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BIOGAS FOR DOMESTIC COOKING

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CONTENTS

ABBREVIATIONS

ACS	Advanced biomass cook stove (including fan or natural draft biomass gasification cook stoves)
aDALYs	Averted disability-adjusted life years
BD	Bag digester
CMD	Composite material digester
EUR	Euro
HAP	Household air pollution
ICS	Improved cook stove (including modern fuel cook stoves and renewable-fuel cooking technologies)
IFAD	International Fund for Agricultural Development
IRENA	International Renewable Energy Agency
IWA	International Workshop Agreements
LPG	Liquefied petroleum gas
m^3	Cubic metre
MFI	Microfinance institution
NBMMP	National Biogas and Manure Management Programme (India)
nm^3	Normalised cubic metre
OCD	Onsite-constructed digester
PBD	Prefabricated biogas digester
R&D	Research and development
TCS	Traditional cook stove (including three-stone fires and basic charcoal stoves)
USD	United States dollar

HIGHLIGHTS

Biogas is a modern form of bioenergy that can be produced through anaerobic digestion or fermentation of a variety of biomass sources. These include, but are not limited to, livestock manure, food waste, agricultural residues, energy crops, sewage and organic waste from landfills. It is a versatile fuel that can be used for cooking, heating, lighting, power generation, and combined heat and power generation, as well as, when upgraded to boost its methane content, in transport applications. It also can provide dispatchable energy to power grids so that a higher share of electricity can be generated from variable wind and solar energy. Biogas typically consists of 50–75% methane, which provides its energy content, and 25–50% carbon dioxide, which potentially can be captured and stored.

Different technology options are available to replace traditional cook stoves (TCSs) in developing countries. TCSs typically are fuelled by wood or charcoal through inefficient and incomplete (dirty) combustion processes. Inefficiencies result in additional fuel requirements and in households spending excessive amounts of time to collect fuel or money to buy it, and can place undue pressure on wood resources in local forests. Incomplete combustion results in carbon monoxide and/or carbon (soot) being produced in addition to carbon dioxide. This combination is commonly known as "smoke", generating indoor air pollution which results in significant health risks and in excess morbidity and mortality.

Improved cook stoves (ICSs), which are more efficient and promote complete combustion, can greatly alleviate health problems. ICSs can use a variety of energy forms, including traditional biomass such as wood, charcoal or dung. Additionally, renewable sources can be used including biogas, sustainably harvested wood or biomass residues in the form of briquettes, pellets or ethanol, or solar power in the case of solar cook stoves.

Biogas cook stoves are attractive in places with wood scarcity. They displace the use of wood or charcoal entirely, and they are particularly viable in agricultural locations due to the readily available feedstocks. Biogas can be produced from locally available agricultural residues or from animal or human waste, with valuable organic fertiliser as a by-product, and it is easy to store and transport.

Cook stoves based on biogas and other sustainably produced renewable fuels can greatly improve health and welfare. Over 3 billion people worldwide currently use TCSs fuelled by wood or charcoal (WBA, 2016). Roughly 50 million biogas cook stoves have been installed worldwide, and the number is growing at about 10% annually (IRENA, 2014a). China leads the world in biogas digester installations for cooking, accounting for over half of all installations globally. African countries, specifically sub-Saharan countries, also would stand to benefit from their uptake.

Environmental benefits – Biogas cook stoves have positive environmental performance (Smith et al., 2000), matched only by that of solar cook stoves (Kammila et al., 2014) and a comparable combustion efficiency and particulate emissions profile to liquefied petroleum gas (LPG) or ethanol (Berkeley Air Monitoring Group, 2012). Emissions otherwise resulting from biogas decay are foregone, thereby reducing the release of pollutants including black carbon, carbon monoxide and methane (Grieshop et al., 2011). Biogas stoves avoid the use wood or charcoal, which often is unsustainably sourced.

Health benefits – Each year, household air pollution (HAP) is estimated to cause 4 million deaths worldwide (WHO, 2012). Biogas stoves reduce HAP and associated diseases as measured by averted disability-adjusted life years (aDALYs) (Smith et al., 2015). The health benefits are greatest for women and children who are present when cooking occurs. Other health benefits can be found with the reduction of volumes of rotting organic waste and associated pathogens, as this waste is used to produce biogas (IRENA, 2016a).

Economic and social benefits – Even though household biogas digesters have high upfront costs, in the range of USD 500 to USD 1 500 (Putti et al., 2015), they have one of the lowest annualised costs of all technology options for cooking in developing regions such as sub-Saharan Africa (Kammila et al., 2014), including both capital and operating costs. They also can improve the livelihoods of rural households by raising the productivity of agriculture through by-products of biogas production such as slurry and fertiliser. Biogas digesters greatly reduce the amount of time that women and children need to spend collecting wood, creating more time for women to work in productive enterprise and for children to study.

Barriers to deployment – The production potential of domestic biogas has not been fully exploited. Deployment barriers include limited awareness about opportunities for biogas applications, the initial cost of installation, lack of skilled labour for installation and operation, inadequate and intermittent government support, feedstock availability, need for consistent maintenance, behavioural and social acceptance, and competition from fossil fuel-based alternatives. Deployment of biogas systems for cooking often requires subsidies to reduce the upfront cost of system installation.

International support – Several international development aid programmes support national or sub-national efforts to deploy affordable domestic biogas plants. Lower cost, pre-fabricated biogas digester units constructed of fibre, plastic or lightweight bags also can make biogas systems cheaper to install. Ongoing investments in the biogas value chain, from installation to maintenance, can further reduce costs and encourage system deployment.

