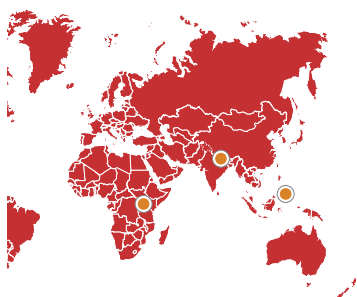


CASE

Biogas from fecal sludge and kitchen waste at prisons

Krishna C. Rao and Kamalesh Doshi



Supporting case for Business Model 3

Location:	Nepal, the Philippines and Rwanda
Waste input type:	Fecal sludge, wastewater, kitchen waste
Value offer:	Biogas, bio-fertilizer
Organization type:	Public entity
Status of organization:	First biogas plant operational since 2000
Scale of businesses:	Small, medium and large
Major partners:	International Committee of Red Cross (ICRC); Local technology partners in Nepal, Philippines, Rwanda

Executive summary

The International Committee of Red Cross (ICRC) under its water and habitat unit has implemented numerous institutional biogas sanitation systems across prisons in Rwanda, Nepal and the Philippines in partnership with local organizations for the last 10 years. Biogas sanitation systems are seen as a promising technology for institutional settings in developing countries as they combine effective treatment of human excreta and kitchen waste in a safe and environmentally-friendly manner, while at the same time generating a renewable fuel source for cooking while reducing indoor air pollution and a nutrient-rich fertilizer. The projects reduce the prison costs and contribute to reduction of deforestation from reduced use of fuelwood.

ICRC's prison biogas plants use human waste and in some cases kitchen waste to generate biogas, which is used as fuel for cooking in the prison. The biogas systems consist of fixed dome digesters of varying sizes according to the number of detainees in each prison. The digesters used are of size 10 m³, 20 m³, 35 m³ and 100 m³ with one to two digesters in each prison. The prison biogas projects resulted in improved sanitation of prisons thereby reducing health risks of inmates. The Nepal prisons are much smaller and the number of detainees ranges from 106 to 270. The prisons in Rwanda are large and typically house around 5,000 detainees.

KEY PERFORMANCE INDICATORS (AS OF 2009)

Capital investments:	USD 12,960 for all three prisons in Nepal; USD 27,700 for Cagayan de Oro City prison, Philippines; and USD 74,000 for 500 m ³ plant in Rwanda					
O&M cost:	2% of capital investment					
Output:	25–62 L/person/day of biogas (higher when kitchen waste is used)					
Potential social and/or environmental impact:	Improved health of detainees, improved sanitation of prisons, reduced air pollution in the kitchen/reduced GHG emissions, reduced deforestation, renewable source of energy for cooking and better landscaping (by use of bio-fertilizers)					
Financial viability indicators:	Payback period:	1.5–5.4 (Nepal prisons)	Post-tax IRR:	N.A.	Gross margin:	N.A.

Context and background

Prisoners are among the world's most discriminated groups often suffering from detrimental sanitary conditions. The main objectives of the systems that are implemented by the ICRC are to improve the sanitary conditions, reduce the health risks and provide a renewable and smoke-free source of cooking fuel. From 2002 to 2009, the ICRC helped build 13 biogas systems in 11 prisons of Nepal (Kaski, Chitwan, Kanchanpur), the Philippines (Cagayan de Oro, Davao, Sultan Kuradat, Manila, Cradle) and Rwanda (Muhanga, Gikongoro, Cyanguu), two of which (Manila and Cradle) were not functioning during surveys between 2009 and 2011.

In 2007, an agreement between ICRC and the local expert partner Biogas Sector Partnership Nepal (BSP-N) was signed to implement five biogas sanitation systems in three district jails in Nepal. The Philippines' prisons, managed by the Bureau of Jail Management and Penology (BJMP), are overcrowded and underfinanced due to a legal system that is unable to keep up with the influx of new suspects. The ICRC implemented biogas systems in several jails including the Cagayan de Oro City jail, which houses more than 1,000 prisoners. In 2009, the BJMP banned the use of firewood in its prisons, due to the deforestation issues it was creating. In Rwanda, the Kigali Institute of Science Technology and Management (KIST) in partnership with ICRC installed large-scale biogas systems including the construction of the system, providing on-the-job training to both civilian technicians and prisoners. Half of the construction cost was paid by ICRC and overseen by ICRC and National Prison Services. The first prison biogas plant (Cyanguu) started its operation in 2001 and has since run with no problems. Since then, KIST has installed biogas digesters in almost half of the 30 prisons in the country. With even the national newspaper reporting on it, it is hoped that more NGOs and government agencies will see the value in small-scale projects like this that not only address sanitation, but also financial, social, and other environmental issues too.

