

Biomass For Cooking Gas Generation: Technologies, Feedstocks, System Design, And Socio-Environmental Impacts

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Abstract- Biomass-based cooking gas generation is an important pathway for expanding access to clean household energy, especially in rural and peri-urban regions where conventional fuels are expensive, unreliable, or environmentally damaging. This paper examines the production of cooking gas from biomass, with emphasis on biogas generated through anaerobic digestion and producer gas/syngas generated through gasification. The study reviews biomass feedstocks, conversion technologies, process conditions, system components, gas composition, purification requirements, performance metrics, and practical applications for domestic cooking. It also evaluates economic feasibility, environmental implications, public health relevance, and implementation challenges. The paper finds that anaerobic digestion is the most suitable biomass-to-cooking-gas route for household and community-scale deployment because it produces a relatively clean combustible gas from animal dung, food waste, sewage, and crop residues under controlled biological conditions. Gasification, while technically viable, is generally more appropriate for institutional or semi-industrial settings due to tar formation, stricter gas cleaning needs, and operational complexity. The paper concludes that biomass-based cooking gas systems can reduce dependence on fuelwood and fossil liquefied petroleum gas, lower greenhouse gas emissions, improve sanitation, and support circular rural economies when supported by proper feedstock management, user training, financing, and policy incentives.

Keywords: Biomass, Cooking Gas, Biogas, Anaerobic Digestion, Gasification, Renewable Energy, Household Energy, Clean Cooking

I. INTRODUCTION

Access to clean cooking energy remains a major development challenge in many parts of the world. A large share of households still rely on traditional fuels such as fuelwood, charcoal, agricultural residues, and kerosene for daily cooking (Abbasi et al., 2011).

These fuels are often inefficient, polluting, and labor-intensive. Their use contributes to indoor air pollution, deforestation, greenhouse gas emissions, and adverse health outcomes, especially among women and children who spend more time near cooking areas.

Among the available alternatives, biomass-derived cooking gas offers a promising solution because it converts locally available organic materials into combustible gaseous fuels. Rather than burning raw biomass directly, these systems transform biomass into a cleaner gaseous energy carrier that can be used in modified stoves, burners, and heating systems (Bridgwater, 2012). The two principal routes are:

1. Anaerobic digestion, which produces biogas rich in methane.
2. Thermochemical gasification, which produces producer gas or syngas containing carbon monoxide, hydrogen, and methane.

For household cooking applications, the most widely adopted option is biogas, usually generated from cattle dung, poultry litter, food waste, kitchen residues, and human or animal excreta.

A biogas system can simultaneously provide cooking fuel, organic fertilizer, and a waste-management service. In contrast, biomass gasification typically requires dry, well-prepared feedstock and more complex gas cleaning before the gas is suitable for small-scale cooking.

This paper presents a full research-oriented review of biomass for cooking gas generation, covering technical principles, feedstocks, system design,

applications, benefits, limitations, and future prospects.

II. LITERATURE REVIEW

Biomass as an Energy Resource

Biomass refers to organic material derived from plants, animals, and biodegradable wastes. It stores solar energy in chemical form through photosynthesis and is considered renewable when harvested and managed sustainably (Rao, 2010). Biomass energy can be used directly through combustion or indirectly through conversion into solid, liquid, and gaseous fuels.

Common biomass sources include:

- agricultural residues such as rice straw, maize stalks, and cassava peels;
- animal wastes such as cattle dung and poultry droppings;
- forest residues and sawdust;
- food waste and market waste;
- municipal organic waste and sewage sludge.

The suitability of a biomass resource for cooking gas generation depends on moisture content, biodegradability, ash content, carbon-to-nitrogen ratio, lignocellulosic structure, and local availability.

Clean Cooking and Energy Access

Traditional cooking methods often involve open fires or simple stoves with incomplete combustion. This causes high emissions of particulate matter, carbon monoxide, black carbon, and volatile organic compounds (Bond & Templeton, 2011). Clean cooking transitions aim to replace such practices with fuels and technologies that are safer, more efficient, and less polluting.

Biomass-based gases can support this transition by:

- reducing smoke and soot compared with direct biomass burning;
- improving thermal control during cooking;
- decreasing fuel collection time;
- lowering exposure to harmful emissions;
- creating local energy systems from waste streams.