PROCESS AND TECHNOLOGY STATUS

Biogas is a viable cooking fuel for any household that has access to sufficient organic feedstock or that can purchase biogas from producers. Its use for cooking is mainly in emerging and developing economies, where it helps households through its numerous social, environmental, health and economic benefits.

Box 1: TYPES OF COOK STOVES

This brief focuses on biogas for cooking, and thus considers the use of a domestic biogas digester or plant in combination with a biogas cook stove. This combination also is referred to as a biogas system. Different types of digesters are discussed in the text. The biogas cook stove is a type of improved cook stove (ICS) known as a "renewable-based stove", as explained below.

A traditional cook stove (TCS) consists of a pot being heated above a fire based on fuelwood (solid biomass) or charcoal. The pot is placed either on three stones arranged in a triangle shape (three-stone cook stove) or on a foundation of bricks, clay and/or ceramic.

ICS is the overarching term for cook stoves that have increased efficiency compared to the TCS in terms of reducing both time and fuel consumption through improved combustion. One method to compare the improved efficiency and safety, and reduced emissions, is by using the performance criteria shown in Figure 2 and Table 5 of this brief (GACC, 2016a; WBA, 2016).

Within the group of ICSs, several different fuels are used, leading to additional categorisation (GACC, 2016b; GACC, 2016c; WBA, 2016):

- **Improved charcoal stoves** comprise better-insulated stoves with optimised air circulation.
- **Advanced biomass cook stoves** (ACSs) represent cook stoves that achieve high performance levels based on crop residues and/or biomass pellets and briquettes. Examples of ACSs are the forced air stove, which optimises complete combustion by means of a fan that introduces additional air, and the gasifier stove and rocket stove, which also use the product of incomplete combustion within the stove, helping to achieve complete combustion.
- **Modern liquid fuel stoves**, which make use of liquid fuels such as alcohols (ethanol and methanol) and LPG.
- **Renewable-based stoves**, such as solar and biogas cook stoves. One example of biogas cook stove can be seen below.


Photograph: Heifer International

Biogas is primarily a mixture of methane and carbon dioxide and is produced through anaerobic digestion of biodegradable organic materials, such as manure, food processing residues, wastewater treatment sludge and energy crops (IRENA, 2015). The anaerobic digestion process occurs in airtight biogas digesters, and, depending on the feedstock and other parameters, the process can last several hours (sugars and alcohol) to several weeks (hemicelluloses, fat and protein). Anaerobic digestion typically occurs at temperatures of 20 to 45 degrees Celsius (IRENA, 2016b).

A biogas system has several elements including the feedstock storage, the receiving and mixing area, the digester or reactor, the gas holder and the digester residue storage.

A range of biogas digester types exists, and their geographical and contextual applicability should be taken into consideration to optimise productivity.

Table 1 provides an overview of the main types of small-scale biogas digesters and their core regions of development. These digester types are illustrated in Figure 1. Large-scale biogas reactors – the batch reactor, the continuous flow reactor, the plug flow reactor and the continuously stirred tank reactor – are not within the scope of this brief.

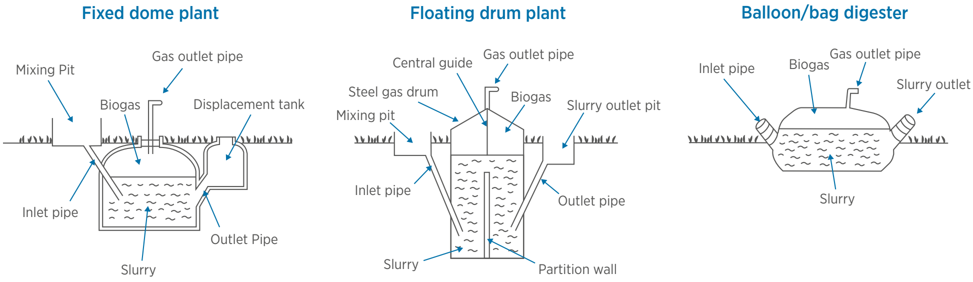
This technology brief, as its title indicates, focuses on household-scale or domestic biogas digesters for cooking purposes.

Table 1: Descriptions and regional prevalence of the three main small-scale biogas digester types

Type of digester	Description	Regional deployment
Fixed-dome plant	Has an inlet chamber (and, optionally, a lavatory) feeding into the digester which is topped by a dome expansion chamber with a gas release point. A slurry outlet from the digester can feed into a compost pit, providing high-quality fertiliser.	Developed in China, employed in diverse developing countries
Floating drum plant	Consists of two parts: an underground digester and a moving gas-holder. Gas is collected in a gas drum which rises or falls according to the amount of gas present and is kept upright by a frame. Can be used by either a small or medium-sized farm with a digester size of 5–15 cubic metres or in larger industrial agricultural settings with a digester size of 20–100 cubic metres.	India
Balloon/bag digester	A plastic bag is connected to an input pipe, introducing the feedstock, and to an output pipe which removes the slurry. A third pipe at the top of the bag functions as the biogas outlet pipe.	Latin American countries

Source: IRENA, 2016b

Figure 1: Illustrations of the three main small-scale biogas digesters: fixed dome plant, floating drum plant and balloon/bag digester



Fixed dome plant

Floating drum plant

Balloon/bag digester

Source: IRENA, 2016b

Box 2: BIOGAS PLANT SCALE

In general, biogas plants are categorised into small- and large-scale plants. The term mid- or medium-scale is primarily mentioned in combination with either small- or large-scale.

