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Chronological innovations in biogas biodigesters design technology in Ethiopia

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Abstract

Biodigester design of National Biogas Programme of Ethiopia (NBPE) was modified five times from the year 2009 to 2023. Three more design model biodigesters were introduced. The objective of this study is to demonstrate the chronological innovations in biogas biodigesters design technology in Ethiopia so as to promote and recommend further modifications. The five biodigesters modified were SINIDU 2008, SINIDU 2010, Solid State Digester (SSD), Black Cotton Soil Digester (BCD) and MITIN 2012 (2.5m^3). The introduced ones were medium sized fixed dome biodigesters, and small and medium scale prefabricated plastic geomembrane. Simplicity during construction, affordability, environmental conditions and needs of users were the main benefits obtained in chronologically improved SINIDU biodigester models. In NBPE, the last modified biodigester used in all environmental conditions was SINIDU 2010 that replaced both SINIDU and SINIDU 2008. Modification of the design did not have considerable change on daily biogas production rate. For example, SINIDU, SINIDU 2008 and SINIDU 2010 produces 2m^3, 1.75m^3 and 1.75m^3 biogas per day with 50kg of daily cow dung, respectively. Introduced alternative prefabricated design was suitable for the users and masons as the design is easy to install and adaptable to different environmental conditions. Introduction of solid baffle to SINIDU 2008 and its following version to get less volume of buffer resulted in less Hydraulic Retention Time (HRT) from 50 days in SINIDU model to 35 days in SINIDU 2008. Other design modification was for MITIN 2012 biodigester which the manhole is at the top of the dome and sealed but for other models it is through outlet chamber. The design for BCD is robust than other designs due to its spherical/oval shape but for SINIDU model and its version, the shape of the digester is cylindrical. Innovations such as SSD and *injera mitad* and stove were at pilot stage and not scaled up. Therefore, research institutes and universities should strengthen additional roles on further modification/development of *injera mitad* and stove to get easy access to market penetration.

Keywords: biodigester, fixed dome, feed stock, labour, and water stress

Introduction

Biogas is a gaseous fuel obtained from waste fermentation, which is of interest in producing clean and renewable energy for electricity, cooking, heating, and biofuels for vehicles [1,2]. The production of biogas from waste fermentation offer some additional benefits, namely reduction in pathogens, foul odour, and methane emission as greenhouse gas (GHG) from landfill sites where these wastes are ordinarily disposed. It also produces an organic fertilizer called bio-slurry. Anaerobic digestion of organic waste in digesters occurs in four stages, namely, hydrolysis, acidogenesis, acetogenesis, and methanogenesis in a system called biogas digester or biodigester. These four stages results in production of biogas comprising of methane (55–70%) and carbon dioxide (30–45%) with traces of other gases such as hydrogen sulphide, hydrogen, and nitrogen [1]. Biogas is considered as a low carbon fuel source, in livestock rearing urban and rural communities in for producing alternative energy so as to perform the Sustainable Development

Goal 7 (SDG 7). There are different models/designs of household biodigesters being in use today. Broadly, they can be classified as fixed dome, movable dome and plug-flow biodigesters. There are parameters to be considered for the selection of biodigesters model/design such as feeding materials, adaptability to climatic and geo-physical condition, technological parameters (structural durability, methods of construction/ installation/ supervision, time and effort in quality control, suitability for operation and maintenance, adoptability to different geographical context for mass dissemination), affordability and purpose. In National Biogas Programme of Ethiopia (NBPE), there were many technological improvements of biodigesters in order to improve the affordability of the technology, improve construction simplicity, consider local soil and climate condition, and address the needs of some pro-poor groups of beneficiaries. Therefore, as a programme development, documentation on the technological innovation practices that indicate the state of the art on all design improvement is highly important and helpful for the next phase of the programme implementation. The objective of the study was to conduct the technological innovations made during implementation of household and medium scale biodigester by national biogas programme of Ethiopia (NBPE) in its scale up programme (NBPE+) for promotion and further modification.

Methodology

Secondary and primary data were used in a thorough assessment of biodigesters, and appliances. Secondary data was collected from literatures in the biogas programme from year 2009 to 2023. Then primary data interviews of three household/ domestic level field observations of *MITIN* 2012, small size 2.5m^3 biodigester in Welmera district, and three productive energy linked to the families and commercial farms or institutions was conducted. Three individual experts in Biogas Construction Enterprises (BCE), and three professional biogas engineers who designed the five designs of innovated household biodigesters, who were staff members of Netherlands Development Organisation (SNV) were interviewed. Since the present study planned on chronological design innovation, it did not include the common household biodigesters which are well studied by other previous works.

Three field observation sites (districts) were selected because of their proximity to the capital city Addis Ababa and availability of less information on productive function of biogas. These were Sululta district, Sebeta district, and Welmera district (Figure 1). In Sululta district, Northern part of Addis Ababa, a private dairy farm was observed; in Sebeta district, in Southern Addis Ababa, a public institution or school was observed, and in Welmera district, Western Addis Ababa, smallholders biogas village emphasizing *Mitin* 2012 and prefabricated medium size biodigester, used for feed processing was observed. The data analysis was done by summarizing and narration.

Development of national domestic biogas programmes

Since the mid-2000s, Hivos and SNV (Netherlands Development Organisation) jointly aimed for the development of biodigester markets in Africa. The Directorate General of International Cooperation (DGIS) of the Netherlands Ministry of Foreign Affairs (MoFA) has been supporting their work as prime donor. Since 2009, national domestic biogas programmes have been established especially in East Africa, and also in West and Southern Africa. SNV has been supporting the federal programme in Ethiopia since the start, first through a feasibility study in 2006, and from 2009 with technical support as part of the African Biogas Partnership Programme (ABPP) managed jointly by the Dutch NGO Hivos and SNV in five countries. Ethiopia established the National Biogas Programme of Ethiopia (NBPE) in 2008 - a joint effort of Ethiopian Rural Energy Promotion and Development Centre (EREDPC) under Ministry of Water and Energy (MoWE) and SNV Ethiopia. Implementation of NBPE commenced in 2009 and it has passed three phases. The first phase was from 2009-2013 and the second phase was from 2014-March 2019 and both phases were under the support of African Biogas Programme Partnership (ABPP). The third phase, which started in April 2017 and ended in January 2024 was called Biogas Dissemination Scale –Up programme (NBPE+) and co-funded by Ethiopian

Government and European Union (EU). Since April 2017, SNV acts as the programme manager of the stand-alone Ethiopian Government and EU funded NBPE+ scale-up programme (2017-2022/2024). During the third phase, 21,196 household biodigesters were installed (72% achievement) of 29,326 plan and more than 234 active masons/BCEs were worked on the biodigester promotion and construction at nine programme regions [3].