Market environment

According to a study done by the International Centre for Prison Studies (ICPS) in 2008, more than 10 million people are held in penal institutions throughout the world. For every 100,000 population, western Africa and southern African countries have 47 and 219 prisoners respectively. In Asia, South Asian countries has a median rate of 42, while in eastern Asian countries, it is 155. Prison population are growing across the world.

Prisons mostly use fossil fuels or firewood for cooking and incur significant costs. Biogas is a reliable alternative to reduce cost incurred from consumption of these fuels. The need for the biogas systems also arose mainly due to lack of proper sanitation systems in prisons and the associated health risks, risk of groundwater pollution from outdated septic tanks, the high costs of obtaining firewood for fuel,

as well as the increase in deforestation and GHG emissions. The biogas systems reuse fecal sludge and wastewater in a safe manner to produce cleaner energy thereby solving most of the problems faced by prisons.

Macro-economic environment

In developing countries including Nepal, the Philippines and Rwanda, consumption of firewood far exceeds annual production, causing deforestation. In order to curb this problem, governments are launching different programs and strategies. The Government of Nepal has a long tradition, dating back 1975, for promoting biogas in Nepal through the provision of low-interest-rate loans and subsidies for biogas systems to promote the technology.

In the Philippines, prisons managed by BJMP are posing environmental and fiscal problems due to high prison populations which are consuming much of the BJMP's budget in their need for food. In 2009, the BJMP banned the use of firewood in its prisons and started installing biogas digesters in prisons.

Under the Economic Development and Poverty Reduction Strategy (EDPRS), one of the long-term strategies of the Government of Rwanda is to reduce fuelwood consumption from 94% to 50% through the installations of biogas digesters in both residential homes as well as institutions with a large number of residents such as schools, hospitals and prisons.

