Mobile for Development Utilities

Emergence BioEnergy, Inc.
Energy from biomass for telecom towers and communities in Bangladesh

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Mobile for Development Utilities

The Mobile for Development Utilities Programme promotes the use of mobile technology and infrastructure to improve or increase access to basic utility services for the underserved. Our programme focuses on any energy, water or sanitation services which include a mobile component such as mobile services (voice, data, SMS, USSD), mobile money, Machine to Machine (M2M) communication, or leverage a mobile operator's brand, marketing or infrastructure (distribution and agent networks, tower infrastructure). The Programme receives support from the UK Government.

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The Innovation Fund

The Mobile for Development Utilities Innovation Fund was launched in June 2013 to test and scale the use of mobile to improve or increase access to energy, water and sanitation services. In two phases of funding, grants were competitively awarded to 34 organisations across Asia and Africa. Seed grants were awarded for early stage trials, Market Validation grants for scaling or replication of business models, and Utility Partnership grants to foster partnerships between utility companies and innovators.

The specific objective of the Innovation Fund is to extract insights from the trial and scaling of these innovative models to inform three key questions for growing the sector:

- How can mobile support utility services?
- For a mobile-enabled solution to be adopted at scale, what building blocks are needed?
- What are the social and commercial impacts of delivering community services to underserved mobile subscribers?

These insights, as well as grant-specific learning objectives, are included in individual case studies such as this one, as well as thematic reports that will be published throughout 2016.

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Executive Summary

In January 2014, the Mobile for Development Utilities Programme awarded the US-based company, Emergence BioEnergy, Inc. (EBI), a Seed grant to trial an innovative, small-scale, biomass-fuelled Stirling engine[1] in Bangladesh as the generation technology for telecom towers and businesses and households in the vicinity of the towers.[2] The Stirling engine was expected to be particularly suitable to meet the 99% uptime requirement of telecom towers because it can operate continuously, is low-maintenance and can be powered by multiple fuels.

The secondary objective was to evaluate the commercial potential of the service to generate revenues from the sale of power as well as fertiliser, a by-product of energy generation. Originally, EBI proposed to generate biogas from cow dung but switched to chicken litter[3] as it was more easily available and has a higher calorific value.

Bangladesh has an overall grid electrification rate of 60%.[4] Over 99% of its population is covered by mobile networks indicating that most of those without access to grid electricity live within the coverage radius of a telecom tower. This means that 61 million people could possibly access energy services by leveraging mobile networks.[5] EBI partnered with Grameenphone, Bangladesh's largest mobile network operator, to power two of its telecom towers during the trial.

EBI had chosen US-based Infinia Corporation as its Stirling engine vendor. Just before the grant was awarded, in November 2013, Infinia was acquired by Israel-based Qnergy.[6] The ensuing transition imposed delays in the supply of a new engine and EBI was forced to start the project with an old prototype engine at one site. While this engine taught EBI some valuable operational lessons, it failed beyond repair in November 2014 rendering the first site non-operational. A new engine, with nearly commercial-ready technology, was delivered to EBI in the same month and installed at the second site. After initial success, the new engine also suffered from technical failures. Faced with repeated deployment difficulties, EBI's board of directors decided first to cease operations in Bangladesh and later to shut down the company. Despite the final outcome, important lessons were learned during the project. Key findings include:

1. A Stirling engine requires an external heat source as opposed to an internal combustion engine (ICE) which means it can be powered by a variety of fuels. Since there are no explosions as in an ICE, a Stirling engine is comparatively very quiet. See http://auto.howstuffworks.com/stirling-engine.htm for more details.
2. The model in which energy is sold to a telecom tower as an anchor customer as well as to business and household customers around that tower is known as Community Power from Mobile (CPM).
3. Chicken litter is a mix of excreta, spilled feed, feathers and bedding material. See https://en.wikipedia.org/wiki/Poultry_litter for more details.
4. World Bank estimate for 2012. See http://wdi.worldbank.org/table/3.7
5. GSMA estimate
6. Stirling-engine developer Qnergy acquires US-based Infinia: http://www.prnewswire.com/news-releases/stirling-engine-developer-qnergy-acquires-us-based-infinia-232874841.html

The success of EBI's model depends on several factors: Even though EBI was trialling a relatively small, 3.5 kW[7] Stirling engine, the expectation of 24-hour operation meant it would need 1,200-1,600 square feet of land to construct the digester[8] and associated infrastructure,[9] which is larger than the area required for a standard telecom tower. Finding such a large plot of land in the vicinity of a telecom tower was not easy and EBI had to evaluate several sites before selecting one.

Apart from sufficient land, an ideal site has to meet several other criteria. First, the site has to be in a grid-deficient area. Second, ample biomass and water must be easily available. Third, there must be sufficient demand, in addition to the telecom tower, for the energy generated. Finally, neighbours around the site must be tolerant of the smell. The last constraint may seem trivial but to avoid upsetting local neighbours, EBI had to transport chicken litter late at night, complicating operations.

Fertiliser sales presented unanticipated operational constraints: EBI was unable to sell fertiliser from either site. At the first site, the quantity produced was too small to be of interest to commercial purchasers. At the second site, large quantities were expected to be produced, but the project did not last long enough to discover the market.

