve community resilience to climate change and food security, reduce nature loss, and promote sustainable development.

Clean cooking includes a shift to clean fuels such as liquefied petroleum gas (LPG), ethanol, biogas, and efficient cooking stoves. This brief focuses **on opportunities for small-scale biogas production and use in rural areas to promote clean cooking** and the use of feedstocks generated from local activities such as agricultural residues, animal dung, and food waste. In contrast with many previous programs for clean cooking that focus on cooking devices, we propose **pathways** that relate technological improvement with livelihoods and opportunities for income generation; particularly connected to the development of agriculture and food supply chains. This is an integrated approach to the challenge of clean cooking, moving away from narrow perspectives that have proven inadequate to address the full scale of the problem.

Biogas is a versatile fuel that can be used for cooking, heating, lighting, and power generation as well as biomethane production. Biogas solutions can be implemented at household and community levels. By-products can be used as fertilizers, boosting agricultural productivity. The low heat in the biogas production can be effectively used for water purification. Biogas deployment provides a pathway for residue management and valorization that improves energy efficiency and the total efficiency of rural economies, promoting a circular economy. Biogas for domestic cooking offers an immediate solution to mitigate 50% of global black carbon emissions, environmental impacts, and health problems that affect women and children in particular, while also promoting low-carbon pathways for rural development. **It is a well-proven technology widely used at different scales on various continents.**

Despite its technology maturity and all of the known benefits, the full potential of biogas has not yet been systematically explored for clean cooking purposes. In 2018, only 6% of the global estimated biogas potential of 570 Mtoe available was being used. To realize the potential, a rural biogas strategy needs to overcome affordability, adaptability, institutional support, and local knowledge barriers. A household biodigester costs between US $200 and $820 – with the exact cost depending on local conditions, including feedstock and water availability and technical knowledge This is a large sum of money for small farmers who comprise 75% of the Sub-Saharan population. But, despite the high upfront cost compared to wood fuel and charcoal cooking options, the operating cost of a biogas solution is less than one-fourth of the cost of a LPG stove and less than one-fifth of the cost of a traditional charcoal stove. A life cycle assessment of low-cost biodigesters carried out for small farms in Colombia showed that biogas could substitute LPG for cooking and synthetic fertilizers, resulting in an 80% reduction in costs associated with fuel and fertilizer purchase, and an 80% reduction in environmental impacts.

We propose **implementation pathways for small-scale biogas-based clean cooking** that relate technological improvement to livelihoods and opportunities for income generation supported by the climate and SDG agenda to overcome technical, institutional, and economic barriers. For example, biogas clean cooking solutions can be integrated with existing livelihoods in developing regions, contributing to income-generating activities connected to agriculture and local industries in food supply chains. Such an approach will help mobilize funding and overcome affordability barriers which are detrimental to the broad adoption of clean cooking solutions. Concerted actions will accelerate the deployment of biogas while promoting residue valorization and total efficiency of local production systems, reducing emissions and environmental degradation, and improving public health. The investment needed to achieve universal clean cooking access has been estimated at US $8 billion per year, which is a small fraction of the global expenditure on energy every year.

Stakeholders must work together to guarantee the flow of funds and to support the assistance necessary to tap into this opportunity. If properly assisted, rural communities can overcome the implementation thresholds in terms of upfront costs, knowledge, maintenance, and safety, while becoming self-sufficient in cooking fuels and more resilient to climate change. In addition, scalability in the rural context will require an assessment of the water-energy-food nexus and measures to guarantee technical support, service performance, and safety. Therefore, clean cooking fuels must be part of a broad strategy to address poverty, clean energy access, environmental protection, and climate change.

The challenge of providing clean cooking universally is not a strictly technical challenge but rather a systems challenge. It includes more than a shift to clean fuels and the adoption of efficient devices for cooking. The challenge must be addressed as part of a dynamic process that builds capacity in rural communities and empowers them to deal with climate change and food security in addition to sustainable development. A clean cooking strategy will help address important global challenges such as climate change, poverty alleviation, and deforestation; and additionally help to deliver on multiple SDGs.

Biogas solutions offer an opportunity to create pathways for development that go beyond clean cooking. With a targeted program to fit regional characteristics and local resource availability, including technical design and support, standardization, and market scale, costs can be further reduced, and scale can be achieved. This is an opportunity to engage rural communities in climate action and help strengthen their resilience and pave the way for sustainable development. An integrated approach to biogas deployment in rural areas will help to ensure that universal access to clean cooking will be reached by 2030. Ultimately, the overarching goal must be to improve the livelihoods of rural households and pave the way to sustainable development.

Overall, this brief explores opportunities for **small-scale biogas solutions for clean cooking in rural areas of developing countries**. In contrast with many previous programs for clean cooking that focus on efficient cookstoves,[1] our focus is on **a possible pathway** that relates a proven technological improvement with livelihoods and opportunities for the agri-food sector and income generation in rural areas. In line with the SDGs, our recommendations synthesize steps to accelerate the deployment of small-scale biogas in rural areas and broaden access to clean cooking fuels during this decade.

THE CHALLENGE

The international community needs to strengthen its efforts to achieve SDG 7: affordable and clean energy access for all. This means ensuring universal access to affordable, reliable, and modern energy services, upgrading technology for supplying modern and sustainable energy services, and improving energy efficiency.

Biogas technologies are proven technologies that can be deployed in synergy with the development of agri-food industries to improve access to clean cooking fuels, enhance climate resilience, and generate income and welfare in the rural areas of developing countries.

1. Clean Cooking Alliance, "Clean Cooking Catalog."

What does it take to make the dissemination of this technology a sustainable option for clean cooking, and, further, a step-stone toward welfare creation in rural areas of developing regions?

