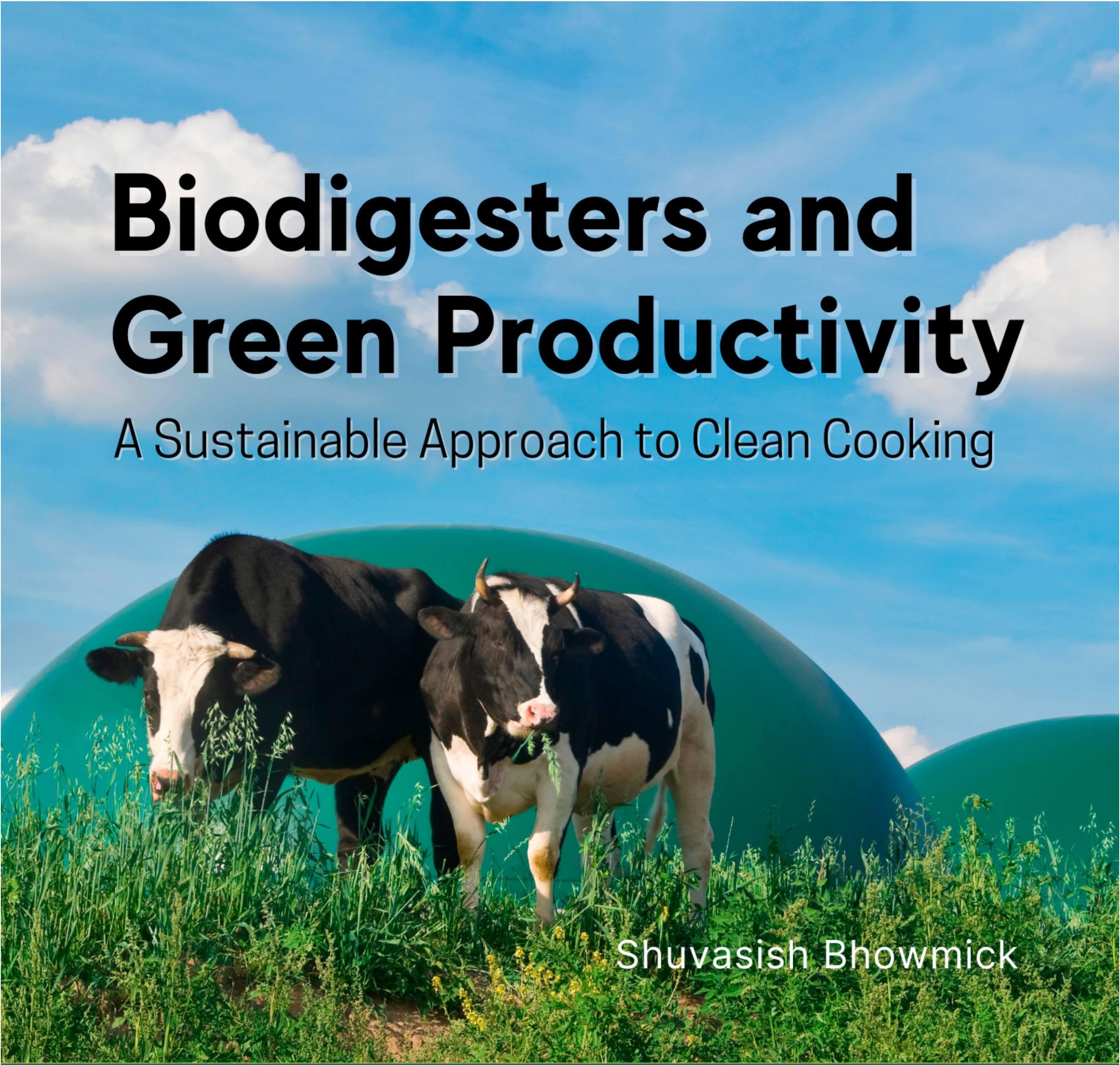
Biodigesters and Green Productivity

A Sustainable Approach to Clean Cooking



Shuvasish Bhowmick

Productivity *Insights* Vol. 3-2

Asian Productivity Organization

The Asian Productivity Organization (APO) is an intergovernmental organization that promotes productivity as a key enabler for socioeconomic development and organizational and enterprise growth. It promotes productivity improvement tools, techniques, and methodologies; supports the National Productivity Organizations of its members; conducts research on productivity trends; and disseminates productivity information, analyses, and data. The APO was established in 1961 and comprises 21 members.

APO Members

Bangladesh, Cambodia, ROC, Fiji, Hong Kong, India, Indonesia, Islamic Republic of Iran, Japan, ROK, Lao PDR, Malaysia, Mongolia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Turkiye, and Vietnam.

Biodigesters and Green Productivity

A Sustainable Approach to Clean Cooking

MARCH 2023 | ASIAN PRODUCTIVITY ORGANIZATION

PRODUCTIVITY INSIGHTS Vol. 3-2
Biodigesters and Green Productivity: A Sustainable Approach to Clean Cooking

Shuvasish Bhowmick wrote this publication.

First edition published in Japan
by the Asian Productivity Organization
1-24-1 Hongo, Bunkyo-ku
Tokyo 113-0033, Japan
www.apo-tokyo.org

Designed by Convert To Curves Media

CONTENTS

PREFACE

The P-Insights, short for "Productivity Insights," is an extension of the Productivity Talk (P-Talk) series, which is a flagship program under the APO Secretariat's digital information initiative. Born out of both necessity and creativity under the prolonged COVID-19 pandemic, the interactive, livestreamed P-Talks bring practitioners, experts, policymakers, and ordinary citizens from all walks of life with a passion for productivity to share their experience, views, and practical tips on productivity improvement.

With speakers from every corner of the world, the P-Talks effectively convey productivity information to APO member countries and beyond. However, it was recognized that many of the P-Talk speakers had much more to offer beyond the 60-minute presentations and Q&A sessions that are the hallmarks of the series. To take full advantage of their broad knowledge and expertise, some were invited to elaborate on their P-Talks, resulting in this publication. It is hoped that the P-Insights will give readers a deeper understanding of the practices and applications of productivity as they are evolving during the pandemic and being adapted to meet different needs in the anticipated new normal.

INTRODUCTION

The world faces numerous problems that need urgent solving, some of which impact over one billion people. Humans have been trying to solve one major problem since we learned to control fire: how to source fuel for cooking. From the Stone Age until the current era, humans have used many primary fuels (Figure 1) for cooking, like crop residues, charcoal, wood, dung sticks, briquets, kerosene, and other biomass fuels. But most of these solutions were not clean and sustainable.

