Global Methane Initiative

Establishing Biogas-Powered Cold Storage in Rural India for Methane Mitigation and Sustainable Food Systems

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Contents

Executive Summary

Mitigating post-harvest food loss can result in economic benefits for farmers, increase food security, and reduce methane emissions from organic waste. An estimated 30 percent of food produced in India is lost or wasted, despite the country ranking 94th out of 100 on the 2020 Global Hunger Index (Bagai, 2020). Almost half of post-harvest food losses in India are attributed to the lack of a reliable cold chain, the integrated network of refrigerated storage facilities, transportation, and merchandising technologies that maintain food quality moving from harvest to the consumer (Peters et al., 2019). Cold-chain technologies are energy intensive and typically powered by fossil fuels. In recent years, there has been a focus on clean energy powered cold-chain solutions, including renewable energy powered cold storage facilities that store commodities immediately after harvest.

The U.S. Environmental Protection Agency (EPA) conducted a financial pre-feasibility assessment on the potential for direct biogas-powered cold storage facilities in Maharashtra, India. EPA used the Global Methane Initiative's (GMI) Organics Economics (OrganEcs) and Anaerobic Digestion Screening Tool to assess an anaerobic digestion system processing livestock manure into biogas which is then used by an absorption cooling technology to generate off-grid cold storage without electricity. Data collected from farmers in Maharashtra included the potential crops available for cold storage and commodity prices. Project developers and technical experts provided data on the facility capital and operating costs, as well as sale prices for biogas, digestate, and cold storage fees.

The internal rate of returns determined from the pre-feasibility assessment suggest that a biogas-powered cold storage facility pilot in Maharashtra is a potentially profitable refrigeration solution for the rural village with limited grid connection. The analysis identified a range of prices for biogas, digestate, and cold storage fees to make the system financially viable. Additionally, farmers can sell more of their harvest at potentially higher prices with available storage. As for climate benefits, the pilot project could provide an estimated 79 percent reduction of total annual GHG emissions in megatons carbon dioxide equivalent (MtCO2e) and an 83 percent reduction in annual methane emissions.

To develop the pilot project demonstrating project viability, stakeholders can leverage ongoing initiatives and funding from the Government of India and corporate social responsibility (CSR) funds to increase biogas production and reduce methane. The Swachh Bharat Mission (Clean India Mission) provides funding to productively use agricultural waste and crop residues to generate biogas in rural areas. The Galvanizing Organic Bio-Agro Resources (GOBAR)-DHAN scheme provides funding to create clean villages in India by using livestock manure and solid agricultural waste to produce biogas or bio-CNG. With a successful demonstration project, off-grid biogas-powered cold storage facilities could be scaled across India and internationally. The pre-feasibility assessment process utilizes GMI's existing tools and can be easily replicated by stakeholders seeking renewable energy powered cold storage in remote locations in India and abroad.

1. Introduction

This study examines the potential for biogas-powered cooling systems in India by conducting a financial pre-feasibility analysis for a pilot project in the state of Maharashtra. More than two-thirds of the workforce in the country relies on agriculture as their livelihood, with more than 600 million people involved in agriculture or agriculture-related activities (GMI, 2020). Post-harvest food loss results in economic losses for farmers, reduced food security, and methane emissions as organic material breaks down. Food loss, also known as post-harvest loss, is defined by the Food and Agriculture Organization (FAO) of the United Nations as a "decrease in quantity or quality of food resulting from decisions and actions by food suppliers in the segment of the chain excluding retail, food service providers, and consumers (2021)." In India, post-harvest losses pose the following challenges:

- Social: An estimated 30 percent of food is lost or wasted in India despite the country ranking 94th out of 100 on the 2020 Global Hunger Index (Bagai, 2020).
- Economic: A 2016 report from the Central Institute of Post-Harvest Engineering and Technology (Punjab Agricultural University) estimated annual post-harvest food loss of over US $12 billion in India alone (Agarwal et al., 2021). Additionally, when all farmers harvest and bring commodities to market on the same schedule, the surplus drives commodity prices down reducing revenue potential of India's farmers.
- Environmental: Agriculture is responsible for approximately 16 percent of the nation's greenhouse gas (GHG) emissions (Timperley, 2019). The primary sources of agricultural methane emissions are livestock enteric fermentation, livestock waste management, rice cultivation, and agricultural waste burning (GMI, 2013). Of these, livestock waste management, which represents seven percent of global methane emissions, offers a viable, near-term opportunity for methane recovery and utilization (GMI, 2013). Additionally, agriculture is an energy and water intensive process, which is wasted when post-harvest foods are lost.