Business model

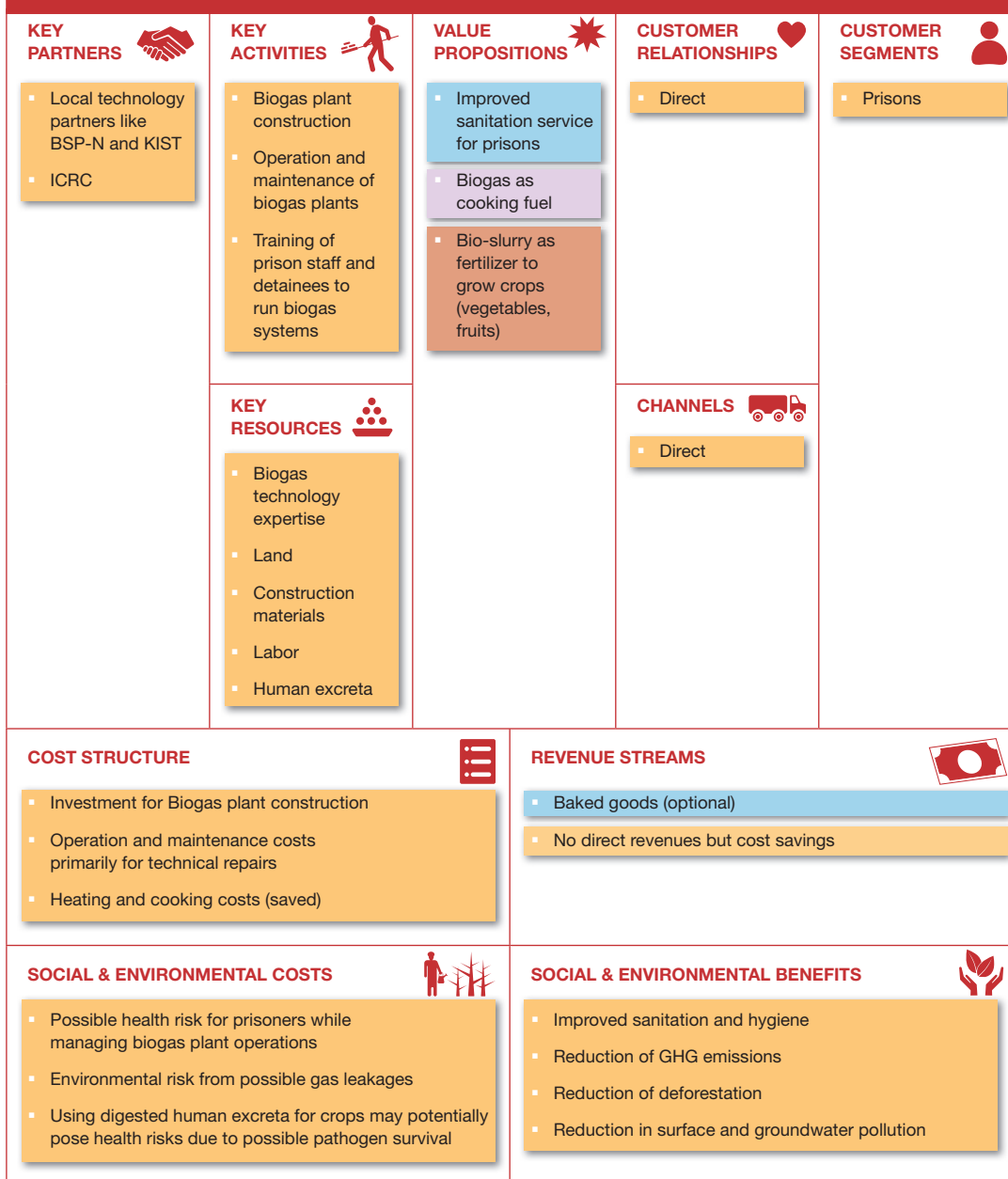
The key value proposition of the biogas plant is to provide improved sanitation service to prison inmates using biogas digesters to process and treat the human waste generated at the prison facility (Figure 28). In the process, the system provides two additional value proposition: a) biogas as a cooking fuel and b) bio-slurry from biogas plant that can be converted into organic compost. Biogas replaces fossil fuels and firewood while the bio-slurry turned into organic compost is used onsite for growing crops and trees. Both these value propositions result in savings for the running of prison operations in terms of money spent on fuelwood or fossil fuel and fees for emptying septic tanks. In the Philippines, the prison has organized its inmates to undertake baking activities to create new livelihood opportunities for inmates. Potentially, this could be a source of revenue where baked goods cooked using biogas from human waste is sold in nearby towns.

Value chain and position

The prisons in Nepal, the Philippines and Rwanda rely on the ICRC and local partner organizations to provide the infrastructure, equipment, maintenance toolkit and training for the implementation and operation of a biogas system. The maintenance and operation of the system falls in the hand of prison staff or detainees (Figure 29). ICRC partners with local organizations to provide technical support for the implementation of biogas. By means of user trainings/workshops, the detainees are informed about the biogas system and its operations and maintenance (O&M) requirements of cleaning and flushing toilets, benefits of adding kitchen waste and countermeasures in case of blockages. The vast majority of detainees perceived the biogas systems positively, mainly because it provides a smoke-free source of cooking fuel that contributes to money saving and because it improved the hygienic conditions in and around the prison.

