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1-Biogas production in Indian scenario

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ABSTRACT

Cheap, clean, renewable, naturally occurring, and underutilized as an energy source is biogas. It ignites between 650°C and 750°C in temperature range and weights 20% less than air. It burns as a colorless, odorless gas with a blue glow. It typically burns with 60% efficiency in a regular biogas burner and has a caloric value of 20 MJ/m3. India's vast population means that it has a high energy requirement. Even though India produces less energy than is needed, up to now, forest resources have been used to meet this demand. Furthermore, this demand is increasing at a 4.6% annual rate due to the worldwide shortage of fossil fuel supplies. Biomass seems to be the most viable energy source, despite government exploration of energy production and sources, energy supply security, and carbon dioxide (CO_2) emission reduction. To begin with, biomass is a sustainable energy source. Secondly, using anaerobic digestion to convert biomass to bioenergy, such as biogas.

Keywords- Biogas, Methane, Anaerobic digestion, Hydrolysis

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INTRODUCTION

The process of anaerobic digestion produces biogas. Reducing the quantity of waste products by turning biodegradable trash into usable fuel is crucial. Additionally, anaerobic digestion helps eliminate microorganisms that cause sickness. Microorganisms break down organic materials in anaerobic digestion when there is no oxygen present, the substance is sealed, and the temperature, pH, and moisture content are all controlled.

HISTORY OF BIOGAS IN INDIA

1859- First digestion plant was built at leper colony in Bombay, India
1897-Biogas used for lighting at Matunga leper asylum, Bombay.
1946-The first biogas plant designed IARI, Delhi.
1952-Development of the floating dome model, Grama Laxmi- III by Jashbai Patel.
1962-KVIC's entry into the field of biogas technology
1977-Development of Janata Model Biogas Plant
1981- Development of National Project on Biogas Development
2008- Incorporation of BDTC at IIT-Delhi
2009- Bio-CNG production/ utilization-Demonstration of integrated Technology Package on Biogas- Fertilization Plants (BGFP)
2013 - Bio-CNG production/ utilization forms part of 'Programme on Energy from Urban, Industrial and Agricultural Wastes/ Residues'
2013/2016- BIS Standard for Biogas Composition/further modification
2017 - Sustainable Alternative Towards Affordable Transportation (SATAT) launched for Bio-CNG/ CBG purchase and dispensation as auto fuel

The biological process that converts organic carbon to CO_2 and methane (CH_4) involves several steps: acidogenesis, acetogenesis, hydrolysis, and methanogenesis.

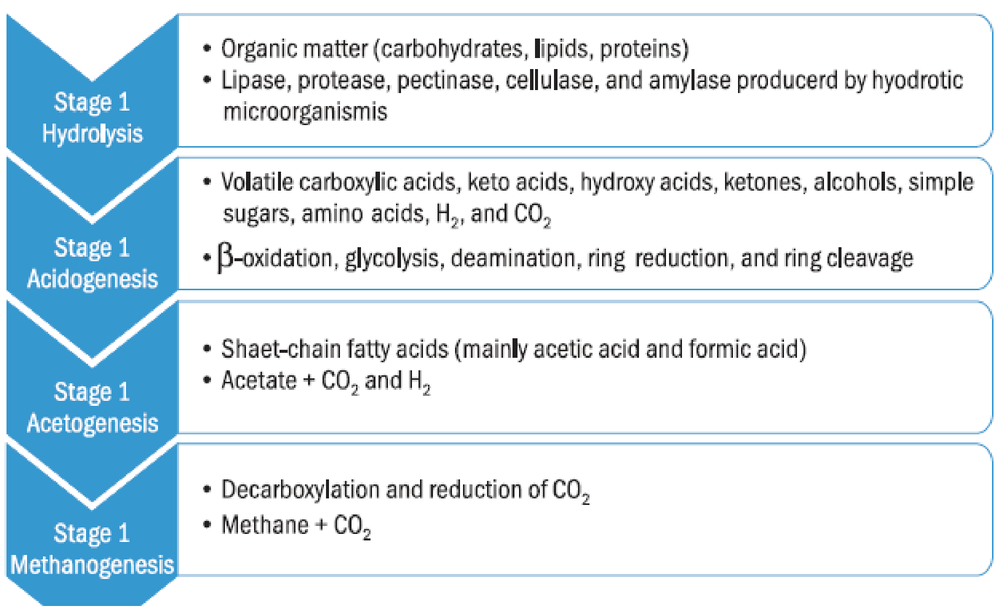
Steps involved in biogas production

HYDROLYSIS

The initial step of hydrolysis involves the breakdown of long chains of complex carbohydrates, proteins, and lipids into shorter forms such as sugars, amino acids, and fatty acids, respectively. This process is relatively slow and has the potential to constrain the overall rate of anaerobic digestion.