Overview of Biomass-to-Gas Pathways

Biomass can be converted to cooking gas through biochemical and thermochemical processes.

Biochemical conversion

This mainly involves anaerobic digestion, in which microorganisms decompose organic matter in the absence of oxygen to produce biogas.

Thermochemical conversion

This includes gasification, where biomass reacts at high temperature with limited oxygen, steam, or air to produce combustible gas.

Among these pathways, anaerobic digestion is generally preferred for household cooking because the gas contains substantial methane and can be used in simple biogas stoves after basic cleaning and moisture removal (Khandelwal, K & Mahdi, 1988).

Biomass Feedstocks for Cooking Gas Generation

The choice of feedstock strongly affects gas production, process stability, and system economics.

Animal Dung

Animal dung is one of the most common feedstocks for domestic biogas plants. Cow dung is particularly suitable because it contains active anaerobic microbes and has moderate solids content.

Advantages:

- readily available in farming communities;
- easy to slurry with water;
- stable digestion characteristics;
- produces nutrient-rich digestate.

Limitations:

- gas yield per kilogram may be lower than some food wastes;
- collection and handling can be labor-intensive;
- availability depends on livestock ownership.

Food and Kitchen Waste

Food waste has high biodegradability and often yields more biogas than dung. It includes leftover food, fruit peels, vegetable scraps, and restaurant waste.

Advantages:

- high methane potential;
- useful for urban and institutional digesters;
- supports waste reduction.

Limitations:

- may acidify quickly if overloaded;
- requires sorting to remove plastics and metals;
- can attract pests if poorly managed.

Agricultural Residues

Examples include rice husks, maize cobs, straw, sugarcane bagasse, cassava peels, and groundnut shells.

These residues may be used in two ways:

- as feedstock for gasification when dry and properly sized;
- as digester feedstock after pretreatment, co-digestion, or size reduction.

Highly lignified residues digest slowly in anaerobic systems, so pretreatment may be needed to improve biodegradability.

Sewage and Human Excreta

Human waste and sewage sludge are suitable for biogas production in household, institutional, and municipal settings.

Benefits:

- improved sanitation;
- reduced pathogen exposure after treatment;
- simultaneous waste disposal and energy recovery.

Concerns:

- cultural acceptance;
- pathogen management;
- stricter hygiene requirements.

Municipal Organic Waste

Organic fractions of municipal solid waste can be digested or processed into gas, particularly in urban centers.

Challenges include segregation at source, contamination, odor control, and logistics.

Technologies for Cooking Gas Generation from Biomass

Anaerobic Digestion for Biogas Production

Anaerobic digestion is a microbial process in which biodegradable organic matter is decomposed in oxygen-free conditions. The final product is biogas, typically containing methane, carbon dioxide, and traces of hydrogen sulfide, ammonia, and water vapor (AFRICA, 1986).

Stages of anaerobic digestion

The process occurs in four main stages:

1. **Hydrolysis**
Complex organic compounds such as carbohydrates, proteins, and fats are broken down into simpler soluble molecules.
2. **Acidogenesis**
These molecules are converted into volatile fatty acids, alcohols, hydrogen, carbon dioxide, and other intermediates.
3. **Acetogenesis**
Intermediate compounds are further converted into acetate, hydrogen, and carbon dioxide.
4. **Methanogenesis**
Methanogenic microorganisms convert acetate and hydrogen/carbon dioxide into methane.

III. BIOGAS COMPOSITION

A typical biogas composition is:

Component	Typical range
Methane (CH ₄)	50-70%
Carbon dioxide (CO ₂)	30-45%
Water vapor	Saturated
Hydrogen sulfide (H ₂ S)	Trace to several thousand ppm
Ammonia, nitrogen, hydrogen	Small amounts

The methane fraction determines the energy value of the gas. Higher methane content generally means better flame quality and heat output.