The large-scale plants are set up mainly in industrialised regions, using large volumes of sludge obtained from large-scale wastewater treatment plants, agricultural and food industry waste, or industrial waste. They therefore also are referred to as industrial-scale biogas and sometimes are supplemented with energy crops to increase the biogas yield (SSWM, 2010a).

The term mid-scale is not widely applied, as this category also can be merged with large-scale biogas plants. The terms mid- or medium-scale to large-scale plants often are used for plants with medium to large feedstock farms.

Several names are used to indicate small-scale biogas plants: domestic, household, decentralised, farm and communal. These plants are employed mainly in rural areas. The feedstock consists of animal manure and/or human waste and/or crop residues (SSWM, 2010b; IRENA, 2016b).

As demonstrated in Table 2, biogas is composed primarily of methane, which provides its energy content. Considering the biogas yield of different livestock, cows have a particularly high yield of feedstock and corresponding biogas product per year (Table 3). The methane yield per hectare of land can vary widely, as shown in Table 4, depending on factors such as climate, rainfall, soil fertility, seed and farming technique.

Table 2: Biogas composition

Component	%
Methane (CH_4)	50–75
Carbon dioxide (CO_2)	24–45
Water vapour (H_2O)	2–4
Nitrogen (N_2)	<2
Oxygen (O_2)	<2
Others: ammonia (NH_3), hydrogen (H_2), hydrogen sulphide (H_2S), trace gases	

Source: WBA, 2013

Table 3: Examples of biogas methane yields from livestock

Biogas source	Feedstock per year	Biogas methane yield per year (nm³)*
1 cow (milk)	20 m^3 liquid manure	500
1 pig	1.5–6 m^3 liquid manure	42–168
1 cow (beef)	2–11 tonnes solid manure	240–880
100 chickens	1.8 m^3 dry litter	242

Source: Murphy, 2011; WBA, 2015; Biogas-info.co.uk, 2016

* nm^3 = normalised cubic metre

Table 4: Examples of biogas methane yields from crops

Feedstock	Tonnes of dry stock per hectare	Methane yield (m³/tonne volatile solids)	Biogas methane yield per hectare
Maize (whole crop)	9–30	205–450	1 660–12 150
Grass, cut	10–15	298–467	2 682–6 305
Sudan grass	10–20	213–303	1 917–5 454
Red clover	5–19	-300–350	1 350–5 985
Reed canary grass	5–11	340–430	1 530–4 257
Sugar beet	9.2–18.4	236–381	1 954–6 309
Wheat (grain)	3.6–11.75	384–426	1 244–4 505
Barley	3.6–4.1	353–658	1 444–2 428
Alfalfa	7.5–16.5	340–500	2 295–7 425
Rapeseed	2.5–7.8	240–340	540–2 387
Potatoes	10.7–50	276–400	2 658–18 000

Source: Murphy, 2011

Supply-side biogas innovation – Biogas digester innovation is leading to lower costs and standardised quality. A key approach uses prefabrication construction, which offers lower purchasing costs, ease of installation and correspondingly low installation fees. Reduced transport costs are encountered in the case of reduced volume and/or for lightweight biogas digester components.

Prefabricated biogas digesters (PBDs) are either composite material digesters (CMDs) or bag digesters (BDs). In comparison to onsite-constructed digesters (OCDs), PBDs offer a swifter installation time resulting in a cost reduction. However, import costs may be an issue, as either the unit itself or its components may need to be imported for use in developing countries. These costs need to be taken into account.

Lightweight bag digesters are flexi-biogas systems that use balloon or tube digesters constructed from polyethylene or a plastic bag. They are cheaper, use less material, can be set up in a single day, require less manure for start-up, and convert waste into energy more quickly (Kammila et al., 2014).

From 2011 to 2014, 500 such systems were distributed in Kenya by the International Fund for Agricultural Development (IFAD) and Biogas International. IFAD also piloted such systems in India, Rwanda and São Tomé and Príncipe, while the Multilateral Investment Fund installed some in Mexico (REN21, 2015). As these systems are not well insulated, they may operate poorly in cold conditions.

Another supply-side innovation for biogas is the transport of surplus biogas. Surplus biogas may be transported in gasbags, which are low in cost and easy to manage. Typical gasbags on the market hold 2 cubic metres of biogas to fuel four hours of cooking. Gasbags also offer economic opportunities for biogas-producing households with surplus biogas for sale (GASL, 2015).

Biogas is produced through anaerobic digestion of biodegradable organic materials

PERFORMANCE

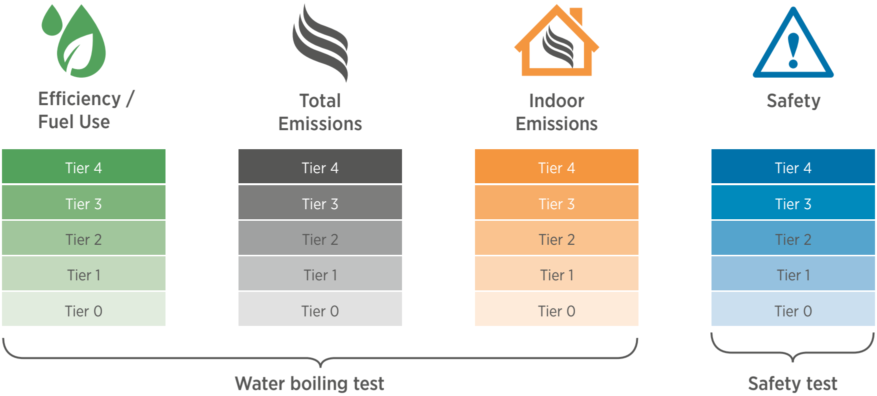
For households without access to grid-based electricity or gas for cooking, cook stove options include a range of technologies with varying degrees of efficiency to burn traditional biomass such as charcoal and fuelwood, LPG, kerosene, ethanol, pellets, briquettes and biogas. Biogas offers a superior performance compared to these fuels by a number of measures, as elaborated below.