$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + H_2$ [1]

Fig. 1. Scheme of anaerobic digestion



ACIDOGENESIS

In this step, the products of hydrolysis serve as substrates that are subsequently converted into higher organic acids such as propionic acid and butyric acid, which are further metabolized into acetic acid by acidogenic bacteria.

$C6H12O6 \rightarrow 2CH3CH2OH + 2CO_2$

$C6H12O_6 + 2H_2 \leftrightarrow 2CH3CH2COOH + 2H2O$ [2]

$C6H12O6 \rightarrow 3CH3COOH$

ACETOGENESIS

The acetogenic bacteria then transform the higher organic acids into acetic acid and hydrogen gas as part of the process.

$CH_3CH_2COO- + 3H_2O \leftrightarrow CH_3COO- + H+ + HCO3- + 3H_2$

$C6H12O_6 + 2H2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2$ [3]

$CH3CH2OH + 2H2O \leftrightarrow CH_3COO- + 3H2 +H+$

METHANOGENESIS

In the final step, methanogenic bacteria metabolize acids, alcohols, carbon monoxide, carbon dioxide, and hydrogen to produce methane. These bacteria are highly sensitive to their environment, functioning exclusively under strict anaerobic conditions (Lettinga, van Nelsen, Hobma, et al. 1980).

$CH3COOH \rightarrow CH_4+ CO_2$

$CO_2+ 4H_2 \rightarrow CH4 + 2H2O$ [4]

$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH3COOH$

BENEFITS OF BIOGAS

ENERGY PRODUCTION—POTENTIAL IN INDIA

In India, the usage of chemically manufactured fertilizers and fossil fuels is expected to be surpassed by biogas. For instance, 7.3 million tonnes of LPG and 22.7 billion m3 of natural gas (not including natural gas from liquefied petroleum gas, shrinkage, and LPG) were used in 2001–2002. In terms of heat energy, the annual amount is 1.08×10^{12} MJ, which is less than the 1.3×10^{12} MJ potential heat value that may be obtained from the biogas produced annually from animal excrement (Sevilla-Espinosa, Solorzano-Campo, and Bello-Mendoza 2010; Shastry, Nandy, Wate, et al. 2010).

The technology utilized in the production of biogas is more adaptable and valuable in an agro-ecosystem. The biogas can also be used as a fuel in place of firewood, agricultural waste, electricity, and other resources, depending on the kind of activity, availability, and other factors. It therefore supplies energy for lighting and cooking. Following anaerobic digestion, biogas facilities also produce leftover organic waste, which is more nutrient-dense than cattle excrement and typical organic fertilizers since it contains ammonia. Mix of installed electrical capacity in India

Types of biogas plants in India

The types of biogas plants commonly used in developing countries are as follows:

(i) Bag digester plant
(ii) Fixed dome digester plant
(iii) Floating drum digester plant
(iv) Vacvina biogas plant

(1) BAG DIGESTER PLANT

The bag digester plant, also known as a balloon plant, was first constructed in Taiwan in 1960. Typically, it consists of a plastic or rubber digester bag designed to be UV resistant, often made from materials such as neoprene, rubber, and RMP (red mud plastic). Organic waste, along with slurry, is introduced into the biodigester via inlet and outlet ducts for degradation. Biogas produced accumulates at the top of the bag, although in some instances, it may be collected in a separate bag. Residue is collected in the lower section. Functioning primarily as a plug flow reactor (PFR), the bag digester operates such that materials added daily theoretically move through the digester as a unit mass until the hydraulic retention time (HRT) is achieved. Subsequently, the digested mass exits the digester bag as a unit. A portion of the effluent is reintroduced into the inlet to serve as a seed for re-inoculating the bag digester (Kaparaju, Serranoa, and Angelidaki 2009).