FIGURE 1

ANCIENT FIRELIGHTING.

Source: Reproduced with permission from BBC [1].

Cooking without clean fuels releases toxic pollutants into the environment. It puts the health and well-being of billions of people around the world in peril. The use of open fires and inefficient stoves in cooking emits black carbon and other pollutants and contributes to climate change, sea ice melting, and deforestation. Additionally, open flames produce indoor air pollutants that increase the risk of major illnesses and even death for families residing in those dwellings.

The lack of access to clean, modern cooking services is a critical issue for more than half of the world's population. Seventy-three percent of

Bangladeshi households suffer from this, and 65% of those households use biomass (wood, straw, dry leaf, etc.) as their main cooking fuel. This heavily affects women, who spend at least 13 hours a week in the kitchen and inhale toxic smoke generated from biomass fuel. This leads to around 4 million deaths per year, which is three times higher than the global death rate from traffic accidents. The overall impact of this unsafe fuel usage creates a dent of USD2.2 trillion in the world economy. At a macro level, this is more than the national GDP of Italy, while at a micro level, it equates to an economic opportunity loss of USD3,000 in each of those households, which earn less than USD10 per day.

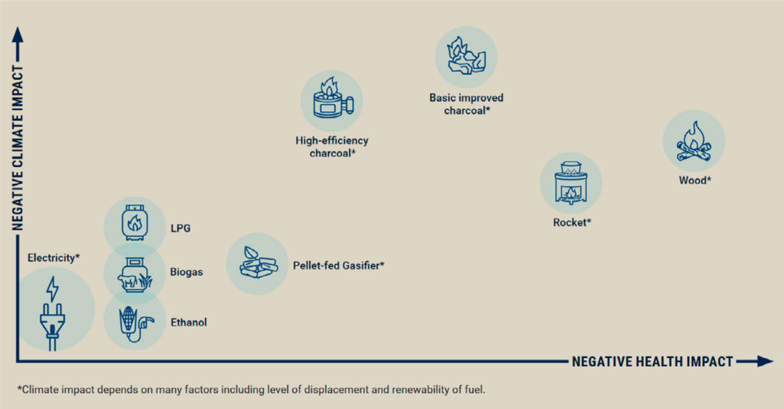
Clean cooking could be the solution. A group of fuel-stove combinations with emission performance that complies with the World Health Organization's recommendations for indoor air quality is referred to as "clean cooking solutions." Electric stoves, pressure cookers, ethanol, biogas, LPG, high-efficiency charcoal, and biomass stoves are all included in this category (Figure 2). Context-specific solutions that satisfy customer needs and willingness to pay are necessary.

Cooking in emerging economies rarely makes a total switch from one fuel to another as households move up the energy ladder with rising incomes. Instead, changes in cookstoves and fuel "stacking," or the use of various stove and fuel cooking combinations inside the same family, occur in households. The dynamics of user preference and adoption are at the core of initiatives to broaden access to modern cooking services and lessen the effects of traditional cooking's negative environmental effects [2].

Figure 2 shows that cooking with wood has the most negative health impacts, and cooking with charcoal has the most negative climate impacts. The lack of uptake of clean cooking fuels is not a matter of people not wanting to change. People are ready for better solutions as they continue to progress economically and lift themselves out of poverty, according to those with direct field experience in working with homes over the past few years. Contrary to what we may occasionally hear, most people do not want constant biomass use. But why are there still 4 billion users? The simple answer is that in the market for clean cooking solutions, the trifecta of high quality, low cost, and scalable distribution has not yet been attained. The expansion of the smartphone market has only addressed the issue of information access.

FIGURE 2

DIFFERENT FUEL SOURCES AND THEIR IMPACTS ON HEALTH AND CLIMATE.



Source: Reproduced with permission from Clean Cooking Alliance [2].

Access to clean cooking solutions would have a significant influence on households' health and way of life, as well as the environment as a whole. More than the emissions produced by the entire world's commercial aircraft industry (915 million tons/year), the transition away from burning wood and other biomass would reduce global climate emissions by 1 billion tons annually.

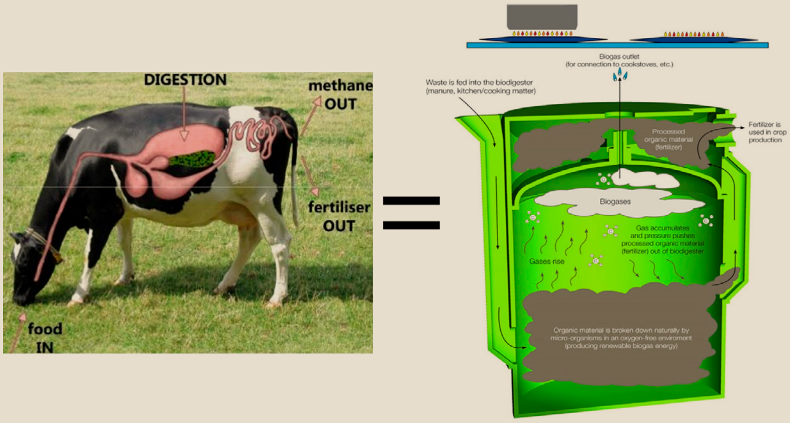
Biogas is one of the most environmentally friendly options with few adverse effects on human health and the climate. Biodigesters are the equipment or structures in which the biological process of anaerobic digestion of various organic materials by bacteria takes place and creates burnable biogas and a nutrient-rich slurry. Biogas is a gas combination primarily made up of methane and carbon dioxide (CO_2). A biodigester uses organic waste, especially excreta from people and animals, to create fertilizer and biogas. Biodigesters can treat any kind of organic waste, including crop or plant waste. This kind of waste requires additional prior processing to break down particles and facilitate the work of the bacteria.

WHAT IS A BIODIGESTER?

A biodigester is a mechanical stomach (Figure 3). It is fed with organic material, which is broken down by bacteria in an oxygen-free (anaerobic) environment to produce biogas (methane and bioslurry), which is then utilized as fertilizer.

FIGURE 3

WORKING PRINCIPLES OF BIODIGESTERS.



Source: Reproduced with permission from ATEC [3].

What Is Biogas?