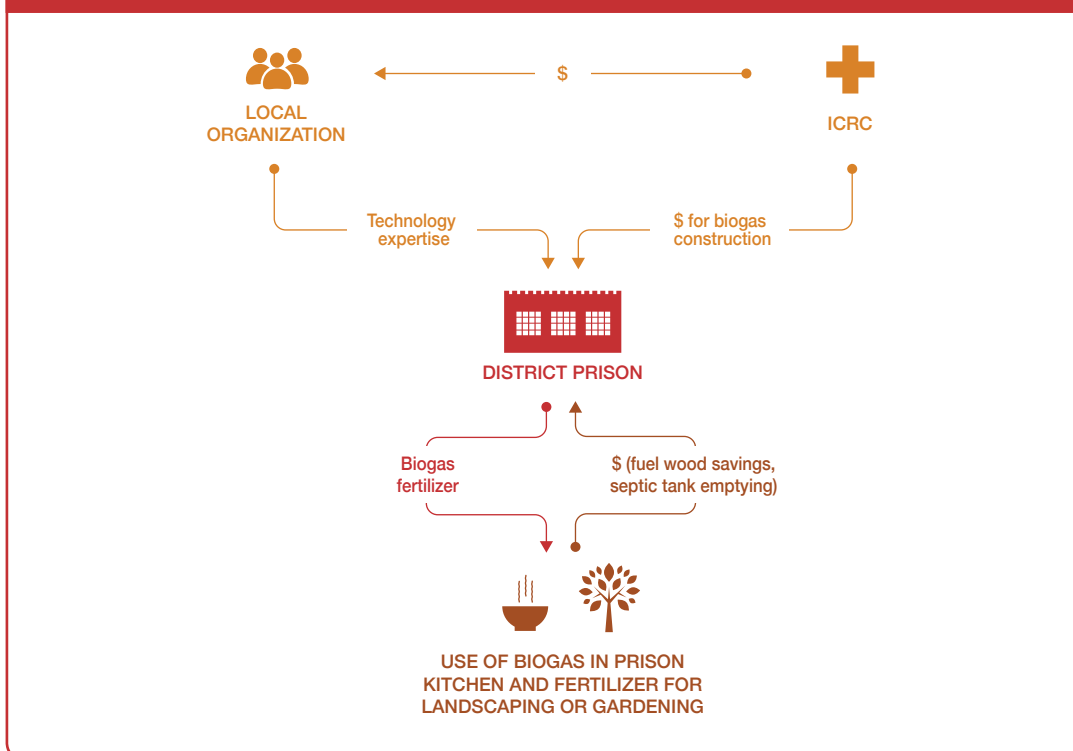
In 2007, with the help of ICRC, biogas sanitation systems were installed in three Nepalese District jails. All five fixed-dome digesters (sizes of 10 m³, 20 m³ and 35 m³) revealed gastight domes and showed high process stability with no accumulation of inhibitory substances. Kitchen waste is added to three out of five digesters to enhance gas production. In the case of the other two digesters, the organic waste is sold to pig farmers.

FIGURE 28. ICRC PRISON BIOGAS BUSINESS MODEL CANVAS



Rwanda has 13 prisons with around a total of 54,000–58,000 prisoners in 2007–2015, who previously consumed around 10 tonnes of firewood a day, costing of around 1 billion Rwandan francs (USD 1.7 million). The Rwanda Correctional Services (RCS) started building large bio-digesters in all 13 prisons, financed by the Ministry of Internal Security, and Penal Reform International, with contribution from KIST. Biogas is used for more than 60% of all cooking fuel. KIST staff manage the construction of the system and provide on-the-job training to both civilian technicians and prisoners. They have

FIGURE 29. ICRC PRISON BIOGAS VALUE CHAIN



constructed a drainage line to take effluent from a prison biogas plant to a test site where experiments are conducted into growing water hyacinth in the effluent treatment ponds. The water hyacinth will be harvested and added to the biogas plants to increase gas production above the rate possible using sewage alone. Rainwater harvesting will be used to dilute effluent as it enters some of the treatment ponds, allowing fish to be farmed there as well. To date the project has trained a total of 150 artisans and technicians, out of which three private businesses have so far been established. It is planned that by 2013, no prison will be using firewood. After at least one year of operation, 11 systems out of the 13 implemented systems were in operation with satisfactory process parameters with daily biogas production ranging between 26 L/person and 62 L/person (obtained in prisons where kitchen waste was added to the digester). The first prison biogas plant started its operation in 2001, and has run with no problems since then.

Institutional environment

Biogas Sector Partnership Nepal (BSP-Nepal) is a professional organization involved in developing and promoting appropriate rural and renewable energy technologies, particularly biogas, effective in improving livelihood of the rural people. It was established in 2003 under District Administration Office, Kathmandu under the Social Organisation Act of the Government of Nepal. The Biogas Support Programme (BSP) was established by the SNV Netherlands Development Organisation (SNV) with the objective of promoting a wide-scale use of biogas as a substitute for fuelwood, agricultural residues, animal dung and kerosene that are generally used for cooking and lighting in most rural households in Nepal. BSP-Nepal is the implementing agency of BSP. BSP-Nepal was established as an NGO in 2003 to take over the implementation responsibility of BSP, which formerly was managed directly by the SNV.