The advantages of using the bag (balloon) digester are follows:

i. It is the most cost-effective option compared to other types of digesters.
ii. Installation and setup are straightforward and can be completed swiftly within hours.
iii. It features simple cleaning mechanisms, making maintenance hassle-free.

- The digester heats up along with its contents due to thin partitions in the reactor, utilizing sunlight or external heat source- The disadvantages of the bag (balloon) digester are as follows:
- Its lifespan is relatively short, approximately around 5 years.
- The digester is susceptible to damage and may pose challenges in restoration.
- Sludge removal and transportation to the field demand significant labor.
- It necessitates a consistent temperature.
- Insulating the digester is challenging.
- It relies on high-quality plastic, particularly PVC.

(2) FIXED DOME DIGESTER

This is a Chinese model biogas plant, first built in China around 1936. In this design, the digestion chamber and gas holder are integrated into a single unit. Examples of this design include Deenbandhu, Chinese fixed dome, CAMARTEC, as well as Janata and Janata II models.

Bacteria within the digester convert biomass into a liquid known as slurry (digested waste) and biogas. The biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2), along with traces of other gases. Once collected in the dome-shaped gas holder, the slurry is transferred to the offset tank. The quantity of slurry produced is contingent upon factors such as the feed loading rate, its utilization, and gas generation. During gas production, the slurry is pressed backward and sideways, then directed to the offset tank. As gas is utilized, slurry is returned from the offset tank to the digester. These reciprocal movements facilitate the mixing of slurry phases, leading to altered phases through gradation mixing. Therefore, according to Stalin (2007), this model is regarded as a mixed digester reactor (CSTR, continuously stirred tank reactor).

The fixed dome digester is relatively inexpensive, making it economically viable with a lifespan of approximately up to 20 years. Because the majority of the structure remains below the earth's surface, it is safe and able to withstand cold temperatures. Additionally, the fluctuation in temperatures between day and night inside the biodigester is conducive to better biogas production by methanogens.

The advantages of the fixed dome digester are as follows:

4. Despite being low-cost, it offers significant advantages compared to other types.

5. It is reliable and has a lifespan of up to 20 years.
6. With its complete insulation and underground construction, it is considered the optimal digester type for biogas generation in colder climates, such as in countries like Bolivia.

The disadvantages of the fixed dome digester are as follows:

(i) Building it in bedrock areas poses significant challenges.

(ii) Technical skills are crucial for constructing the fixed dome and ensuring proper sealing to prevent gas seepage due to design flaws.

(iii) The lifespan of the fixed dome digester exceeds that of the Khadi and Village Industries Commission (KVIC) plant.

(3) FLOATING DRUM DIGESTER

This model is commonly referred to as the KVIC model, as it was endorsed and approved by KVIC (Jashu Bhai J. Patel developed the design of the floating drum biogas plant in 1962), and its utilization is widespread in India and around the globe.

The main or reactor tank is enclosed by a concrete wall and comprises two components: (i) an inlet for supplying slurry to the tank, and

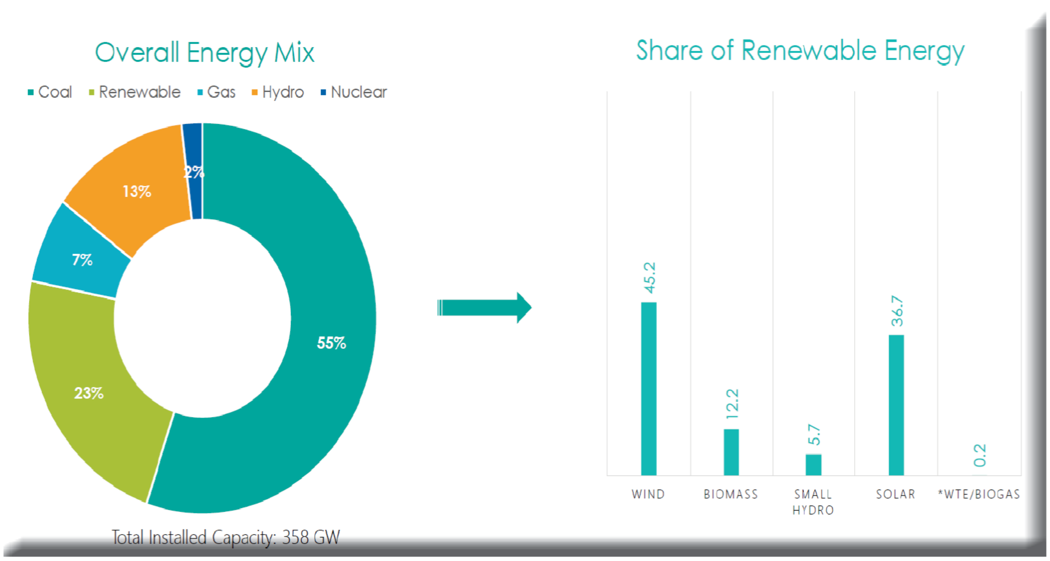
(ii) a stainless steel cylindrical dome positioned atop the slurry, housing an outlet pipe for collecting the gas produced. As the decomposed matter expands, the slurry overflows into the subsequent compartment, which can then be utilized as natural fertilizer.