Methane and CO_2 make up the majority of biogas composition. Lower levels of nitrogen, H_2S, and several other compounds are also present. Diesel oil ignites at 350°C and gasoline and propane at about 500°C, whereas biogas is somewhat lighter than air and has an ignition temperature of about 700°C. About 60% of biogas is methane (CH_4) and 40% is CO_2. Additionally, it contains trace amounts of other compounds, including up to 1% H_2S.

What Makes Biogas Burn?

Methane is the main ingredient (55–70%) in biogas. Natural gas contains approximately 95% methane, and LPG contains no methane but instead contains propane. The methane content depends on the digestion temperature. Low digestion temperatures give high methane content, but less gas is then produced. The methane content depends on the feed material. Some typical values are as follows:

- Cattle manure 65%
- Poultry manure 60%
- Pig manure 67%
- Farmyard manure 55%
- Straw 59%
- Grass 70%
- Leaves 58%
- Kitchen waste 50%
- Algae 63%
- Water hyacinths 52%.

What Makes Biogas?

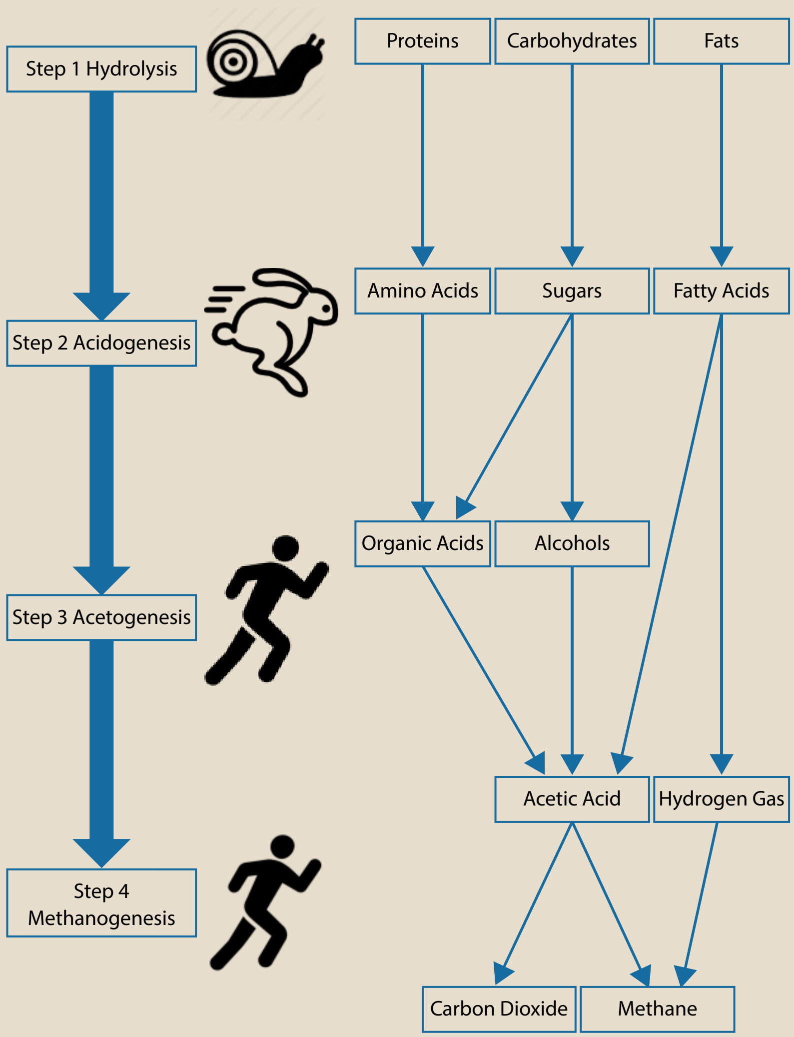
Not everything biodegradable yields biogas. The right bacteria, i.e., methanogens or methane-producing bacteria, are required. These bacteria live in anaerobic conditions, e.g., the stomachs of ruminant animals (cows, sheep, goats, buffalo). Other biodegradable material will produce biogas if methanogens are introduced. However, if methanogens are overloaded with other waste, they will die. Loading rates are therefore important.

Methane Gas Production Process

It can be useful to understand the methane gas production process (Figure 4), which helps us understand why feeds other than cow manure can cause issues if fed too quickly. The methane gas production process consists of four steps, and the speed of each step is shown by the icons next to those steps in Figure 4.

FIGURE 4

METHANE GAS PRODUCTION PROCESS.



Source: Reproduced with permission from ATEC Internal Documents and images captured from ICON Archive [4].

Step 1: Hydrolysis

Hydrolytic bacteria break organic matter into smaller pieces. For example, carbohydrates are converted into simple sugars, proteins are converted into amino acids, and fats are converted into fatty acids. However, problems can occur in this step. For example, if fat is contained in the feed, it is converted into fatty acids that have a foul odor. This is why users must not feed food waste containing fat and meat into biodigesters.

Step 2: Acidogenesis

Acidogenesis involves acidogenic bacteria. A biodigester typically crashes at this stage if it is overfed since it easily offers more acidic food than the rate at which methogenic bacteria can consume it. This is the fastest step. Sugars are transformed into organic acid in this stage.

Problems that occur in the acidogenesis step include the following:

- If the feed is high in carbohydrates (which are broken down into sugars in the hydrolysis step) such as is likely when pigs are fed grain or with food waste, then too much acid accumulates and inhibits step 4, when bacteria and methogens are inhibited from producing methane. CO_2 and therefore gas are still produced but contain no methane and therefore are not burnable.

- It is in this step when the biodigester will smell of alcohol and vinegar if the feed contains too much fruit waste.

Step 3: Acetogenesis

Larger organic acids like fatty acids, which smell horribly, and amino acids from proteins are broken down by acetogenic bacteria into simple acetic acid (vinegar) and hydrogen gas.

Step 4: Methanogenesis

Hydrogen gas and acetic acid are used as the food to produce methane by two different classes of bacteria in step 4. Twenty-five percent of the methane is from hydrogen gas produced by hydrogenotrophic bacteria, and the other 75% is from acetic acid converted by bacteria called aceticlastic methanogens. It should be noted that if a biodigester is overfed and pH drops, steps 2 and 3 will continue to occur and additional acid will be produced, but step 4 will cease as methanogenic bacteria require the pH to be between 6.5 to 8. A healthy biodigester operates at pH 7. Given that during the wet season much of the feed water is from rain, which has a pH of 5.5, it is likely that gas production may decrease during this time.