ENVIRONMENTAL PERFORMANCE

Biogas is among the environmental friendliest and cleanest of all cooking technologies (Putti et al., 2015) and outperforms traditional cook stoves in several ways. Upgrading to biogas from a TCS improves indoor air quality, reduces deforestation (of otherwise unsustainably sourced fuelwood), reduces cooking time, treats waste that otherwise would rot, and provides organic fertiliser from the digester residue (Putti et al., 2015). Replacing fossil fuel or traditional biomass fuel sources with biogas furthermore reduces emissions while improving the air quality (Lukehurst and Bywater, 2015). Although the combustion of biogas produces similar emissions to LPG, the foregone emissions otherwise resulting from biomass decay results in a better net environmental performance for biogas.

Biogas cook stoves reach top performance levels at Tiers 3–4 of the interim international guidelines for stove performance, emissions and safety developed through the International Workshop Agreements (IWA) process of the International Organization for Standardization, as illustrated in Figure 2 and indicated with the different criteria in Table 5 (WBA, 2016; GACC, 2016a).

Figure 2: IWA tiers of performance indicating stove performance, including efficiency, total emissions, indoor emissions and safety



Note: Tier 0 represents the lowest performance and Tier 4 indicates the highest performance.
Source: GACC, 2016a.

Table 5: Cook stove high performance criteria

	Carbon monoxide emissions		2.5 microgram particulate emissions		Indoor emissions		Fuel use efficiency		Safety
	High power (g/ MJd)*	Low power (g/ min/L)**	High power (mg/ MJd)***	Low power (mg/ min/L)	CO (g/ min)	PM2.5 (mg/ min)	High power efficiency (%)	Low power efficiency (MJ/ min/L)	Scale of 0-100
Tier 0	>16	>0.20	>979	>8	>0.97	>40	<15	>0.050	<45
Tier 1	≤16	≤0.20	≤979	≤8	≤0.97	≤40	≥15	≤0.050	≥45
Tier 2	≤11	≤0.13	≤386	≤4	≤0.62	≤17	≥25	≤0.039	≥75
Tier 3	≤9	≤0.10	≤168	≤2	≤0.49	≤8	≥35	≤0.028	≥88
Tier 4	≤8	≤0.09	≤41	≤1	≤0.42	≤2	≥45	≤0.017	≥95

* g/MJd is grams per megajoule delivered to the pot.

** g/min/L is grams per minute per Liter at (near) minimum energy use.

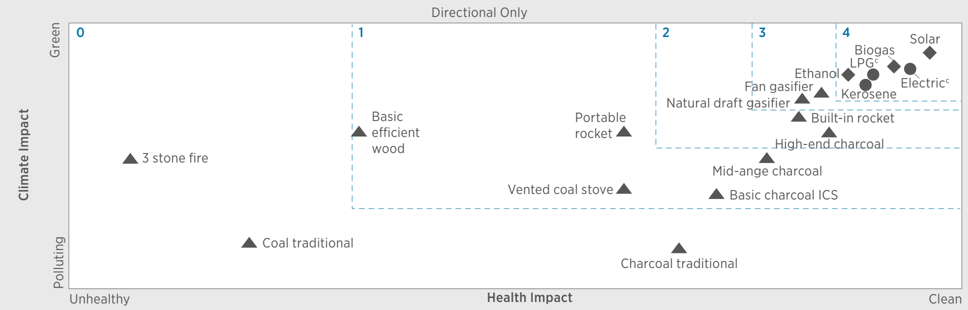
*** mg/MJd is milligrammes per megajoule delivered to the pot.

Source: WBA, 2016; GACC, 2016a

A distinct advantage of biogas is the use of organic wastes and by-products for energy production, reducing the waste volume and associated disposal challenges (WBA, 2013). Emissions from decomposition therefore also are reduced. In addition, a decrease in contamination of resources including ground and surface water is found due to the reduction of over 90% of harmful pathogens (Lukehurst and Bywater, 2015). Post-treatment, biogas effluent can provide high-quality organic fertiliser, feed additives, pesticides, seed-soaking and top-dressings, which can substitute the import or production of synthetic nitrogen fertilisers.

Compared to other cooking fuels and technologies, biogas stoves are highly rated in terms of health and climate impacts, as shown in Figure 3.

Figure 3: Indicative health and climate impact by stove type, including the tiers categorisation indoor emissions and safety



Source: Putti et al., 2015

ECONOMIC AND SOCIAL PERFORMANCE

Key performance indicators for biogas and other cooking fuels are compared in Table 6.