The floating drum digester offers the advantage of maintaining constant gas pressure due to the weight of the drum.

However, its disadvantage lies in the use of stainless steel for the construction of the floating chamber, which is costly and requires ongoing maintenance and observation to prevent rusting.

(4) VACVINA BIOGAS PLANT

The VACVINA model represents an advancement from earlier biogas designs such as fixed dome and plastic container types. It features a



rectangular-shaped digester constructed with a volume capacity exceeding 5 m3, suitable for smaller animal farms.

Animal waste is supplied as feed from a trench located behind or below the animal shed. Biogas produced from the digester is collected and stored in two or three plastic bags, serving as fuel for the kitchen range. The advantages of the VACVINA model include:

I. Its simple design with minimal defects.
II. It is relatively inexpensive to maintain and can be constructed in limited space.
III. Suitable for colder climates due to the underground biogas digester and the external plastic gas reservoir.
IV. It has a higher probability of a longer lifespan.

Types of Biogas Reactors

According to Angelidaki and Sanders (2004) and Parawira, Murto, Zvauya, et al. (2004), achieving biodegradability of organic matter and surplus biogas generation in batch processes can be accomplished through the conventional anaerobic digestion method. This process proves effective due to the controlled and stable supply, as well as the steady state of the bioreactor, thereby maximizing production. The selection and classification of reactors are determined by the mixing of fluid (sludge

	Definition	**Installed Base**	**Future Potential**
SMALL BIOGAS PLANT	These consist of biogas plants of the size between 1 to 10 cubic meter capacities	A cumulative total of 4.8 million family type biogas plants have been set up in the country	Estimated potential of 12 million family plants
MEDIUM BIOGAS PLANT	Power generation capacity between 3 KW to 250 KW	There are about 300 small and medium biogas plants (5-25 KW)	Currently insignificant to be sized
LARGE BIOGAS PLANT	Equivalent power generation capacity above 250 KW	Few large scale installations, (50- 60 No.) most on demonstration basis:	The estimated potential from urban municipal wastes is projected at c. 5000 MW equivalent by 2023
INDUSTRIAL & MUNICIPAL WASTE BIOGAS PLANT	Plants based on feedstock derived from Industrial and Municipal waste	~ 40 power projects installed so far	The estimated potential of generation of power from industrial solid and liquid wastes is expected to increase to 2000 MW

and substrate) or particulate solid contents in the reactor, as reported by Stalin (2007). High-rate biofilms such as EGSB and UASB are employed for treating organic soluble matter, while slurry and solid wastes are treated in CSTRs (Kato, Field, and Lettinga 1997; Angelidaki, Ellegaard, Sorensen, et al. 2002).

I. CONTINUOUSLY STIRRED TANK REACTOR

Demirel and Scherer (2008) documented the successful utilization of CSTR in the anaerobic digestion of energy crops and food remains. In the CSTR process, biomass is suspended in the main liquid and subsequently removed along with the effluent. By maintaining this process for 10–20 days, the hydraulic and sludge retention times become equivalent, thereby preventing the washout of slow-growing methanogens (Boe, 2006). Boe and Angelidaki (2009) observed that a single CSTR produces less CH4 compared to serial CSTRs when using the same industrial slurries or an equivalent volume of manure. Despite this, the CSTR process is practical, simple to operate, and offers numerous advantages (Kaparaju, Serranoa, and Angelidaki 2009).