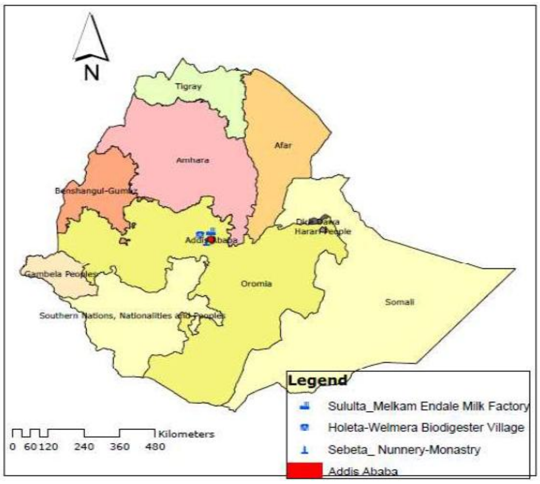

Figure 1. Location of biogas villages visited (Author's own sketch)

Household Biodigester Design/Model categories

There are different models/designs of household biodigesters. Broadly, they can be classified as fixed dome and floating dome biodigesters [4]. A fixed-dome biodigester comprises of a dome-shaped immovable biogas holder to the biodigester and the biogas is stored in this area. Whereas a floating type consist of an underground digester and a moving biogas holder. The biogas holder floats either directly on the fermentation of bio-slurry or in a water jacket of its own [5]. Based on the feeding mode, biodigesters are classified as batch type and continuous flow type. The biodigesters included in this study are continuous flow type where the feed materials are added on a daily basis and an equivalent amount of residue (bio-slurry) is discharged from the biodigester [6]. Other models included were prefabricated plastic moulded model (with a portable and very simple system that consists of a round- or square-shaped plastic biodigester tank with an inlet, a displacement tank with an outlet for bio-slurry, and a gas pipe connected to the cooker) [7], and others [8, 9] flexible bag model (the substrate flows through a tubular polyethylene or polyvinyl chloride (PVC) bag (the reactor) from the inlet to the outlet [8], higher-end polyethylene models (the membrane comes as tightly packaged kit in sizes ranging from 6 to over 600 m^3). It includes an inlet feeding tank, bio-slurry storage, and a full range of thermal, mechanical and electrical biogas appliances [9]. These biodigester models have some advantages and limitations specially with cost and durability (Table 1).

Table 1. Advantages and limitations of different biodigester types

Biodigester type/category	**Advantages**	**Limitations**	**Relevance to NBPE**
Fixed dome	Fixed dome digesters offer low-cost construction and long lifespans (20+ years). Low initial construction costs as they use local materials (brick/concrete). **Underground**	Gas pressure varies, which can complicate gas utilization. Requires highly skilled masons to prevent gas leaks. Hard to determine the amount of gas stored. Difficult to	Fixed dome digesters are appropriately selected for all biodigesters constructed for many of the poor people in Ethiopia's NBPE that need low cost.

	Installation Saves space, provides natural insulation, and protects against temperature changes. **Local Employment:** Construction creates jobs within the community.	repair if cracks form in the dome.	
Floating dome	Provide constant pressure and easier maintenance due to visible gas storage, Provides steady gas pressure, making it ideal for gas lamps and engines. The drum rises and falls, allowing for easy monitoring of gas production. Generally easier to build than fixed-dome, with less complex masonry. Ideal for constant, high-volume, small-scale usage.	More expensive due to the cost of the steel or fiber-reinforced plastic (FRP) drum. The metal drum is highly susceptible to corrosion and rust. Requires regular painting to prevent corrosion. Shorter service life compared to fixed-dome systems.	
Batch type	Simple construction and operation, suitable for rural areas with limited, high-solid waste. Ideal for wastes that are not continuously available. Easy to manage the start-up and termination of the digestion process. offer simple, low-cost operation ideal for small-scale	Biogas generation stops when the batch is finished, requiring multiple digesters for constant supply. Requires manual loading and unloading for each cycle. Generally produces less methane per unit volume compared to continuous systems.	Batch digesters are best suited for smaller, decentralized, or batch-processed waste streams, like urban wastes in Ethiopia while continuous flow systems are designed for large-scale, consistent, industrial level biogas production like livestock producing rural areas and livestock butchery, abatters in Ethiopian NBPE for further consideration in NBPE is required as all the biodigesters in urban and rural continuous type.
Continuous flow type	Continuous feeding allows consistent biogas production. Often uses CSTR (Continuous Stirred-Tank Reactor) technology, allowing for higher, more efficient nutrient conversion. Suitable for large-scale, automated industrial applications.	Require consistent feeding, high technical expertise, and incur higher maintenance, Requires significant investment in infrastructure and technology. High risk of failure if feed composition changes or if the system suffers from operational issues like clogging. Requires trained personnel for monitoring and maintenance.	
Prefabricated plastic moulded	Low cost and easily installed when compared to the concrete type	Easily damaged after installation	NBPE started to introduce from foreign countries and local manufacturing is needed
Flexible bag	**Low Cost** to construct and often utilizes locally available materials, making them suitable for low-income areas. Can be installed quickly (often within 8 hours) on a level patch of ground, requiring no specialized, complex	The PVC or polyethylene material typically lasts only 3–5 years, necessitating frequent replacement compared to concrete options. Highly susceptible to punctures, vandalism, or damage from animals, which can	

	construction skills. Lightweight and easily transportable or relocated, eliminating the need for secure or permanent land tenure. Dark-coloured materials allow for better heat absorption, which can increase gas production in temperate climates. Simple to load with waste, with a design that allows for easy unblocking and cleaning	lead to gas leaks. Lack of insulation means production drops significantly in colder temperatures or at night. Usually designed for small-scale, household, or residential use, limiting their suitability for larger agricultural or industrial applications. They can produce low or fluctuating gas pressure compared to fixed-dome systems.	
Higher-end polyethylene	Higher-end polyethylene (PE) biodigesters are a durable, corrosion-resistant, and relatively low-cost solution, cheaper than steel or concrete and highly resistant to corrosion from chemical reactions in the anaerobic process. They are lightweight, making them easier to transport and install, especially in rural, small-scale, or household settings. Many high-end PE designs have no moving parts, reducing mechanical failure rates. Higher-end models may incorporate better, modular designs that allow for linking multiple units in series to increase capacity. They provide a hygienic way to dispose of waste while reducing greenhouse gas emissions by capturing methane.	The plastic material can be easily punctured or damaged during installation or by animals. Compared to concrete systems, PE digesters often struggle with low gas pressure, which can fluctuate based on the volume stored. They can float to the surface if the soil is saturated (if not properly installed) and may deform under excessive soil pressure. Being above ground or partially buried, they may be less effective in very cold climates compared to insulated, underground concrete alternatives. While durable, they generally have a shorter functional lifespan compared to concrete, fixed-dome systems.	NBPE should strengthen using plastic types to convert agricultural or livestock waste into energy with a low cost.