On the ground technical expertise is critical: EBI's technical expert was based in the United States. Although he travelled to Bangladesh, trained a local engineer, remotely monitored systems and advised how to debug failures, the first engine went down several times and eventually became inoperable. The failure of the second engine would not have been prevented by on the ground expertise but it may have been understood more quickly allowing vendor engineers to provide a solution in a more timely manner.

The GBP 200,000[10] grant enabled the trial of a promising high-risk new technology. Although the project failed to meet its objectives, it does not automatically suggest that Stirling engines do not have a future for electricity generation for telecom towers. However, it is evident that the technology needs more development and testing before it can be commercially deployed.

Gas meter at Site 1 indicating normal pressure in the digester

7. This was the smallest available engine capacity from the vendor.
8. A digester is used to convert organic waste to biogas. See https://www.americanbiogascouncil.org/biogas_what.asp for details.
9. EBI estimate
10. The original grant amount was GBP 200,000. As the project progressed, it became clear that EBI would not need the entire amount and the grant was revised down to GBP 179,772.

Introduction

Emergence BioEnergy, Inc. (EBI), a Delaware (USA) corporation, was founded in 2008. EBI opened a branch office in Bangladesh in 2013, prior to the grant award.

The company aimed to deploy small scale, farm waste-to-energy, distributed power generation systems in remote locations. To achieve this, EBI repurposed Stirling micro-combined-heat-and-power (micro-CHP) technology to produce multiple values from agricultural waste, including electricity, organic fertiliser and cold-storage. Expected features of the micro-CHP engine included: continuous operation, limited maintenance requirements, ability to operate from widely available renewable fuels like biogas and capacity to turn rejected heat produced during power generation into cooling. These properties made it an ideal solution for remote power generation in rural environments.

EBI would adopt the Community Power from Mobile (CPM) model to sell electricity. In the CPM model, a telecom tower serves as the anchor customer for an Energy Service Company (ESCO) while business and household customers in the vicinity of the telecom tower also benefit from energy services that would not be viable without the anchor customer. The mobile network operator is able to increase revenue by helping to provide energy which keeps mobile phones charged and thus removes a constraint in their use. The bankability of contracts with mobile operators or tower companies makes it easier for the ESCO to raise capital than with a model based on providing energy only to the underserved community. In addition to electricity, EBI would also sell organic fertiliser.

Key Facts about EBI

FIGURE 1

Company Overview as of December 2014

Name	Emergence BioEnergy, Inc.
Sector	Energy (biomass)
Year Established	2008
Country Footprint	Bangladesh, USA
Product/Service	Microgrid and battery charging services powered by agricultural waste
Market Segment	Telecom towers, productive users and households in off-grid areas or areas with unreliable access to the grid
Total Systems/ Customers Served[11]	Two systems installed • One telecom tower per system • One chicken farm • Peak households served: 20 households with lantern rentals or 100 beneficiaries in November 2014
Use of Mobile: Technology and Partnership	• Telecom towers as anchor customer

Grant Objectives

Through this Seed grant, EBI, in partnership with Grameenphone, attempted to verify the feasibility of a 3.5 kW Stirling engine to reliably generate power around the clock. It was expected that:

- Telecom towers would serve as a hub for energy access and economic activity, making each tower a source of increased prosperity for villages
- Smallholder farmers would be able to increase their incomes from their existing farming operations by selling biomass and gain access to energy for critical farming operations like irrigation and
- Local consumers and businesses would benefit from energy access that was previously not available

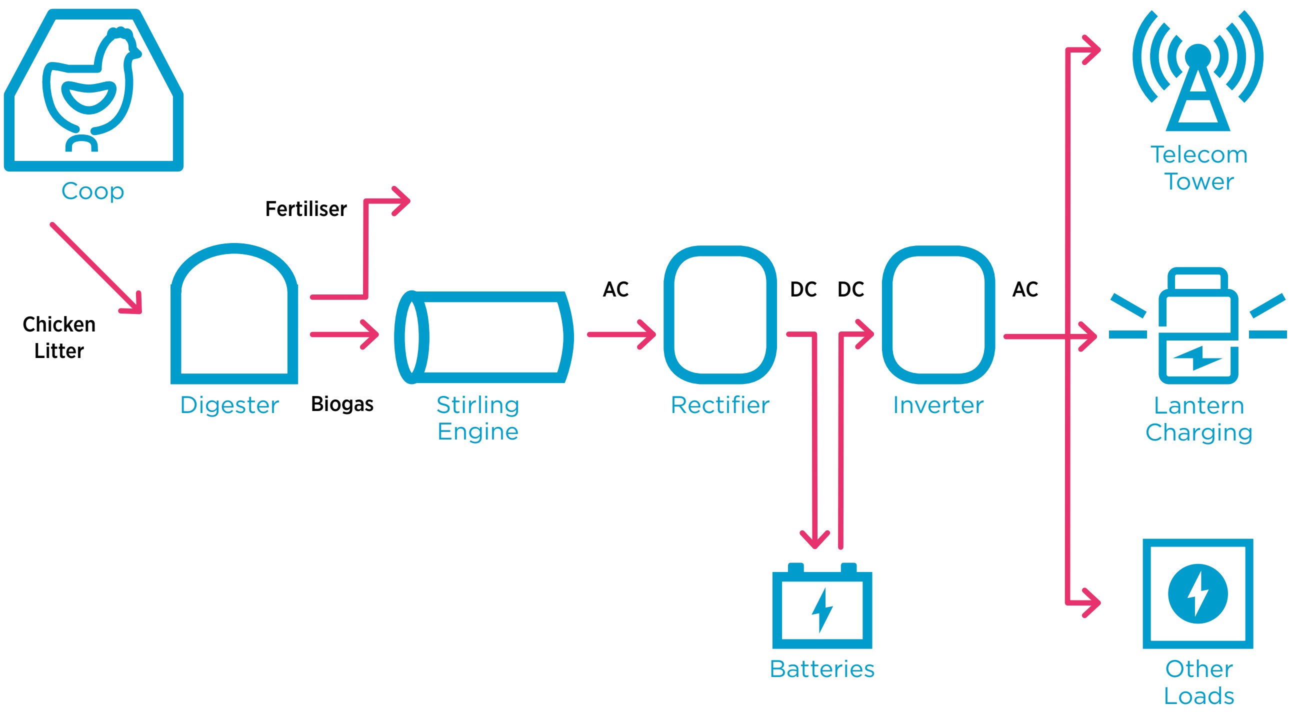
11. Sales and beneficiaries numbers are self-reported by EBI.

