Case Study: Technical and economic feasibility of electricity generation with biogas in Costa Rica

Figure 1. Biogas system; Tubular PVC membrane bags.

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Farmer Alejandro Romero Barrientos and member of the Dos Pinos Dairy Farmers Cooperative (Cooperativa de Productores de Leche Dos Pinos R.L.), advised by the Environmental-Ag Program from this cooperative, has implemented a system with a technical and most importantly an economic feasibility for electricity generation using biogas produced from cow manure. This carries the advantage of complying with the environmental requirements established by Costa Rican environmental Laws.

The farm is located in Costa Rica in the province of Alajuela, at an altitude of 260 to 330 ft, with an annual precipitation of 160 in, an average temperature of 82 F and 80% humidity.

This dairy farm has a common production system of the region, in which cows remain in the pastures a majority of the time year round. The cows remain in a rotating system, in which they are moved to a different pasture daily, giving each lot 30 days of rest before they return to the original pasture. With the purpose of keeping the animals in a fresh environment during the hottest time of the day (from 9 AM to 3 PM) the milking cows are taken to the milking facilities. The cows enter for the milking process at 2 AM, and are sent to the corrals to supplement their feeding (grain, minerals, and grass) until their second milking time (1 PM). After this, cows are sent back to the pastures where they spend the rest of the day.

Mr. Romero milks an average of 80 cows, with an average body weight of 770 lbs, producing 27 lbs milk animal^{-1} day^{-1}. Animals remain in the facilities a little less than 9 hours a day, and considering an excretion average of 8% of the animal's body weight per day (24 hrs), the estimated in-barn manure production is 1900 lbs per day. Regarding the use of water for the cleaning and washing process, the use of 660 gallons per day it's estimated (washing method: hosing).

Much work was done to accomplish an ideal low cost anaerobic digestion system, which includes:

1. Rainfall runoff separation: Rainfall runoff can negatively affect the anaerobic digester, by incrementing the mix volume entering daily and affecting directly the HRT (hydraulic retention time), which consequently will affect the performance of the digester. The installation of gutters was implemented in some areas of the facilities.

2. Sand separator system: Considering animals bring an important amount of sand from the pastures, and an important amount of sand is removed from the floors during the washing process, two sand separators were installed before entering the biogas system. They consist of concrete blocks where water speed is slowed down, letting sand precipitate to the bottom.

3. Fiber solid screen separator: Manure contains an important fraction of low degradable solids with a negligible fraction of methane potential compounds. Considering that manure is washed and then passed through a screen separator, it's estimated that 5 to 10 % methane potential is lost in the fiber. Fibrous solids containing (85% NDF, DMB) are separated and converted into compost. It's estimated that 25% (w/w) from total manure is separated as fiber solids (475 lbs day$_{-1}$).

Figure 2. Fiber solid screen separator

4. Compost: All fibrous solids are pilled and aerated manually, two to three times a week. After 2 weeks of processing, the compost produced is applied to pastures as an organic fertilizer and soil amendment.

5. Anaerobic digestion system: The diluted and separated manure (liquid slurry) is conducted to an anaerobic digestion system. This design is a type of Plug Flow Digester, with influent entering with less than 1% TS. The digester has no temperature control or agitation/mixing system.

The digesters are, two 66 ft long, tubular PVC membrane bags (40 mills thickness), with 8.2 ft in diameter. This type of digester is common of this region due to its low cost; it is culturally called "sausage digester". The tubular PVC membrane bags are installed in the ground. The digester has 32,500 gallons of effective liquid volume with 40 HRT, and 2,700 cu ft of biogas accumulation chamber.

6. Effluent tank: All effluents, after they leave the digester, anaerobically treated with fewer odors and pathogens, as well as a rich, and highly available nutrients, are stored in a 6600 gallon concrete tank for land application. The material is used as a fertilizer for the pastures.

7. Hydrogen Sulfide scrubber: All biogas is vacuumed through a H_2S filter consisting of a commercialized scrubber made of iron oxide; biogas enters containing more then 500 ppm and leaves with less than 1 ppm H_2S. It's estimated that the H_2S filter, may last more than 5 years with no maintenance.

8. Biogas engine generator system: After H_2S has been filtered out, the biogas is sent towards the engine generator. Biogas travels in 1'' pvc pipe 52 yards, from the digester to the engine generator. At the entrance of the generator unit, a blower is used to increase pressure to ~1 psi.

Figure 3. Biogas engine generator unit

The electric generator is a GENERAC 16 kW internal combustion engine, designed for propane and natural gas, with modification for biogas (65% CH_4) done by Agromec in Costa Rica.

The biogas produced power is used to substitute electricity for the milking process, powering a 5 hp vacuum pump 4 hours a day (22 Amperes x 250 volts = 5,5 kWh^{-1} x 4 hour day^{-1} = **22 kWh^{-1} day^{-1}**). An AC-250 Diaphragm flow meter was installed between the blower and the generator. A consumption of 127 cu ft of biogas per hour (25% efficiency) has been measured. The farm can annually substitute up to 8030 kWh^{-1}.