Parts of biodigester

There are six main parts of the fixed dome biodigester (Figure 2). These are inlet (mixing chamber), digester (digestion chamber), biogas holder (gas storage chamber), outlet (displacement chamber), gas conveyance and application system (pipes and appliances) and bio-slurry compost pit (s). The mixture of dung and water (mixed in inlet or mixing chamber) passes through the inlet PVC to the digester. Biogas produced is stored in the biogas holder. The digested bio-slurry passes out from digester to outlet tank (displacement chamber) and flows out to the compost pits through overflow opening in the outlet tank. The gas is then supplied to the kitchen through the pipeline [5].

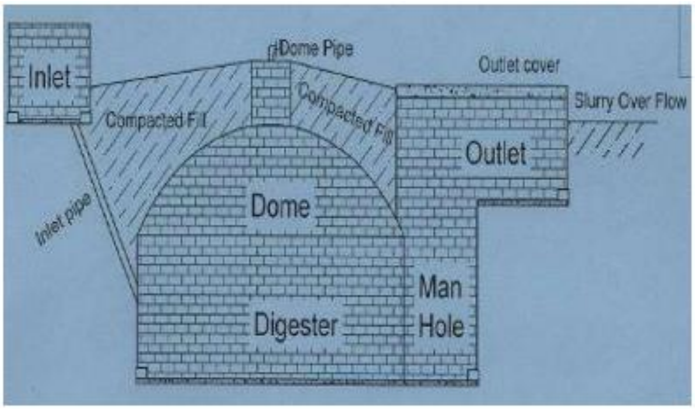

Figure 2. Main component parts of fixed dome biodigester

Parameters for biodigester design/ model selection

There are parameters to be considered for the selection of biodigesters model/design such as feeding materials, adaptability to climatic and geo-physical condition, technological parameters (structural durability, methods of construction/supervision, time and effort in quality control, and suitability for operation and maintenance), affordability and purpose [4,10].

Factors for effective biogas production and design consideration

The process of biomass fermentation and biogas production are affected by factors which must be considered in the design of an anaerobic biodigester system. i) Anaerobic condition: Biogas producing bacteria are the most important group and they are anaerobes in the strict sense and very sensitive to oxygen. They will die or grow very slowly if oxygen appeared in the fermentation environment. Therefore, an airtight biodigester is required [4]. ii) Temperature - Three ranges exist for anaerobic digestion: Psychrophilic range - Between 5° and 25°C: characterized by slower methane production and longer retention time. Mesophilic range - Between 30° and 40°C: the most widely used temperature range [11]. This range balances heating costs with methane production. Conventional anaerobic digestion is carried out at mesophilic temperatures. Thermophilic range – From 50° to 60°C: produces the most methane but is also the most sensitive, due to fewer bacterial species in existence. Upgrading sludge digestion using thermophilic anaerobic digestion (55°C) represent an important alternative to mesophilic anaerobic digestion (35°C) ([12]; [13]). The thermophilic temperature range leads to give faster reaction rates, higher gas production, and higher rates of the destruction of pathogens and weed seeds than the mesophilic temperature range. iii) Retention Time - The Hydraulic Retention Time (HRT) and Solids Retention Time (SRT) are the average lengths of time the liquid or solid portion of manure remains in the digester. HRT is the total time required by a given amount of dung /feed inside the digester before it is completely digested and to produce approximately 80 to 85% of the total biogas [14]. Volume of digester is adjusted so as to retain the dung in the biodigester for a period equal to the HRT to obtain digested bio-slurry. As the HRT depends largely on temperature, retention periods differ from place to place. For the context of Ethiopia the biodigesters are designed with a HRT of 50 days [4]. iv) Potential of Hydrogen (pH) - Optimum pH conditions for methanogenic bacteria (bacteria producing methane) range from 6.4 to 7.6 [14].

Technological innovation of NBPE

National Biogas Programme of Ethiopia (NBPE) in the periods of 2009-2023 implemented and/or piloted different model designs of biodigesters. It also introduced different products/appliances on fixed dome and prefabricated modular biodigesters (Table 2). Initially, in 2008/2009 NBPE introduced fixed dome household Biodigester of Nepalese design called GGC 2047 which was later named as SINIDU model in Ethiopia [15]. It was a concrete dome, and the digester and other chambers were constructed with masonry stones. Constructing this design was tedious as soil was used for dome casting and the soil was removed after dome is casted. In 2015, SNV Ethiopia implemented changes to the design to reduce the construction cost and construction simplicity. Notably, the concrete dome has been replaced with a brick dome. The dimensions were changed to match the effective gas storage capacity, the buffer volume at the top of the digester was reduced and the new design was named "SINIDU 2008" [16]. In 2018, the new biogas programme – Biogas Dissemination Scale-Up Programme (NBPE+) realized that the continuous increment in the cost of construction material (reinforcement bar, cement, sand, and gravel) highly affects the total cost of biodigesters which has a direct impact on affordability. Therefore, another design modification was done on outlet part and named as "SINIDU 2010" (SINIDU 2008 with outlet modification). SINIDU and SINIDU 2008 models faced cracking challenge in areas where black cotton soil predominates due to contractions and relaxations of the soil in different weather conditions, which has increased non-functionality of biodigesters [17]. SINIDU 2008 was modified to fit for black cotton soil and it was named as Black -Cotton Soil Biodigester (BCD). Moreover, NBPE+ made Solid State Biodigester (SSD) for areas where there is a shortage of water, and small size (2.5m^3) biodigester design, "*MITIN* 2012'', for pro-poor families. The programme also introduced different products such as biogas stove, dung mixer, "*injera mitad*" called food plate (*injera* is staple Ethiopia bread like food, and *mitad* is plate. The latest design/model introduced in 2023 by NBPE+ was prefabricated plastic geomembrane biodigester for household energy production and productive use of energy for dairy farms (interview, SNV Ethiopia experts, 2024).

Table 2. The chronological innovation of biodigester design/models in NBPE

Year	Design	Remark
2009	*SINIDU* model was the first fixed dome biodigester introduced to Ethiopia, the Nepalese design called the GGC 2047 with a concrete dome and brick digester chamber	Introduced
2015	Brick-made dome biodigester- '*SINIDU* 2008 ' of 2015	Innovated
2017	*SINIDU* 2010 of 2017 the outlet modification part of the digester '*SINIDU* 2008 '	Innovated
2018	Black Cotton Soil Design (BCD) for black cotton soil area	Innovated
2018	Solid State design (SSD) biodigester for areas where there is a shortage of water availability	Innovated
2019	*MITIN* 2012, small size 2.5m^3 biodigester oval shape with curved bottom concrete, for pro-poor families (piloted in December 2019 and then distributed)	Innovated
2018	Medium and large-scale biodigester of 2018 for productive use of energy	Introduced
2023	Prefabricated designs of over 20 m^3 of 2023, NBPE+ started the introduction of medium scale (Sistema.bio) in 2023.	Introduced

Fixed dome small household biodigester designs/models

The following are major designs/models of fixed dome biodigesters implemented and/or piloted under the three phases of NBPE. The numbers suffixed from SINIDU such as SINIDU 2008, 2010, or MITIN 2012 refers to the Ethiopian calendar when the model was first implemented nearly seven years behind the Gregorian calendar.