A biodigester should be emptied and reseeded whenever the pH falls below 5, as methanogens are likely to perish at that pH level. Feeding procedures should be altered after reseeding to prevent a recurrence of the problem. This entails consuming less food or more water. It is crucial for a food waste biodigester that the maximum feed rate is not started immediately and that the feed is increased gradually over a period of many weeks.

It is a problem if the biodigester pH is between 5–6.4, but that can be resolved by one or more of the following:

- Reducing the feed amount.
- Reducing carbohydrates in the feed.
- Adding more water.
- Asking customers to stop feeding for a few days until the overflow pH increases (because methogens then consume some of the acid).
- Adding an alkaline material such as lime.

Different Feed Types

There are various types of manure besides cow dung that can be used in biodigesters to produce gas.We can obtain approximately 23–40 liters of gas per kg from cow manure. The highest level of gas, ranging from 65 to 116 liters/kg, can be found in leftover poultry. About 30 to 50 liters/kg can be obtained from human waste. We can get between 37 and 45 liters/kg from pretreated crop waste and pretreated water hyacinth.

However, some manures have an overabundance of either nitrogen or carbon, which is an issue. Both are crucial since nitrogen is needed as a nutrient and carbon serves as a source of sustenance (to build the genetic makeup of living things). According to earlier studies, there should be 20–30 times more carbon than nitrogen in the biodigester feedstock. Therefore, the ideal feedstock carbon to nitrogen (C:N) ratio should be 20 to 30. Fortunately, cow manure has a C:N ratio of about 25, which indicates that it digests easily.

Pig dung contains a lot of nitrogen since its C:N ratio is close to 18, which indicates that bacteria will release ammonia as a consequence of too much nitrogen, which is damaging to the bacteria themselves. Fortunately, since the bacteria can adapt to an environment with high ammonia levels, it takes a lot of ammonia before a system stops functioning. There is no need to take action if the smell of ammonia is emitted by a pig manure biodigester but users are otherwise satisfied with the gas supply. Table 1 gives C:N ratios for various feed types. It should also be noted that feeds with high C:N ratios have too little nitrogen and will not digest easily. Sawdust (with a C:N ratio of more than 240), fed by itself, generates very little gas [5].

TABLE 1

C:N RATIOS OF VARIOUS BIODIGESTER FEEDS.

Raw Material	C:N Ratio	Raw Material	C:N Ratio
Duck dung	8	Elephant dung	43
Human excreta	8	Straw (maize)	60
Chicken dung	10	Straw (rice)	70
Goat dung	12	Straw (wheat)	90
Pig dung	18	Sawdust	>200
Sheep dung	19	Food waste	17
Cow/buffalo dung	24	Vegetable scraps	25
Water hyacinth	25	Fruit waste	25–40

Source: ResearchGate [5].

Benefits of Biogas

When in use, biodigesters offer smallholder farmers numerous advantages including greater income, enhanced well-being, less vulnerability, increased food security, and more sustainable use of the environment. Meeting nine of the 17 SDGs could be assisted by biodigester utilization. According to the UNFCCC's most recent methods, a household biodigester could cut greenhouse gas (GHG) emissions by 2.5 to 6 tons of CO_2 equivalent per year.

Basic Types of Biogas Plants

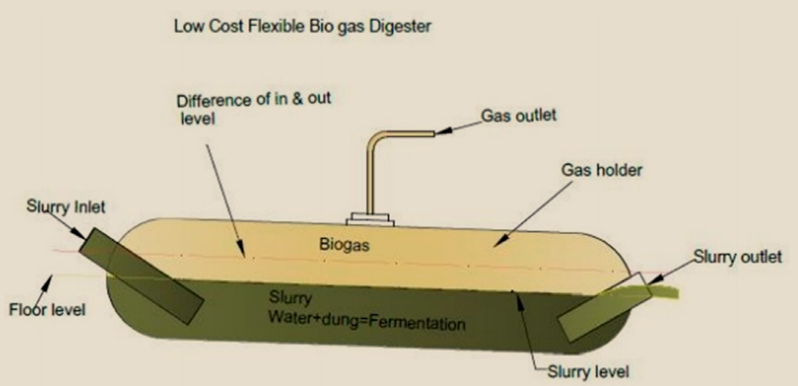
Biogas plants can be divided into four main types: balloon plants; fixed-dome plants; floating-drum plants; and prefabricated low-density polyethylene (LLDPE) plants.

Balloon Plants

A balloon plant consists of a plastic or rubber digester bag, in the upper part of which the gas is stored (Figure 5). The inlet and outlet are attached directly to the skin of the balloon. The plant operates as a fixed-dome plant when the gas area is full since the balloon is not inflated and is not very elastic. The fermentation slurry is agitated slightly by the movement of the balloon skin. This is favorable for the digestion process. Even difficult feed materials, such as water hyacinths, can be used in a balloon plant. The balloon material must be UV resistant. Materials that have been used successfully include red mud plastic (RMP), Trevira, and butyl [6].

FIGURE 5

BALLOON PLANT SCHEME.



Source: Reproduced with permission from Build a Biogas Plant [6].

Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high. Their advantages and disadvantages are summarized in Table 2. One variant of the balloon plant is the channel-type digester with folia and sunshade.

TABLE 2

ADVANTAGES AND DISADVANTAGES OF BALLOON PLANTS.

Advantages	Disadvantages
Low cost	Short life (about five years)
Ease of transportation	Easily damaged
Uncomplicated cleaning, emptying, and maintenance	Does not create employment locally
High digester temperatures	Little scope for self-help

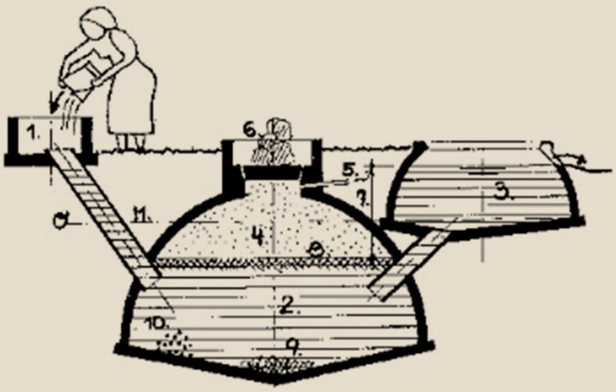
Fixed-dome Plants

A fixed-dome plant consists of an enclosed digester with a fixed, nonmovable gas space (Figure 6). The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, and therefore the volume of the digester should not exceed 20 m³. If there is little gas in the holder, the gas pressure is low.

