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How to cite this publication

Please cite the final published version:

Sovacool, B., Kryman, M., & Smith, T. (2015). Scaling and Commercializing Mobile Biogas Systems in Kenya: A Qualitative Pilot Study. *Renewable Energy*, 76, 115-125. DOI: [10.1016/j.renene.2014.10.070](https://doi.org/10.1016/j.renene.2014.10.070)

Publication metadata

Title:	<i>Scaling and Commercializing Mobile Biogas Systems in Kenya: A Qualitative Pilot Study</i>
Author(s):	<i>Benjamin K. Sovacoola, Matthew Kryman, Taylor Smith</i>
Journal:	<i>Renewable Energy</i>
DOI/Link:	10.1016/j.renene.2014.10.070
Document version:	Accepted manuscript (post-print)

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Scaling and Commercializing Mobile Biogas Systems in Kenya: A Qualitative Pilot Study

Introduction

In this era of enhanced climate change vulnerability, declining food security, and unequitable energy access, it is rare to find solutions that cut across all three themes; that is, practices or technologies that can mitigate greenhouse gas emissions, improve agricultural sustainability, and reduce energy poverty (Brown and Sovacool 2011; Bazilian et al. 2014). Kenya in particular is a country simultaneously confronting the intertwined problems of climate, food, and energy. Yet in this study, we show how Flexi-Biogas Systems (FBS)—devices that can convert manure, human, and agricultural waste into gas used for cooking—can address all three challenges synergistically. FBS can mitigate the emission of methane into the atmosphere, a greenhouse gas far more potent than carbon dioxide. They can produce non-fossil-fuel based fertilizer for use in agriculture, a byproduct of the gasification and digestion process. They can expand access to cleaner cooking fuel while displacing the use of firewood and charcoal in rural areas. In short, such technologies have the potential to become a triple win.

In this article, we examine attempts to distribute 500 FBS units to rural households in Kenya from 2011 to early 2014, which began as part of an International Fund for Agricultural Development (IFAD) pilot program. Based on a comprehensive review of IFAD project documents and the peer-reviewed literature, supplemented with in-country research interviews, this article details the history, benefits, and challenges of the FBS project. It highlights how the FBS project exemplifies how the climate-energy-agriculture nexus can be harnessed to help rural Kenyans expand energy access, generate income, preserve the environment, and bolster community resilience. However, it also documents a series of programmatic challenges including the need for technical training and

maintenance; policy coordination; social stigmatization; poverty; and pollution. The article concludes that although the benefits of FBS units cut across dimensions, scales, and sectors, the policies needed to support them must be synergistic and multidimensional as well.

In approaching the use of FBS units in Kenya this way, the article makes several contributions to the energy studies and renewable energy literature, extending well beyond the domain of energy access and development. One is energy innovation, namely how novel or new energy systems are designed, developed, and commercialized (Fri and Savitz 2014). One is the notion of energy transitions, or how societies and households come to switch (or fail to switch) to different sources of energy production and use (Stirling 2014; Hirsh and Jones 2014; Araujo 2014). One is gender, or how energy use impacts gender roles and can empower women and girls (Sovacool et al. 2013; Ryan 2014; Farhar et al. 2014). A final one is externalities, and how some sources of energy (notably renewable ones) offer positive externalities such as cleaner air and economic security while avoiding negative ones such as climate change and construction cost overruns (Sovacool 2014).

Research Methods and Country Background

To collect data for our study, the authors relied predominately on a review of project documents and academic articles, guided by the main sponsors of the project, the IFAD and Biogas International. Over the course of late 2013 and early 2014, we collected more than a dozen project documents from IFAD as well as 28 peer-reviewed studies published in the last 5 years dealing with rural energy and/or agricultural topics in Kenya, many from this journal. To triangulate the validity of these documents, we supplemented our literature review with in-country semi-structured research interviews with stakeholders in Kenya, primarily with eight program managers at IFAD, the entrepreneurs at Biogas

International, and some FBS end-user households and enterprises. Ideally we would have had a larger sample of respondents, but had limited resources to work with.

As most readers of this journal already know, Kenya lies on the equator in East Africa and is bordered by Uganda to the west, South Sudan to the northwest, Ethiopia to the north, and Somalia to the east. Lake Victoria adorns southwest Kenya and southeast Kenya is marked by the vast Indian Ocean. Kenya has a population of 44 million people and is considered the most developed economy in Eastern Africa with GDP of \$37 billion (CIA, 2014; World Bank, 2013). Kenya's economy and citizens depend heavily on agriculture, which accounts for roughly 30 percent of that GDP (Haines et. al., 2007).

Despite being comparatively well-developed, however, Kenya faces a somewhat pernicious "tri-lemma" of energy poverty, climatic instability, and food insecurity. In terms of the energy sector, unlike many resource-rich African nations, Kenya produces no crude oil, nor does it possess any coal reserves, meaning it must rely on the regional and international trading system to meet local consumption (Kefa, 2005). Thus, almost nine out of every 10 Kenyans (86 percent) rely on traditional fuels such as biomass, charcoal, and dung to meet their heating and cooking needs. National surveys have revealed that:

- Firewood remains the primary fuel for cooking. Nationally 68.3% of all households report utilizing firewood as their "main source of cooking fuel." In rural areas, this amount rises. More than 80% of households in the rural areas rely on firewood for cooking compared to 10 percent of urban households;
- Charcoal is the second most popular type of cooking fuel used by 13.3% of households;
- Kerosene is the third predominant cooking fuel, but is the most frequently utilized among 44.6% of urban dwellers (REEGLE 2014).