- SINIDU model-1st model introduced;
- SINIDU 2008 model -1st version of modification
- SINIDU 2010 model -2nd version of modification
- MITIN6 2012-Smallest size (2.5m^3) –pro-poor design
- Black cotton Soil Biodigester (BCD)
- Solid State Biodigester (SSD).

SINIDU model biodigester

SINIDU was the first model introduced in Ethiopia in 2008/2009 and baptised as SINIDU 8 from Nepalese GGC 2047 model. This SINIDU model is a well-standardized model design of biodigester prepared when the NBPE I was started in 2007 by adapting from Nepal, SINIDU in local language is “ready”. Since then, almost all installed digesters were SINIDU models in size of 4, 6, 8, 10m^3 [18].

The design of this model dates back to 1990 (Nepalese year 2047). The construction steps are first, layout of the digester is made on the level ground and pit is excavated (Figure 3). Then digester is constructed with masonry stone and when construction of the digester is completed and cured, soil is filled back into the digester to make dome shape. Then concrete dome is casted on soil mould.

Figure 3. Dome casting of SINIDU model [4]

After a minimum of 7 days curing, the soil is removed from the digester and plastering of dome, construction of outlet follows [4]. This work was taking at least 15 working days for the masons/Biogas Construction Enterprise (BCE) to complete the work. Filling the soil back to the pit and removing after dome is casted, which usually is an activity manage by the end- user, is considered as a potential obstacle during promotion of the technology (expert interview, SNV Ethiopia experts, 2024).This challenges initiated biogas programme of Ethiopia to modify the design. The following is pictorial representation of construction steps of SINIDU model Biodigester (Figure 4).

Figure 4. Major steps during biodigester construction [4]

Bill of quantity for SINIDU model biodigester

The construction materials necessary for the installation of the biodigester are included (Table 3), which have considerable effect on the cost of the model in comparison with the modified model of SINIDU versions.

Table 3. Bill of quantity for 6m^3 SINIDU Model biodigester [4]

	Bill of quantity for $6m^3$ SINIDU Model biodigester		
	Major items	Units	Quantity
I	Construction materials		
	Cement	100kg bag	9
	Sand	m^3	2.3
	Gravel	m^3	1.7
	Iron bar (6mm diameter)	pieces	5
II	Skilled labour	No.days	10
	Unkilled labour	No.days	26

Note: 1. The year used after the modified version is the Ethiopian Calendar. For example SINIDU 2008 in 2015 in Gregorian calendar that adds 7/or 8 years.

Daily feeding and biogas production of SINIDU model Biodigester

The dimensions of the biodigesters have been determined based upon 50 days retention time and 60% gas storage. This means that the fresh dung and water mix fed (Table 4) into the digester should remain inside it for at least 50 days before it comes out through outlet. Likewise, the plant should be able to store 60% the gas produced in 24 hours. Therefore, the size of the biodigester is determined by the daily available quantity of feeding materials [4]. The design of the SINIDU model biodigester is shown in Figure 5 with dimensions (Table 5).

Table 4. Feeding Vs biogas production of SINIDU Model [4]

Biodigester capacity (m3)	Initial Feeding, cattle dung) (kg)	Initial Feeding, water (litre)	Daily dung feeding (kg)	Daily water required[2] (litre)	Daily gas production (m^3)	Use of Biogas Stove (hour)	Use of Biogas Lamp (hour)
4	2000	2000	20-40	20-40	0.8-1.6	3.5-4	8-10
6	2900	2900	40-60	40-60	1.6-2.4	5.5-6	12-15
8	3800	3800	60-80	60-80	2.4-3.2	7.5-8	16-20
10	4650	4650	80-100	80-100	3.2-4.0	9.5-10	21-25

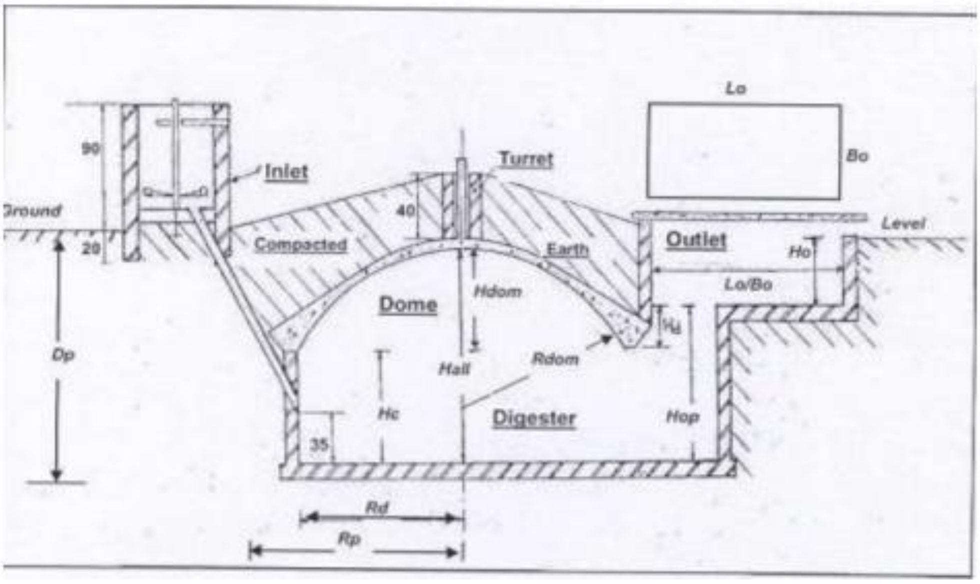

Figure 5. Design of SINIDU model with dimension [4]

Table 5. Dimensions of SINIDU models [4]

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[2] Ratio of water to dung is 1:1

Components	Symbol	Dimension per size			
		$4m^3$	$6m^3$	$8m^3$	$10m^3$
Length of Outlet	Lo (A)	140	160	170	190
Breadth/Radius of Outlet	Bo (B)	120	130	140	160
Height of Outlet	Ho (D)	50	55	60	62
Radius of digester	Rd (F)	110	130	145	155
Radius of pit	Rp ©	132	152	167	177
Height of digester wall	Hc (H)	80	85	90	95
Depth of pit (excavation)	Dp (E)	165	175	185	195
Height of Dome	Hdom	65	70	75	80
Radius of curvature of dome	Rdom	126	156	178	190
Inner height of digester and dome	Hall (J)	145	155	165	175
Height of maximum bio-slurry displacement	Hd	25	25	25	25
Height of outlet passage	Hop (I)	105	110	115	123
Thickness of concrete in dome (side–centre)		15-7	15-7	15-7	15-7
Size of manhole		60x60	60x60	60x60	60x60
Inner Diameter of inlet tank		60	60	60	60
Height of inlet tank		60	60	60	60

SINIDU 2008 Model Biodigester

SINIDU 2008 (2008 in Ethiopian calendar) biodigester was introduced in 2015 because the initial SINIDU model was constructed with concrete dome and masonry stone (digester, inlet, and outlet), which is time taking and costly. Then cost reduction was made from the materials (Table 6). The concrete dome was replaced with a brick dome. The standard for the biogas storage capacity was changed. The dimensions were changed to match the effective biogas storage capacity with the need of the average family and the buffer volume at the top of the digester was reduced. Other change in SINIDU 2008 model was introduction of solids retention baffle in the manhole passage of the biodigester and with this the HRT was decreased and the Solid Retention Time (SRT) increased [.20](SINIDU 2008 Biodigester Construction Manual, 2016). Hence, HRT of 35 days was considered for designing for SINIDU 2008 model. This led to less buffer volume (more active biogas storage volume) for SINIDU 2008 model (Figure 6). Appliance and accessories including pipes, fittings and appliances are imported.