Table 6: Various performance metrics by stove type, where a distinction is made between ICSs, modern fuel stoves and renewable fuel stoves

		Affordability	Fit w/ Custom	Life/Durability	Safety	Fuel Savings	Cooking Time	Environment	Health	Employment
ICS	Legacy Stoves	●	●	◔	◔	◔	○	○	○	◔
	Basic Efficient Stoves	◕	●	○	◑	◔	◔	◔	◔	◕
	Chimney Rocket	◕	◑	◕	◕	◕	◑	◑	◑	◑
	Portable Rocket	◑	◕	◑	◕	◑	◔	◑	◔	◔
	Advanced Charcoal	◔	◕	◑	◕	◕	◑	◑	◑	◔
	Natural Draft Gasifier	◑	◔	◑	◕	◑	◕	●	◕	◑
	Fan Gasifier/Jet	◔	◔	◑	◕	◑	●	●	●	◔
Modern	LPG	◑	◑	●	◑		●	◕	●	◔
	Electricity	○	◑	●	●		◕	◕	●	○
	Kerosene	◑	◑	◕	◑		◕	◕	◑	◕
Renewable	Ethanol	◑	◔	●	◑		◕	◕	◕	◑
	Biogas	◔	◔	◕	◕	◕	●	●	●	◑
	Solar	◑	◔	◑	●	◔	○	●	●	◔
	Briquettes/Pellets	◕	◑		●	◑		●		◕
	Retained Heat Devices		◔	◑	●	◑	○	●	●	◔

Source: Putti et al., 2015

As can be observed, besides top environmental performance, biogas cook stoves have a positive effect on cooking time and health. Fuel savings also are an important advantage. Whereas petroleum-based fuels can impose a heavy financial burden on households in countries which do not subsidise LPG and kerosene, biogas can alleviate this burden. However, the upfront cost of biogas digester installation is a significant barrier to uptake. Financial assistance provided by national governments, non-governmental organisations, development organisations and carbon financing mechanisms often may be necessary to fund the installation of biogas systems.

Another burden for biogas stove deployment is the poor fit with prevailing societal customs. Fuelwood collection is a social activity in some locations (Rupf et al., 2015). If wood-burning stoves are replaced with biogas in such places, other social activities need to be created. Fuelwood collection also can be an important source of income. In some regions, cooking with energy generated from animal waste is considered socially unacceptable. In view of different customs, communications on the benefits of biogas must be tailored to the local context.

On the other hand, biogas offers substantial opportunity for employment throughout the value chain–from the production and harvesting of feedstock, to the production, construction and/or installation and maintenance of the biogas digester unit, or the resale of produced biogas. Present biogas employment figures in leading regions are estimated in Table 7. Globally, the production and use of biogas provided some 333,000 jobs in 2015, and the number should grow as biogas use for cooking and other applications expands.

Table 7: Biogas employment figures

Globally	**333 000**
China	145 000
India	85 000
Germany	45 000
Europe (excl. Germany)	19 000
Other	17 000
Bangladesh	15 000
United States	7 000

Source: Chen et al., 2012; IRENA, 2014b; REN21, 2015; IRENA, 2017

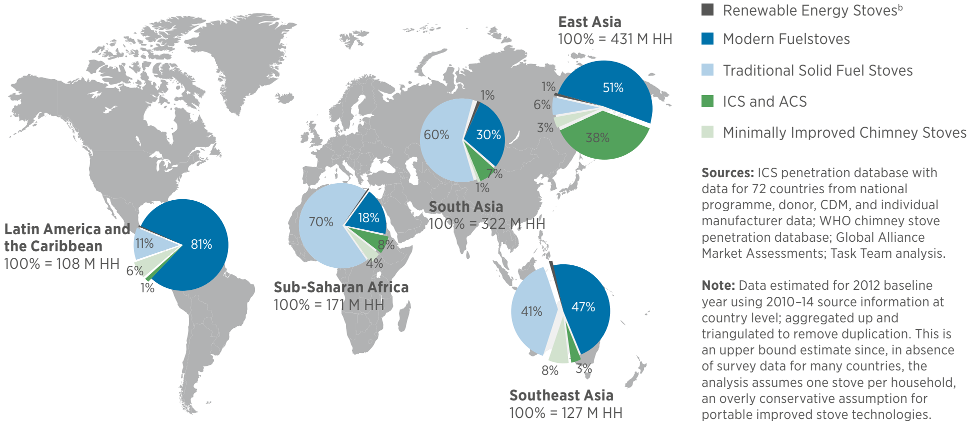
OVERVIEW BY REGION

Globally, roughly 50 million biogas systems are being used for cooking, mostly in Asia and especially in China and India (Putti et al., 2015). Estimating the use of residential-scale biogas for cooking in developing countries is challenging because biogas digester units often are locally sourced, and the resulting energy provision is rarely measured (IRENA, 2013).

Table 8 estimates regional uptake rates, although these likely are not reflective of the full extent of biogas use for cooking. For example, units such as bag digesters may not be reflected in these figures – one estimate indicates 170,000 units in Nepal alone (Cheng et al., 2014). Furthermore, the number of units may not be indicative of use; for example, in India, nearly 5 million units are installed, yet not all are functioning due mainly to a lack of technical skills and to cultural habits (see Chapter 5).

Different cooking technologies dominate in different regions. TCSs predominate in sub-Saharan Africa and in South and Southeast Asia, as illustrated in Figure 4. In Latin America, modern gas and electric cook stoves predominate, relying mainly on fossil-fuelled energy. ICSs, including modern fuel cook stoves and renewable fuel cooking technologies, and ACSs, such as fan or natural draft biomass gasification cook stoves, show the greatest uptake in sub-Saharan Africa and in East and South Asia. The integration of renewable energy stoves (such as biogas and solar cook stoves) is behind in all regions, representing only a small fraction of cooking technology uptake rates globally (Putti et al., 2015).

Figure 4: Biomass cooking technology mix by region, by share of households



Sources: ICS penetration database with data for 72 countries from national programme, donor, CDM, and individual manufacturer data; WHO chimney stove penetration database; Global Alliance Market Assessments; Task Team analysis.

Note: Data estimated for 2012 baseline year using 2010–14 source information at country level; aggregated up and triangulated to remove duplication. This is an upper bound estimate since, in absence of survey data for many countries, the analysis assumes one stove per household, an overly conservative assumption for portable improved stove technologies.