On average, interview respondents told us that a rural Kenyan family will spend \$18 to 25 on firewood, charcoal and kerosene each month. As Figure 1 indicates, wood fuel and biomass account for a staggering majority of national energy supply.

Figure 1: National Energy Statistics for Kenya, 2010

71

72 Source: REEGLE 2014

Thus, Kenya's energy situation is dire. As one study noted, "the majority of the Kenyan population still relies on biofuels (wood, animal waste etc.) as their major source of fuel with consequent adverse effects on health and productivity" (Abdullah and Jeanty, 2011). And, "currently, there is a complete lack of decentralized policy to facilitate the provision for fuel; electrical and mechanical power systems in rural and lower income urban areas—resulting in lack of access to adequate and sustainable energy services for production and households" (Abdullah and Jeanty, 2011). Kenyan households have "limited access to electricity service" which contributes to "a debilitating state of economic, environmental, and health conditions" (Day et. al., 1990). Another study writes that "the high cost of fuel, feed, and fertilizer is a major economic problem" (Kiplagat et. al., 2011). While household electricity access grew an average of 4% per year from 1989 to 2009, more than three out of four Kenyan households lacked electricity access in 2012 (World Bank 2013).

Kenya's energy problems intersect with climate change. Alterations to the ranges of agricultural pests and diseases with warming winters could cause infestations of locusts, whiteflies, and aphids leading to "extensive losses of crop yields" which, in turn, would reduce the ability for rural households to purchase modern energy services or technologies (Prouty, 2009). Another study warned that as many as 75 to 250 million people in Sub-Saharan Africa could be exposed to increased water stress by 2020, something with grave implications given that upwards of 90 percent of farms depend on rainfed water supply (Hay et. al., 2002). Climate change is expected to contribute to the resurgence of malaria (Jones & Thornton, 2003), and to induce widespread economic losses in rural areas (Andersson and Gabrielsson, 2012). As an international research team recently put it, in Kenya and Sub-Saharan Africa, "although the impact of smallholder farmers on global anthropogenic greenhouse gas emissions is minimal, the impact of climate-change-related effects (in terms of heat stress, dwindling water and

land resources, spread of diseases and vectors, and loss of biodiversity) on small-scale farmers and livestock keepers is enormous” (Rota et al. 2012: 6).

Predictions are almost as bleak concerning a third challenge, that of food security and agricultural productivity. As one study explains, “agricultural productivity in East African smallholder systems is notoriously low and food production faces multiple challenges” (De Jager et. al., 2005). It is particularly difficult to farm in Kenya given that soils in arid lands are fragile, low in fertility, and vulnerable to accelerated erosion and leaching (Onduru et. al., 2005). In Kenya as a whole, of the total farmhold population, between 35 to 85 percent lives below the poverty line, depending on location. The entire region faces “rising population pressure, poverty, low agricultural productivity and natural resource degradation,” (Ramisch et. al., 2006) and there has been a “failure of many decades of scientific research to raise the productivity of African farming systems” (Institute of Economic Affairs, 2013).

Thus, Kenya’s energy crisis is intimately linked to its rural poverty and food security crisis, which is in turn inextricably intertwined with its impending climate crisis. In many ways, this synergy is a weakness, but as we will also see, the prospect of biogas can potentially build resilience to each of these three problematic areas.

History of the Flexi-Biogas Project

Biogas, scientifically, is naturally produced from anaerobic fermentation of biomass and solid wastes (Bond and Templeton, 2011). Biogas contains 50-70% methane, and 30-50% carbon dioxide, depending on the substrate input, and smaller amounts of other gases (Ghimire, 2013). At the household level, cattle, pig, and poultry excreta can be fed into small recovery systems that produce biogas for cooking, heating, lighting, or electricity generation. A small household biogas plant of 6 to

10 m³ requires at least 20 kilograms of dung daily – or three head of stall-fed cattle or six adult pigs – to meet a family’s basic cooking and lighting needs (Bond and Templeton, 2011). Larger systems, sometimes used on cooperative farms or shared by communities and neighborhoods, can feed into biogas supply networks even yielding energy for larger industrial ventures. In addition to valuable biogas, these systems also produce sludge, a nutrient rich byproduct used as a fertilizer.

To provide a bit of history, two main types of biogas systems have been implemented around the world to date: fixed dome units and floating drum devices. These digesters, typically made from bricks, concrete, and steel, are larger in size than FBS units and stationary (Perez et. al., 2014). They are constructed underground, with an inlet for waste inputs, an outlet pipe for slurry, and a hose and valve for biogas to rise when gas pressure increases. Their construction requires land security, skilled technicians, transport and logistics of building materials, all leading to significant initial investment. Once constructed, with sufficient regular inputs, these systems tend to be reliable, require low maintenance, and exhibit longevity. It is estimated that at least 18.5 million African households have technical potential to implement biogas digesters (Ghimire, 2013). However, lack of biogas plant maintenance and digester age can significantly affect their performance (Bond and Templeton, 2011). Moreover, being made of concrete, such conventional biogas units tend to be materials-intensive, expensive, and inflexible; that is, they become a permanent fixture of a house, meaning a homeowner cannot take them with them if they move, and that a bank cannot repossess them if a customer defaults on a microfinance loan.