Site Configurations

During the project, EBI deployed one engine of 1.8 kW capacity at the first tower site and one of 3.5 kW capacity at the second tower site. The first engine was a very early version already on the ground in Bangladesh that was retrofitted to allow EBI to kick off the project; the second engine was a nearly commercial-ready version that was expected to generate power continuously. Figure 2 shows the process flow from the input of chicken litter to the distribution of power. Figure 3 draws a comparison between the two sites.

FIGURE 2

Schematic diagram



At the first site, chicken litter was washed out of the coop into the digester every day. The digester converted the organic matter into methane and other gases plus slurry. The slurry, when dried, could be used as fertiliser. Methane was converted into alternating current (AC) electricity by the Stirling engine. This AC electricity was converted into direct current (DC) electricity and stored in batteries. When required, energy was drawn from the batteries, converted back to AC and supplied to the respective loads.

FIGURE 3

Comparison of configurations at the two sites

	Site 1	Site 2
Engine capacity	1.8 kW	3.5 kW
Supplier	Infinia	Qnergy (who acquired Infinia)
Technological maturity	Equivalent to alpha version even after retrofitting; Expected to run 6-7 hours/day	Nearly commercial-ready version; Expected to run 24 hours/day
Digester size	One 4.8 m^3 existing digester; Site owner was in process of augmenting capacity with a new 12 m^3 digester; Both digesters owned by site owner	One 70 m^3 digester constructed and owned by EBI
Source of biomass	Co-located chicken coop owned by site owner; Digester was automatically fed when coop was washed	Large chicken farm about 2 km from the site; Transport was required to move chicken litter and feed it into the digester

The expected learnings as defined by EBI at the outset of the project were:

- Could a small Stirling engine demonstrate the capability to generate power reliably and continuously, to meet the 99% uptime expected for a telecom tower?
- Would it be possible to find suitable sites which met all requirements – a telecom tower within 100 yards, other productive loads in the vicinity, sufficient land for digester construction, plentiful biomass within a couple of kilometres, easy access to site to transport biomass, and ample water supply for mixing with biomass?
- Could the sale of leftover biomass after energy extraction as fertiliser be a significant revenue stream for EBI? What were the logistical challenges associated with the sale of fertiliser?