II. UPFLOW ANAEROBIC SLUDGE BLANKET

The UASB (upflow anaerobic sludge blanket) reactor, developed in the 1970s by Lettinga, van Nelsen, Hobma, et al. (1980), is widely employed for biogas production through the treatment of various wastewater types (Shastry, Nandy, Wate, et al. 2010; Sevilla-Espinosa, Solorzano-Campo, and Bello-Mendoza 2010). In the UASB reactor, an immobilized cell is utilized, retaining biomass while substrate is pumped through, enabling a high organic loading rate. The success of the UASB concept hinges on the formation of a dense sludge bed at the reactor's bottom, where biological processes occur, facilitated by the accumulation of incoming suspended solids and bacterial growth (Seghezzo, Zeeman, and van Lier 1998). Natural turbulence in UASB systems is induced by influent flow, while biogas formation within the reactor enhances contact between wastewater and biomass.
Developed in the 1970s, the UASB reactor is extensively utilized for biogas production by treating various wastewater types. In the UASB reactor, wastewater is pumped through, leading to an increase in the loading rate and retention of biomass through immobilized cells. (Kaparaju, Serranoa, and Angelidaki 2009).

The success of the UASB application relies on the formation of a sludge layer created by suspended solids in wastewater, as it

S. No.	Fuel	Replacement value	Estimated Equivalent with 15083 Mm3 of biogas/annum (in millions)
1	LPG	0.45 Kg	6787.35 Kg
2	Firewood	3.47 Kg	52338.01 Kg
3	Cattle dung cake	12.30 Kg	185520.9 Kg
4	Charcoal	1.4 Kg	21116.2 Kg
5	Diesel	0.52 liter	7843.16 liter
6	Electricity	6.5KWh	98039.5KWh
7	Kerosene	0.62 liter	9351.46 liter
8	Gasoline	0.8 liter	12066.4 liter

is where microbial degradation and digestion of organic matter occur (Seghezzo, Zeeman, van Lier, et al. 1998). The resulting biogas facilitates significant interaction between wastewater and biomass, while influent flow induces natural turbulence in the UASB systems.

III. EXPANDED GRANULAR SLUDGE BED

De Man, Vander Last, and Lettinga (1988) introduced the concept of the expanded granular sludge bed (EGSB) as a modification to the traditional UASB reactor. Both EGSB and UASB utilize granular sludge inoculation; however, adjustments in hydrodynamic settings such as superficial velocity and Ks enhance mixing and contact between sludge and wastewater specifically in the EGSB.

PROBLEMS AND ISSUES ENCOUNTERED

TECHNICAL

The failure of numerous biogas facilities is often linked to technical operational issues, which can manifest in various forms, including inadequate maintenance, negligence, or equipment deterioration such as rusting over time. A 1995 study analyzing a sample of 24,501 biogas plants across 432 villages in India found that only about 53% of these plants were active. Given the prevalence of technical challenges, the subsequent discussion on planning and policies should be taken into consideration.

INPUT PROBLEMS

In India, cattle excreta is commonly collected and utilized as the primary feedstock for biogas digesters, while pig and human excreta are deemed unacceptable (UNAPCAEM 2007). Despite approximately 20% of rural households owning four or five cattle, a biogas plant exclusively relying on cow dung requires a similar number of calves per household for optimal operation. Villagers' reluctance to utilize waste materials other than cattle excrement results in underfed biogas plants, exacerbating the scarcity issue and complicating solutions.

HUMAN RESOURCES

- For the success and sustainability of NBMMP, it is crucial to have well-trained laborers constructing the biogas plants. However, biogas dissemination programs in India often face challenges due to the lack of qualified staff to provide training, supervision, reporting, and program leadership.
- Shortage of staff for training and developing local capacity.

REPORTING

- Inaccurate reporting of achievements:
- Discrepancies were noted in the reporting of data and achievement of goals at the block, district, and state levels by PEO. The PEO highlighted that record-keeping at higher levels lacks authenticity.
- Improper maintenance of reports.