THE CONTEXT: ONE-THIRD OF THE WORLD POPULATION LACKS CLEAN FUELS FOR COOKING

Clean cooking remains a major challenge in developing countries despite its recognized positive effects on public health, the environment, and women's productivity and empowerment. As many as 36% of the world population was using polluting cooking fuels in 2020 as compared to 53% in 1990.[2] While access to clean cooking fuels has improved in Asia and Latin America since 2010, developments have not kept pace with population growth in sub-Saharan Africa, where 1 billion people, or roughly four in every five people, rely on high pollution cooking fuels. Globally, 2.3 billion people still relied on inefficient and polluting cooking systems in 2021. The related impact costs on health, gender, and climate have been estimated at US$2.4 trillion annually.[3] Some 4 billion people are still yet to reach what the World Bank calls, "cooking decency," which translates into, "clean, efficient, convenient, safe, reliable and affordable" cooking solutions.[4]

Although programs for promoting clean cooking have existed for decades and progress has been achieved, these programs fall short of fully addressing the problem. Without proper and accelerated action, 1.9 billion people will still be using polluting cooking fuels by 2030. This would be a failure of one of the key targets of SDG 7, and a missed opportunity to reduce greenhouse gas emissions, improve community resilience to climate change and food security, reduce nature loss, and promote sustainable development.[5]

Clean cooking includes a shift to clean fuels such as LPG, ethanol, and biogas; in addition to switching over to efficient cooking stoves. Improved cooking stoves (ICS) achieve complete combustion, and greatly alleviate indoor air pollution and health problems. Different types of ICS have been implemented around the world using wood, charcoal, pellets, briquettes, and ethanol. New models are continuously being tested. Roughly 50 million biogas cooking stoves have been installed worldwide, and the number is growing at about 10% annually.[6] Nevertheless, a narrow perspective strictly focused on technologies such as cooking devices has proven inadequate to address the full scale of the problem. For example, while improved combustion in cookstoves results in lower fuel requirements to cook meals and improved indoor air quality, it also means less heat to warm homes, an energy service that cannot be ignored in cold areas.[7] Thus, the need for multiple services should be kept in mind when designing programs.

The use of traditional fuels for cooking and heating such as firewood, charcoal, and dung cause environmental impacts such as deforestation and emissions of particulate matter and greenhouse gases. Traditional fuels are responsible for more than 50% of global black carbon emissions. Although short-lived, black carbon is a powerful greenhouse gas.[8] Exposure to indoor air pollution results in premature deaths and respiratory diseases particularly affecting women and children. These fatalities are estimated at 3.7 million per year globally. Women and children spend an average of 5 hours per day gathering fuel, walking

2. Stoner et al., "Household Cooking Fuel Estimates at Global and Country Level for 1990 to 2030."
3. ESMAP. *"The State of Access to Modern Energy Cooking Services".*
4. Zhang et al., *Unlocking Cooking Pathways - A Practitioner's Keys to Progress.*
5. Tracking SDG 7, "The Energy Progress Report."
6. IRENA, "Biogas for Domestic Cooking – Technology Brief."
7. Njenga, M., Gitau, J.K., and Mendum, R. "Women's work is never done: lifting the gendered burden of firewood collection and household energy use in Kenya".
8. Ritter, Benjamin, and Kevin Karl, "Traditional Cookstoves: Fueling a Health and Climate Crisis?"

long distances, and carrying heavy loads.[9] The burden of collecting fuel is detrimental to other income-generating activities, reinforcing the poverty trap.[10] Up to 34% of wood fuel is harvested in unsustainable ways, contributing to forest degradation and climate change, and exacerbating the vulnerability of large populations.[11] Although these are well-known facts, and the problem is pervasive, clean cooking solutions receive limited international attention and climate finance not least when compared with efforts that target the power sector and fossil fuel subsidies.

As the international community looks for more effective ways to address the clean cooking challenge, integrated approaches offer opportunities to create synergy between actions addressing poverty and improving agriculture, and efforts in addressing energy access and climate justice. This requires contextualizing the efforts to design strategies that fit the local realities. For example, 75% of the Sub-Saharan population is dependent on family farming, which produces most of the agricultural output of the region in addition to shaping livelihoods and rural life.[12] Not seldom, farms are one hectare, which is sufficient for the subsistence of a family. It is important to acknowledge that the rural structure in developing a technological deployment system that is aligned with the realities on the ground. The development of agri-food value chains can be integrated with clean cooking, income generation, and actions to address climate change. This is essential to reach the billions that still lack clean cooking fuels and have limited chances to leave the poverty line. Also, this will be a very meaningful way to engage the population in climate action and to improve their resilience to climate change.

Fortunately, there is an increasing recognition of the need to integrate clean cooking programs into climate action, income generation, and overall livelihood improvement programs. Numerous attempts have been made to design roadmaps for different countries, which is an important step in the right direction. Regional contexts vary, but there is already a body of knowledge, and there are options in terms of technology maturity for diverse feedstock and clean fuel deployment opportunities. In this context, it is important to emphasize that clean cooking includes more than a shift to clean fuels and the adoption of efficient devices for cooking. It must be addressed as part of a dynamic process that considers affordability, reliability, and capacity building so that rural communities are empowered to address climate change and food security in addition to pursuing sustainable development.

THE OPPORTUNITY: BIOGAS – A COST-EFFECTIVE SOLUTION FOR CLEAN COOKING IN RURAL AREAS

Biogas is a versatile fuel that can be used for cooking, heating, lighting, and power generation. It can also be upgraded to biomethane and used as a transport fuel. Less than 3% of the overall potential for biogas and biomethane is harnessed today[13] indicating the great potential still available. This brief focuses on **small-scale biogas production and use in rural areas**, with particular emphasis on cooking and the use of feedstocks generated from local activities such as agricultural residues, animal dung, and food waste. In this context, the biogas can also be used for lighting, substituting open fire light or kerosene lamps. By-products of biogas production can be used as fertilizers, boosting agricultural productivity. The low heat in biogas

9. IEA. "A Vision for Clean Cooking Access for All".

10. Njenga, M., Gitau, J.K., and Mendum, R. "Women's work is never done: lifting the gendered burden of firewood collection and household energy use in Kenya".

11. EPA. "Household Energy and Clean Air."

12. Moyo, *Family farming in sub-Saharan Africa.*

13. IEA. "Outlook for biogas and biomethane: prospects for organic growth."

production which is otherwise lost can be effectively used for water purification.[14] Transport of biogas surplus is also manageable at low cost, for example, using gasbags. Typical gasbags on the market hold 2 cubic meters of biogas to fuel four hours of cooking.[15] Their use amplifies the geographical radius for small-scale biogas deployment and the creation of local markets for biogas.