If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gasholder is necessary. Engines require a great deal of gas, and hence large gasholders. The gas pressure then becomes too high if there is no floating gasholder [7]. Table 3 lists the advantages and disadvantages of fixed-dome plants.

FIGURE 6

FIXED-DOME PLANT SCHEME.



Source: Reproduced with permission from Build a Biogas Plant [7].

TABLE 3

ADVANTAGES AND DISADVANTAGES OF FIXED-DOME PLANTS.

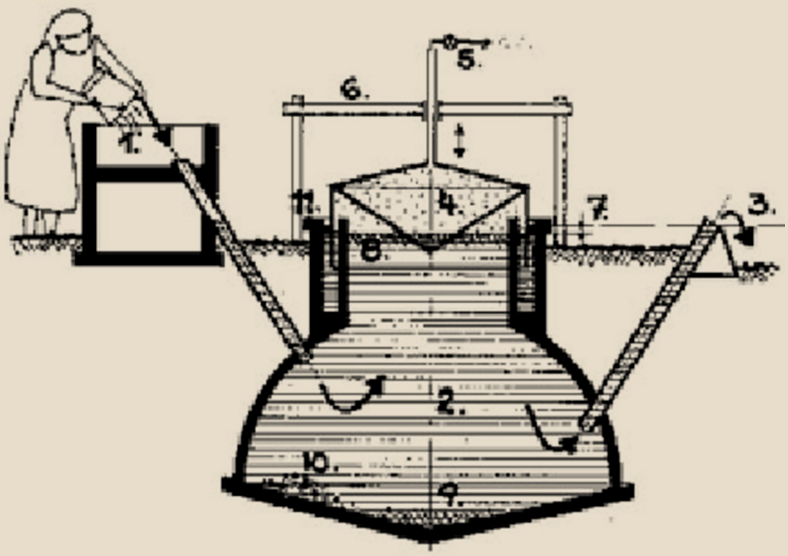
Advantages	Disadvantages
Underground construction	Plants often not gaslit (porosity and cracks)
Creates employment locally	Gas pressure fluctuates substantially
Saves space	Requires experienced technicians
Affords protection from winter cold	Very high/low digester temperatures

Floating-drum Plants

Floating-drum plants consist of a digester and a moving gasholder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own. The gas collects in the gas drum, which thereby rises. If gas is drawn off, its level falls again. The gas drum is prevented from tilting by a guide frame [8]. Figure 7 illustrates the floating-drum plant scheme, while Table 4 lists its advantages and disadvantages.

FIGURE 7

FLOATING-DRUM PLANT SCHEME.



Source: Reproduced with permission from Build a Biogas Plant [8].

TABLE 4

ADVANTAGES AND DISADVANTAGES OF FLOATING-DRUM PLANTS.

Advantages	Disadvantages
Simple, easily understood operation	High construction cost of floating drum
Constant gas pressure	Many steel parts liable to corrosion, resulting in short life
Volume of stored gas visible directly	Regular maintenance costs
Few mistakes in construction	

Prefabricated Linear Low-density Polyethylene Biodigesters

Prefabricated biodigesters consist of two linear LLDPE drums, with one sitting on top of the other and welded together. Slurry is stored in the lower drum, and gas is stored in the upper drum (Figure 8). Their advantages and disadvantages are presented in Table 5.

FIGURE 8

PREFABRICATED LLDPE BIODIGESTER.

Source: Reproduced with permission from ATEC internal sources [9].

TABLE 5

ADVANTAGES AND DISADVANTAGES OF PREFABRICATED LLDPE BIODIGESTERS.

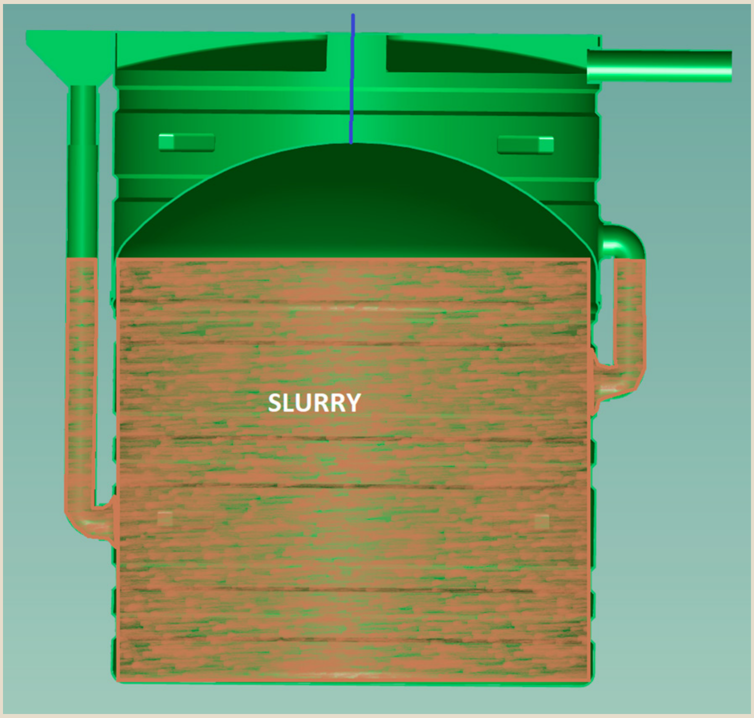
Advantages	Disadvantages
Very easy to install	Relatively high cost
Flood protected	Hard to transport (over 3.0 m^3)
No chance of cracking	Require experienced technicians
Easy to maintain	

Prefabricated LLDPE biodigester systems work in a four-step process:

Step 1: Slurry is fed through the inlet and stored in the lower drum (Figure 9).

FIGURE 9

SLURRY IS STORED IN THE LOWER DRUM OF AN LLDPE BIODIGESTER (STEP 1).