BJMP is an attached agency of the Department of the Interior and Local Government mandated to direct, supervise and control the administration and operation of all district, city and municipal jails in the Philippines with pronged tasks of safekeeping and development of its inmates.

The College of Science and Technology of the **University of Rwanda**, the former KIST in Kigali, Rwanda is the first technology-focused institution of higher education to be created by the Rwanda government in November 1997. Within KIST, the Centre for Innovations and Technology Transfer (CITT) is mandated to transfer technical innovations, managerial and entrepreneurship skills into community applications. In 2005, KIST won an international environmental award in recognition of its innovative work at Cyangugu Prison, the ASHDEN Award for Sustainable Energy. Since winning the ASHDEN Award, KIST has worked in a variety of areas towards goals. They have begun work on a research project to investigate the use of porous volcanic rock inside the digesters. It is hoped that the rock will increase the surface area available for the anaerobic bacteria. After realizing the success of biogas in prisons, the Government of Rwanda introduced the National Domestic Biogas Program (NDBP) to develop a commercial and sustainable domestic biogas sector under the Ministry of Infrastructure with financial and technical support provided by SNV, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Dutch Ministry of Foreign Affairs (DGIS).

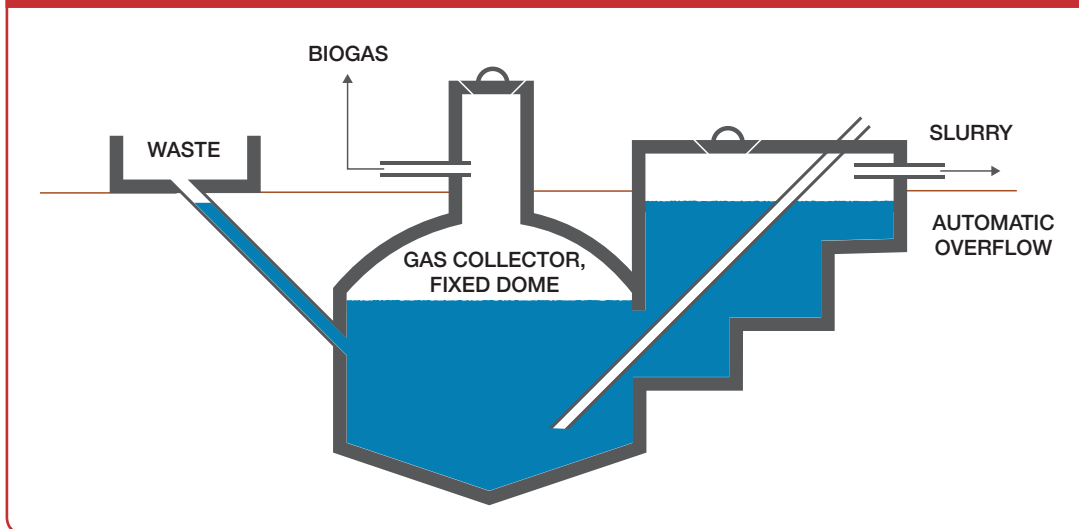
Technology and processes

The biogas system uses a number of individual fixed dome-type digesters, each ranging 10–100 m³ in volume and built in an excavated underground pit. Toilet waste is flushed into the digesters through closed channels, which minimize smell and contamination. The digester is shaped like a beehive, and built up on a circular, concrete base using bricks made from clay or sand-cement. Biogas is stored on the upper part of the digester. The gas storage chamber is plastered inside with waterproof cement to make it gastight. On the outside, the entire surface is well plastered and backfilled with soil, then landscaped. From the manhole cover, the gas is piped underground towards the kitchen where it is used for cooking purposes. The continuous input of waste and the gas pressure push digested effluent out of the bio-digester to a stabilizing tank and from there, to a solid/liquid separation unit. The stabilizing tank allows additional gas production. The solids are composted for three months and then used as fertilizer in the prison gardens. The fertilizer is only used for crops that stand above ground, such as papaya, maize, bananas, tree tomato and similar crops (Figure 30).

The biogas reactor is an anaerobic, sealed chamber that serves as a primary settling tank, with relatively fast passage of the liquid effluent through the chamber and digestion of much of the settled sludge by anaerobic bacteria. In this way, it is much like a septic tank, except that its sealed nature allows all of the biogas (a mixture of methane and carbon dioxide that is released from anaerobic digestion) to be captured and used. Since most of the organic matter is converted to biogas, sludge production is relatively low. The settled sludge usually remains in the unit for several years and, when removed, is relatively pathogen-free, requiring only some post-composting to ensure sterility.