Due to lack of equipment, biogas production hasn't been measured, but it's estimated that this farm may be able to produce between 700 to 900 cu ft a day. The engine generator has been used everyday, which means that the digester has been able to provide no less than 508 cu ft per day; it's estimated that the farm in the near future may be able to power other electric equipments.

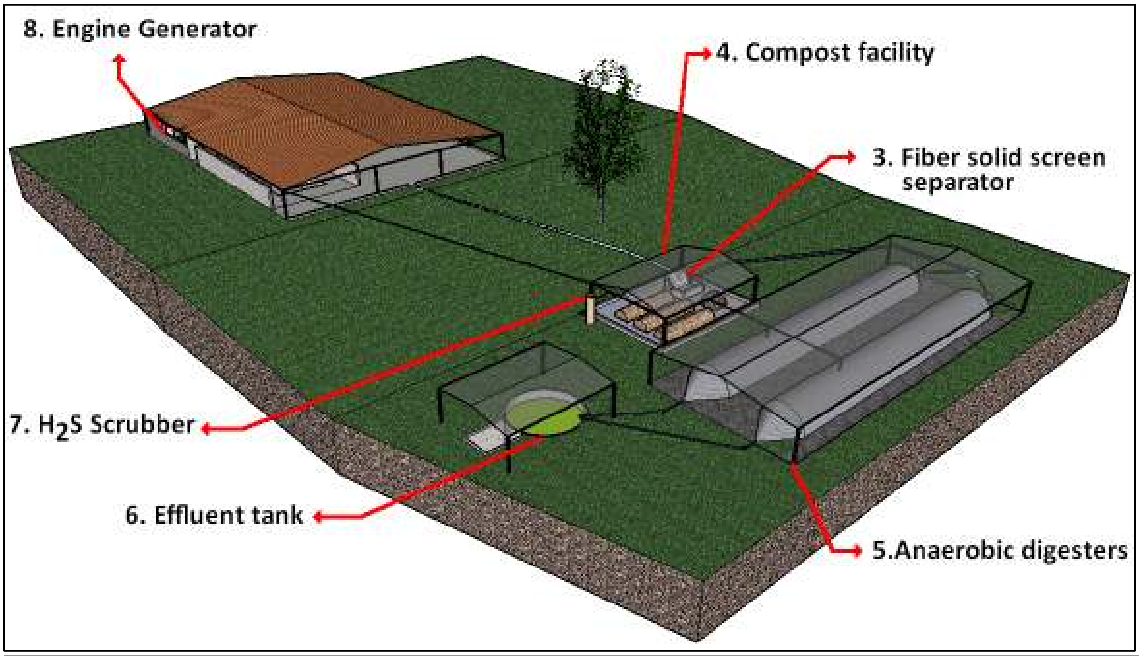

Figure 4. Complete system diagram

Financial information

The cost regarding the complete system, including changes done in infrastructure in the corrals and milking parlors, the sand separator, fiber solid screen separator, anaerobic digesters, effluent tank, H_2S scrubber and electric generator, was calculated at $19,275.

Component	Cost
Fiber solid screen separator	$1940
Compost area	$1435
Anaerobic digesters	$4170
Effluent tank and irrigation equipment	$4980
H_2S Scrubber	$850
Biogas engine generator	$5900
TOTAL	**$19,275**

The integrated, low cost system, for electricity generation, also provides other sources of income, such as the organic compost that can be sold or used in the farm. Also, the effluent used for land application represents another source of income, as the farm becomes less dependent on chemical fertilizer. Finally, and probably most importantly, the system represents a legal and environmental responsibility accomplishment, which allows Mr. Romero to stay in the dairy business.

It's estimated that the farm will produce 300,000 gallons of effluent and 100 tons of organic compost a year. Considering its nutrient content, and the value of nitrogen, phosphorus and potassium in the market, both sources of soil amendments are estimated as an income of \$3,890 $year^{-1}$.

The substitution of 8,030 kWh^{-1} $year^{-1}$ and a cost of \$0.19 kWh^{-1} for electricity is an estimated savings of \$1,525 $year^{-1}$ on electricity.

The cost of maintenance of such system is low. There is no electric equipment such as pumps or mixing/agitation systems; the use of gravity is the main source of water movement through the system. The total cost of maintenance a year, considering labor for the compost and the fiber solid separator area, plus basic maintenance to the generator unit, is \$1560 $year^{-1}$.

The following proves this system can be paid off in 5 years with an internal rate of return of 20%.

Conclusion

- The technical feasibility to install a low cost, integrated biogas system for manure management is a reality, including generating electricity with biogas.
- An integrated project that treats its manure, as well as produce organic compost, liquid fertilizer (effluent), and generates electricity with biogas, shows financial indicators of a feasible project.
- Improving and optimizing the anaerobic digester at a low scale, maintaining a low cost system, may be a solution to improve the financial indicators.
- Combining the possibility of gaining carbon credits (CDM), plus government supports such as attractive loans, or incentives for this type of green projects, may also be a way to increase the number of farms implementing such projects.
- The rule of thumb of needing over 500 cows for a project to be economically feasible may be modified for smaller farmers, using this type of design and technology.

Figure 5. Effluent tank

Figure 6. Compost facility