When livestock manure and organic components in agro-industrial waste decompose, the process produces and emits methane, a potent greenhouse gas with up to 30 times the heat trapping potential of carbon dioxide. Capturing this methane provides an opportunity to lower the amount of methane accumulating in the global atmosphere and harness this renewable energy source. Anaerobic digestion is a biological process in which bacteria break down organic matter in the absence of oxygen. Anaerobic digestion systems utilize airtight chambers where manure, biosolids, food waste, other organic wastewater streams, or combinations of these feedstocks decompose to produce biogas—a blend of methane and carbon dioxide—and digestate, a nutrient-rich output that can be used as fertilizer.

For several decades, biogas systems have been used commercially, including in the agricultural management sector, to reduce methane emissions, improve manure disposal, control odors, and produce biogas for energy (GMI, 2013). Biogas generated from readily available agricultural wastes such as manure can be used commercially as an alternative to fossil fuels, such as natural gas.

In the agricultural sector, biogas can power cooling or refrigeration systems that improve commodity revenue, reduce waste, and reduce reliance on fossil fuels. Expanding access to cold storage systems in rural India could mitigate food and economic losses and improve food security through increased storage of surplus agricultural commodities and increased revenue for farmers selling produce for higher off-peak prices. Cold storage facilities in India's rural communities are limited by funding availability and unreliable electricity. Given the right equipment and financing mechanisms, biogas sourced from animal waste or agricultural residues could provide cheap, reliable, off-grid alternatives to conventional electric powered cold storage facilities in remote locations.

1.1 Current Uses of Biogas in India

At present, biogas generated from agricultural residue, municipal solid waste, and manure is used in India for cooking, heating, transportation, and electricity generation (GMI, 2020). Use of biogas for these purposes not only reduces methane emissions from the waste management systems, but it also can displace the use of other fuels, such as fossil fuels which can provide additional GHG reductions as well as air quality benefits.

1.2 Potential Use of Biogas for Absorption Cold Storage in India

Biogas generation from agricultural feedstocks can be leveraged to provide cooling using a method called absorption cooling. Absorption systems are refrigeration units that are powered by heat instead of mechanical compressors to provide the energy required for cooling. A biogas-powered cooling facility can use the biogas directly as a source of heat or a heat transfer fluid such as hot water heated by biogas in a separate biogas-burning system. Typically, the heat in these systems is supplied as steam, hot water, waste heat, or the combustion of gas. The cold energy generated by the absorption unit is stored in a thermal buffer and released when the cooling occurs (e.g., when the system is turned on to chill produce or milk cans).

These systems use a refrigerant with a low boiling point, such as ammonia. As the refrigerant evaporates within the system, it extracts heat from its surroundings. The heat is transferred to a coolant, often water or a brine solution. Heat is used to separate the refrigerant from the coolant and continue the refrigeration cycle. Unlike the more common compressor-based refrigeration systems, an absorption system does not use hydrochlorofluorocarbons or hydrofluorocarbons as refrigerants, significantly reducing the overall GHG impact. The refrigeration system typically utilizes 22,000 Kcal energy of heat per hour from hot water at 100 to 120°C, to produce a refrigeration effect of 36,000 btu per hour yielding cold storage temperatures up to -5°C in an off-grid system.

Because this technology does not require electricity, it can work without access to the grid and does not require a diesel backup generator, thus significantly improving the opportunities for remote farmers. Using biogas as the heat source, rather than diesel, to drive the refrigeration cycle has many advantages, including improved air quality from reduced diesel emissions and efficient utilization of farm waste to generate the biogas as fuel for the refrigeration system.

While this study analyzes a cold storage system fully powered by biogas, there are also options for a hybrid biogas and solar photovoltaic technology combined for installation of off-grid cold storage systems (Sumon Rashid et al., 2018).