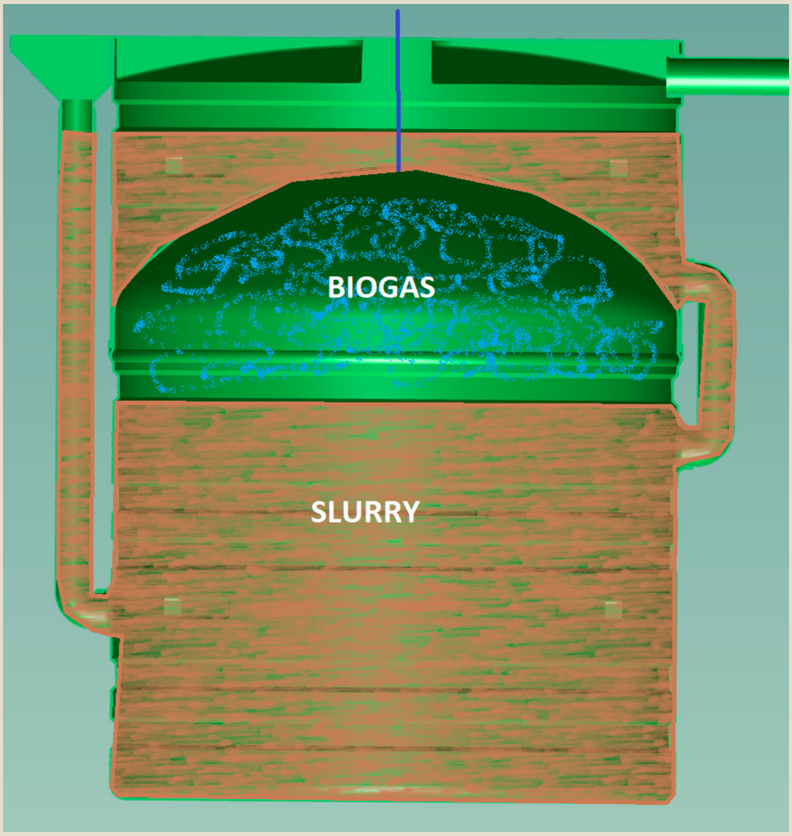


Source: Reproduced with permission from ATEC internal sources [9].

Step 2: The slurry must remain in the digester for a certain amount of time to achieve maximum gas production. The average hydraulic retention time is 30–45 days. When gas is produced, it pushes the slurry from the lower to upper chamber of the biodigester (Figure 10).

FIGURE 10

SLURRY IS MOVED FROM THE LOWER TO UPPER CHAMBER BY THE PRESSURE OF GAS PRODUCED (STEP 2).



Source: Reproduced with permission from ATEC internal sources [9].

Step 3: When gas pressure reaches 10–11 KPA or higher, the slurry moves out of the outlet pipe (Figure 11).

FIGURE 11

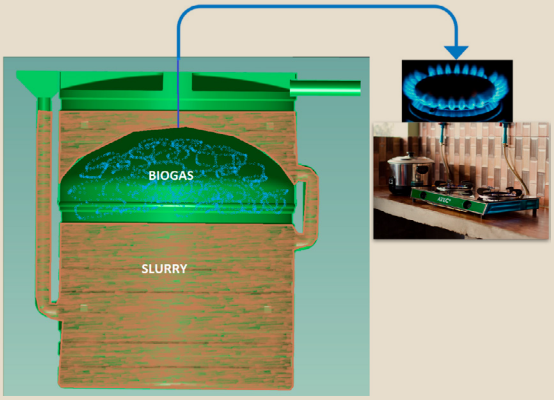
SLURRY IS MOVED FROM THE OUTLET PIPE (STEP 3).

Source: Reproduced with permission from ATEC internal sources [9].

Step 4: Gas is conveyed through pipes to the kitchen/cooking area and connected to the stove/cooktop (Figure 12). Once gas is consumed, the slurry level is reduced and the cycle continues. Consumption patterns vary at different times of the day.

FIGURE 12

GAS IS PRODUCED AND CONNECTED WITH THE STOVE/COOKTOP (STEP 4).



Source: Reproduced with permission from ATEC internal sources [9].

Overall Installation Scenarios and Price Ranges

In 2021, more than 27,000 home biodigesters were constructed in Asia and Africa (Table 6). Those digesters were almost universally fed with animal waste and yield two products: bioslurry, a strong organic fertilizer to increase agricultural yield; and biogas, mostly used for clean cooking. About 20,000 digesters were shipped to Asian nations, primarily Bangladesh, Nepal, and Vietnam. The majority of the 7,000 digesters that were transported to and installed in African nations were in Burkina Faso, Ethiopia, and Kenya. Selected Asian nations had a 21% increase over 2020, despite the fact that Pakistan and Vietnam did not have any support programs in place. African nations saw a marginal 11% decline [10].

TABLE 6

HOME BIODIGESTER INSTALLATION IN ASIA AND AFRICA, 2021.

Country	Digesters	Digesters	2021 versus 2020		Digesters	Remarks
Africa	**installed in 2021**	**installed in 2020**	**(number)**	**(%)**	**installed up to 2021**	
Benin	42	0	42	N/A	249	
Burkina Faso	804	735	69	9%	15,019	
Ethiopia	3,241	4,686	–1,445	–31%	34,693	Security issues
Kenya	2,333	1,962	371	19%	26,768	
Rwanda	190	200	–10	–5%	11,625	
Uganda	420	300	120	40%	9,019	
Zambia	323	380	–57	–15%	5,671	
Total:	**7,353**	**8,263**	**–910**	**–11%**	**103,044**	

Country	Digesters	Digesters	2021 versus 2020		Digesters	Remarks
Asia	**installed in 2021**	**installed in 2020**	**(number)**	**(%)**	**installed up to 2021**	
Bangladesh	4,539	3,930	609	15%	61,634	
Bhutan	902	896	6	1%	7,885	
Cambodia	1,120	1,106	14	1%	30,747	
Indonesia	1,661	385	1,276	331%	26,809	Provincial regulations
Nepal	6,806	4,285	2,521	59%	437,033	
Pakistan	109	73	36	49%	6,358	

(Continued on next page)

(Continued from previous page)

Country	Digesters	Digesters	2021 versus 2020		Digesters	Remarks
Asia	installed in 2021	installed in 2020	(number)	(%)	installed up to 2021	
Vietnam	5,000	5,961	−961	−16%	295,345	
Total:	**20,137**	**16,636**	**3,501**	**21%**	**865,811**	
Grand total:	**27,490**	**24,899**	**2,591**	**10%**	**968,855**	

Note: Nepal numbers as per their FY (2021/22 and 2020/21).
Source: Reproduced with permission from SNV [10].

The model and size of the units, which are in turn governed by a number of criteria including the amount of animal dung available for feeding, are among the elements that affect the investment costs of biodigesters. A summary of the most common digester models and sizes in selected nations is shown in Table 7, along with the unit investment costs in 2021 (in local currency and USD) and any investment subsidies offered by the government, programs, or projects. The most common size, which corresponds to the combined volume of the digester and gas storage, is 4 or 6 m³. Kenya is an anomaly, where the most common size of the prefabricated digester was 12 m³ [10].