Digester types

Common digester designs include:

Digester type	Key features	Suitability
Fixed-dome	Underground,	Rural

Digester type	Key features	Suitability
digester	durable, low maintenance	households
Floating-drum digester	Visible gas holder, stable pressure	Domestic and institutional use
Balloon or tubular digester	Low-cost plastic construction	Warm climates, pilot use
Plug-flow digester	Suitable for thicker slurry	Farms and institutions

Operating parameters

Important factors affecting biogas production include:

- Temperature: Mesophilic digestion typically occurs around 30-40°C, while thermophilic digestion occurs around 50-60°C.
- pH: A near-neutral pH, usually around 6.8-7.5, is favorable.
- Carbon-to-nitrogen ratio: An approximate range of 20:1 to 30:1 is often desirable.
- Hydraulic retention time: This depends on feedstock and temperature, often ranging from 20 to 60 days for small digesters.
- Organic loading rate: Overloading can cause acid accumulation and process failure.
- Mixing: Moderate mixing improves contact between microbes and substrate.

Gasification for Producer Gas or Syngas

Gasification converts carbonaceous biomass into combustible gas under high temperature and limited oxygen conditions (Basu, 2018). The gas produced commonly contains carbon monoxide, hydrogen, methane, carbon dioxide, nitrogen, tar, and particulates.

Gasification reactions

Key reactions include:

- partial oxidation;
- drying;
- pyrolysis;
- reduction;
- char gasification.

Typical producer gas composition

A typical air-blown biomass gasifier may produce gas with approximate composition:

Component	Typical range
Carbon monoxide (CO)	15-25%
Hydrogen (H ₂)	10-20%
Methane (CH ₄)	1-5%
Carbon dioxide (CO ₂)	8-15%
Nitrogen (N ₂)	40-55%

Because producer gas contains significant carbon monoxide and tar, safe household use requires robust handling and cleaning systems.

Gasifier types

Common gasifier types include:

- fixed-bed updraft gasifiers;
- fixed-bed downdraft gasifiers;
- fluidized-bed gasifiers;
- entrained-flow gasifiers.

For cooking gas production, small fixed-bed systems are the most realistic, but they still demand skilled operation and proper cleaning units.

System Design for Household Biogas Generation

A household biomass-to-cooking-gas system based on anaerobic digestion generally includes the following units:

1. Feedstock collection unit
Organic wastes are collected and sorted.
2. Mixing tank
Feedstock is mixed with water to form slurry.
3. Digester chamber
Anaerobic microbes break down the slurry and produce gas.
4. Gas holder or storage section
Gas accumulates and is stored under low pressure.
5. Gas pipeline
Carries gas to the kitchen.
6. Gas cleaning system

Removes moisture and hydrogen sulfide where needed.

7. Biogas stove or burner

Burns gas efficiently for cooking.
 8. Slurry outlet/digestate pit
 Collects digested residue for use as fertilizer.

Gas Purification and Upgrading
 Raw biomass-derived gas often requires cleaning before use.

Biogas cleaning
 Biogas from digesters may contain:

- water vapor, which can condense in pipelines;
- hydrogen sulfide, which is corrosive and toxic;
- carbon dioxide, which lowers heating value.

For household cooking, complete upgrading is not always necessary. Basic treatment often includes:

- moisture traps or condensate removal;
- iron filings or iron oxide filters for hydrogen sulfide removal;
- proper piping and pressure control.

If biogas is to be compressed or injected into a gas grid, advanced upgrading would be required to raise methane concentration, but this is usually beyond household-scale systems (Surendra, et al., 2014).

Producer gas cleaning
 Gasification gas cleaning is more demanding and may involve:

- cyclone separators for particulates;
- scrubbers for tar and dust;
- filters;
- cooling systems.

This complexity is one reason gasification is less common than digestion for direct domestic cooking gas use.

Performance Evaluation
 The effectiveness of biomass cooking gas systems can be assessed through the following indicators:

Gas yield
 Gas yield depends on feedstock type, solids content, biodegradability, and reactor conditions. Food waste often produces higher gas yields than raw dung, while lignocellulosic residues may require pretreatment.

Methane content and calorific value
 For biogas, a higher methane percentage improves combustion performance. For cooking, the gas must provide a stable flame and sufficient thermal output.

Stove efficiency
 The performance of the burner or stove affects the useful energy delivered to cooking vessels. Poorly matched stoves waste gas and reduce user satisfaction.

Retention time and digester stability
 A stable digestion process avoids sharp drops in pH, foam formation, scum buildup, and incomplete gas production.

Digestate quality
 The residual slurry should remain suitable for agricultural application, with good nutrient recovery and reduced pathogens where properly processed.