1.3 Biogas-Powered Cold Storage Technologies

Table 1-1 identifies technology providers, primarily in India, offering biogas-powered off-grid cold storage products. As of fall 2021, the reviewed technologies appear to have been implemented as small-scale pilot projects with hopes to expand broadly in India. Research identified relevant projects in India using New Leaf's GREENCHILL technology but did not uncover India-specific feasibility studies or implementation updates for rural biogas-powered cold storage. Solar power appears to be popular in India for containerized cold-storage services in off-grid locations. These implementations can provide some insights into successful business models, although the technology itself is different.

Table 1-1: Commercialized Biogas-Powered Cooling Technologies

Technology Provider	Technology Overview	Webpage
GREENCHILL	New Leaf is based in New Delhi and has successfully designed, developed, manufactured, and installed 'GreenCHILL', an off-grid, compressor-free, renewables-based refrigeration system, powered by farm waste such as biogas, cow dung cakes, biomass pellets, wood and hay. To date, New Leaf has installed and commissioned 9 units in Gujarat and Northeast India. In Gujarat, the units are sold to individual farmers for cold storage and ripening of agricultural produce and fruits. In the Northeast they are sold through government channels mainly for fisheries.	New Leaf (newleafdynamic.com)
Fraunhofer - India	Self-contained off-grid unit that hosts a digester as well as separate food-storage unit. The system can also be combined with solar and combined heat and power plants.	Biogas driven Cold Storage for India (fraunhofer.de)
Greenrich	Chennai-based (Tamil Nadu, India) company. Biogas fired NH_3/H_2O-absorption chiller is being used to provide cooling. The residual of fermentation can be used as a fertilizer.	Containerized Biogas To Cold Storage – Greenrich Enviro Solutions Pvt Ltd
Kyanko CleanTeach + BERT Technologies	BERT KANKYO (Indian + German initiative) is a biogas-driven cold storage system which runs on unused organic waste such as municipal solid waste, food waste, agricultural waste, market waste, and biowaste.	Company video on biogas for cold storage: https://www.youtube.com/watch?v=kmgp5DHFD8A

2. Pilot Project Research in Maharashtra

Karanjkhop and Randullabad, located approximately 3.5 km apart in the Satara district of Maharashtra state, were identified for study due to Gram Panchayat, the local village government, and farmer interest in developing biogas plants under the Galvanizing Organic Bio-Agro Resources (GOBAR-DHAN) scheme from the Ministry of Drinking Water and Sanitation. At present, both villages have small-scale biogas plants at the household level that are used to generate gas for cooking. Additionally, each village has a small electric-powered cooling facility used for storing milk. Nearby villages in Maharashtra utilize electric-powered cooling facilities to store potatoes and onion seed.

Figure 1: Randullabad and Karanjkhop Village Map. According to 2011 census data, Randullabad had a total population of 1,857 with 395 households and Karanjkhop had a total population of 2,950 with 633 households (Government of India, 2011).

2.1 Information Collection

To understand the viability of a biogas-powered cold storage system, EPA collected information on each village's commodity production and feedstock availability, including:

- Business model assumptions, including land ownership, operational ownership, potential funding sources, and the structure of the cooling storage revenue stream.
- Commodity information, including crops available for storage, harvest period, and prices.
- Feedstock information, or the amount of organic material available for use in the AD system.

Village site visits with Gram Panchayat heads and farmers occurred in late 2021. Farmers provided the commodity production estimates, harvest period, and market prices. Farmers also provided livestock herd estimates, including animal types and counts, which were used to calculate average manure production used as a feedstock in the AD system.

Because of limitations in the availability of feedstocks and commodities in Randullabad, EPA focused this pre-feasibility analysis on a pilot project only in Karanjkhop, using manure and commodities available in the village. Upon the Karanjkhop pilot project's success, the project could be expanded to include storage of commodities from Randullabad.

2.1.1 Business Model Assumptions

Under the GOBAR-DHAN scheme, the Gram Panchayat could provide the land for the anaerobic digestion and cold storage facilities at no cost, reducing the total capital investment. The Panchayat expressed interest in seeking funds for both systems through current government schemes and corporate social responsibility (CSR) funding. For example, the Bharatiya Agro Industries Foundation (BAIF), a non-profit organization in India focused on rural development, has used CSR funds to support development projects in Maharashtra.