Progress and Challenges

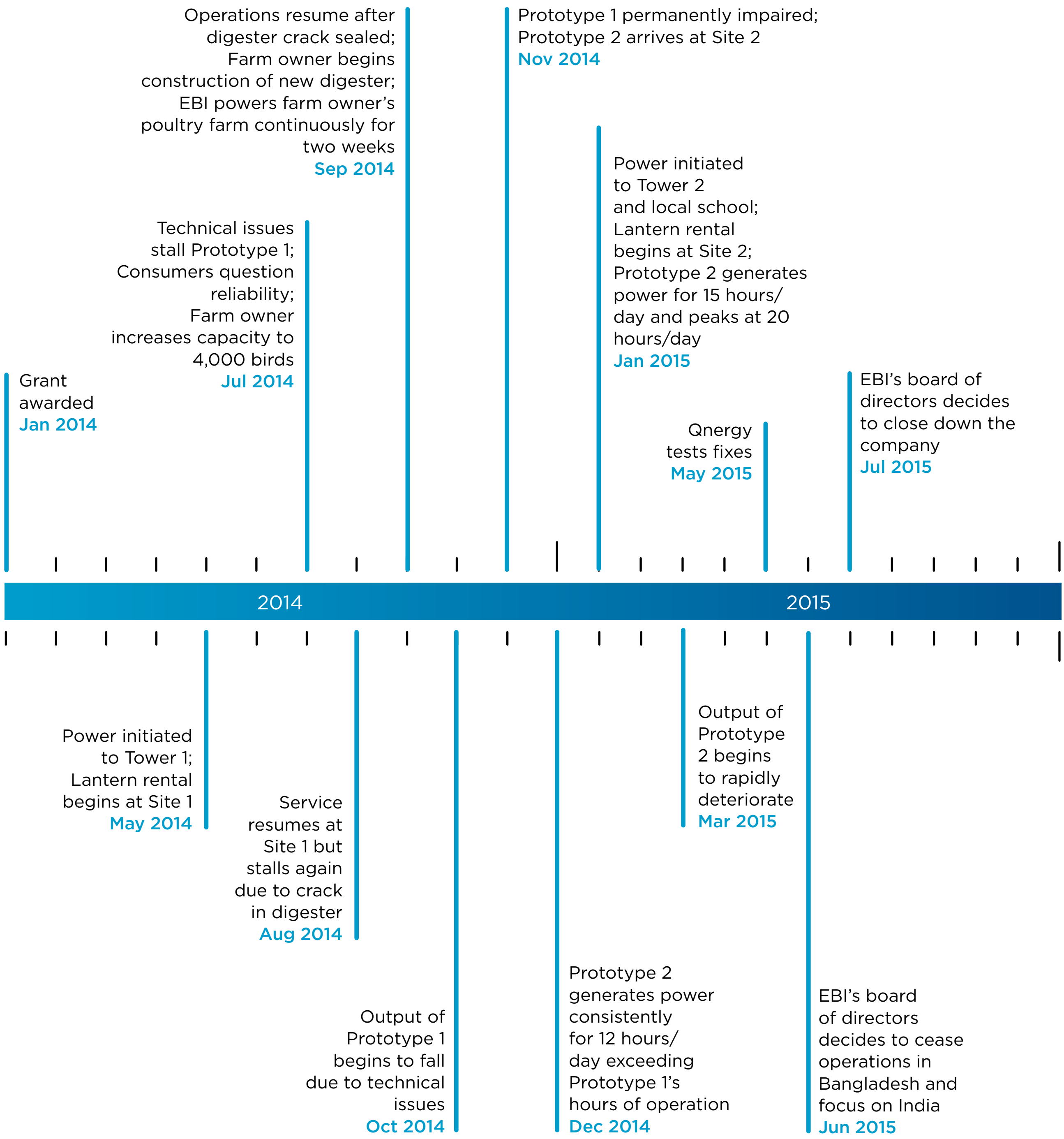
The EBI project initially aimed to install two engines of 3.5 kW capacity, one close to each of the two selected tower sites. These engines were to be supplied by Infinia Corporation. However, in November 2013, Qnergy acquired Infinia. Qnergy agreed to honour the contract but only after instituting a thorough design review before manufacturing new engines. In order to get the project underway, EBI decided to retrofit an older 1.8 kW Infinia engine that was already in Bangladesh and install it at the first site. This engine is referred to as Prototype 1. The new prototype, supplied by Qnergy, was initially expected to be on site in May 2014. However, it was delayed several times and only arrived at the second site in November 2014.

Both sites selected were within reasonable driving distance of Dhaka for manageable commutes for EBI staff, investors and Grameenphone staff. However, this meant the sites had access to grid electricity for most of the day. Thus, these sites precluded a true market trial.

There were successes, but these were outweighed by challenges throughout the implementation of the project. These are summarised in Figure 4 below.