Biogas is produced through anaerobic digestion of organic matter. It is a well-proven technology widely used in rural and urban areas at different scales on various continents. Nevertheless, the potential is only marginally utilized. IEA calculates the global biogas potential at 570 Mtoe, enough to cover 20% of the world's gas demand, yet production was limited to only 35 Mtoe in 2018. Animal manure and crop residues comprise the largest feedstock potential in all continents, followed by municipal solid waste. IEA's focus has previously been on the large-scale potential of biogas, but the agency acknowledges that biogas for clean cooking could serve 200 million people by 2040, half of them in Africa.[16]

Recent scenarios indicate the relevant role of modern bioenergy in guaranteeing clean cooking in rural areas, particularly in the coming decade before other options become more widely available.[17] In this context, food residues and domestic organic waste as well as agricultural and animal waste can serve as feedstock for small-scale domestic or community-owned digesters. These feedstocks can be sourced locally in more efficient ways than the collection of traditional fuel that prevails in many rural areas, causing deforestation and occupying most of the women's productive time.

Figure 1 illustrates how different organic matter can be used to produce biogas and satisfy multiple service needs of rural communities.

Thus, biogas offers an opportunity to create pathways for development that go beyond clean cooking. In addition to providing clean cooking, biogas can improve agri-food value chains which, in turn, will enhance the capacity of communities to respond to food crises and become more resilient to climate change.[18] For example, energy is needed for food processing which, in turn, improves food security as it allows storage and trade. In addition, agri-food system emissions are increasing in ways that correlate with the use of traditional fuels, further justifying increased attention to clean cooking fuels as part of food supply chains in developing regions.[19] An integrated approach to clean cooking access can serve to address barriers such as affordability and acceptance of new cooking practices while providing the technical support required to scale up deployment and reduce emissions.

14. Khan, Ershad Ullah, Brijesh Mainali, Andrew Martin, and Semida Silveira, "Techno-Economic Analysis of Small Scale Biogas Based Poly-generation Systems in Bangladesh, Sustainable Energy-Discoveries and Applications."
15. IRENA, "Biogas for Domestic Cooking – Technology Brief."
16. IEA Paris, "Outlook for biogas and biomethane: Prospects for organic growth."
17. IEA Paris, "A vision for clean cooking access for all."
18. International Food Policy Research Institute, *Rethinking Food Crisis Responses 2023.*
19. Tubiello et al., "Pre- and post-production processes increasingly dominate greenhouse gas emissions from agri-food systems."

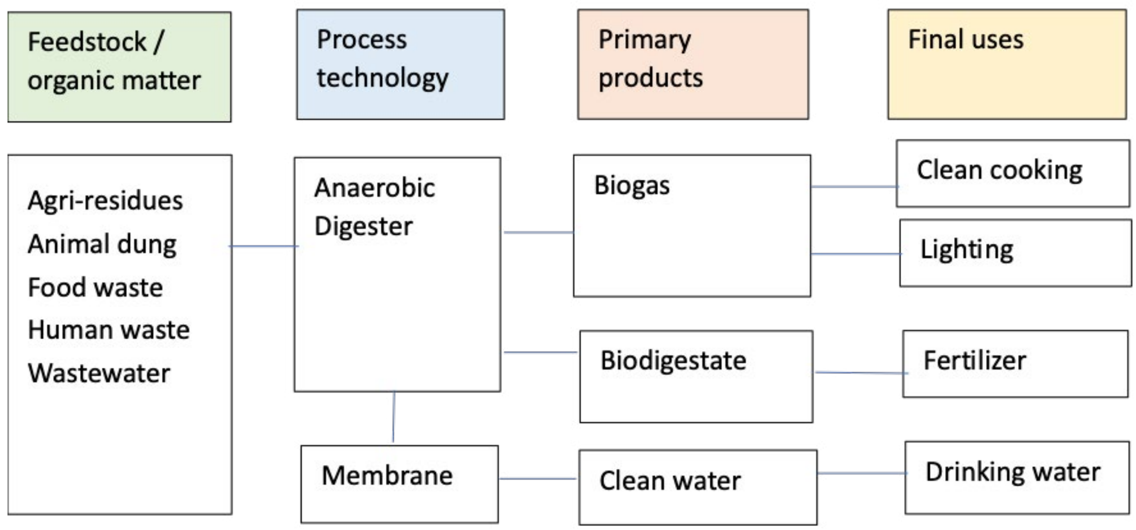

Figure 1: Opportunities for small-scale biogas production for multiple service provision in rural areas. Source: Graph created by authors.

THE COSTS – TRANSITIONING TO CLEAN COOKING WITH SMALL-SCALE BIOGAS

Poverty and lack of clean cooking fuels go hand in hand. High initial capital costs and/or recurring fuel costs are often a barrier for poor households to shift to clean fuels. In a rural context in which wood fuel, dung, and agricultural waste have a zero-market value, the shift to clean fuels requires more than technology deployment. Thus, a narrow approach to clean cooking cannot deliver on the multiple needs of poor regions. Any effective strategy to address this challenge must be based on actions that combine technology and fuel transition with mechanisms to generate income and improve affordability. For example, reducing the amount of time that women use to collect and prepare traditional cooking fuels will release time that can be used for income-generating activities.

The UN calculates that a transition to improved cooking solutions to cleaner fuels will come at an average cost of US $80-222 per household. This range reflects the variety of contexts of developing regions as well as the different costs of technology deployment. Between 2015 and 2022, the World Bank invested US $562 million to provide clean cooking fuel to 43 million people in 30 countries.[20] A typical household in Sub-Saharan Africa has 6.9 individuals, thus the World Bank invested an average of US $90 per household. This was at the low end of the cost window indicated by the UN but also the result of the focus on cooking appliances.

It is difficult to pinpoint the exact cost of installing a biodigester in a rural setting of a developing country. The IEA indicates a range between US $200 and US $820 per household biogas unit in 2018.[21] A few years earlier, small-scale biogas installation costs were calculated in the range of US $500 to 1,500.[22] Installation costs of around US $630 were reported for a pilot small-scale balloon digester for Bali, Indonesia in 2017. In this case, the provision of both clean cooking and lighting improved the total

20. World Bank. "Moving the Needle on Clean Cooking for All."
21. IEA. "Outlook for biogas and biomethane: prospects for organic growth."
22. Kammila et al., "Clean and Improved Cooking in Sub-Saharan Africa: A Landscape Report."

economic attractiveness of the deployment.[23] On the use side, biogas cooking stoves are highly rated in terms of health and environmental impacts, in comparison with other cooking options. The annual operating cost of a biogas cooking stove is less than one-fourth of the annual operating cost of an LPG stove or less than one-fifth of a traditional charcoal stove.[24] In a lifespan of 30 years, biogas is by far the cheapest option to provide clean cooking.