Figure 6. SINIDU 2008 dome construction (left), solid baffle introduced (right)

Table 6. Bill of quantity for $6m^3$ *SINIDU* 2008 Model Biodigester [19]

I	**Construction materials**		
	Major items in	unit	quantity
	Cement	m3	7.5
	sand	m3	4
	gravel	m3	1
	Iron bar(8mm diameter)	pcs	3
III	**labor**		
	skilled labor	no. days	10
	unskilled labor		15

Daily feeding and biogas production rate of SINIDU 2008 model

Daily biogas production for 6m3 size biodigester on average is 1.75 m^3 (Table 7) for SINIDU 2008. This indicates slightly less daily biogas production than SINIDU. This may be due to improvement on the reduction of the volume of the dome (Figure 7).

Table 7. Feeding Vs biogas production of SINIDU 2008 Model [16]

Size (m^3)	**dung for initial feeding (kg)**	**Water for initial feeding (litre)**	**max. daily dung feeding (kg)**	**max. water for daily feeding (litre)**	**max. daily gas production (m^3)**	**Volume of effective gas storage(m^3)**	**Volume of Buffer (m^3)**
4	1600	1600	30	30	1.03	0.685	0.485
6	2400	2400	50	50	1.75	0.9	0.6
8	3450	3450	70	70	2.45	1.35	0.85
10	4800	4800	100	100	3.5	1.935	1.165

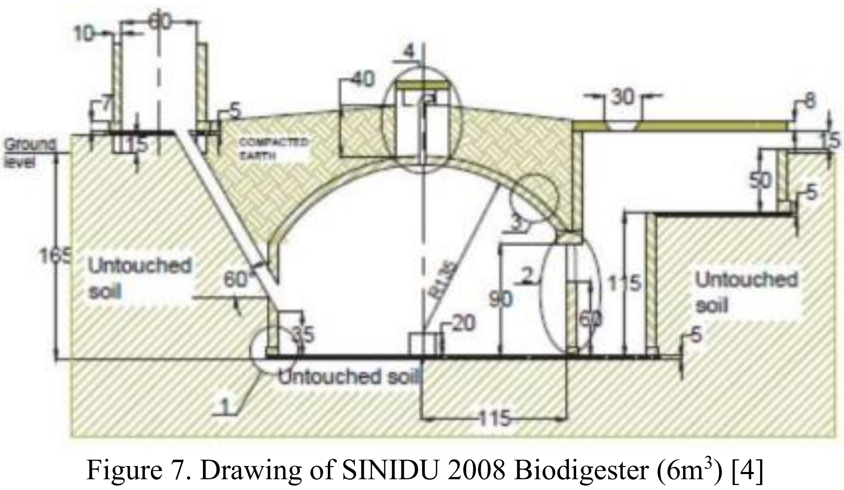

Figure 7. Drawing of SINIDU 2008 Biodigester (6m^3) [4]

Dimensions for SINIDU 2008

Modification of outlet from rectangular volume to dome shaped volume reduced the use of iron rod by 75% which in turn reduced the cost of bio-digester but practically does not have any technical impact on bio-digester performance and functionality [16]. Therefore, dimensions of the SINIDU 2008 showed a relative reduction from the previous SINIDU (Table 8).

Table 8. Dimensions of the different parts of *SINIDU* 2008

Components	4m^3	6m^3	8m^3	10m^3
Radius outlet (cm)	65	75	85	95
Height outlet (cm)	50	50	55	65
Radius digester (cm)	100	115	130	145
Height digester wall(cm)	75	90	100	110
Radius dome curvature(cm)	110	135	150	165
Height of radius stick support (cm)	30	20	25	30
Height of dome (cm)	65	65	75	85
Height of digester + dome(cm)	140	155	175	195
Height of bio-slurry displacement (cm)	25	25	30	35
Height of outlet passage (cm)	100	115	130	145
Volume digester (L)	2,360	3,740	5,300	7,270
Volume dome (L)	1,170	1,500	2,200	3,100
Volume gas storage (L)	685	900	1,350	1,935
Volume buffer(L)	485	600	850	1,165
Total plant volume(L)	3,570	5,240	7,500	10,370

SINIDU 2010 Model biodigester

In 2017, NBPE+ implemented another design called SINIDU 2010 for the prevailing cost of construction material and modified two outlet parts of the digester. This Biodigester was modified from SINIDU 2008 and the modification was on the outlet part. Cylinder shaped outlet is changed into dome shaped with main objective of reducing the cost incurred for iron rod purchase used for outlet slab making and improve affordability. Hence, the improvement reduced 75% of outlet construction cost (outlet modification document, 2018). Since the improvement is on the outlet part, shape modification (Figure 8) without compromising volume of the outlet, there was no change on size of the biodigester, daily feeding and biogas production.

Figure 8. Before modification (left) and after modification (right)

Daily feeding and biogas production rate for SINIDU 2010 Model

SINIDU 2010 model had no change on the biodigester volume (Table 9), and the daily feeding and gas production was the same with SINIDU 2008 model (Figure 9).