Source: Putti et al., 2015

Table 8: Household-scale biogas digester units in selected countries, 2014

Region/Country	Number of units
Asia	
China	43 000 000
India	4 750 000
Nepal	330 000
Viet Nam	182 800
Bangladesh	37 060
Cambodia	23 220
Indonesia	15 890
Pakistan	5 360
Laos	2 890
Bhutan	1 420
Africa	
Kenya	14 110
United Republic of Tanzania	11 100
Ethiopia	10 680
Uganda	5 700
Burkina Faso	5 460
Rwanda	1 700
Cameroon	300
Benin	110
Latin America	
Bolivia	500
Nicaragua	280

Source: REN21, 2015; REN21, 2017

AFRICA

In sub-Saharan Africa, most households rely on traditional cook stoves for cooking, with some 900 million people estimated to rely on TCSs by 2020. Smoke from cooking with TCSs results in 600 000 deaths in the region each year, with an estimated loss of 2.8% of gross domestic product which includes USD 29.6 billion in lost productive time spent on fuel gathering and the cooking process. Biogas for cooking can help address these health and economic issues and reduce solid fuel use by 66–80% (Kammila et al., 2014). Even though biogas systems have high upfront costs of USD 500 to USD 1 500 (Kammila et al., 2014), lifetime costs are the lowest among cooking technologies.

To encourage adoption of biogas and realise its many benefits, several international development agencies and country programmes have installed biogas systems for free or at reduced costs to households. The Africa Biogas Partnership Programme, a public-private partnership between Hivos and SNV Netherlands Development Organisation, had installed 46 000 digesters by 2016 and announced plans to extend the programme to a further 100 000 households by 2017 in East Africa (Kenya, Ethiopia, Uganda, the United Republic of Tanzania) and West Africa (Burkina Faso) (IRENA, 2015).

Biogas use in Africa has been mostly from agricultural waste and human excrement in urban settings (Kammila et al., 2014), since livestock waste and agricultural residues are hard to collect from widespread grazing lands. A promising means of biogas uptake may be centralised production and low-volume resale, with the transport of biogas by gasbag, or the resale of biogas for small-scale rural heat and electricity generation.

Livestock, agricultural and horticultural production sites can offer scale opportunities for biogas feedstock which then may be resold in smaller volumes or used for on-site heat or power generation. Alternatively, lower-cost small-scale digesters and other models may make rural biogas production more practical.

Biogas cooking helps to address health and socio-economic issues, as well as reducing solid-fuel use

A 2011 survey on the co-benefits of biogas in Uganda showed that 61% of respondents strongly agreed that the installed biogas digester had greatly reduced their work load, 72% reported that bioslurry had effectively fertilised their gardens, and 84% reported enhanced farm productivity and income. According to the survey, biogas use reduced weekly average lighting and cooking costs from EUR 40 to less than EUR 15. While cooking is typically performed by women, the ease of cooking with biogas has apparently inspired some participation in cooking duties by men (ABPP, 2014).

ASIA

In Asia, tens of millions of small digesters are used in households or on small farms to produce gas for cooking. China, Nepal, India and parts of Southeast Asia have seen exceptional uptake of biogas in the past decade (Putti et al., 2015). As in other regions, the health, environmental and economic benefits of upgrading to biogas for cooking are substantial. In South Asia, HAP from solid fuels is estimated to have killed 3.5 million people in 2010 (Somanathan and Bluffstone, 2015). A study conducted among 6 000 Nepalese households found that the use of biogas for cooking is associated with a nearly 50% reduction in yearly household fuelwood collection and is accompanied by significant time savings (Somanathan and Bluffstone, 2015).

China has been developing biogas since the 1960s and is a global leader in the direct use of biogas for heat, accounting for 90% of biogas installations globally (REN21, 2015) with 42.6 million units installed at the end of 2016 (REN21, 2017). In 2012 alone, 5 to 7 million new biogas digesters were deployed in the country (Kammila et al., 2014). Between 2003 and 2012, total investments in biogas were near USD 15 billion (IRENA, 2014c). In 2014, it was estimated that biogas use in the country cut annual carbon dioxide emissions by 61 million tonnes (Zuzhang, 2014).

Two biogas patterns prevail in China: household-scale digesters for dispersed farming households, and biogas plants for centralised biogas production. In 2010, around 90% of total biogas production occurred in small-scale units (IRENA, 2014c). Biogas produced by centralised biogas plants in China is transported to households by pipeline for cooking after being dehydrated and desulphurised (Chen et al., 2012). Biogas use largely replaces solid biomass and liquid fossil fuels for cooking in rural households and accounts for approximately 1.2% of total Chinese energy use (IRENA, 2014b).

Box 3: CURRENT, PLANNED AND POTENTIAL BIOGAS CAPACITY AND SUBSIDIES IN CHINA

There is significant potential to expand biogas production in China. The reference case for household biogas users in 2030 is 175 million, and the estimation under IRENA's REmap 2030 scenario is 240 million. The reference case for mid- and large-size biogas plants in 2030 is 40 billion cubic metres, and the REmap 2030 estimation is 80 billion cubic metres per year (IRENA, 2014c).

Subsidies also play an important role in uptake. Government subsidies for biogas digester units are USD 261 in China's central region and USD 237 in the western region (Zuzhang, 2014). Rural distributed biogas digesters receive USD 192 to USD 516, while large-scale projects receive subsidies of 25–45% from the national government and 5–25% from local governments.