A recent report comparing metrics for various clean cooking options indicates the specific challenges for biogas as being upfront costs and scalability.[25] Surely, there will be a higher upfront cost to install the digester compared to using wood fuel or charcoal. But, over a lifetime, it is an attractive option with multiple benefits. A life cycle assessment of low-cost biodigesters carried out for small farms in Colombia showed that biogas could substitute LPG for cooking and synthetic fertilizers, resulting in an 80% reduction in costs associated with fuel and fertilizer purchase, and an 80% reduction in environmental impacts.[26] This is very relevant as LPG is a fossil fuel that is commonly suggested as the fuel of choice in many clean cooking programs. Other benefits include improved health of women and children, released time for other chores, and reduced black carbon emissions. The biodigestate is a valuable by-product of biogas generation that can be used as fertilizer. Markets for feedstocks and fertilizer can be formed as part of an integrated strategy. Moreover, as income increases, production can be expanded, and biogas can provide other energy services, for example, electricity. These multiplying effects and benefits are seldom properly evaluated or quantified when a program is strictly focused on clean cooking.

Biodigesters provide a pathway for residue valorization that improves the total efficiency of local production systems while also reducing emissions of residue decomposition and deforestation, improving public health, and creating a circular economy. According to IRENA,[27] biogas lifetime costs are the lowest among cooking technologies. Thus, the investment cost for a biodigester will require program support to overcome affordability among the rural poor but can be shared by a community. As the discussion above indicates, the cost of installation is going down. Biogas stoves have shown great performance, but attention is needed to address the upfront costs, affordability, and scalability.

IEA estimates the investment needed to achieve universal clean cooking access at US $8 billion annually, which is a small fraction of the global expenditures on energy every year.[28] Fossil fuel subsidies alone reached US $532 billion in 2021 and were estimated to reach US $1 trillion in 2022.[29] Approximately half of the investment should be done in Sub-Saharan Africa. With a targeted program to fit regional characteristics and local resource availability, including technical design and support, standardization, and market scale, costs can be further reduced, and scale can be achieved. In addition, it is important to provide the right training and technical support to avoid disruptions in biogas production which can discredit the technology among users, and result in leakages that compromise the climate benefits.

With integrated approaches, the deployment of clean cooking fuels will bring multiple benefits, help address various SDGs (i.e., poverty alleviation, zero hunger, health, clean water and sanitation, and economic growth), and contribute to mitigating

23. Ghiandelli, "Development and Implementation of Small-Scale Biogas Balloon Biodigester in Bali, Indonesia."
24. Putti et al., "The State of the Global Clean and Improved Cooking Sector".
25. IEA. "A Vision for Clean Cooking Access for All".
26. Garfi, M. et al. "Evaluating environmental benefits of low-cost biogas digesters in small-scale farm in Colombia: a life cycle assessment."
27. IRENA, "Biogas for Domestic Cooking – Technology Brief."
28. IEA, "A Vision for Clean Cooking Access for All".
29. IEA, https://www.iea.org/topics/energy-subsidies

climate change. Ultimately, it is about improving the livelihoods of rural households and making them more resilient, not simply providing a clean cooking solution.

THE TECHNOLOGY – TECHNICAL ASPECTS OF SMALL-SCALE BIOGAS

Biogas is produced by the anaerobic digestion of organic matter and comprises methane (50-75%), CO2 (25-50%), and small quantities of other gases. The precise gas composition will depend on the feedstocks and technologies used. A small biogas system includes a digester tank with an inlet sink to feed the digester, a gas tank to collect the gas, a pipe to connect the gas collector to the stove, and a biogas stove. The digester will take 30 to 60 days to yield biogas. Since anaerobic digestion is a biological process carried out by living organisms, the quality, amount, and characteristics of the feed determine the ability of methanogenic bacteria to survive and thrive. Finding the right composition will require an evaluation of how the feedstock available contributes to stimulating or inhibiting anaerobic digestion, ultimately affecting biogas production. Digestion time varies for the different feedstocks and is affected by temperature and humidity. The digestion process works smoothly with temperatures above 10^{o} C.

One cow provides enough dung per day (10-20 kg) to generate 40 liters of biogas, enough for a family to cook two meals. With two cows, the household would have enough gas for lighting using biogas lamps. Food waste can also be used even if it does not generate high gas yields. Agricultural residues can be advantageously used to boost biogas production. In any case, low yields are not a limitation if the initial focus is on providing clean cooking and lighting which amounts to low energy demand. A combination of feedstock and some care in positioning the digester will have a direct impact on the yield. Different inputs could stimulate or inhibit the biogas yield. For example, animal medication can inhibit the digestion process and affect the quality of the biodigestate. Appropriate training is required to ensure that the biogas operator understands how to place the digester, dose the feed to maintain healthy biology, monitor leakages, and guarantee safety while deploying biogas.

Water is also an important factor to consider when it comes to biogas production. For the digestion of 20 kg of cow dung, approximately 20 liters of water is needed. Thus, water can be a limiting factor for biogas deployment in arid areas. Overall, the water-energy-food nexus is strong in poor regions, and water scarcity could be exacerbated by climate change and reduced rainfall.[30] Water scarcity and seasonal and local variability could be mitigated, for example with water recycling, rainwater collection, and synergy with fishponds.[31] Still, the conditions for biogas deployment need to be carefully considered as they will likely vary significantly depending on feedstock and water availability. Additionally, the time to fetch water needs to be factored in when considering biogas dissemination. Like in the case of wood fuel, women are the ones fetching water. If releasing them from the wood fuel burden results in an extra water burden, the benefits for women's health, education, and overall welfare will not be accrued.

An important issue when it comes to the deployment of biogas relates to human health and safety. As the digestor is fed with waste, certain pathogens may proliferate around the site. A vaccination program may be required to avoid endangering the health of the family. Biogas contains methane, a health hazard if inhaled. There is also potential for combustion and explosion. Furthermore, depending upon the feed, it may contain hydrogen sulfide (from a few hundred parts per million to approximately 2-3%), an extremely poisonous gas, lethal at very low concentrations.

30. Conway et. al." Climate and southern Africa's water-energy-food nexus".
31. Bansal et al. "Water for small-scale biogas digesters in sub-Saharan Africa."

There are methods to remove hydrogen sulfide from the gas and methods to prevent methane leakages. It is important that these methods are applied, and the operators receive proper training.