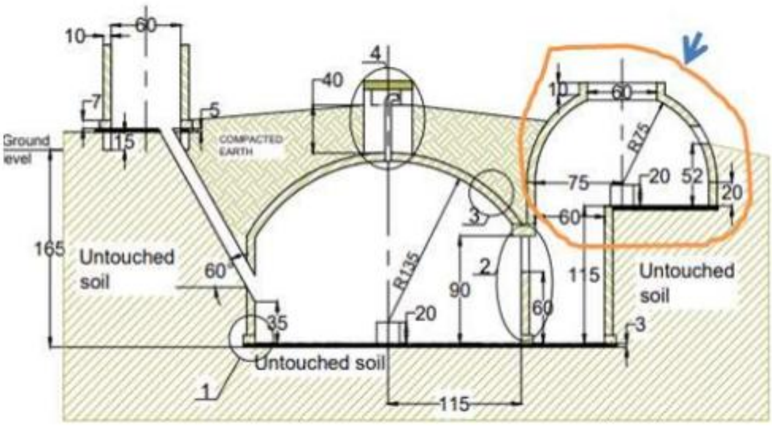

Figure 9. SINIDU 2010 biodigester with modified outlet (6m^3)

Table 9. Dimension for modified outlet SINIDU 2010

No.	Specification/digester volume	4m^3	6m^3	8m^3	10m^3
1	Radius of curvature for dome (RC)	65	75	85	95
2	Radius of outlet base (Ro)	65	75	85	95
3	Height of overflow (Ho)	53	52	56	68
4	Height of cylidrical wall (hc)	20	20	25	25
5	Height of support stick (hs)	20	20	25	25
6	Radius of manhole on the top of the outlet (rd)	30	30	35	35
7	Radius of manhole on the top of the outlet (hd)	20	20	20	20

Source: (outlet modification document, 2018)

MITIN 2012 model biodigester

The National Biogas Program of Ethiopia (NBPE) used the smallest size of biodigester of 4m^3 for households to collect at least 30-40 kg of dung per day. However, there are families with 2 heads of cattle and that need a biodigester. In order to provide a digester for this segment of families with the average weight of 250kg cattle and able to collect 15-20 kg of dung every day, the NBPE+ designed a modified biodigester size of 2.5m^3 [20] (Figure 10).

Figure 10. MITIN 2012 biodigester, Welmera district, Holeta

MITIN 2012 design (Figure 11) was not only smallest in size, but also has different feature than other biodigester models indicated in previous sections. The outlet chamber is connected with digester using PVC pipe (110 mm diameter) and the other unique feature is that manhole is at the top of the dome and the cover slab is sealed with clay soil and kept wet (to prevent biogas leakage) by water (field observation, welmera district). The bottom of the digester is oval, and this also makes it unique from SINIDU, SINIDU 2008 and SINIDU 2010 model.

Figure 11. Top of digester filled with water (left), bottom of biodigester (right)

NBPE+ piloted the 2.5m^3 biodigester for the first time in December 2019 for two users at Wondo Genet district, Sidama region, previous SNNPR and continued scale up with installation of two at Welmera district of Oromia region (visited during field assessment).

Feeding and biogas production for MITIN 2012 biodigester

The 2.5m^3 biodigester has a daily feeding of 15-20 kg of dung with equal volume of water but the completion manual states the water amount 8-10 litres. The biogas production is about 700–1000 litres and with this amount of biogas households can cook for about 2 to 3 hours using single burner biogas stove [20] (Figure 12).

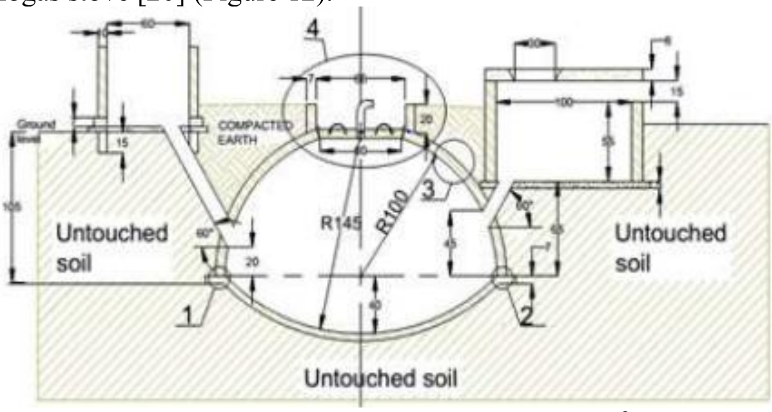

Figure 12. MITIN 2012 drawing (2.5m^3)

Black Cotton Soil biodigester model

In areas where black cotton soil or clay soil, predominates, SINIDU model in particular is facing challenges of cracking due to the contractions and relaxations of the soil in different weather conditions, which has increased non-functionality of biodigesters. For this SINIDU 2008 was modified to fit for black cotton soil by changing circular and rectangular parts into spherical/oval shape to increase structural strength. The main difference from SINIDU 2008 is on bottom part of the digester (inverted dome) and the other parts are similar.

Feeding and biogas production

For black cotton soil biodigester, the volumes designed are 4, 6, 9, 14 and 21 m^3 and the daily feeding and biogas production are shown in Table 10 with design shown in Figure 13.

Table 10. Daily feeding and biogas production for BCD [17]

Volume (m^3)	Dung for initial feeding (kg)	Water for initial feeding (litre)	Range of daily dung feeding (kg)	Average feeding per day*(litre)	Max.daily biogas production (litre)	Digester volume (litre)	Volume of effective biogas storage (litre)	Volume Buffer (litre)
4	1000	1000	20-40	30+30	1,050	2,890	750	460
6	1700	1700	40-60	45+45	1,575	4,200	840	660
9	2550	2550	60-80	75+75	2,625	6,350	1,450	1,150
14	3967	3967	80-140	115+115	4,025	10,140	2,000	1,900
21	5950	5950	140-220	200+200	7,000	15,250	3,500	2,900

*Dung and water in 1:1 ratio

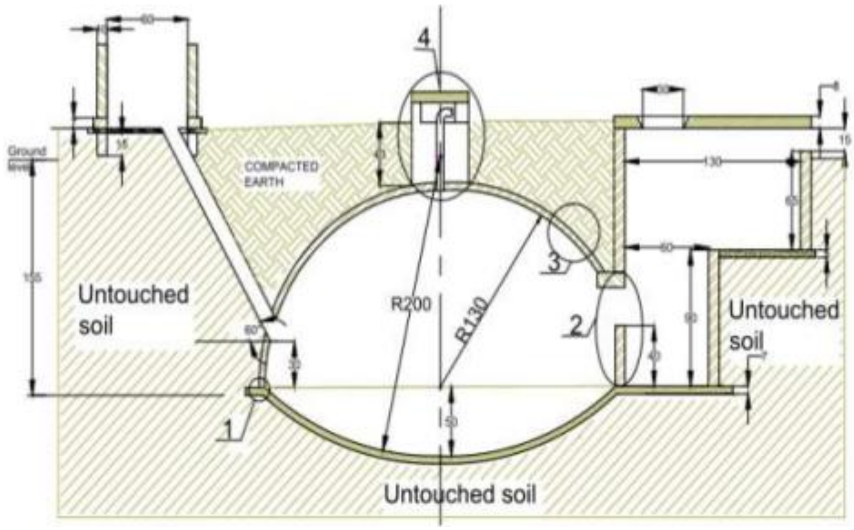

Figure 13. Drawing of black cotton soil biodigester ($6m^3$)