Comparison of Anaerobic Digestion and Gasification for Cooking Gas

Criterion	Anaerobic digestion	Gasification
Main product	Biogas rich in methane	Producer gas/syngas
Best feedstocks	Wet biodegradable wastes	Dry solid biomass
Scale suitability	Household to community	Institutional to industrial
Operational complexity	Moderate to low	Moderate to high
Gas cleaning need	Low to moderate	High
Cooking suitability	High	Limited for households
By-product value	Digestate fertilizer	Biochar/ash depending on system
Safety concerns	Methane leakage, H ₂ S	CO toxicity, tar, hot surfaces
Capital cost	Often moderate	Often higher for safe clean systems

From this comparison, anaerobic digestion emerges as the more practical and user-friendly route for domestic cooking gas generation.

Environmental Impacts

Biomass-based cooking gas can provide significant environmental benefits when systems are properly designed and sustainably supplied.

Reduced deforestation

When households shift from fuelwood to biogas, pressure on nearby forests and woodlots can decline.

Greenhouse gas mitigation

Biogas systems can reduce methane emissions from unmanaged manure and waste decomposition while offsetting fossil fuels and inefficient biomass combustion.

Waste management improvement

Organic waste that would otherwise rot in open dumps or waterways can be collected and treated productively.

Soil fertility improvement

Digestate from anaerobic digestion can be used as an organic fertilizer, returning nutrients to agricultural land.

However, poor system management can reduce these benefits. Gas leaks, slurry discharge into water bodies, and unsustainable biomass harvesting can undermine environmental performance.

Health and Social Impacts

The shift to cleaner cooking gas from biomass can improve quality of life in several ways.

Health benefits

- reduced indoor smoke exposure;
- lower risk of respiratory and eye irritation;
- cleaner kitchens and utensils;
- reduced burns associated with open fires.

Social benefits

- less time spent collecting firewood;
- improved dignity and convenience in cooking;
- local employment in plant construction, maintenance, and waste collection;

- support for schools, clinics, and farms through decentralized energy access.

Gender dimension

In many communities, women bear the burden of fuel collection and smoke exposure. A transition to biomass-derived cooking gas can reduce this burden and create time for education, income generation, or rest.

Economic Analysis

The economic viability of cooking gas generation from biomass depends on local conditions, plant size, feedstock availability, labor cost, and substitute fuel prices (Karellas et al, 2010).

Cost components

Key cost elements include:

- digester or gasifier construction;
- feedstock collection and preparation;
- water supply;
- gas piping and stove equipment;
- maintenance and repairs;
- training and supervision.

Economic benefits

Benefits may include:

- savings on firewood, charcoal, kerosene, or LPG;
- reduced expenditure on chemical fertilizers through digestate use;
- better waste management outcomes;
- possible income generation through community-scale gas distribution or fertilizer sales.

Barriers to affordability

Common barriers include:

- high upfront capital costs;
- lack of access to credit;
- irregular feedstock supply;
- poor maintenance culture;
- low technical support in rural areas.

A system may appear cost-effective over its lifetime but remain inaccessible without subsidies, loans, revolving funds, or cooperative ownership models.

Challenges to Adoption

Despite its promise, biomass-based cooking gas generation faces multiple constraints.

Technical challenges

- inconsistent gas production due to temperature fluctuations;
- digester leakage or poor construction;
- clogging, scum formation, or sediment accumulation;
- inadequate gas purification;
- limited suitability of some feedstocks without pretreatment.

Social and cultural challenges

- reluctance to handle certain waste materials;
- preference for traditional cooking methods;
- limited user awareness;
- concerns about reliability and cooking speed.

Institutional and policy challenges

- weak extension services;
- insufficient technical standards;
- poor after-sales support;
- limited financing for household systems;
- fragmented waste and energy policy frameworks.

Safety concerns

For safe use, systems must address:

- methane leakage and fire risk;
- hydrogen sulfide exposure in raw biogas;
- carbon monoxide risk in producer gas systems;
- pressure regulation and burner design;
- hygienic digestate handling.

Future Prospects and Innovation

The future of biomass for cooking gas generation is likely to be shaped by advances in engineering, microbiology, digital monitoring, and circular economy models.