Biogas technology promotion and management in China is supported by a vast network. By the end of 2016, biogas promotion activities employed 145 000 people (IRENA, 2017). This training infrastructure was complemented by a service system consisting of 756 county-level service stations and 79 177 rural service outlets which construct biogas plants and conduct operations management, maintenance and repair (Chen et al., 2012). Still, technical service shortages remain a challenge. By the end of 2011, USD 400 million had been invested in these services (Zuzhang, 2014). To promote biogas over the longer term, there is also a vigorous programme of research and development (R&D); In 2012, more than 1 500 professional and technical employees were engaged in biogas R&D (Chen et al., 2012).

In India, domestic energy consumption accounts for 40% of total primary energy demand and is met primarily through the traditional use of biomass, resulting in harmful levels of indoor air pollution. Only 0.4% of rural Indian households use biogas as a cooking fuel, with almost 5 million biogas digesters installed (REN21, 2015; Patel et al., 2016). The National Biogas and Manure Management Programme (NBMMP) provides subsidies for family biogas plants to encourage the uptake of biogas for cooking and lighting (Raha et al., 2014).

China, India, Nepal and parts of Southeast Asia have seen rapid biogas uptake

Although India has actively supported biogas development for several decades, uptake of biogas remains very low, crowded out by the use of fuelwood and LPG. This could be explained by a reluctance to alter habits related to the social acceptance of using animal and human waste for cooking, but also by the inability to gather enough feedstock from cattle. Another reason for the low biogas uptake is a lack of knowledge and training among women in maintaining the biogas units–while women are responsible for this work, the men are the ones trained (Raha et al., 2014).

In southern Viet Nam, low-cost technology based on flexible balloon digesters has supported successful biogas uptake. Balloon digesters have a lower upfront cost than fixed-dome plants and are well suited to the pig manure which dominates rural feedstock supply. Such digesters originally were supported by a 25% construction subsidy which has since been withdrawn, slowing deployment. In northern Viet Nam, fixed-dome digesters have been the focus of support since farmers have smaller land holdings requiring smaller-scale technology. These have the added benefit of requiring less maintenance than balloon digesters. The contrasting approaches in the north and south show the need to promote technologies tailored to the local context (Smith et al., 2013).

The Vietnamese Ministry of Agricultural and Rural Development and SNV Netherlands Development Organisation, set up a biogas promotion project, known as the Biogas Programme. The programme consisted of the following parts: training of biogas masons, training of government technicians, quality control, demand creation, provision of an end-user subsidy, R&D and development of an exit strategy. The end-user subsidy provided on average about 10% of the total investment. More than 150 000 domestic biogas digesters have been implemented with help from this programme (IRENA, 2016a).

COSTS

The costs of household biogas digesters can be found in Table 8, which provides the cost ranges for different types of biogas digesters in different countries and globally. Significant lifetime cost-saving opportunities exist even after accounting for the comparatively high upfront costs associated with acquiring biogas infrastructure for cooking (Lambe et al., 2015). Biogas solutions contribute to fuel and time savings compared to other cooking technologies and fuel sources, including 60–80% savings in fuel expenses and fuelwood collection times (Putti et al., 2015).

As noted in the “Highlights” section, innovative prefabricated biogas digesters (PBDs) can reduce upfront costs by half without compromising performance (Putti et al., 2015). Another innovation employs gasbags and cylinders that allow more households to benefit from biogas where gas pipeline infrastructure is not in place. At a Kenyan slaughterhouse, biogas is available for sale for approximately half the price of a similar volume of LPG (Mungai, 2015).

Table 9: Household-scale biogas digester costs, selected regions and/or biogas digester types

Region/country, type	Cost per unit (USD)	Source
Asia, biogas digester	612	REN21, 2015
Africa, biogas digester	886	REN21, 2015
China, domestic biogas digester	368–792	Zuzhang, 2014
India, PBD Sintex Industries	350–750	Putti et al., 2015
United Republic of Tanzania, PBD SimGas	350–750	Putti et al., 2015
South Africa, PBD Agama Biogas	2 800	Cheng et al., 2014
World, bag digester	20–200	Cheng et al., 2014
World, composite material digester (CMD)	100–300	Cheng et al., 2014
World, household biogas plant and stove	500–1 500	Putti et al., 2015
World, onsite-constructed digester (OCD)	300–800	Cheng et al., 2014

Biogas cooking solutions offer savings either in fuel costs or collection time

A simple comparison of levelised cooking costs for a few cooking technologies, exclusive of environmental, health and social costs, is illustrated in Table 9. Of the technologies presented, biogas has by far the lowest levelised cooking costs even in conventional economic terms. Taking into consideration the opportunity costs of traditional fuelwood use (which requires time-intensive gathering), the external costs of greenhouse gas emissions and health impacts, and the lower efficiency of TCSs, the performance of biogas for cooking is still more beneficial over time.

Table 10: Levelised cost of cooking assuming 30-year lifespan (USD)

Stove type	Average upfront cost	Annual operating cost	Levelised annual cooking cost over 30-year lifetime assuming no discount rate	Levelised annual cooking cost over 30-year lifetime assuming 5% discount rate	Levelised annual cooking cost over 30-year lifetime assuming 10% discount rate
Biogas digester	950	50	82	79	77
Built-in rocket stove	24	90	91	86	82
Wood rocket stove	23	100	101	96	92
Advanced ICS stove	45	120	122	115	110
High-end charcoal ICS	33	140	141	134	128
LPG stove	56	220	222	211	201
Traditional charcoal stove	5	260	260	247	236
Electric stove	30	300	301	286	273

Source: Putti et al., 2015

Behavioural and cultural barriers present a major constraint in the adoption of biogas for domestic cooking

BARRIERS TO THE UPTAKE OF BIOGAS FOR COOKING

While biogas use for cooking has substantial benefits, the deployment and implementation of biogas needs to overcome several barriers to be able to reach its potential. The main barriers to adoption of biogas digesters and systems are the upfront cost of installation, limited feedstock availability, lack of technical construction and maintenance expertise, shortcomings in energy markets, and a range of behavioural and cultural factors (Putti et al., 2015).