Government restrictions in Indonesia which required farmers with animals to install a digester led to the development of a tiny (1 m³) prefabricated digester. Interviews with knowledgeable stakeholders revealed that, although demand is still quite small, niche markets are developing for medium-sized digesters (up to 100 m³) and large ones (typically up to 1,000 m³) in a number of nations, including Bangladesh, Ethiopia, Kenya, Nepal, and Vietnam. The majority of digesters are still built onsite using conventional building materials like sand, gravel, and cement, but prefabs are gaining popularity. The most common size biodigester investment expenses in Africa and Asia are between USD500 and USD700. Indonesia and Kenya are exceptions. In Kenya, the higher investment cost is caused by the larger size (12 m³). The lower investment cost of Indonesia's most popular digester (prefab) is due to its smaller size (1 m³).

An investment of USD500–700 for a rural household is challenging, even though the technical lifetime of the digester surpasses 15 years. In the case of in-situ construction, part of the financing may be covered by the household through the collection of traditional construction materials like sand and gravel and/or through the utilization of unskilled labor [10].

TABLE 7

INVESTMENT COST OF BIODIGESTERS IN DIFFERENT COUNTRIES.

Region/ country	Investment costs						Financing					
	Most popular size	Specification	Local currency	Exchange rate	Average investment cost for most popular size		Subsidy amount		Net investment by household	Share of household financing		Remarks
										in cash	through loan	
	(m^3)		(LCU)	(LCU:USD)	(LCU)	(USD)	(LCU)	(USD)	(USD)	(%)	(%)	
Africa												
Benin	4	in-situ	CFA	555	400,000	721	300,000	541	180	100%	0%	
Burkina Faso	4	in-situ	CFA	555	320,000	577	160,000	289	289	100%	0%	
Ethiopia	6	in-situ	ETB	35	25,000	716	13,050	374	342	99%	1%	
Kenya	12	pre-fab	KES	110	100,000	912	0	0	912	20%	80%	Suppliers credit (24 months)
Rwanda	4	in-situ	RWF	989	650,000	657	100,000	101	556	100%	0%	
Uganda	6	in-situ	UGX	3,587	2,343,000	653	0	0	653	97%	3%	
Zambia	6	in-situ	ZMW	20	12,800	639	3,000	150	490	100%	0%	
Asia												
Bangladesh	6	in-situ	BDT	85	60,000	705	20,000	235	470	90%	10%	
Bhutan	6	in-situ	BTN	74	45,000	609	22,500	304	304	100%	0%	Cost-sharing mechanism
Cambodia	6	pre-fab	USD	1	700	700	0	0	700	10%	90%	Suppliers credit (27 months)
Indonesia	1	pre-fab	IDR	14,308	6,250,000	437	3,250,000	227	210	95%	5%	Provincial Regulations
Nepal	6	in-situ	NPR	118	101,000	855	30,000	254	601	98%	2%	
Vietnam	6	pre-fab	VND	23,160	12,000,000	518	0	0	518	95%	5%	

Note: 1) Exchange rates 2021 by WB: https://data.worldbank.org/indicator/PA.NUS.FCRF. 2) Digester sizing in Bangladesh (6 m^3) is derived from gas production (2.4 m^3/day)
Source: Reproduced with permission from SNV [10].

Key Design Points

There are two key biodigester design points to keep in mind: 1) the volume of the overflow chamber is equal to the maximum usable gas volume at any point in time; and 2) the amount of the maximum usable gas is different from the daily gas production amount. The rule of thumb is that the overflow chamber volume is 50% of daily gas production, so for a 1.8 m^3 biodigester, there is about 0.9 m^3 of storage.

Main Barriers to and Opportunities for Market Scaling

Barriers and opportunities are grouped by demand, supply, and enabling environment. Most barriers are seen on the demand and supply side; fewer are present in the enabling environment. It is crucial to emphasize that some of the identified obstacles are national in nature. On the demand side, the biggest obstacles to market expansion are perceived to be customers' limited access to financing and their lack of knowledge of the advantages of (new) technology. On the supply side, it is noted that installed digesters have poor performance and little private-sector involvement. The inability and unwillingness of governments to provide economic support for biodigester installation and use are main barriers in the enabling environment.

When it comes to opportunities, most of these are interestingly seen in the enabling environment, followed by demand and supply. On the demand side, stakeholders expressed high hopes that the improved use of bioslurry would result in scaling the market because of the increased prices of chemical fertilizer. The high technical potential of the market is seen as an opportunity. Medium- and large-sized digesters are seen as an opportunity on the supply side. In the enabling environment, the availability of carbon revenues or subsidies and enhanced government support are seen as the main opportunities. Waste management is also mentioned. This gives food for thought that larger-sized digesters and waste are mentioned as opportunities, as this may require moving away from manure-fed household digesters.

Factors Affecting Biodigester Performance

The main factors in the production of biogas have been identified as [11]:

1. Sublayer composition;
2. Temperature inside the digester;

3. Retention time;
4. Working pressure of the digester; and
5. Fermentation medium pH.

Sublayer Composition

The feedstock utilized in the anaerobic fermentation process (digestion) to produce biogas should guarantee a favorable environment for the growth and ideal metabolic activity of the microorganisms participating in the process. Manure, agricultural residues or by-products, energetic crops (corn, rye, Miscanthus, sorghum, etc.), organic waste from the food industry (of plant and animal origin), the organic fraction of municipal solid waste, wastewater from the food industry and zootechnics, and sludge from wastewater treatment facilities are the most common types of sublayers in biogas technology.

Operating Temperature

Digesters are designed to run at different target temperature ranges. The temperature ranges are typically 86–100°F for mesophilic and 122–140°F for thermophilic operations. There are different populations of anaerobic microbes that thrive in these temperature zones.

Generally, thermophilic anaerobic digestion (AD) would be used when greater pathogen kill is necessary. This temperature range can produce "class A biosolids." Class A biosolids is a designation for dewatered and heated sewage sludge that meets US Environmental Protection Agency guidelines for land application with no restrictions. Thus, class A biosolids can be legally used as fertilizer on farms and in vegetable gardens and can be sold to home gardeners as compost or fertilizer. Thermophilic digesters require less time to process feedstocks but may have higher costs and be more difficult to operate. In general, mesophilic digesters are easier to operate and maintain but will not result in sufficient pathogen kill to produce class A biosolids.