In Kenya, biogas technologies, beginning with fixed dome and floating drum digesters, have been available since the 1950s, but adoption rates remain low (Kiplagat et. al., 2011). To address these challenges and harness the potential of biogas, the International Fund for Agriculture Development (IFAD), with a mission of supporting projects that reduce rural poverty, hunger, and malnutrition,

began piloting a new, innovative biogas system in 2011, in cooperation with Biogas International. This technology, unlike the conventional models mentioned above, has been termed the “flexi-biogas system,” (FBS) as it uses balloon (or tube) digesters made from a polyethylene or PVC bag. The typical FBS includes four key parts: plastic input and output pipes, a reinforced plastic digester bag shown in Figures 2 and 3, plastic piping to transport biogas to home or storage, and a plastic greenhouse covering. As Table 1 indicates, these FBS digesters have innumerable advantages over traditional units. They can usually be constructed in one day and are covered with a greenhouse-type plastic to increase their inner temperature (which is essential in colder or high altitude regions) (Perez et. al., 2014). They cost less, use fewer materials, are mobile, and also require less start up manure and possess shorter retention times. To be clear, the FBS is a patented technology distinct from other tubular plastic systems in the biogas sector.

Figure 2: Operational Flexi-Biogas System (FBS) Installed in Kenya, 2013

Source: Photo courtesy of Biogas International

Figure 3: Technical Schematic of a Flexi-Biogas System Unit

Source: Vijay 2014. Note: As a rule of thumb, a typical tubular FBS model requires a start-up of 200 kg to 400 kg of fresh cow manure and an equal amount of water is required. Subsequently, a daily feeding rate of 20 kg of manure and 20 liters of water will yield about 700 – 1,000 liters of gas, equivalent to 2-3 hours of activity on a cookstove.

Table 1: Comparative Features of Biogas Systems

	Fixed Dome Biogas Systems	Floating Drum Biogas Systems	Flexi Biogas Systems
Cost (US\$)	1000	900-1200	410-810
Retention time (days)	45-100	45-100	15
Lifetime (years)	20	10-15	15 (greenhouse replacement every 5)
Construction time (days)	20	20-25	1
Main materials	Masonry, wood	Masonry with steel gas holder	Plastics and PVC tarpaulin bag
Portability	Fixed	Fixed	Mobile
Start Up Manure Required (tons)	5	5	1

* Refers to pilot testing price, not the actual price of systems today.

Convinced that FBS technology held immense promise, IFAD launched a pilot project in early 2011 distributing 10 units in Kenya and 10 units in Rwanda. Then, based on feedback from these pilot

projects, IFAD worked with Biogas International from late 2011 to early 2014 on prototype development and market commercialization in Kenya, which it determined had more immediate market potential. More specifically, IFAD:

- Scouted and screened future rural sites;
- Conducted market analysis;
- Undertook technology testing and further trials;
- Assisted with business plan development;
- Solicited and attracted investment;
- Performed monitoring and impact evaluation;

These activities enabled IFAD and Biogas International to distribute 500 FBS units in total. The systems are manufactured in Kenya with an above ground system allowing users to view the level of biogas available for consumption and to make immediate maintenance adjustments (Biogas International, 2013). FBS are uniquely suited to smallholder farmers because they are portable, affordable, easy to install, and their operation is comparatively simple. Though most of the 500 FBS units are at households such as the one shown in Figure 4, the pilot project successfully brought units to dairy farms in conjunction with IFAD's Smallholder Dairy Commercialization Programme in Nakuru (IFAD, 2012). Four systems were also installed at an orphanage school in Naivasha, where biogas from kitchen and human waste powers electricity for lighting, cooking and even internet access (IFAD, 2012). Through its Adaptation for Smallholder Agriculture Programme, the IFAD intends to deploy about 1000 more systems over the course of 2014-2016, and it is piloting other FBS projects in India and Rwanda, and it has also seen one prototype unit built in São Tomé and Príncipe using entirely local resources and human capital.

188 **Figure 4: Two FBS Units Sitting Outside a Home in Kenya**

189

190 Source: Photo courtesy of Biogas International

191 Programmatic Benefits

192 As already mentioned, as of early 2014, IFAD and Biogas International have deployed about
193 500 units throughout Kenya. This includes systems distributed through IFAD's pilot program,
194 including 9 installed in farming households in Nakuru and multiple systems at an orphanage school for
195 children in Naivasha. All but 3 of the 500 total digesters are currently still in operation, a compliance
196 and acceptance rate difficult to achieve. This section presents the most substantial benefits of the FBS
197 program: expansion of energy access, technological improvement, income generation, reduced
198 degradation of the environment, and social improvement.

199   **Expansion of energy access**

200   The most direct benefit of FBS dissemination concerns expanded access to modern forms of
201   energy; in this particular instance, buildings equipped with the FBS use it primarily for cooking,
202   lighting and space heating. This versatility and multi-functionality means that systems can provide
203   multiple energy services at once, ranging from heat and electricity to cooking gas and illumination, as
204   Figure 5 depicts.