Satisfactory operation of a biogas system can be achieved if adequate attention is given to the site selection and dimensioning of the system. For this, it is crucial to understand the local climatic and geotechnical conditions, sanitary habits, waste flows and power relations in the prisons. Kitchen waste addition can boost (even double) the biogas production, but its use might be in conflict with potential competitors (e.g. local farmers who use it as animal feed). To deal with high fluctuation in detainee numbers, it is advised to install digesters in series instead of a single large one. It is absolutely essential to install condensation traps at the lowest points of the gas pipe. Vapour, a natural component of biogas, condenses in the pipe and eventually leads to blockage of the pipeline so that the gas does not reach the kitchen anymore. Regular emptying of these water traps is crucial.

FIGURE 30. SCHEMATIC DIAGRAM OF TYPICAL FIXED DOME DIGESTER



Regarding digester volume, 100 L of digester volume is required per person, (e.g. a prison with 200 detainees needs a 20 m³ digester). This is based on the estimation that 3.3 L/pers. of diluted substrate (feces, urine and flush water) is added and a Hydraulic Retention Time (HRT) of 30 days is envisaged.

Funding and financial outlook

Funding for the implementation of the prison biogas systems was provided by the ICRC in partnership with local institutions. The average cost of a biogas system is 250 USD/m³ in Nepal, 230 USD/m³ in the Philippines and 300 USD/m³ in Rwanda. The total cost of all five digesters in Nepal amounts to USD 12,960, for the Philippines USD 27,700 and for a 500 m³ plant in Rwanda, it is about USD 74,000 which is paid for by the Ministry of Internal Security. The operational and maintenance costs are 2% of the total investment cost.

Implementation of biogas systems is an advantage for the prison management in terms of savings from substitution of fuel. The firewood savings are 22.5 tons/year in Nepal, approx. 40 tons/year in the Philippines and 6.35–7.35 tons/year in Rwanda. For the project in Rwanda, all 75,500 L of biogas are used for cooking. For an average 6,000-person prison population, where the prison once paid RWF 1,000,000 per month for firewood, the cost has been reduced to RWF 800,000 per month.¹ The savings in one year are RWF 200,000 × 12 = 2,400,000. Given the total investment of RWF 19,000,000 for the system, the payback period is roughly eight years. When evaluated on the basis of kerosene replacement, the payback period would be seven years. However, further savings are realized with the use of the improved manure in place of the imported mineral fertilizer. On the other hand, the post-treatment rids the wastes of the health hazards that may otherwise result in costly medical care and the loss of productive labor. The treatment of wastes in this way generates biogas, which can offset firewood consumption by 80%, thus mitigating the rate of deforestation and conserving the environment. On the bases of the demonstrated benefits, resources should be mobilized to utilize anaerobic treatment technology in a wider application for greater impact.

Socio-economic, health and environmental impact

The biogas systems are favourably perceived by the vast majority of detainees as energy systems rather than as sanitary treatment systems due to general improved living conditions of detention by:

- 1) Improving sanitary and hygiene conditions in toilets with cleaner surrounding areas resulting in less outbreaks of disease and fewer complaints from neighbours about odor and overflowing feces.
- 2) Reducing local deforestation by eliminating the need for firewood.
- 3) Reducing the emission of greenhouse gases by using the carbon-neutral biogas and surface and groundwater pollution.
- 4) Reducing the surface and groundwater pollution and removing sight and smell of the sewage, and their related health risks not only for prisoners but also for neighbouring areas, caused by the input of essentially untreated wastewater into the local environment.
- 5) Providing a renewable and smoke-free source of cooking fuel saving fuelwood as well as time for cooking and pot cleaning and removing unpleasantly hot and smoke-filled environment for the chefs. The biogas supply was assured unlike shortages of fuelwood.
- 6) Reducing costs to the prison by reducing the need for the purchase of cooking fuel.
- 7) Empowering the lives of the prisoners by engaging them in a new income-generation activities like inmate-run bakery that is fuelled in part by the biogas, keeping them busy and learning useful skills that they can apply when released.
- 8) Providing sludge as bio-fertilizer to benefit crop/vegetables production and fuel plantations by restricted irrigation, reducing costs further by eliminating the need for fertilizer purchases and also promotes sustainability by using the waste for local food production.
- 9) Development of private biogas companies by providing technical and business training to the civilian graduates, technicians, as well as prisoners. To date, over 30 civilians and 250 prisoners have received training, and three private biogas businesses have been started in Rwanda.