Finally, methane fugitive emissions need to be avoided due to their climate impact (methane's global warming potential is approximately 80 times higher than CO_2). Fugitive emissions may happen at many stages of the process. Proper management of excess gas production is the most important aspect to monitor in the rural context. Collection of excess methane for sales and flaring are options to avoid release into the atmosphere. Thus, biogas has its inherent risks as all other technologies but there are proven ways to avoid or limit the problem to make this a safer option in rural areas.

Despite technology maturity and all the known benefits, the full potential of biogas has not been systematically explored for clean cooking purposes. Worldwide, there is a growing interest in the production of biogas for upgrading into biomethane particularly in urban areas using solid waste and wastewater. This is followed by increasing interest in monitoring leakages to guarantee the full environmental benefits of biogas production.[32] However, these developments are focused on large-scale solutions suitable mainly for urban contexts or large farms. It is important not to lose sight of the potential of small-scale biogas as a cost-effective solution for providing clean cooking and lighting for small farmers, as well as for improving the livelihoods of poor rural communities.

Across the world, the development of small-scale biogas is uneven. China has by far the largest number of small-scale biogas digesters, followed by India. But many countries have experience with the technology as will be illustrated in the success stories below and some of the lessons they bring from different parts of the world.

THE SUCCESS STORIES: BIOGAS- A CLEAN COOKING FUEL TO ADDRESS POVERTY AND CLIMATE CHANGE

In this section, we highlight successful experiences in small-scale biogas deployment in poor countries and emerging economies. These experiences capitalize on biogas as part of the solutions to achieving universal access to clean cooking but also show different approaches to tackling opportunities and promoting the technology. Building on these experiences, we can design programs that will help accelerate the much-needed penetration of clean cooking fuels in developing regions while also promoting sustainable development.

Experiences from Nepal:[33] Biogas stoves are used by tens of thousands of Nepalese households providing an important contribution to the clean cooking transition not least in remote regions and areas where households are reluctant to pay for cooking fuel. There is good acceptance for biogas in the country, but a recent study showed that there is room for performance improvement in both digesters and stoves. The need for adapting designs to higher altitudes and colder temperatures has been pointed out as part of a strategy to expand the deployment of biogas in the country.

Lessons learned: The Nepalese experience shows the importance of contextualizing biogas programs to take into consideration local conditions such as altitude and temperature, the types of feedstocks available, and the ideal feedstock composition for optimal system performance. For domestic biogas plants, one challenge may be the seasonal characteristics of the biogenic waste – both in terms of availability and its macro/micronutrient apportion. Therefore, biogas deployment programs must include technical support systems which can comprise training materials and education for biodigester owners, and routine and service contracts for regular maintenance.

32. EBA. "Design, build and monitor biogas and biomethane plants to slash biomethane emissions."

33. Clean Cooking Alliance, "Increasing the Potential for Biogas to Satisfy Household Cooking Needs in Nepal."

A narrow focus on upfront costs may jeopardize efforts to establish biogas as a reliable and sustainable solution in rural areas.

Experiences from Burkina Faso:[34] In Burkina Faso, 85% of the population lives in rural areas and 90% of the population is engaged in agriculture. 86% of the energy used comes from firewood. The country has launched a market-oriented program (Programme National de Biodigesteurs BNF – BF) aimed at constructing home biodigesters in rural and peri-urban areas, with volumes ranging from 4-10 m3. Two phases of the program between 2010 to 2018 resulted in the construction of almost 18,000 biodigesters at an approximate cost of US $600 per unit.[35] While the program targeted clean cooking, the fertilizers generated became useful inputs for rice, sorghum, and sesame crops. The fertilizers substituted synthetic alternatives and, for some households, provided a new source of income.

Lessons learned: The program was successful because it was integrated with livestock and agriculture to generate clean energy and fertilizers. It was also attentive to the development of the private sector to guarantee a sustainable delivery of the technology. The outcome shows that biodigesters can be scaled up also in the dry climates of the Sahelian region. The program also confirms the role that biogas can play in improving livelihoods, not least creating income opportunities. This experience also highlights the importance of a broad approach to safeguard technology delivery and maintenance.

Experiences from Uganda:[36] The Clean Cooking Supply Chain Expansion Project (2017–20) was a pilot project funded by ESMAP, the World Bank's Energy Sector Management Assistance Program. Lessons from the pilot project have informed the design of a program to scale up the clean cooking component (US $20 million) in the US $638 million **Uganda Electricity Access Scale-up Project** approved in 2022. Co-financed by the Clean Cooking Fund (CCF) and the IDA, the clean cooking component is expected to leverage another US $10 million in private-sector financing. The strategy includes a debt facility for supplier and consumer financing of off-grid solar and clean cooking solutions, and an RBF mechanism for clean cooking solutions including LPG - liquefied petroleum gas, ethanol, biogas, and electricity.

Lessons learned: The experience in Uganda shows how schemes for biogas deployment can start at a pilot level to define a model that matches the local needs and features. It also shows how, once the technology demonstration is established and understood in the local context, a funding mechanism can be devised for scaling it up, leveraging on international funds as well as the combination of public and private financing.

Experiences from Rwanda:[37] Home biogas units were installed in 500 households in Uganda in a region of fuelwood scarcity. The units provide 6 hours of cooking energy with the dung of up to two cows. The biodigestate provides fodder for the cow thus creating a self-supporting system. The company that delivered the technology provided capacity building so that there is technical support in the community. It also provided a three-year guarantee for the digester (which has a life expectancy of ten years). The unit cost is approximately US $1,000 which poses challenges of affordability. Still, the experience has been so successful that UNDP Rwanda presently plans to scale up the project to at least one million households. Local manufacturing of the home biogas unit is also being considered.

34. World Bank Group, Agriculture and ESMAP, *The Power of Dung – Lessons Learned on farm biodigester programs in Africa*.; Verbist, Bruno and I Kaboré, "Evaluation du Programme PNB – Burkina Faso. Rapport de l'enquête auprès les ménages."

35. Verbist, Bruno and I Kaboré, "Evaluation du Programme PNB – Burkina Faso. Rapport de l'enquête auprès les ménages."

36. Querio, "Uganda Clean Cooking Supply Chain Expansion Project (P153679)."

37. https://www.undp.org/rwanda/blog/dung-dinner-biogas-transforming-cooking-energy-rwanda

Lessons learned: The experience of Rwanda shows the impact that biogas biodigesters can bring to low-income families, particularly in areas of fuelwood scarcity. A demonstration program can serve as a testing ground and proof of concept while also helping sensitize policymakers about the full potential of biogas opportunities. For example, in Rwanda, the upscaling strategy is contemplating local biodigester manufacturing to capitalize on biogas market development. A supportive policy framework will include funding mechanisms to overcome upfront costs.