205   **Figure 5: Energy Service Functionality of Flexi-Biogas Systems (FBS)**

Moreover, FBS units can be installed more cheaply, expediently, and with less labor costs than the brick and mortar construction of dome systems. Typically installed in just one afternoon, FBS can produce gas after a few days (as long as the sun is shining). Furthermore, FBS can be fed with anything that is biodegradable. In fixed dome systems, fed with waste, saw dust or other various byproducts of animal husbandry, the heavier items tend to sink to the bottom and the lighter particles float to the top. This causes fixed dome units to stop functioning because the material fed into the digester separates. Thus, fixed dome users are restricted to using only cow or pig dung. The shallow tubular design of a FBS, by contrast, enables all of the substrate to flow from one end to the other. This natural agitation allows the input to ferment, and the byproduct is forced out the other end. The system can be supplemented with vegetable waste once the dung has been used to catalyze the bacterial process. The ability to use several waste alternatives makes the FBS suitable for a variety of users. As one farmer enthusiastically remarked:

We have never imagined in our lives that cow dung could be of so much benefit to us. The biogas has made our lives a lot more convenient. The utilization of biogas for cooking saves time but also makes cooking more comfortable in comparison to the traditional methods where smoke and soot would pollute our kitchen.

Similarly, another one of our interview participants remarked, “I assembled a system on a Friday and we cooked beans and rice on Tuesday with it.”

Time, labor, and materials savings equal overall cost savings for households. Installing a fixed dome system is expensive relative to the average income of a Kenyan. FBS are about one-fifth the upfront cost. The permanent structure of a fixed dome system is difficult to repair, whereas a malfunction of the FBS can be serviced quickly, typically to resolve insignificant issues such as clogging. In contrast to a fixed dome, a FBS can be relocated and does not have to be abandoned if the family moves. This is a significant household consideration because of the widespread lack of land

tenure rights in Kenya. The whole kit is light, weighing about fifty kilograms, and packs small enough to be transported by bicycle or motorbike, as Figure 6 depicts. Lastly, FBS are efficient. A mini greenhouse encases the system to collect solar heat, and this warms the system to produce greater quantities of gas. The greenhouse tunnel keeps the temperature in the digester fairly constant at 38°C.

Figure 6: (Left) Five FBS units ready for dispatch, (Right) Two motorists transporting a FBS

Source: Photographs courtesy of Biogas International

These attributes of FBS make them exceedingly scalable, and allow the units to reach the poorest rural households at less expense than traditional systems. Also notable, FBS can provide the same output of gas as the large fixed dome systems. Dominic Wanjihia, the designer and Creative Director of Biogas International behind FBS units, told us that:

With conventional systems, you need to have a minimum of about five cows to get enough gas to cook enough food for a family of four to six people. Because of the efficiency of the FBS, you only need the dung from one cow, and it will give you the same volume of gas as the dome systems.

This means the systems are affordable for a greater economic range of customers. Our interview respondents suggested that “two big buckets of dung per day” were sufficient to keep a household of 6 sufficiently supplied with gas. Additional biodegradable waste materials can be used to supplement a portion of the dung. Households reported to IFAD (2013) using biogas for cooking between 45 to 170

minutes daily, depending on whether or not they are accommodating guests. At the children's home based in Naivasha called Prayers Beyond Boundaries, biogas is reliably used for cooking an average of 3-5 hours every day.

Technological improvement

A secondary benefit has been significant improvement of FBS technology over the course of time as it has been standardized and economies of scale reached. Feedback from the 20 units initially piloted in Tanzania and Rwanda indicated that the "pilot" unit, with technical attributes described in Table 2, had retention times that were too quick. That is, fertilizer came out not fully digested. IFAD and Biogas International discovered that this difficulty could be eliminated by better welding, which added only \$50 to the total cost but resulted in a much more reliable unit. Then, as feedback on the "small" system (with improved welding) accumulated, it became apparent that the system did not provide enough gas for cooking during the rainy season, given that "fuel" was often muddy and had higher than ordinary rates of substrate. This problem was solved by introducing the "medium" system which had a larger circumference and a double burner. A final improvement was made with the largest system, currently being marketed as the "Total FBS" because it can meet a household's entire energy needs: it can provide enough gas for both cooking and the generation of electricity sufficient for lighting and the recharging of small electric appliances.

Table 2: Technical Attributes of Four Types of FBS Units

	Pilot	Small	Medium	Large
Persons	4 to 6	4 to 6	8 to 10	18 plus
Digester capacity (m³)	1.3 to 3	3.5	5.5	9
Digester bag	PVC tarpaulin	PVC tarpaulin	PVC tarpaulin	PVC tarpaulin
Greenhouse tunnel	Polyethylene plastic	Polyethylene plastic	Polyethylene plastic	Polyethylene plastic

Inlet/outlet pipe	15m gas delivery pipe	15m gas delivery pipe	15m gas delivery pipe	15m gas delivery pipe
Length	6 meters	6 meters	6 meters	6 meters
Circumference	3 meters	3 meters	3.75 meters	4.5 meters
Burner	Single	Single	Double	Double
Personnel	2 technicians	2 technicians	2 technicians	3 technicians
Welding	Single	Double	Double	Double
Cost (US\$)	410	460	640	810

Source: IFAD, November 2012; research interviews.

Looking to the future, in the context of “scaling up” IFAD has already reached out to the Indian Institute of Technology (IIT) to help refine the FBS so that its reliability can be further improved and its costs lowered. In anticipation of deployment in India, IIT researchers are focusing on how certification and standardization can further enhance the design of FBS units, and on how manufacturing and distribution can be optimized. They are also investigating certification processes that take into consideration water scarcity and stress, fodder versus input for substrate scarcity, veterinary services for livestock, and the recycling of plastic to make FBS units more socially and environmentally sustainable. Moreover, Biogas International is exploring the potential of using cheaper plastic components (specifically for large-scale balloon biogas systems) from China. In Fuzhou, China, for example, such plastic can be purchased for about \$3.50 per square meter compared to roughly \$10 per square meter in Kenya. It is hoped that suppliers of these components can improve the quality of FBS units and also lower fabrication and production costs, creating a “win-win” for suppliers and farmers as prices decline and the technology becomes even more affordable.