Solid State Biodigester

Household size biodigester installed so far in Ethiopia use cattle dung as substrate and every day require water in quantity equal to the dung for satisfactory operation of biodigesters. So, biogas technology has not been accepted in water scarce and drought prone regions of the country. Besides, a number of biodigesters under operation become non-functioning every year because feeding is stopped due to scarcity of water during dry months (solid state biodigester construction manual, 2018). The water requirement for fixed dome solid state biodigester (SSD) design is very low or almost nil [21]. Therefore, the design is, in general, suitable for all regions and more specifically for water scarce regions [21]. The basic biodigester design is a fixed dome biodigester design functioning same as SINIDU model biodigester. Its basic design is a modified SINIDU 2008 that has undergone some further modification on the inlet part to allow stiff material like fresh undiluted cattle dung to flow in and out of the system easily. The major modification is making the inlet a square opening of 40cmx40cm instead of using 110mm diameter PVC inlet pipe. The whole idea is to use lesser water in mixing the substrate [21]. This biodigester is initially fed with a mixing ratio of dung to water/urine 1:1, and once a plant has started producing gas, the ratio/consistency can now be changed gradually, i.e. from 1:1, 3:1, 4: 1 and lastly undiluted fresh dung only without varying the amount of fresh dung to be fed into the digester provided that bio-slurry will be able to flow by itself in and out of the system [22]. NBPE+ piloted two biodigester at Dera district of Oromia region in 2018 (interview, SNV Ethiopia experts, 2024).

Daily feeding and biogas production

Only data for $6m^3$ biodigester (Table 11), that was piloted, is documented and included on the SSD manual with initial feeding of 1500 and 2500 kg.

Table 11. Daily feeding and biogas production for $6m^3$ SSD

Size	**Dung for initial feeding (kg)**	**Water for initial feeding (kg)**	**Avg.daily dung feeding (kg)**	**Daily biogas production (m^3)**	**Avg. daily water to mix (litre)**	
					Initial	Normal/ final
6	2000	2000	60	3.4	60	15-20

Fixed dome medium and large scale biodigester

Biogas programme Ethiopia also introduced medium scale biodigesters for both cooking and productive use of energy. Medium size biodigester technology was introduced in 1962. About 120 medium size biodigesters were registered in Ethiopia in 2009 with volume of 12 to $350m^3$ [23]. About 47% of the biodigesters were not functioning because of lack of care by the owners, poor construction, mismatch of the digester size and the amount of gas demand, lack of appliance and spare parts for damaged appliances and lack of maintenance [24]. In 2019, SNV made a quick assessment and developed biodigester implementation strategy for large and medium size biodigesters. Then, pilot training was conducted by the support of international expert and five local consultants working on the energy and eight BCEs were trained [24]. Following pilot training, implementation started at two region and fixed dome biodigester of size from $30\text{-}80m^3$ were installed [24] (Figure 14). During this study, it was visited a fixed dome biodigester size of $80m^3$ with $30m^3$ separate biogas storage bag constructed at Sululta and a $60m^3$ size constructed at Sebeta district. The owner of the biodigester installed at Sululta had a milk processing factory and the biogas was used for productive energy use for biogas generator that supplies energy for milk cooling (milk kept at 5˚C and Yorghut at 50˚C). Moreover, the biogas was also used for cooking food for workers. The other visited biodigester located at Sebeta was mainly installed for mass food cooking using two big (double burner) stoves.

Figure 14. Top view of a $60m^3$ fixed dome biodigester (left), stove (right)

Daily feeding and biogas production rate of SINIDU 2008 model

The feed used in the biodigesters was a mixture of dung, urine and a small amount of water. Since the mixture of dung and urine was sufficient to flow to the digester, the amount of water added was just small to clean the pipe line that goes to the digester. Daily biogas production for

60m^3 and 80m^3 size fixed dome biodigester on average was 20m^3 and 36 m^3, respectively (interview, SNV Ethiopia experts, 2024) (Table 12).

Table 12. Feeding Vs biogas production of SINIDU 2008 Model

Size (m^3)	**Dung for initial feeding (kg)**	**Water for initial feeding (litre)**	**Max.daily dung, urine and water feeding (kg)**	**Max.daily gas production (m^3)**	**Volu.of effective gas storage (m^3)**
60	25,680	25,680	700	20	20
80	34,240	34,240	1200	36	36

Source: Field data from interview of users (SNV Ethiopia experts, 2024), initial feeding by using the mean feeding of household biodigesters

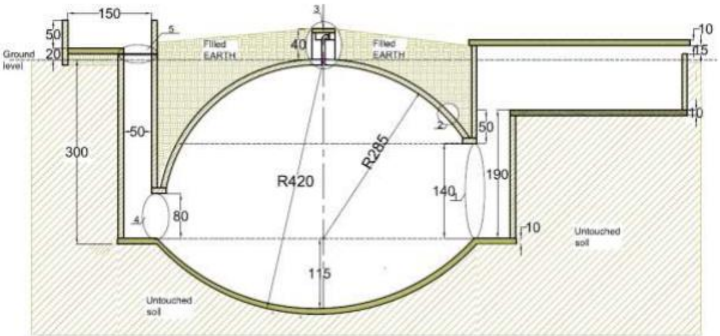

Figure 15. Drawing of medium size Biodigester (60m^3) [25]

Prefabricated Household biodigester

Prefabricated plastic biodigesters are made of plastic (tubular polyethylene, PVC or polyethylene geomembrane). All these materials are usually available locally in any country. Since biodigesters are made of flexible plastic, they must be semi-buried in an open trench in the ground (Figure 16). Prefabricated plastic moulded model with a portable and very simple system consists of a round- or square-shaped plastic digester tank with an inlet, a displacement tank with an outlet for bio-slurry, and a gas pipe connected to the cooker [7]. Case studies revealed that prefabricated plastic (tubular, molded, or bag-type) digesters were preferred by farming communities because of ease of construction, affordability, easy operation, emptying, and maintenance, and suitability for all soil types [26]. In the NBPE+, 125 prefabricated digesters were introduced from Kenya to Ethiopia with ten years warranty period. From those digesters, ten were medium scale digesters designs (with size of 20, 30, and 40 m^3). These digesters with modified Outlet Tank, and ease of installation are viable option for water logging soils and soil with upper ground water table.

Figure 16. Plastic geomembrane polyethylene biodigester

The plastic geomembrane biodigester can last from 5 to 6 years. After this time the plastic needs to be replaced, while other materials last longer. Proper carrying of biodigesters can elongate the service year to 11 years without replacing the plastic. However, if care is not taken to stop animals from entering, a biodigester can be broken within a few days after installation [27].

Comparative Advantages of Fixed Dome and Prefabricated Plastic Biodigesters

Although most of the constructed digesters were fixed dome type; after 2020 new prefabricated plastic digesters were introduced for household level and institutional use with a size of medium level. These have different comparative advantages (Table 13).