Experiences from Ethiopia:[38] Ethiopia has experienced significant economic growth in past decades but still 85% of the population lives in rural areas. Small farms cover 95% of the agricultural land and produce 90% of the output. Biogas has a long history in Ethiopia and projects of different sizes were developed over decades. Initially, these projects were developed as enclaves with little integration with the overall context. More recently, biogas production plants ranging from 2.5 to 200 m^3 were installed in households, communities, and institutions. The National Biogas Program of Ethiopia (NBPE) started in 2009 and has run in two phases until 2022 with the aim to develop domestic biogas on a commercial basis. By 2017, 18,000 digesters had been installed though this was below the targets initially set. The yield of digesters was low due to poor feeding, unsuitable design, lack of technical maintenance, and lack of water indicating the need for better technical assistance and maintenance programs. Interestingly, many users mention biogas for lighting and the digestate as an important value. They also indicated continued use of wood fuel for specific dishes when enough biogas was not available for cooking. There is strong government support for biogas in Ethiopia but there are also divergencies among implementing agencies as some prefer a market-oriented approach with a focus on regions with greater potential, while others focus on poverty alleviation and equity with larger dissemination across regions.

Lessons learned: The Ethiopian experience illustrates the role of biogas in providing lighting and fertilizer, and the household strategies to cope with the uneven supply of biogas for cooking. This highlights the need to provide technical assistance to guarantee technology performance and reliability in the biogas supply. The continued use of wood fuel may denote some cultural preferences but has not been a barrier to acceptance. Ethiopia's experience also highlights the importance of aligning goals and strategies among implementing agencies to reach scale and reliability and avoid delays in deployment.

Experiences from Brazil:[39] In Brazil, LPG has been widely deployed in both rural and urban areas. However, particularly in times of economic recession, many families revert to the use of wood fuel as they cannot afford the cost of LPG. A total of 713 units were installed in six different states of Brazil. This is a small number resulting from social projects driven by NGOs but indicates the interest and role small-scale biogas deployment can play in family farms in Brazil and elsewhere. In the State of Pernambuco in the Northeast of the country, for example, biogas digesters were successfully integrated with small-scale agroecological farms. In addition to providing an affordable source of clean cooking fuel, the biogas biodigestate became a source of income for many families. It also provided a substitute for chemically synthesized inorganic fertilizers, thus reducing cost, and addressing an issue of growing concern in the country. However, there were cases of deactivation of the biodigesters due to a lack of enough feedstock and technical issues. Policy, institutional and technical support could help make it a solution for many farmers in Brazil.

38. World Bank Group, Agriculture and ESMAP, *The Power of Dung – Lessons Learned on farm biodigester programs in Africa*; Kamp, Linda Manon and Esteban Bermúdez Forn, "Ethiopia's emerging domestic biogas sector: current status, bottlenecks and drivers."

39. de Souza, Reginaldo Alves, Marília Regina Costa Castro Lyra, and José Coelho de Araújo Filho, "Sertanejo biodigestor: a social technology source of energy."

Lessons learned: The Brazilian experience illustrates how biogas production can improve the socio-economic resilience of communities and pave the way for more sustainable agriculture, in addition to reducing greenhouse gas emissions. Biogas provides an alternative to fossil fuels used for cooking, making the community more self-sufficient and less vulnerable in the face of gas price variations.

Experiences from China:[40,41] China is a pioneer in biogas utilization and has the second-largest biogas production in the world after Europe. Government policies have played a central role in this deployment. For example, between 2001 and 2019, more than 20 institutions were involved in biogas policies. Most of the Chinese biogas production is from small-scale biogas digesters that use animal manure so there is still a large untapped potential in the country. Biogas programs for rural areas emerged in the 1970s and became part of national strategies in the 1980s. Design improvements for digesters were made in the 1990s. The number of rural household biogas plants increased fourfold between 2000 and 2015, from less than 10 million to approximately 42 million. However, after 2016, the number of biodigesters went down to approximately 30 million in 2020. This was due to a combination of factors including structural changes in the rural economy, urbanization, lack of follow-up support, and grid extension to meet increasing energy demand in rural areas. The Chinese government has gradually shifted attention to larger biogas projects. From a focus on energy access in rural areas, biogas can come to play a major role in the country's low-carbon strategy.

Lessons learned: The central role of policy and institutional support explains the scaling up of household biogas solutions in China. The structural transformation of rural and urban areas points to the need to monitor the changing energy demand patterns and review policies. While clean energy access has been the focus for decades, this has proven insufficient to tap the large feedstock availability and the new demands of rural areas. Broadening the view of the multiple benefits of biogas will enhance its role in the circular economy and the low carbon economy.

Funding experience from Africa:[42] Spark+ Africa Fund is a $70 million impact investment fund that was first announced in 2022. This fund supports profitable and scalable companies that offer products throughout the value chains of different cooking fuels in the clean cooking market. The aim is to finance companies that offer next-generation, distributed cooking energy solutions to the large markets of sub-Saharan Africa and reduce the risks of what is perceived as a high-risk business. One important aspect is the diversification of the fund supporting a variety of technologies and fuels, including liquified petroleum gas (LPG), biofuels such as ethanol and pellets, electric appliances, and efficient biomass stoves. This will help develop solutions that can compete commercially for the growing clean cooking market in Africa. The fund is supported by the African Development Bank and other financial institutions, as well as international donors and foundations.

Lessons learned: The creation of this fund builds upon learned lessons from many previous efforts to address clean cooking. More specifically, there is an in-built understanding of the need to address the whole value chain of clean cooking technologies and fuels anchored in the local economy to guarantee a reliable solution.

40. Wang, Y. et al. China's biogas industry's sustainable transition to a low-carbon plan – a socio-technical perspective. *Sustainability.* Vol 15 (6), 5299.