Income generation and savings

FBS provide not only energy access; they can, when put to productive uses, expand income and generate economic savings. In rural areas where households are dispersed and segregated from the national electric grid, a decentralized, renewable source of energy such as biogas can be considered the

most cost-effective way to provide energy services. An important feature of biogas technology is that virtually the entire cost is expended for installation with very low operating costs, as the feedstock is usually waste, and systems require minimal labor.

Thus, in practice, each system installed so far has seen a positive cash flow, with new income opportunities still being realized. The most direct economic benefit of biogas is as a reduction in fuel expenses. A comparison with traditional biomass sources shows that an average household can save up to 1,445 Kenyan shillings (KES) per month (US\$17) on traditional fuels such as firewood, charcoal, saw dust, kerosene and LPG (IFAD, 2013). The children's home spent an average of 15,900 KES (US\$187) on firewood and charcoal each month, most of which is now retained as savings (IFAD, 2012). With these savings, some users purchased livestock, and some reinvested money into the farm by buying chickens to begin brooding and now sell eggs for profit (IFAD, 2013). Among other benefits, farmers report that they have an easier time making payments for school fees, book buying, and purchasing medicines.

Indeed, one positive dimension to such income generation is that it occurs among formerly marginalized groups such as women. Female heads of households that have adopted FBS have cited improvements in their own financial status. Keziah Wanjiru, one woman that was interviewed, started saving money within her first month of FBS use. Over a period of two months during the beginning of her use of the FBS, she managed to save 930 KES, (US\$11) which she has used in buying four chickens that are laying eggs. Selling the eggs will earn extra income for her household. And while \$11 may not sound like much, most recent calculations conclude that 43 percent of 44 million Kenyans live on less than \$1.25 per day (The World Bank, 2013). An increase in income of \$11 over just a few months can have a significant positive impact for those still living beneath the poverty line.

At a broader level, serious potential exists for a commercial market for biogas products, especially among small and medium enterprises. Bottling the excess methane, compressing, and selling it could easily double the income of FBS-adopting households. It was mentioned in several interviews that biogas programs are seen as lacking a market approach, and that orienting them so that people can make a profit remains a missing business opportunity in Kenya. To fill this perceived need, Biogas International is currently seeking to expand a Compressed Natural Gas (CNG) plant to pack biogas in canisters. This type of business model, illustrated in Figure 7, would enable FBS in rural areas to essentially compress and sell gas for use in urban areas where it is infeasible to install FBS units. In addition, there are many slaughterhouses in Kenya that can benefit from the waste management of biogas systems. The owners typically pay for the transport of waste away from their facility, but they could profit from compressing and retailing the biogas. Cleaned, scrubbed, and bottled biogas could also be utilized as a transportation fuel in vehicles. As one respondent exclaimed, “Compression of biogas for sale by households is very exciting because it can significantly improve incomes.”

Figure 7: FBS Model for Distribution in Urban Areas

A second novel business opportunity is utilizing biogas for the brooding of chickens. As one respondent told us:

What is amazing about the FBS is that there is potential to use biogas stoves to warm chicks during their first 20 days – crucial for keeping them alive. Because biogas is clean at its point of use it is the only fuel that can be used with poisoning the dales. Also, the droppings of the chicken can be used thus creating a closed-loop system.

The business potential of biogas applications in this sector could be quite large. For instance, poultry farming is often a mainstay of rural economies: more than 80 percent of rural households raise some type of livestock and there are 20 chicks for every house in Kenya; the poultry sector employs 3 million Kenyans; and 0.7 percent of national GDP is derived from poultry farming (Okello et al. 2010; Omiti 2009).

Environmental preservation

A fourth benefit to the FBS program relates to the reduced strain on surrounding forests and avoided greenhouse gas emissions. The Kenya Forest Service (2010) recently estimated that national forest cover amounted to only 1.5% of the country's territory, and that amount includes indigenous forests and plantations. A combination of exploitation and an already sparse forest cover makes gathering firewood an increasingly laborious experience, usually involving several kilometers of walking. The FBS have reduced the demand for firewood in most of the households, promoting conservation of limited resources.

Moreover, the use of free and available cow dung and biodegradable resources therefore reduces carbon emissions in four ways: (1) directly from capturing methane that would otherwise be vented into the atmosphere, and indirectly from (2) lessening the need to combust fossil-fuels such as diesel and kerosene, (3) reducing rates of deforestation related to firewood collection, and (4) by displacing the use of fossil-fuel-intensive fertilizers. The average Kenyan household has 4.5 persons, with an average wood-fuel usage of 1 ton per person per year. Therefore, according to our interview respondents, one FBS can replace up to 4.5 tons of wood-fuel per year. This is equivalent to roughly 6.75 tons of CO₂ annually. When taking into consideration that the trees are not being felled, this brings the total CO₂ reduction to more than 13.5 tons CO₂ per year—and this calculation ignores the indirect carbon savings from displaced fossil fuels, deforestation, and fertilizer use.