TRAINING/MONITORING

- To ensure that troops participating in NBMMP are well-informed and satisfied with their duties, training plans are essential.
- Moreover, systematic monitoring is lacking. Each RBDTC is required to conduct random case verifications of 500 biogas plants established in a specified region

at predetermined times. However, due to the shortage of administrative manpower, this goal is rarely achieved. The effectiveness of the reporting mechanism is compromised, and progress reports for these biogas plants are often submitted without proper oversight and authorization.

POLITICAL/BUREAUCRATIC:

- In India, the FTBP is a government-funded program that involves multiple states, district bureaus, funding institutions, training centers, and NGOs.
- Agency multiplicity and procedural delays- Additionally, because the clearance procedure is so drawn out and bureaucratic, firms encounter delays in receiving technical approval for raw materials like steel and cement. The government controls the transportation of steel and cement, which are in short supply in India, and sets the pricing for transportation based on quotas.

Biogas Programme

(PHASE-I) FOR FY 2021-22 TO 2025-26

A government of India initiative through Ministry of New and Renewable Energy.

- There is significant potential for setting up biogas plants in India, given the large livestock population of 535.78 million, which includes approximately 302 million bovines (comprising cattle, buffalo, mithun, and yak). The livestock sector makes a substantial contribution to India's GDP and is expected to grow further. The dissemination of biogas technology represents a boon for Indian farmers, offering both direct and collateral benefits (Fu, Achu, Kreuger, et al. 2010).
- Biogas typically comprises about 55-65% methane, 35-44% carbon dioxide, and traces of other gases like hydrogen sulphide, nitrogen, and ammonia. In its raw form, without any purification, biogas can serve as a clean cooking fuel similar to LPG, for lighting, motive power, and electricity generation. It can also substitute diesel in diesel engines, with replacements of up to 80% achievable, and in 100% biogas engines. Moreover, biogas can be purified and upgraded to attain up to 98% methane content purity, transforming it into Compressed Bio-Gas (CBG), suitable for transportation or filling cylinders at high pressures of around 250 bar.
- Initially, biogas plants were designed for digesting cattle dung. However, technological advancements over time have enabled the bio-methanation of various types of biomass materials and organic wastes. Biogas plant designs are now available in sizes ranging from 1 m3 to over 1000 m^3, with multiples of that size possible to achieve larger plant sizes. These plants can be installed for various purposes, including family/household use, small farmers, dairy farmers, and for community, institutional, and industrial/commercial applications, depending on the availability of raw materials.

About the Biogas programme

The Ministry of New and Renewable Energy (MNRE), Government of India, introduced the National Bioenergy Programme on November 2nd, 2022. MNRE has extended the National Bioenergy Programme for the period from FY 2021-22 to 2025-26, with implementation planned in two phases. Phase-I of the Programme has been approved with a budget outlay of Rs. 858 crore, including Rs. 100 Crore allocated for the Biogas Programme. This funding aims to support the establishment of small (1 m3 to 25 m3 biogas per day) and medium-sized biogas plants, ranging from above 25 m3 to 2500 m3 biogas generation per day. These plants are expected to have corresponding power generation capacities ranging from 3 kW to 250 kW from biogas or raw biogas for thermal energy/cooling applications. (Puyol, Mohedano, Sanz, et al. 2009; Kalogo and Verstraete 1999).

The Ministry of New and Renewable Energy, Government of India, launched the Biogas programme with the following objectives:

- Setting up of biogas plants for clean cooking fuel, lighting, meeting thermal and small power needs of users which results in GHG reduction, improved sanitation, women empowerment and creation of rural employment.
- **ORGANIC ENRICHED BIO-MANURE:** The digested slurry from biogas plants, a rich source of manure, shall benefit farmers in supplementing / reducing of use of chemical fertilizers.

Conclusion

For several decades, biogas has proven to be the most suitable machinery for utilizing available resources efficiently. It is recognized as a clean, hygienic, and cost-effective fuel that is environmentally friendly. With biogas, women in villages no longer need to spend hours gathering firewood for cooking and burning, freeing up time for other activities. Additionally, a smokeless and soot-free kitchen reduces the risk of lung and throat infections for women, enabling them to live longer, healthier lives. Furthermore, biogas has the capacity to fulfill the fuel demands of households, agricultural lands, and industries comprehensively.

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