Scalability and replicability considerations

The key drivers for the success of this business are:

- Government support for renewable energy and improvements in living conditions in prisons.
- Existing funding resource to finance the investment for construction of biogas plant.
- Strong partnership with local partners, technology provider and prison authorities.
- High cost of fuel wood for cooking.
- Lack of proper sanitation systems in prisons and associated health and environmental problems.

With regard to operational aspects, the total organic waste management including issues of strong ownership and responsibilities for maintenance work needs to be examined carefully before dimensioning a biogas system and detainees should be convinced of the benefits of human waste feeding into the digester. The organization of anticipated kitchen waste feedstock has to be elaborated with the responsible persons. In terms of slurry use, there is a certain risk of public perception in the use of human excreta based product on food. Studies have shown that restricted irrigation is possible, and instead of promoting the use of slurry on vegetables, the irrigation of banana trees seems to be promising. If not properly operated and maintained, the adverse effects such as methane emissions or health risks of leaking gas pipes in the kitchen can clearly exceed the benefits.

Given above mentioned constraints that could be fairly resolved, this business case has high potential for widespread replication and scaling across institutions providing residency such as prisons, hostels, hospitals, hotels and so on. CITT has already undertaken smaller installations in three residential

schools in Rwanda. To ensure the replication of this success, the United Nations Development Programme (UNDP) is supporting a KIST-implemented biogas project for Kigoma Prison, with funding from the Netherlands Embassy. In addition, the Ministry of Internal Security, in partnership with the Red Cross, has plans to provide three prisons per year with biogas systems.

Summary assessment – SWOT analysis

The key strength of the business case is its strong local partnership with the prison authorities and local technology supplier to install the system and train prison inmates and officials to operate the plant (Figure 31). The weakness is in reliance on donor money to install the infrastructure. The business has threats of health risk of cultivating crops from bio-slurry. If the human waste is not treated appropriately killing pathogens, there is health risk for operators and inmates who come in direct contact with the bio-slurry. The business has high potential for replication and opportunities to expand its revenue source to include carbon offset.

FIGURE 31. ICRC PRISON BIOGAS SWOT ANALYSIS

	HELPFUL TO ACHIEVING THE OBJECTIVES	HARMFUL TO ACHIEVING THE OBJECTIVES
INTERNAL ORIGIN ATTRIBUTES OF THE ENTERPRISE	STRENGTHS <ul style="list-style-type: none"> Continuous supply of input Strong partnership with prison authorities and local technology suppliers Reduced public expenditure to run prisons from reduced fuel cost An inclusive business model that improves sanitation for prisoners – a discriminated group Short payback period for an investment that improves sanitation 	WEAKNESSES <ul style="list-style-type: none"> No financially viable plan set up for financing repair and maintenance of the plant Heavy dependence on donor money to finance construction of biogas plant Lack of strong management arrangement at the operational level to take the business to scale Irregular feeding, and lack of operation and maintenance Relatively high requirements of strong ownership and responsibilities for maintenance work
EXTERNAL ORIGIN ATTRIBUTES OF THE ENVIRONMENT	OPPORTUNITIES <ul style="list-style-type: none"> Potential to increase revenue by bundling the biogas projects at different prisons and applying for carbon offset Potential to expand the business model to prepare cooked food and provide it to local market High potential for replication at other institutions providing food and residential services like hospitals, schools, hotels, etc. 	THREATS <ul style="list-style-type: none"> Potential health risk from direct human contact with bio-slurry used for crop production and associated public perception risk Leakage of gas causing environment damage Resistance to change and perceptions of people on use of sludge from fecal waste

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Case descriptions are based on primary and secondary data provided by case operators, insiders, or other stakeholders, and reflect our best knowledge at the time of the assessments (2015/2016). As business operations are dynamic, data that can be subject to change.

Note

- ¹ RwF 800,000 was depending on the year about USD 1,100–1,400 in the assessment period.