In fact, the production of organic, non-fossil fuel based fertilizer has benefits that extend beyond mitigating emissions. A byproduct of the methanogenic process, rich organic fertilizer, replaces the need for chemical fertilizers and generates substantial cost savings. Used as fertilizer, the slurry has been recorded to increase yields by 6-10%, and in some cases 20% (Bond and Templeton, 2011). Each of the farmers that have utilized the slurry, that were interviewed, commented on noticeable

agricultural productivity. These include improvements to maize, beans, potatoes, bananas, and castor oil plant production. Similarly, the children's home grows sukuma wiki (kale) in their garden, and the staff members report the plant leaves are showing larger and more nutritious vegetable growth. They have extended the garden to account for this new growth, and are especially pleased to use the slurry due to the fact that the crops are used to supplement their school meals. Households and cooperative farms can also profit from the sale of slurry to flower and vegetable producers. Slurry use from FBS is important because the majority of Kenya's fertilizer is inorganic, imported, and susceptible to international price swings (Sheahan, et. al, 2012). Further, overall fertilizer use has stagnated in many areas of rural Kenya due in part to inconsistent fertilizer subsidy policy. Therefore, FBS is an ideal incentive for convincing households to apply slurry to their crops to increase food security at little to no personal or environmental cost other than drying and selling it.

Social improvement and community resilience

Interestingly, the benefits of FBS are not only expanded energy access, contributions to income generation, and displaced emissions. Additional social benefits include gender empowerment, enhanced health, and expanded educational opportunities.

In terms of gender, since adopting the FBS, many women have reported improved quality of life at home. Unlike firewood, which is time-intensive and tedious to collect and difficult to burn during inclement weather (no fresh food or tea in the mornings after it rains), the FBS *can* operate during wet weather, enhancing the quality of life for women as they start their day. Ann Mukami, another villager that we interviewed, says that her workload has been reduced because she does not need to spend entire afternoons searching for firewood. Biogas provides the ready fuel for cooking. And when it is time to prepare land for planting, she can spend more time on the farm. The installation of the systems had an unexpected impact on gender roles: the attitudes of men towards cooking have

422 begun to shift. Another woman remarked that “whenever I’m not at home or come late my husband or
423 my son normally cooks because they find it easy, fast and convenient cooking with biogas as compared
424 to firewood.”

425 The improved health of community members has also been noticeable. In the words of Lucy
426 Kimani, another villager:

427 *Since I got the biogas there is no smoke in the house. With my previous cooking using firewood*
428 *I can’t even describe how much my eyes used to water. Now I only need a packet of cow dung*
429 *every day and my cooking is finished so fast. My eyes used to ache because of the smoke and at*
430 *times I would wear goggles when cooking. Nowadays the situation is much better.*
431

432 Biogas promotes the health of not only these women, but households and communities at large. With
433 biogas, public health is improved by providing farmers a tool to manage and dispose of household and
434 farm waste in a more effective, sanitary way. Similarly, the children’s home utilizes FBS to integrate
435 human waste to act as a waste management technology for improving sanitation and the surrounding
436 environment.

437 Benefits in education have also accrued. Participating households have reported that they have
438 an easier time paying fees and buying textbooks. Students at the children’s home have demonstrated
439 that they understand the nature of the technology. Children help to feed and operate the system. One
440 IFAD monitoring and evaluation officer asked them during a site visit “What are the advantages of
441 biogas?” Joseph Mbote, a student, answered: “Biogas is free and cheap as it comes from cow dung and
442 is available all the time” (IFAD, 2012). Their awareness has proved encouraging and reveals that an
443 emerging generation acknowledges the productive uses of biogas.

444 Interestingly, biogas’s relationship to education works both ways. Not only does a household’s
445 use of biogas seem to facilitate educational opportunities – education levels correspond to biogas use.
446 Though done before the FBS program, one study of the socio-economic factors affecting biogas use in

Kenya reported that households with higher education levels are more likely to own a biogas plant (Mwirigi, 2009). Thirty-one percent of college, and 9% of university graduates were found to use biogas, compared to 13% and 3% respectively that did not use biogas and had not attained that level of education (Mwirigi, 2009). A symbiotic or mutually constitutive relationship between biogas use and education seems to exist: biogas use frees up time and money to pursue and fund educational opportunities and those manifest in continued or expanded biogas use.

Programmatic Challenges

Notwithstanding the benefits mentioned above, this section examines the ongoing challenges identified by respondents and system users. These barriers include technical difficulties, policy coordination, poverty and financing, and environmental challenges.

Technical difficulties

Although the FBS are simpler to use than conventional models, and require less maintenance, there are technical complications that can arise when units are not managed properly. Table 3 overviews the most common technical difficulties facing units. One challenge is the amount of dung being fed into the system. If the system is overfed, it will not produce sufficient gas. Another issue is that water moisture condenses in the pipes on cold nights, blocking the gas from traveling through to the cookstoves. However, farmers have been shown how to fix this with help manuals provided by Biogas International. If there is a more significant obstruction in the system, which can occur, the digester bag must be opened and the contents agitated. Lastly, although the bag is made out of reinforced PVC tarpaulin, sharp objects should not come into contact with the bag or the greenhouse dome covering it. The system is very durable, however it is not indestructible.