FIGURE 4

Major events during project implementation



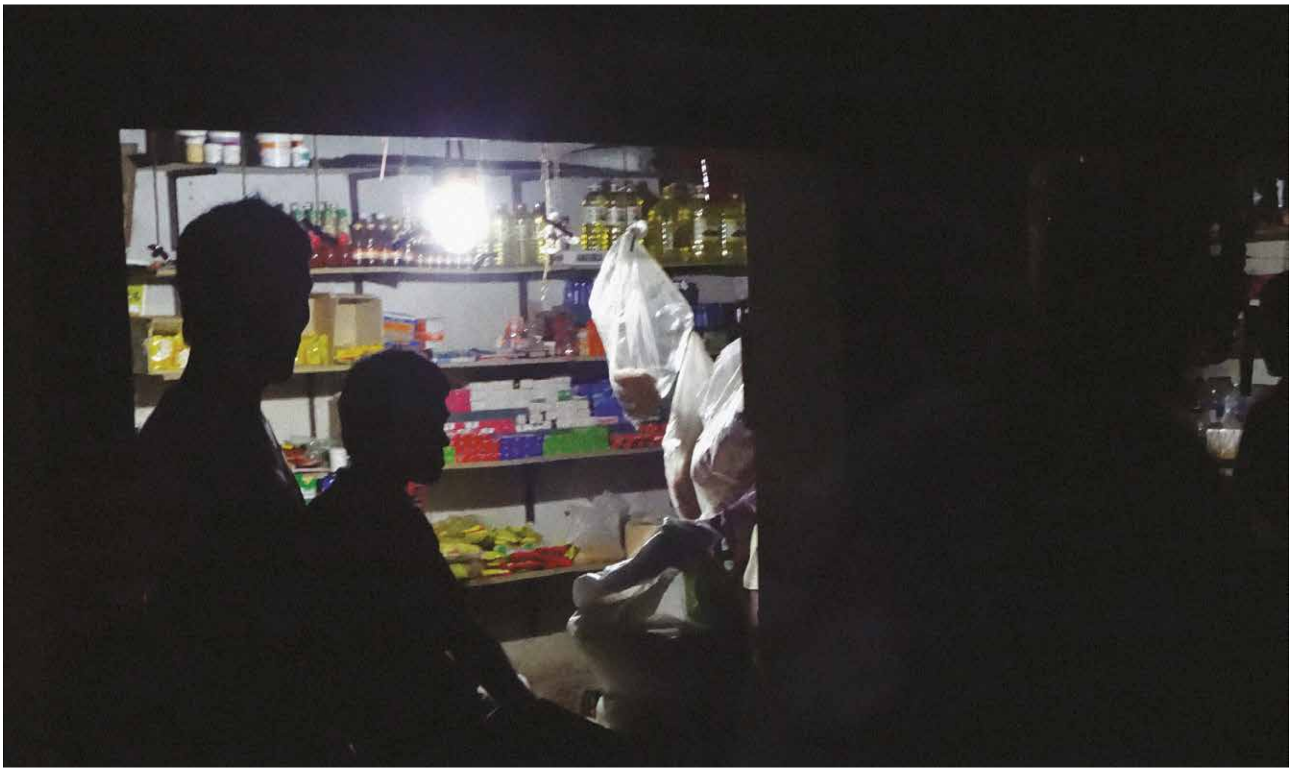
Site 1

A Site 1 was located on a chicken farm with about 1,100 birds. The site already had a 4.8 m^3 digester which EBI repaired and upgraded. In May 2014, the engine started producing power and supplying the Grameenphone tower and charging several of the 25 lanterns EBI had purchased to offer rental services.

Prototype 1 engine

In order to compete with the local diesel generator operator who charged a daily fee of BDT 6 (USD 0.079[12]) per lantern, EBI rented charged lanterns at BDT 5 (USD 0.066). Furthermore, with the EBI service, consumers did not need to invest in a lantern, which costs BDT 185 (USD 2.42) on average.[13] Most lantern models for offgrid use have mobile phone charging capability. However, EBI's lanterns did not offer this feature because consumers were able to charge their phones when grid electricity was available. Lanterns were generally rented to shop owners in the neighbouring marketplace who would use the residual charge to light their homes after closing their shops.

12. Values in BDT converted to USD using an exchange rate of BDT 1 = USD 0.0131009, the average exchange rate for December 2014 obtained from the OANDA Online Currency Converter
13. EBI data



EBI lantern lighting up a shop

EBI lantern at a carpenter's workshop

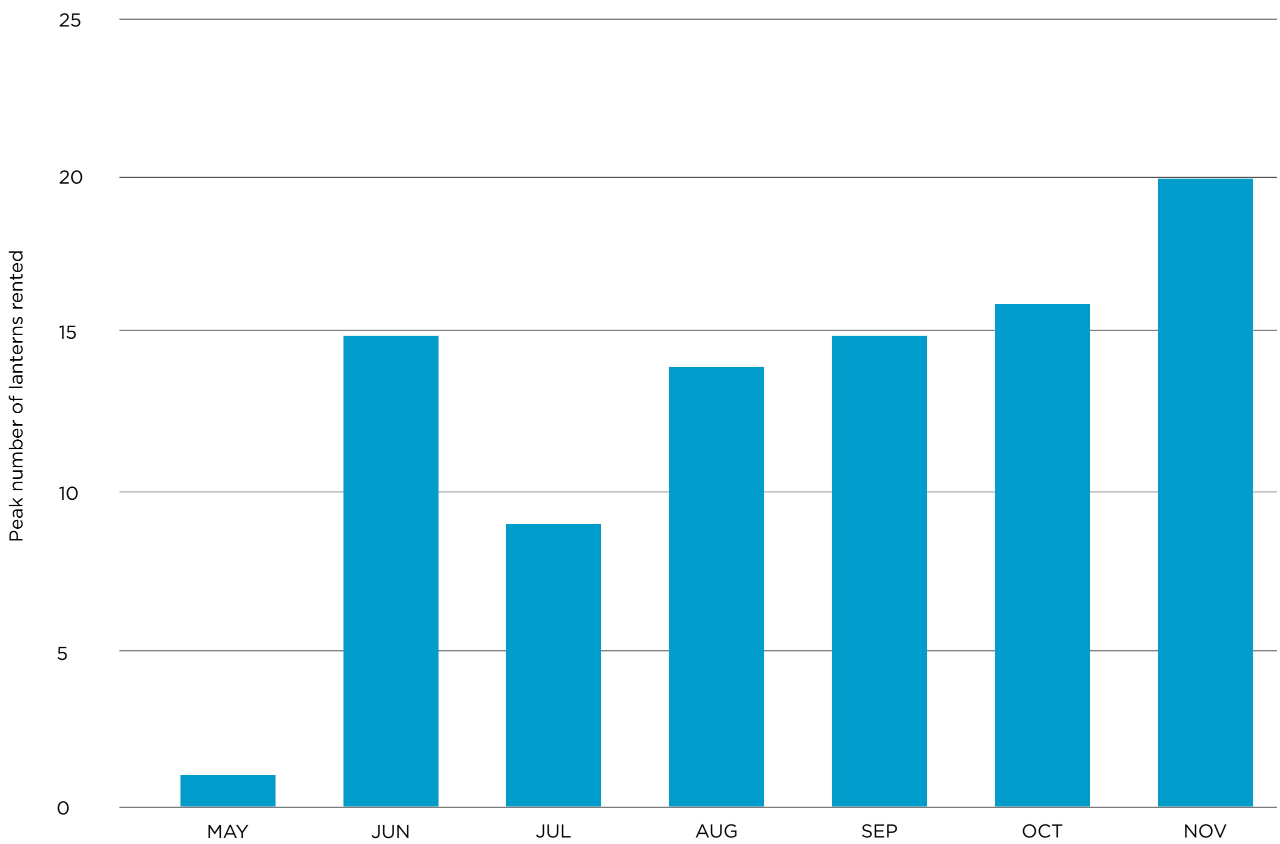
At Site 1, EBI paid rent to the owner of the chicken farm and also purchased chicken litter from him. Buoyed by the initial success of the EBI engine, the farm owner decided in July 2014 to increase the farm's capacity by purchasing 3,000 more birds. Unfortunately, around the same time, Prototype 1 started to encounter technical issues and was eventually taken offline. With the system down, consumers began to lose interest and the morale of EBI staff also suffered. Service resumed in August 2014 but shut down almost immediately because the existing digester had cracked and began to leak gas.