Table 1. Comparative advantages of fixed dome and prefabricated plastics

Type of digester	Parameters	Comparative advantages
Fixed dome digesters	Cost	Requires less water but requires complex materials for construction and then costly
	Construction material availability	Locally available
	Ease of construction	Difficult to construct and takes 6 to 15 or more days
	Susceptibility to damage	Not Susceptible because it is constructed below ground.
	Heat retention efficiency	Less fluctuating in retaining heat and suitable for all agroecological zones
	Hydraulic retention time	35 to 60 days
	Gas pressure	High gas pressure and suitable for lighting bulb
Prefabricated plastic digesters	Cost	Depends on the production of the plastic geomembrane, if it is produced in foreign country, the importing could be expensive because of tax. Then tax exemption as other energy materials such as solar system is needed at government policy
	Construction material availability	Plastic geomembranes are available but it needs proper manufacturing. It is not suitable to connect with toilet.
	Ease of construction	Easily installed in small pits within one day and can be changed the place of installation. Suitable for water logging areas and areas with high water table and cracking soil.
	Susceptibility to damage	Highly susceptible to damage because of exposure, therefore, requires fencing or some sort of guarding.
	Heat retention efficiency	Low heat retention because of the variability of cold and heat condition. Therefore, this is not suitable for cold agroecological zones.
	Hydraulic retention time	Two weeks in around 20°C and 2500m altitude above sea level in Holeta, Wolmera woreda (district) was responded by experts.
	Gas pressure	Low gas pressure and therefore, not suitable for lighting bulb
	Additional accessories	The digester has H_2S remover

Conclusion

In National Biogas Programme of Ethiopia (NBPE) that span from 2009-2023, the initial Nepalese GGC 2047, SINIDU fixed dome biodigester model was modified five times (*SINIDU* 2008, *SINIDU* 2010, Solid State Digester (SSD), Black Cotton Soil Digester (BCD) and *MITIN* 2012) and three more designs (small and medium scale prefabricated plastic geomembrane and medium sized fixed dome biodigesters) were introduced. The modifications of the design were in response to cost affordability, environmental conditions and needs of the users without basic change on daily biogas production. Introduction of alternative design (prefabricated) to fixed dome biodigester was preferable by the users and masons as the design is easy to install and adaptable to different environmental conditions. The medium size fixed dome and prefabricated geomembrane plastic biodigesters were used for productive use of energy such as biogas generator, grass chopper and mass cooking in dairy farms milk processing. The innovated products such as Solid State Biodigester (SSD), Black Cotton Soil Digester (BCD), 2.5m^3 biodigester (*Mitin* 2012) should be scaled up in collaboration with research institutes and universities.

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References

[1] O. W. Awe, Y. Zhao, A. Nzihou, D. P. Minh, and N. Lyczko, “A review of biogas utilisation, purification and upgrading technologies,” Waste and Biomass Valorization, vol. 8, no. 2, pp. 267–283, 2017.
[2] G. Caposciutti, A. Baccioli, L. Ferrari, and U. Desideri, “Biogas from anaerobic digestion: Power generation or biomethane production?,” Energies, vol. 13, no. 3, 2020.
[3] L. M. Kamp and E. B. Forn, “Ethiopia’s emerging domestic biogas sector: Current status, bottlenecks and drivers,” Renewable and Sustainable Energy Reviews, vol. 60, pp. 475–488, 2016, doi: 10.1016/j.rser.2016.01.068.
[4] EREDPC/SNV Ethiopia, “Trainee’s manual,” Addis Ababa, Ethiopia, 2008.
[5] Energypedia, “Types of biogas digesters and plants,” 2025. [Online]. Available: https://energypedia.info/wiki/Types_of_Biogas_Digesters_and_Plants. Accessed: Nov. 17, 2025.
[6] M. Berglund, “Biogas production from systems analytical perspective,” Ph.D. dissertation, Lund University, Lund, Sweden, 2006.
[7] BiogasSA, “BiogasSA,” 2018. [Online]. Available: http://www.biogassa.co.za. Accessed: Nov. 11, 2023.
[8] Biogas International, “Biogas International,” 2018. [Online]. Available: https://biogas.co.ke. Accessed: Nov. 11, 2023.
[9] Sistema.bio, “Sistema.bio biodigester systems,” 2019. [Online]. Available: http://sistema.bio. Accessed: Nov. 11, 2024.
[10] NBPE+, “Sinidu biodigester construction manual,” Addis Ababa, Ethiopia, 2017.
[11] T. G. Poulsen, “Anaerobic digestion,” in Solid Waste Management, Aalborg University, Aalborg, Denmark, 2003.
[12] J. Zabranska, M. Dohanyos, P. Jenicek, and J. Kutil, “Thermophilic process and enhancement of excess activated sludge degradability: Two ways of intensification of sludge treatment in Prague central wastewater treatment plant,” Water Science and Technology, vol. 41, pp. 265–272, 2000.
[13] S. Mace, D. Dosta, D. Bolzonella, and J. Mata-Alvarez, “Full scale implementation of AD technology to treat the organic fraction of municipal solid waste in Spain,” in Proceedings of the 4th International Symposium on Anaerobic Digestion of Solid Waste, Copenhagen, Denmark, vol. 1, pp. 34–51, 2005.
[14] E. C. Price and P. N. Cheremisinoff, “Biogas: Production and utilization,” Ann Arbor Science Publishers, Ann Arbor, MI, USA, 1981.
[15] National Biogas Programme, “Trainee’s manual,” Addis Ababa, Ethiopia, 2018.
[16] SINIDU, “Bio-digester construction manual,” Addis Ababa, Ethiopia, 2016.
[17] SINIDU, “Black-cotton soil biodigester design construction manual,” Addis Ababa, Ethiopia, 2018.
[18] M. K. Gebretsadik, “Field based assessment on the performance of household biogas plants in Bishoftu area, Ethiopia,” M.Sc. thesis, 2012.
[19] National Biogas Programme, “SINIDU 2008 BoQ operational manual,” Addis Ababa, Ethiopia, 2017.
[20] NBPE+, “2.5 m^3 piloting completion report manual,” Addis Ababa, Ethiopia, 2022.
[21] NBPE+, “Solid state biodigester (SSD) construction manual,” Addis Ababa, Ethiopia, 2018.
[22] J. M. Debora, N. N. M. Alfred, and L. M. Revocatus, “Optimization of biogas production process in solid state digesters in semiarid areas of Northern Tanzania,” Tanzania Journal of Science, vol. 44, no. 3, pp. 205–213, 2018.

[23] HoA-REC/N and GIZ, "Report on national survey on current status of institutional biogas systems installed in Ethiopia," Addis Ababa, Ethiopia, 2009.
[24] SNV/NBPE+, "Guidelines for piloting larger size bio-digesters," Addis Ababa, Ethiopia, 2018.
[25] SNV Ethiopia, "Biogas manuals," Addis Ababa, Ethiopia, 2016.
[26] World Bank, "The power of dung: Lessons learned from on-farm biodigester programs in Africa," 2019.
[27] IDEASS, "Innovation for development and South-South cooperation," 2009. [Online]. Available: www.ideassonline.org. Accessed: Dec. 20, 2023.