Table 3: Common technical problems facing Flexi Biogas digesters

Problem	Probable Explanation	Solution
Bag digester not rising	-No gas formed -Leakage in the system	-Dilute the digester by adding water. -Ensure no leakage in the system.
No gas at the appliance	-No gas is formed -Not enough pressure in the system to force gas out of the digester to the appliance.	-Ensure no leakage in the system. -Consider solution number 1. -Water in the pipe.
No gas formed	Toxicity in the digester. -Inappropriate cow dung water mixture.	-Flush out the content of the digester with water. -Add more cow dung to the digester. -Add seeder from another flex digester.
Inadequate quantity of gas being formed	-Inappropriate water cow dung ratio. -Slurry too thin or too thick.	-Add more cow dung to the digester. -Add more water to the digester.
Flame dies off quickly at the appliance	Pressure from digester too high.	Adjust the inlet of the appliance. -Reduce weight on the digester if any
Plastic zips closing biogas digester breaks down	Strenuous zipping	Replace zipper

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470 We should mention that most of these problems are both minor and rare. One of the novelties
471 that distinguished the FBS from other tubular systems is the ease of opening and closing the systems
472 without damaging them. Once farmers are taught how to open the system and re-close it, they need
473 virtually no other training. The FBS is thus a technology with a degree of long-term sustainability
474 because the absorptive capacity of farmers to understand, maintain and operate the system is high.

475 An additional complication with the FBS involves the procurement of materials necessary to
476 construct it. While many of them, especially plastic piping, are available locally, some must be
477 imported with attendant taxes and cost. Once imported, the materials are assembled in Kenya in an
478 “artisanal” fashion with high quality control, but also corresponding costs. The IFAD and Biogas
479 International are exploring opportunities to outsource aspects of the production and procurement of
480 materials. According to some estimates, overall FBS costs could be halved by better coordination with

481 manufacturers in China. However, for that to occur, common standards for protection of intellectual
482 property and consistent financing attend to this next phase of FBS development. Properly supported
483 and managed, the FBS could overcome this challenge while decreasing overall price, improving
484 consistency and quality of after-market services, and encouraging biogas expansion.

485 **Poor policy coordination**

486 Promoters of biogas have faced difficulty integrating the program into Kenya's commercial
487 sector and energy development plans. According to one respondent, Kenya's National Environmental
488 Management Authority has yet to consider biogas a viable solution to widespread energy needs. In
489 addition, there are no safeguards or guidelines for compressing biogas for sale. Historically, biogas has
490 been promoted as a household technology, therefore few market assessments have occurred, and formal
491 technical assessments comparing it with the cost-effectiveness of other renewable energy systems such
492 as wind, hydroelectricity, and solar energy are rare.

493 Multiple dimensions of this coordination barrier manifest themselves. One is that because FBS
494 technology is so new, most development programs continue to promote fixed dome digesters or
495 simpler, and cheaper, improved cookstoves running on firewood, even in Kenya and in direct
496 competition to the FBS program. This mitigates interest and support for the IFAD program. Another
497 obstacle is attempting to scale up the pilot project into something more. The Flexi Biogas team has
498 been successful at installing their 500 systems; however the program has a long way to go before
499 digesters can support a majority of the rural poor that need them. With more than two-thirds (70%) of
500 the rural poor concentrated in the central and western regions, areas with strong agricultural potential,
501 government intervention made be needed to enable the program to become accessible to a wider group
502 of citizens.

For instance, if nationally coordinated, FBS dissemination might be ideally coupled with an ongoing World Bank project entitled the BioCarbon fund. That project is developing the first approved methodology for sustainable agricultural practices that also sequester carbon in soils. Smallholder farmers in Western Kenya (Kisumu and Kitale) are beginning to benefit from carbon credits (World Bank, 2014). Such credits have created a revenue stream for farmers, and the land practices have also helped to increase their yields, all the while sequestering carbon in the soil. There is potential for FBS users to be woven into this program, because crediting includes practices relating to organic fertilizer use and residue management, thereby creating further incentives to use biogas and its many benefits (Kenya Agricultural Carbon Project, 2010). There is also considerable potential for FBS units to be tied into global financing streams based on the sale of carbon credits, on smallholder agricultural assistance programs throughout Sub-Saharan Africa, and other “South-South” initiatives that seek to advance private sector development among developing economies as a whole.

Stigmatization

Interestingly, and more difficult to identify and overcome, FBS have had to confront a series of negative perceptions that have partially stigmatized biogas use in Kenya. One is the nature of using “shit” or “excrement” as a source of energy itself. Some households have expressed doubts over the “cleanliness” of biogas coming from these types of waste. Another negative perception relates to previous biogas programs that used different designs and “failed.” For instance, entrepreneurs introduced in the 1990s a Colombian-designed, low-cost, plastic biodigester that spurred Kenyan government promotion. Awareness campaigns and efforts to increase biogas usage at the household level were championed by NGOs and the Kenyan government through the 1990s. However, widespread adoption of biogas technology remained relatively low compared to its massive potential (Kiplagat et. al., 2011). For example, in 2004, only an estimated 800 plants had been constructed and

only one-in-four of those initially constructed were still operational three years later in 2007 (Mwirigi, 2009). Several reasons have been attributed to the low adoption rate, including: inadequate information about biogas production and its benefits, prohibitively high design costs, lack of rural household water access, lack of land tenure, limited private sector involvement, and negative associations from failed biogas plants. This has, unfortunately, damaged the reputation of the biogas sector as a whole. A final negative perception, though rare, relates to uncertainty and skepticism over the FBS design in particular, especially due to past failures of other balloon technology.