41. Giwa, A. S. et al. "Prospects of China's biogas: fundamentals, challenges and considerations".

42. SparkFund Africa, "Spark+ Africa – Investing in Modern Cooking."

Opportunities to expand biogas systems in Bangladesh:[43] More than 60% of the population in Bangladesh lives in rural areas. Significant improvements in energy access have been achieved in the past decade. Still, there are many underserved communities. A techno-economic performance study was carried out for a scheme designed to meet the demand for electricity, cooking energy, and safe drinking water in 30 households in a rural village in Bangladesh. In this case, animal manure is used. The digestor produces fuel for cooking and electricity and provides biodigestate as a by-product. A membrane distillation unit is installed to clean water using the low heat of the digestion process. Water contamination with arsenic is pervasive in the country, and the opportunity to provide clean water at a low cost is an important value added to the scheme. The project payback period was between 2.6 and 4 years.

Lessons learned: The results of this project provide evidence for the competitiveness of the integrated approach to biogas deployment. In this case, not only energy needs could be met but also the demand for clean water. This integrated concept shows the opportunity to combine electricity access with clean cooking and water purification at the community level.

THE ROAD AHEAD – RECOMMENDATIONS FOR SMALL SCALE BIOGAS DEPLOYMENT

Worldwide, 2.3 billion people rely on traditional cooking fuels. The challenge of providing clean cooking universally is a systems challenge, not strictly a technical challenge. A clean cooking fuel transition can be promoted through the deployment of affordable, reliable, and small-scale biogas solutions in combination with other programs to address clean energy access, agricultural development, poverty alleviation, and climate change. Biogas is a well-known technology that can be adjusted to local needs and regional contexts and integrated with existing livelihoods in developing regions. Stakeholders must work together to guarantee policy support, the flow of funds, and the technical assistance required to tap into this opportunity. If properly assisted, rural communities can overcome the implementation thresholds in terms of upfront costs, know-how and maintenance, becoming self-sufficient in cooking fuels, and more resilient to climate change.

Biogas solutions can be implemented at household and community levels, bringing clean fuel for cooking, lighting, and organic fertilizers to rural communities. Where appropriate the biogas process can be combined with water purification and electricity generation. Integrated approaches involving food supply chains contribute to income-generating activities and self-reliance of rural communities, improving food security and health, and reducing environmental impacts and greenhouse gas emissions. Beyond agri-food synergies, biogas deployment could contribute to building other local industries for artisan ceramics, foundry, metal treatment, etc. The deployment of biogas can help build industries and businesses along the biogas supply chain.

The CEET proposes implementation pathways that relate technological improvement to livelihoods and opportunities for income generation supported by the climate and SDG agenda. Such an approach will help mobilize governmental support and funding to overcome affordability barriers which are detrimental to achieving broad adoption of clean cooking solutions. Concerted actions will accelerate the deployment of biogas while promoting residue valorization and total efficiency of local production systems, generating income, reducing emissions and environmental degradation, as well as improving public health. A clean cooking strategy will help address climate change, poverty alleviation, and deforestation, and deliver on multiple SDGs.

43. Khan, Ershad Ullah, Brijesh Mainali, Andrew Martin, and Semida Silveira, "Techno-Economic Analysis of Small Scale Biogas Based Poly-generation Systems in Bangladesh, Sustainable Energy-Discoveries and Applications."

Biogas solutions offer an opportunity to engage rural communities in climate action while paving the way for sustainable development.

The following ten recommendations offer guidance for the implementation of an integrated rural biogas pathway to enhance access to clean cooking in developing countries.

1. **Form a task force to create roadmaps and a policy framework to support integrated rural biogas solutions for clean cooking.** Government and funding support will be essential to guarantee the attractiveness and competitiveness of biogas and overcome deployment barriers such as high upfront costs. This includes the definition of national and regional clean cooking policies and targets, program priorities, institutional support for policy implementation, allocation of funds, and the review of subsidies given to other fuels. National and regional task forces can be formed and connected to agri-food initiatives.

2. **Allocate funding and define mechanisms for funding access.** Bring together national governments, development finance institutions, and multilateral development banks to elaborate funding programs specifically targeting small-scale biogas pathways integrated with agriculture development and agri-business development, particularly in Sub-Saharan Africa where the clean cooking gap is the largest. Coordinated actions will help leverage concessional loans and private finance and ensure that resources trickle down to rural communities in a biogas-based clean cooking strategy, on the other hand.

3. **Develop guidelines for the implementation of small-scale rural biogas cooking solutions.** The guidelines for rural biogas systems deployment shall include technical and institutional guidance, and cooperation modalities for the engagement of multiple stakeholders. Regional assessments should start with the evaluation of feedstock availability and the water-energy-food nexus. Guidelines shall be based on lessons learned worldwide highlighting solutions for various phases of program implementation and the role of stakeholders. The latter comprise funding organizations, public institutions for technical support and training, universities, NGOs, community associations, and local business ecosystems.

4. **Foster bilateral exchange to build upon lessons learned.** Advance bilateral knowledge exchange between countries to scale success stories particularly fostering South-South cooperation. The progress achieved in countries such as China, South Africa, Ethiopia, and others serves as a testament to successful program models and offers valuable insights to design programs to accelerate the deployment of rural biogas. By fostering bilateral knowledge exchange and drawing from the successes and failures of others, countries can build upon learned lessons while adapting solutions to their own specific context.

5. **Enhance the implementation capacity for small-scale biogas with technical support.** Engineers are needed to assess and approve technologies and project designs, ensuring efficiency, safety, as well as environmental and health considerations. Multiple expertise is required to support feasibility assessments based on the local conditions to inform policy design, funding allocations, and investment. Training of plant operators, the establishment of regular inspections, and technical assistance are essential to guarantee the delivery of biogas-based clean cooking integrated into local economies.

6. **Create a biogas ecosystem to scale up small-scale biogas solutions for clean cooking.** Technical and institutional support for the development of rural biogas includes demonstration centers, capacity-building programs, and local funding opportunities for business development. Innovation Labs can be created to foster private capital inflow, nurture entrepreneurship, and develop bankable, commercially profitable, and innovative business models.

Innovation Labs enable ideation, prototyping, and testing of ideas, expediting the development of effective and scalable solutions. They encourage partnerships and facilitate knowledge exchange.

7. **Develop research on small-scale biogas technologies and business models to help build know-how and capacity.** Local universities must be engaged to help develop and adapt technologies, integrate them into agricultural development programs, and define development pathways for clean cooking. This will give depth and continuity to knowledge creation and capacity building for lasting impact. Research should also aim at standardized models for small-scale biogas digesters and cookstoves that guarantee safety, efficiency, and high environmental performance adapted to temperature, feedstocks, and overall socio-technical conditions of the communities. Standardization and deployment will contribute to cost reductions. Research shall also serve to monitor performance and achievements creating feedback loops for continuous program development. Market assessments aligned with technical performance assessments will contribute to adjusting policies, fine-tuning financial instruments, and tapping business opportunities along the whole supply chain.