Retention Time

The hydraulic retention time (HRT) it is the average range in which the sublayer for the AD process is retained in the digester, in contact with biomass (bacterial mass). Sublayers containing simple compounds are easily decomposed and require a short HRT, while sublayers containing complex compounds are harder to decompose and require a longer HRT.

Working Pressure in the Fermenter

In the production process of biogas, pressure is of great significance. Experiments have shown that when the hydrostatic pressure in which the operating methanogenic bacteria are fermenting increases to over 400–500 mm H_2O, biogas production ceases.

Fermentation Medium pH

In the hydrolytic stage, the acidogenic bacteria require a pH in the range 5.5–7.0.

Applications of Biogas

The followings are some of the applications of biogas [12]:

1. Biogas as cooking fuel
2. Biogas as lighting fuel
3. Biogas for pumping water and miscellaneous other applications
4. Biogas as fuel for internal combustion engines
5. Biogas as vehicle fuel
6. Biogas for power generation
7. Biogas in fuel cell-linked biogas systems.

How Are Biofertilizers Beneficial?

The digestive process results in the creation of ammonia (NH_3) from gaseous nitrogen (N). Nitrogen is available to plants as a nutrient in this water-soluble form. If both dung and urine are digested, a fertilizer that is especially rich in nutrients is produced. If the fermentation slurry is to be stored before being distributed over the field, layers of earth should be placed on top of it. This further lessens nitrogen losses due to evaporation.

Biofertilizers are preferred over chemical fertilizers because they are not harmful as they contain organic materials, while chemical fertilizers are made up of chemicals that are harmful to consumers. In addition, biofertilizers:

- Increase crop yield by 20–30%.
- Replace chemical nitrogen and phosphorus by 25%.
- Stimulate plant growth.
- Activate the soil biologically.
- Restore natural soil fertility.
- Provide protection against drought and some soil-borne diseases.

CONCLUSION

We all require a sustainable method of cooking, and a biodigester is a fantastic solution to this significant issue. In contrast to natural gas, which is a fossil fuel created by geological processes, biogas is a renewable energy source created biologically through AD. Additionally, biogas production on farms can reduce the odors, insects, and pathogens associated with traditional manure stockpiles.

The demand for fuel wood is higher than the forests' sustainable supply. Saving substantial amounts of fuel wood helps to reduce GHG emissions. Due to the decrease in fuel wood consumption, more trees are being saved. Conserving trees and reducing GHG emissions both help to slow climate change. The percentage of persons who experience and frequently contract ailments linked to the smoke from burning wood has been sharply declining. After biodigester installation, there is also considerable time saving. According to individual preferences, the time saved can be used to work on tasks like feeding animals, cleaning the house, taking better care of children, participating in charitable and religious endeavors, and generating cash.

In many countries, soil degradation is a big problem, and farmers are using more chemical fertilizers than organic fertilizers, resulting in soil degradation. When the slurry is composted, agricultural production is also seen to increase among families that use organic fertilizer. By avoiding chemical fertilizers, each household can save a significant amount of money. Although biofertilizers cannot completely replace chemical fertilizers, they can reduce the excessive use of chemicals.

Biogas utilization is a green technology with favorable effects on the environment. Utilizing municipal solid waste from urbanization and accumulated animal waste from food production together is made possible by biogas technology. Methane production is decreased by the conversion of organic waste into biogas because CO_2 is produced instead of methane during effective combustion. Given that methane is nearly 21 times more effective in trapping heat in the atmosphere than CO_2, biogas combustion results in a net reduction in GHG emissions. The average GHG reduction per home biogas plant of 2-m^3 capacity (if properly fed with cattle manure and properly operated by its owner) would be 4–6 tons per year. This reduction can be converted into sellable carbon credits.

Carbon credits, also known as carbon offsets, are permits that allow the owner to emit a certain amount of CO_2 or other GHGs. One credit allows for the emission of one ton of CO_2 or another GHG equivalent. Companies that pollute are given credits that allow them to do so up to a limit that is periodically decreased. In the interim, the business may sell any credits it does not require to another business that does. Thus, private businesses have two incentives to lower GHG emissions. If their emissions exceed the cap, they must first pay extra for credits. Additionally, by lowering their emissions they can sell their excess allowances.

The ultimate goal of carbon credits is to reduce the emission of GHGs into the atmosphere. As noted, a carbon credit represents the right to emit GHGs equivalent to one ton of CO_2. According to the Environmental Defense Fund, that is the equivalent of a 2,400-mile drive in terms of CO_2 emissions. Companies or nations are allotted a certain number of credits and may trade them to help balance total worldwide emissions. Companies working in biogas industries and giving 360-degree solutions to their customers can claim these carbon credits, sell them to different buyers worldwide, and transfer the benefit to the clients' level to make the product more affordable.

Biogas technology is one of the best energy sources since it produces energy, while on the other hand, it lowers GHG emissions. Additionally, it preserves the forests by using less fuel wood and has numerous other beneficial socioeconomic effects that improve people's capacity for adaptation and lessen communities' susceptibility to climate change.

The findings discussed above help to increase people's adaptive capacity and reduce GHG emissions. Biodigester technologies should be promoted to reduce GHG emissions, soil degradation, health hazards, and cooking time, thus making our world a better place to live for everyone.

REFERENCES

[1] http://ichef.bbci.co.uk/images/ic/1600xn/p02hrkqs.jpg.

[2] https://cleancooking.org/wp-content/uploads/2022/08/Accelerating-Clean-Cooking-as-a-Nature-Based-Climate-Solution.pdf.

[3] ATEC Australia International Ltd.

[4] ATEC Australia International Ltd. and images captured from https://icon-archive.com/.

[5] https://www.researchgate.net/figure/C-N-Ratios-of-some-organic-materials_tbl1_228495285 (accessed 19 January 2023).

[6] https://www.build-a-biogas-plant.com/balloon-digester/.

[7] https://www.build-a-biogas-plant.com/fixed-dome-biogas/.

[8] https://www.build-a-biogas-plant.com/floating-drum-biogas/.

[9] ATEC Australia International Limited's patented mold design.

[10] https://snv.org/assets/explore/download/SNV%20biodigester%20status%20brief%20%28final%29.pdf.

[11] https://www.academia.edu/37346650/Factors_Affecting_the_Production_of_Biogas.

[12] https://www.geographynotes.com/biogas-2/applications/applications-of-biogas-top-8-applications-bioenergy/6675.

LIST OF TABLES

LIST OF FIGURES