Poverty and financing

A more systemic, and perhaps entrenched and intractable barrier, is the endemic and widespread nature of poverty in Kenya, which makes it difficult for users to afford the upfront cost of the system. Although the FBS are much less costly when compared to the fixed dome models, they are still beyond the means of most rural households. The average income of a Kenyan is US \$1,800 per year (CIA, 2012). With this in mind, purchasing even the smallest FBS (insufficient to meet cooking needs throughout the rainy season) without a subsidy amounts to roughly one-quarter of a person's annual income. As one respondent bluntly put it, "The biggest constraint is cost - the cost for farmers." Users and developers alike hope that the government and development agencies can intervene in terms of price, or provide attractive financing options or repayment plans, which would make the technology more available to the poorest groups in Kenya. Importantly, several respondents noted that FBS should not be distributed for free because creating a sense of ownership is critical to FBS longevity. Tellingly, of the 500 or so installed FBS units, the only 3 abandoned were provided at no cost to the household.

Environmental challenges

Despite the environmental benefits of reduced firewood consumption, the mitigation of carbon pollution and production of organic fertilizer, FBS units do present environmental risks. Foremost, the actual reduction in firewood consumption is inconsistent. Although a large majority of users do in fact use firewood significantly less, some still prefer firewood for cooking. An ongoing issue is that people want to use biogas for lighting and firewood for cooking. This results in firewood collection continuing unabated. In other instances, although farmers realize that they no longer need to use firewood, they still prefer to sell bundles to their neighbors as a source of income. Several respondents believed that to optimize the project, coupling the biogas system with a small solar panel for lighting (enough to power 1-2 bulbs) could help ensure that people use biogas for cooking, arguably a more productive use from an environmental standpoint. As one respondent wryly noted, “in Kenya, biogas will not be the full solution – it requires other solutions as well.”

In addition, limited availability of water in some areas presents a serious impediment. The biodegradable material inputted into the digester must be mixed with water in a ratio of 1:1. Typically, this results in average water use of 20 liters per day. During the dry season, many people have to walk long distances to find that water, creating an additional strain on users. It also means that FBS units simply won’t work in areas of extreme water stress or scarcity, a situation that could worsen under some projections of climate change.

The scaling up of the Flexi Biogas program also risks potential problems with plastic pollution. Currently the systems consist of ultraviolet resistant, durable plastic. Their durability and lifespan (at least fifteen years) can also create hurdles. In the event that there is widespread use, plastic components could spread throughout the country. This is a concern if the systems are eventually abandoned or left in disrepair, such plastics will persist throughout the natural environment. If use of

the systems becomes rampant, the introduction of recyclable or biodegradable components could mitigate this concern. Additionally, IFAD and Biogas International are exploring after-market uses for the plastic greenhouse covers and (as already mentioned) research conducted with IIT is seeking to design certification measures that ensure the system is truly sustainable.

Conclusions and Policy Implications

Although the FBS project remains in its piloting phases, we nonetheless believe that its experience offers at least three salient conclusions, for those in Kenya but also for those interested in energy access and technological adoption. First, the FBS project underscores the synergism between three of Kenya's most pressing problems—climate change mitigation, agricultural sustainability, and energy access—and how this nexus can be utilized to bring benefits to Kenyans that cut across each of the three areas. FBS units, though simple and artisanal, can simultaneously enable households to achieve energy access in ways that displace greenhouse gas emissions and deforestation, contribute to food security, and support more efficient farming practices. They truly are a single solution that can respond to three pressing social and environmental problems at once, and this will likely hold true for rural or agrarian communities well beyond Kenya.

Second, given the innovativeness and cross-sectoral nature of FBS technology, it is perhaps even more telling that the systems have so far failed to achieve widespread use. Here we have an innovative, incredibly simple yet elegant solution to energy, agricultural, and climate problems that is being practically ignored by international donors and entrepreneurs in other parts of Kenya. Such a situation goes counter to how many studies predict cost-effective technologies ought to be adopted or to how energy transitions ought to occur (Brown and Sovacool 2011; Lund 2010; Schot and Geels 2008; Geels and Smit 2007). We have a paradoxical situation where a low-cost, reliable biogas system,

disseminated according to sound design and implementation principles (Sovacool 2012a; Sovacool 2012b), is not taking off as one might expect. Part of the explanation is the fragmented policy environment of Kenya, previous biogas failures which have led to a stigma against biogas as a whole, exacerbated by lack of positive, countervailing information and the sheer poverty of rural Kenyan households.

Third, the presence of the aforementioned barriers implies what policy efforts need to be undertaken so that FBS units can be commercialized and achieve widespread dissemination. Technical difficulties need to be countered with capacity building and training efforts. Poor policy coordination needs to be alleviated by consistent standards and regulations adopted by national planners, and by creating incentives for broader commercial applications such as compressing biogas for use in urban areas. Stigmatization needs to be addressed, and it initially has been through a Kenyan multimedia awareness campaign sponsored by the social communications team Well Told Story. This campaign has reproduced comic strips and posters locally showcasing the advantages of the new generation of biogas systems. Communication campaigns such as this one need to continually expand their outreach. Poverty and financing issues can be overcome with payment plans, loans, and micro-financing programs. Efforts to further reduce the cost of FBS can be realized by production agreements with manufacturers in China, which could cut costs by half (to as low as \$200 per unit, according to one respondent). Environmental challenges can be managed by integrating FBS units with other energy access programs providing electricity or end-use devices such as fluorescent bulbs and mobile phones so that the “total” energy needs of communities is met; by targeting FBS deployment in areas that have sufficient water; and by adopting guidelines for proper disposal. For those beyond Kenya, this situation reminds us that while the benefits of a particular, innovative energy system may be

613 multifarious and varied, the policies that support them must be synergistic and implemented at multiple
614 scales as well.

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