8. **Develop metrics to monitor the impact of integrated programs for the deployment of small-scale rural biogas systems.** Access to clean cooking can be measured in the number of households that shift to clean fuels and technologies, while an integrated approach requires a broader understanding of the impact of clean cooking policy on the development of the communities. New metrics could include clean cooking use, employment generation, emissions reductions, health reports, innovation, and overall impact on human development. Data collection and new metrics will serve to assess the impact of investments and actions, inform policy and funding agents, and promote policy adjustments for accelerating clean cooking fuel access.

9. **Prepare a communication campaign to mobilize efforts, engage stakeholders, and accelerate rural biogas deployment.** Such a campaign should include briefs to policymakers and funding agencies, and preparation of materials such as guidelines, course content, and videos showing successful experiences in different country contexts. It could also include access to a portfolio of successful experiences and experts. It is important that the opportunities at hand become better known and understood.

10. **Promote systems integration as a pathway to sustainable development.** While the breakdown of programs is a proven strategy for pursuing project implementation, integrated approaches are essential to addressing global challenges such as climate change and sustainable development at large. Governments, institutional arrangements, and funding organizations are seldom well-equipped to operate under such an integrated approach, which requires strategies that cut across sectoral dimensions. Technological innovation allows such integration as never before and it is important to dedicate serious effort to tap into the new opportunities to promote sustainable development. This brief has shown how the deployment of biogas for clean cooking can serve as an entry point for rural development if integrated with agrifood value chains to help support livelihoods, build resilience, and enhance food and social security.

ANNEX 1: EXAMPLES OF BIOGAS PLANTS

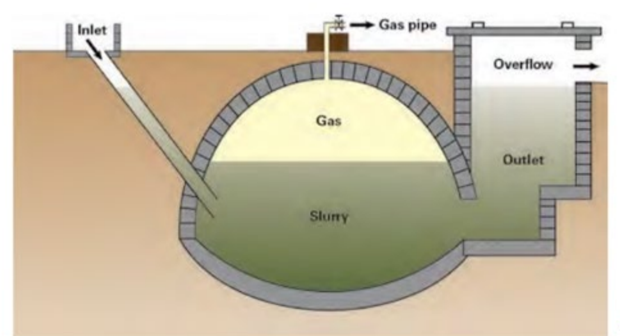

Figure 1A: Fixed-dome biogas plant. Source: Yvonne Vögeli et. al., "Anaerobic Digestion of Biowaste in Developing Countries – Practical Information and Case Studies." (Eawag, 2014) Figure 6.

Figure 1B: Fixed-dome biogas plant. Source: Anaerobic Digestion Community, "Biogas Digester Facts." (Anaerobic Digestion Community, 2018).

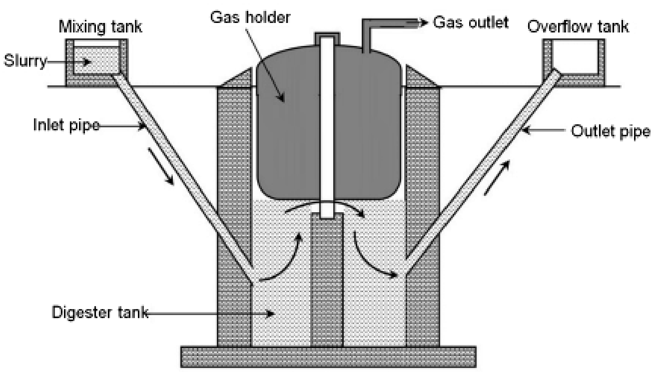

Figure 2A: Floating drum biogas plant. Source: Martha Osei-Marfo et. al., "Biogas Technology Diffusion and Shortfalls in the Central and Greater Accra Regions of Ghana." (Water Practice &Technology, 2018).

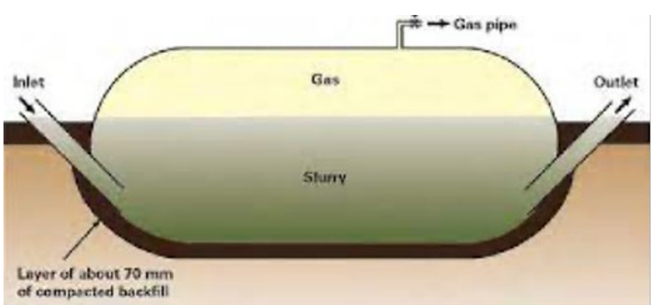

Figure 3A: Balloon/bag digester. Source: Yvonne Vögeli et. al., "Anaerobic Digestion of Biowaste in Developing Countries – Practical Information and Case Studies." (Eawag, 2014) Figure 8.

Figure 3B: Balloon/bag digester. Source: Marco Ghiandelli, "Development and Implementation of Small-scale biogas balloon biodigester in Bali, Indonesia." (KTH Industrail Engineering and Management, 2017).

Typical Feedstocks					
Manure	**Source of nutrient; high buffet capacity. Usually in co-digestion with straw.**				
Type	Organic content	DM%	VS% of DM	C:N ratio	Biogas yield [m^3/kg VS]
Pig	Carbohydrates, proteins, lipids	3–8	70–80	3–10	0.25–0.50
Cattle	Carbohydrates, proteins, lipids	5–12	80	6–20	0.20–0.30
Poultry	Carbohydrates, proteins, lipids	10–30	80	3–10	0.35–0.60
Agriculture residues	**Source of cellulose, lignin, and starch. Need pre-digestion.**				
Type	Organic content	DM%	VS% of DM	C:N ratio	Biogas yield [m^3/kg VS]
Straw	Carbohydrates, lipides	70–90	80–90	80–100	0.15–0.35
Grass		20–25	90	12–25	0.55
Organic household waste	**High variability of composition. Easily digestible. May inhibit the process for acidification.**				
Type	Organic content	DM%	VS% of DM	C:N ratio	Biogas yield [m^3/kg VS]
Fruit waste		15–20	75	15–20	0.25–50
Food residues		10	80	—	0.50–0.6

Table 1. Chart of typical feedstocks. Source: Martina Pilloni and Tareq Abu Hamed. "Small-size biogas technology applications for rural areas in the context of developing countries." (Anaerobic Digestion in Built Environments, 2020).

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