September 2014 was the best month at Site 1. EBI repaired the crack and generated sufficient power to entirely replace the diesel generator at the chicken farm for two weeks. With the end of the monsoon season, the farm owner also began the construction of a new, larger digester of 12 m^3 capacity to match the increase in the number of birds. With this expansion, the biogas generation capacity would increase by more than 350%.

Unfortunately, the output power of Prototype 1 began to fall at the end of October 2014. The engine could not be repaired remotely and was declared permanently impaired in November 2014. Figure 5 shows the daily peak number of lanterns rented by EBI each month.

FIGURE 5

Peak number of lanterns rented daily at Site 1 by month in 2014



Site 2

Selecting Site 2 was much more difficult than selecting Site 1 due to the larger engine capacity and capability to operate for longer hours. The constraints were as follows:

1. Larger digester: Prototype 2 required a 70 m^3 digester as compared to the 16.8 m^3 digester (after expansion) at Site 1. This large digester and associated infrastructure required 1,200-1,600 square feet of land. In contrast, a typical tower requires about 1,000 square feet.

2. More chicken litter: Prototype 2 required litter from nearly 14,500 birds or about 1 ton/day compared to 4,000 birds at Site 1. Since no farms of this size were available near a telecom tower, EBI had to arrange for daily transportation from a large chicken farm. The cost of chicken litter was BDT 750/ton (USD 9.83/ton). Further, EBI had to pay a person to transport the chicken litter and feed it into the digester. In contrast, the digester at Site 1 was automatically fed when the chicken coop was washed.

3. Larger loads: EBI had to find more or larger loads beyond the telecom tower to consume the higher power generated by Prototype 2.

After several iterations, EBI selected a suitable site about 2 km from a large chicken farm which housed 100,000 birds. EBI began preparing the site in September 2014. Prototype 2 eventually arrived on site in November 2014.

Completed shed at Site 2

Digester under construction

Initial results were promising. EBI was able to bring up the new engine within days. In December 2014, the engine was running for 12 hours/day at 2 kW capacity which was more than Prototype 1 had achieved. Power supply to the Grameenphone tower was initiated on January 1, 2015. Prototype 2 achieved 20 hours of operation in a day later that month. However, the engine's output began to deteriorate in March 2015 and power production was brought to a halt. While Qnergy remotely diagnosed the failures and worked on fixing the issues, EBI's board of directors decided in June 2015 to halt operations in Bangladesh and focus on India instead. In July 2015, EBI's board decided to close down the company entirely.

Lessons Learned

The stop-start nature of operations during the project limited the opportunity for EBI to learn the expected lessons previously outlined. Nevertheless, some important lessons emerged from the project.

Land constraints are a significant factor in biomass generation

Digesters can require a large amount of land. The original site EBI selected for Site 2 had very little land available so even though it was perfect in other regards, EBI could not use it. Even in a relatively open space, EBI's decision to use a single 70 m^3 digester (requiring 1,200 square feet) instead of two 35 m^3 digesters (requiring 1,600 square feet) was governed by land availability. The two digester configuration offered EBI resilience against failure but required 33% more land. Even with this compromise, the land requirement exceeded that of an average telecom tower, which only needs about 1,000 square feet.