Cost barriers – While biogas systems greatly reduce the costs of cooking over their lifetimes, as illustrated in Table 9, their high upfront capital costs restrict uptake. This is especially important for biogas digesters, which have a higher upfront cost than TCSs or even ICSs. Based on the cost range of USD 500 to USD 1 500 for a household biogas digester and cook stove, only an estimated 20–30% of households in the South Asian, Southeast Asian and African region will be able to afford the domestic biogas systems (Putti et al., 2015). To bring these within the financial reach of a broader population, governments may need to reduce their upfront costs to consumers or to provide means to distribute the costs over time.

Product warranties and risk insurance help to ease upfront costs and overcome consumer hesitation

Greater investments in R&D, distribution and other points along the value chain are essential to reduce costs and to provide a range of biogas solutions, with the PBDs and flexi-weight systems as examples. This includes the need to adapt biogas solutions to feedstock availability–such as through lower-volume digesters–and solutions which can function in a range of climates.

Innovative business models for distribution and consumer finance can bring benefits closer to the consumer while distributing costs over time. Evidence from a range of Asian countries has demonstrated that tailored financing mechanisms lead to increased adoption rates (Raha et al., 2014), for example in the form of subsidies in India with the NBMMP and in Viet Nam with the Biogas Programme.

"Pay-as-you-go" solutions may be another effective approach to easing the burden of upfront costs on consumers. A traditional lay-away model also can be applied whereby consumers make a down payment and continuing monthly payments to a distributor (Putti et al., 2015). Microfinance institutions (MFIs) are another option for financing domestic biogas digesters. In the case of Nepal, MFIs have shown to be an effective method for farmers to install domestic biogas plants (SNV, 2009).

Consumer risk aversion to biogas systems with high upfront costs and delayed benefits also can be addressed through product warranties or risk insurance. But these will not be sufficient for the many consumers in developing countries who cannot afford to purchase the systems on their own. For those consumers, who are unable or unwilling to own a biogas system, the resale of biogas to use with appropriately designed cooking installations can make this compelling fuel source available to a wider population.

Financial skill barriers – Financial expertise often is lacking to appropriately value the revenue streams that a domestic biogas plant for cooking will generate, making it hard to obtain loans for such facilities (Klaus, 2015). An effective approach to overcome this barrier could be training courses for loan officers to better evaluate the impact of technology uptake on income flow. The Inter-American Development Bank has a programme in Colombia which teaches loan officers to properly evaluate the value of energy efficiency projects, including the expected return on investment which could be used to increase the cash flow and corresponding loan collateral value (Pegels et al., 2015).

Technical skill barriers – A shortage of construction and maintenance skills, which affects many developing countries, is a key reason why not all of the installed biogas plants in India are actually in use. As discussed previously, the discrepancy of training men when women are responsible for maintaining the biogas system results in a lack of effective knowledge, reducing the number of plants in use. Thus, cultural and social customs should be taken into account with the transfer of knowledge. In addition, building technical capacities in remote areas is key to expanding biogas use for cooking.

Market barriers – Competitive and well-functioning markets for biogas products and services will be essential to raise quality and reduce costs (Raha et al., 2014). Increasing local production capacity and reducing high import tariffs on some biogas products such as PBDs could reduce costs and bring biogas into the financial grasp of a broader population. Properly functioning markets require prices that internalise the health and environmental impacts of competing technologies.

Enabling policies and incentives can help boost the market for biogas technologies, reducing costs and increasing efficiency over time. Border adjustment measures such as tariffs on biogas cooking technologies may contribute to burdensome costs. Tariff reductions can be balanced with other initiatives to scale up national production and maintenance capabilities.

Behavioural and cultural barriers – These are major constraints to the ongoing adoption of biogas. Biogas and the use of animal and especially human waste may have a significant "psychological footprint" that must be overcome, given the associated stigma and other physical factors. Consumer awareness campaigns should focus on the harmful effects of traditional solid fuels and on the benefits of biogas for cooking, seeking to better inform the consumer's cost-benefit calculation by promoting the effective use of waste and its resulting slurry, the ease of cooking with biogas and the cost efficiency of the fuel.

Behavior Change Communication, a programme from the Global Alliance for Clean Cookstoves, increases consumer insights and assists in capacity building among local institutions, specifically to promote clean cook stoves and fuels (GACC, 2016d). Such campaigns must, at the same time, be backed up with access to finance: a study on the uptake of improved cook stoves in Bangladesh has demonstrated that well-designed communications campaigns can pale in comparison to the severity of the financing obstacle (Mobarak et al., 2012).

Engaging local opinion leaders is another way to enhance consumer awareness of the benefits of biogas for cooking as well as the acceptance of the necessary behavioural changes. This ensures greater rates of implementation and forgoes costly redesign or device abandonment.

Another means of overcoming, understanding or acceptance of barriers can be through demonstration projects which provide a tangible means of communication. For transportable biogas systems, "road shows" can be a feasible means of awareness building (GACC, 2016e).

Overall, a combination of continued strong policy incentives, adequate training for maintenance, construction and financial evaluation, and increased awareness of the benefits of biogas for cooking in order to overcome some of the cultural barriers is of a great importance for biogas uptake. All of these factors would be essential to increase the implementation and use of domestic biogas plants in developing countries.

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