Promising directions include:

- co-digestion, where multiple feedstocks are blended to improve yield and nutrient balance;
- pretreatment methods for fibrous residues to improve digestion;
- small biogas bottling and compression for localized distribution where economically justified;
- smart sensors for monitoring gas production, pressure, and pH;

- modular community digesters serving clusters of households;
- integration with sanitation systems, livestock farms, and food markets;
- bio-slurry valorization into commercial fertilizer products.

Research is also expanding into membrane upgrading, biological desulfurization, and low-cost digester materials that can extend system lifespan and reduce maintenance burden.

IV. CONCLUSION

Biomass is a viable and valuable resource for cooking gas generation, especially in settings where organic waste is abundant and access to modern fuels is limited or costly. The two main pathways, anaerobic digestion and gasification, differ significantly in complexity, gas quality, and practical suitability. For household cooking, biogas from anaerobic digestion is generally the most appropriate option because it can convert wet organic wastes into a relatively clean gaseous fuel using manageable technology. In addition to energy production, biogas systems offer co-benefits in sanitation, fertilizer recovery, waste reduction, and environmental protection (Mshandete & Parawira 2009).

Gasification also has an important role, particularly for dry biomass and larger-scale applications, but its greater technical demands make it less suitable for ordinary household cooking without strong support systems.

The success of biomass-based cooking gas programs depends not only on engineering design but also on feedstock logistics, cultural acceptance, financing, user education, and long-term maintenance. With proper implementation, biomass-derived cooking gas can contribute meaningfully to clean cooking access, rural development, and sustainable energy transitions.

V. RECOMMENDATIONS

Based on the research, the following measures are recommended:

1. Prioritize anaerobic digestion for domestic cooking applications: It is the most suitable

technology for small-scale cooking gas generation from wet biodegradable biomass.

2. Match feedstock to technology: Wet wastes should be directed to digesters, while dry lignocellulosic residues may be reserved for gasification or other uses.
3. Promote co-digestion: Combining dung with food waste or other organics can improve gas yield and process balance.
4. Strengthen training and technical support: Users need guidance on feeding rates, maintenance, leak detection, and slurry management.
5. Support financing mechanisms: Microcredit, subsidies, carbon finance, and cooperative models can improve access.
6. Develop technical standards: Standardized digester and stove designs can improve safety and durability.
7. Integrate agriculture and sanitation planning: The fertilizer value of digestate should be part of project design, not treated as a secondary issue.
8. Encourage applied local research: More location-specific studies are needed on feedstock availability, gas yield, user preferences, and lifecycle economics.

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REFERENCES

- [1] Abbasi, T., Tauseef, S. M., & Abbasi, S. A. (2011). *Biogas energy* (Vol. 2). Springer Science & Business Media.
- [2] Bond, T., & Templeton, M. R. (2011). History and future of domestic biogas plants in the developing world. *Energy for Sustainable development*, 15(4), 347-354.
- [3] Khandelwal, K. C., & Mahdi, S. S. (1988). *Biogas technology: a practical handbook*. Tata McGraw-Hill.
- [4] Rao, P. V., Baral, S. S., Dey, R., & Mutnuri, S. (2010). Biogas generation potential by anaerobic digestion for sustainable energy

development in India. *Renewable and sustainable energy reviews*, 14(7), 2086-2094.

- [5] AFRICA, S. F. (1986). Project Manager of Biogas Plants, Deutsches Zentrum für Entwicklungstechnologien (German Appropriate Technology Exchange), GTZ/GATE, PO Box 5180, 6236, Eschborn 1, Federal Republic of Germany. *Biogas Technology, Transfer and Diffusion*, 120.
- [6] Surendra, K. C., Takara, D., Hashimoto, A. G., & Khanal, S. K. (2014). Biogas as a sustainable energy source for developing countries: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, 31, 846-859.
- [7] Mshandete, A. M., & Parawira, W. (2009). Biogas technology research in selected sub-Saharan African countries—A review. *African journal of biotechnology*, 8(2).
- [8] Basu, P. (2018). *Biomass gasification, pyrolysis and torrefaction: practical design and theory*. Academic press.
- [9] Bridgwater, A. V. (2012). Review of fast pyrolysis of biomass and product upgrading. *Biomass and bioenergy*, 38, 68-94.
- [10] Karellas, S., Boukis, I., & Kontopoulos, G. (2010). Development of an investment decision tool for biogas production from agricultural waste. *Renewable and sustainable energy reviews*, 14(4), 1273-1282.