EBI's microgrid model with a telecom tower as an anchor load requires a confluence of factors for success

Apart from sufficient land, EBI's model of generating electricity requires the following factors to converge in the vicinity of the generator:

1. Sufficient biomass
2. Twice as much water as biomass to maintain the consistency of the slurry
3. Telecom towers and other large consumers of electricity with intermittent or no grid access
4. Neighbours who are tolerant of smell

To run the 3.5 kW engine at Site 2 for 24 hours and generate 84 kWh of electricity, EBI needed a ton of chicken litter and 2,000 litres of water. Part of the energy generated would have been consumed by EBI to pump water and an average telecom tower would have consumed 36 kWh.[14] EBI would have had to find other consumers to purchase the remaining electricity in order to make its operations profitable.

Initially, it was thought that Site 2 could also be located in a small chicken farm which would supply part of the biomass requirements. However, there was strong resistance to allowing EBI to bring chicken litter from other farms because fecal matter is a vector for bird flu.[15]

A further complication with chicken litter is its strong smell. EBI's plan to transport large quantities of chicken litter to Site 2 was met with local resistance and so they had to move the material at night from the chicken farm, complicating operations.

Site 2 met the above requirements but the number of iterations required to find a suitable site is a clear indicator that the potential for scaling EBI's model, with a telecom tower as an anchor load, is constrained.

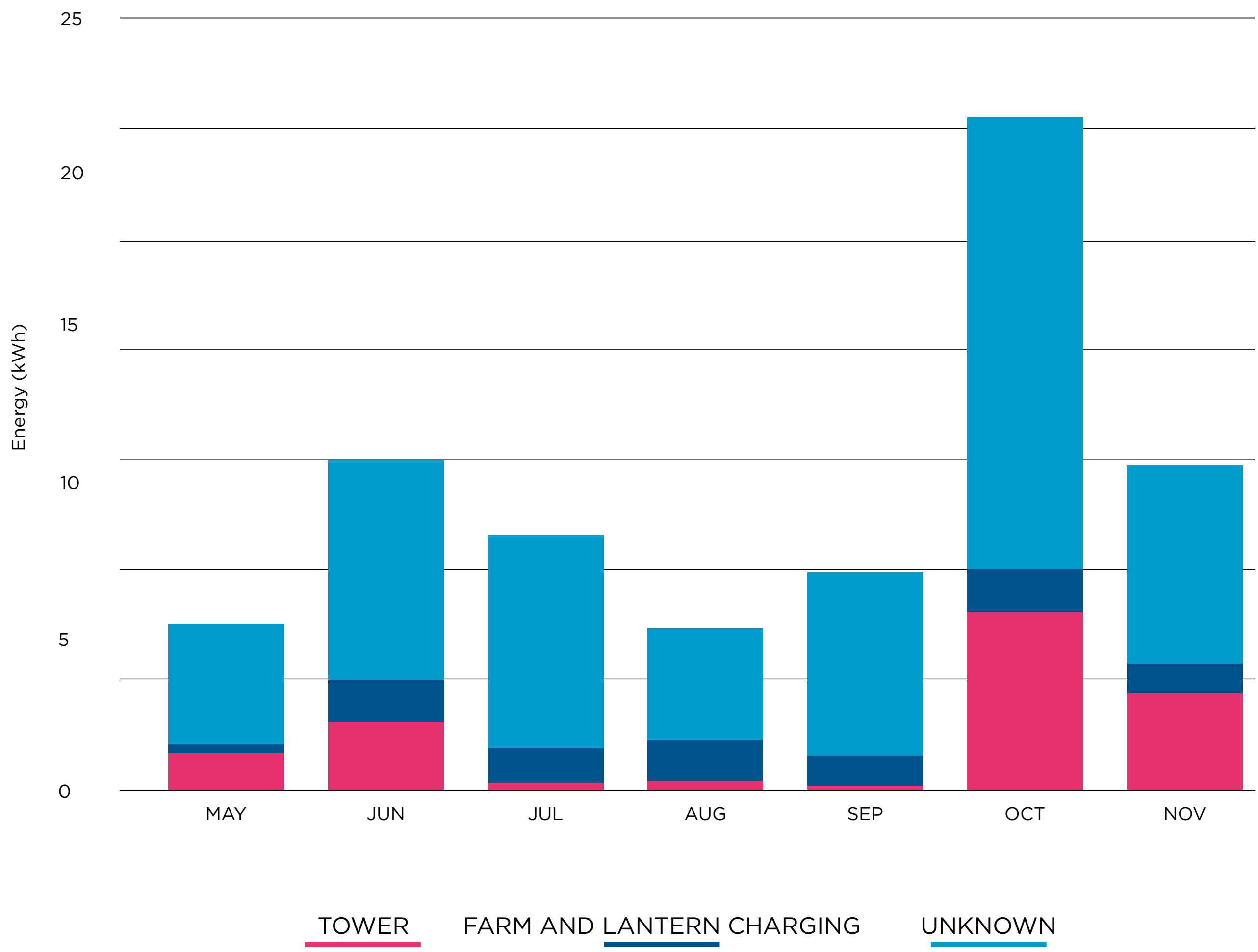
14. Assuming an average tower load of 1.5 kW
15. FAO website: http://www.fao.org/avianflu/en/qanda.html#7

Energy generation technology is important but it must be backed by a robust energy storage and distribution system

EBI's focus was on generation technology and on the operations leading to generation. This led to insufficient attention to maintenance of batteries and on the design of the electrical distribution system. At Site 1, the ratio of power supplied to power generated ranged between 16% and 39% which means up to 84% of the power generated was lost to self-consumption, dissipation or wastage. This ratio was at its lowest in the months of May 2014, when the system was being brought online and August 2014, when it had to be taken offline for debugging. Faulty batteries were responsible for part of the loss. Once they were replaced in September 2014, the ratio rose above 30%. It was unclear what the target for this ratio should have been and the root cause of losses was never fully understood. Figure 6 depicts the distribution of energy generated at Site 1. Insufficient data was available for Site 2 because the engine failed very quickly.

FIGURE 6

How energy generated at Site 1 in 2014 was used



Fertiliser sales were expected to be a significant source of revenue but operational constraints were not well understood at the outset

EBI expected to generate a significant amount of revenue from fertiliser sale. In fact, it was expected to generate more revenue than the sale of power.[16] However, fertiliser sales were not realised at either site for different reasons.

It was found that fertiliser buying companies would not pick up less than two tons of dried fertiliser. At Site 1, the quantity of fertiliser generated was too low to be of interest for a bulk sale. Even more importantly, the farm owner claimed rights to the fertiliser because he owned the land and digesters. Site 2 would have generated very large quantities of fertiliser but another challenge arose – that of finding the space to store and dry it. Unfortunately, EBI was never able to reach the point at which it could discover the price and solve the operational challenges of fertiliser sale.

On the ground technical expertise is critical to the success of a time-bound new technology trial

EBI was trialling a technology that had been lab-tested in the US and Israel but not tested under demanding field conditions such as dust, heat, humidity, vibrations, etc. Further, the engine had not been lab-tested for the exact composition of biogas generated by EBI's digesters. EBI encountered several technical challenges in operating the engine, especially Prototype 1 which had outdated technology. However, an expert was not available full-time or even for the majority of the time in Bangladesh. Although EBI's US-based expert trained a local engineer, the technology was too complex for the local engineer to grasp it fully. The situation was further complicated by the unavailability of spare parts in Bangladesh. With senior management in the US, vendor Qnergy in Israel and the project site in Bangladesh, it became impossible to successfully manage the technology trial. Eventually, Prototype 1 was declared irreparable. Moreover, just understanding the cause of the failure of Prototype 2 took weeks. By the time the vendor had a potential fix for the failures, EBI's board of directors had run out of patience.

16. As per revenue assumptions in EBI's application to the Innovation Fund

Conclusions

EBI set out to prove the technical and operational feasibility of converting biogas into electricity with a small-scale Stirling engine to test its suitability to power telecom towers and meet other market demand for the electricity. This proved to be an extremely ambitious goal for a 12-month project because EBI tried to solve technological, operational and business challenges all at once. The situation was further complicated by the acquisition of Infinia, EBI's vendor, which led to a long delay in the delivery of Prototype 2 leaving no time for iterations within the grant timeline. Eventually, EBI's board of directors decided that it could not support any further trials.

Key challenges prevented EBI from testing the commercial viability of its service. Not only was EBI unable to negotiate rates with Grameenphone because the service never stabilised, it was also unable to test demand for fertiliser. Thus, the major revenue assumptions remained unverified.

The reasons for the failure of the project were multidimensional but the immediate cause was technology failure. Was EBI, a system integrator, the right entity to try to prove a high-risk technology in a remote country in tough field conditions? Do such high-risk projects require a close partnership with the vendor or should they actually be driven by the vendor? While the exact model of vendor involvement does not emerge from this project, it is clear that a high-risk technology trial requires technical expertise on the ground to triage problems and a commitment to turn around solutions quickly. For such projects to succeed, the vendor needs to be sufficiently invested. Furthermore, technology projects with a significant hardware component like the Stirling engines are riskier than software-centric projects because shipping time coupled with local import regulations can prolong the turnaround time.

In conclusion, the technology failure prevented the testing of the Community Power from Mobile business model – that of using telecom towers as anchor loads for electricity generation and distribution businesses – in off-grid areas or in areas with an unreliable grid in Bangladesh. Further tests of this business model are necessary to explore the conditions under which it can be viable.

Appendix: Case Study Methodology

Overview: This case study is based on learnings that emerged throughout Emergence BioEnergy, Inc.'s Seed grant with the Mobile for Development Utilities programme. These were tracked through the following:

Grantee reporting: Monthly reports were completed on activities, project risks and mitigation, and key performance indicators. These were discussed during a one-hour call with the grant manager each month. Quarterly reports were completed to document progress on milestones, the grantee's learning objectives, barriers and other key project developments as well as financial compliance.

Limitations of this study: The study aims to provide only the key learnings from EBI's grant and cannot possibly cover all the day-to-day learnings from EBI. It also aims to share learnings with the broader sector without releasing commercially sensitive data from EBI or Grameenphone.

For more information on the Mobile for Development Utilities programme visit: www.gsma.com/mobilefordevelopment/

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