Efficient business models play a major role in successful deployment of off-grid technologies in developing economies. In addition to loans and government grants for individual procurement and on-site installation, cooling-as-a-service is a popular business model for cold storage where the customer pays for cooling on a usage basis rather than purchasing the cooling equipment directly. Each user is typically given a space and reusable tray or crate for commodity storage. This model creates incentives that optimize efficiency and maintenance (Ideas to Impact, n.d.). This approach to cooling is attractive in off-grid settings due to its low capital intensity and minimal technical capacity requirement for the end user. EPA's analysis evaluates a pay-as-you-store business model due to the pilot project's target audience of small market vendors. Pay-as-you-store models are particularly attractive for small market vendors who wish to prolong the shelf life of perishable goods but do not currently have access to electricity or other secure storage areas (Ideas to Impact, n.d.).

2.1.2 Anaerobic Digester Feedstock Availability

In both villages, livestock manure is mainly used for agriculture and horticulture activity. A small number of farmers and villagers use livestock manure as dung cakes for cooking or heating applications.

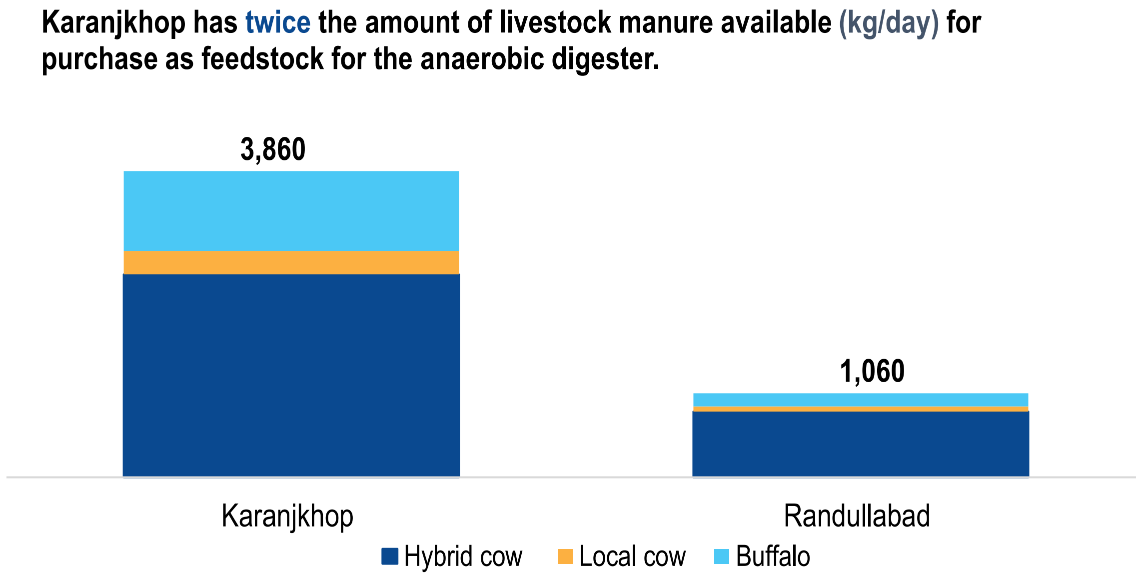

Figure 2: The manure available in Karanjkhop can be purchased from farmers by the digester to use as a feedstock. In both villages, manure is currently stored in a pile for approximately eight months before being used for pasture applications. EPA obtained feedstock availability by counting livestock and estimating manure per livestock type during the site visit in 2021. EPA studied livestock manure as the only feedstock type for the anaerobic digester. However, there is potential for agricultural residues and food waste to be used as feedstocks in future projects.

2.1.3 Commodity Production and Harvest

Karanjkhop primarily produces four commodities that could be stored in a cooling facility: tomatoes, peas, custard apples, and beans. Randullabad primarily produces three commodities that could be stored in a cooling facility: tomatoes, peas, and custard apples. Figure 3 shows the monthly harvest for Karanjkhop.

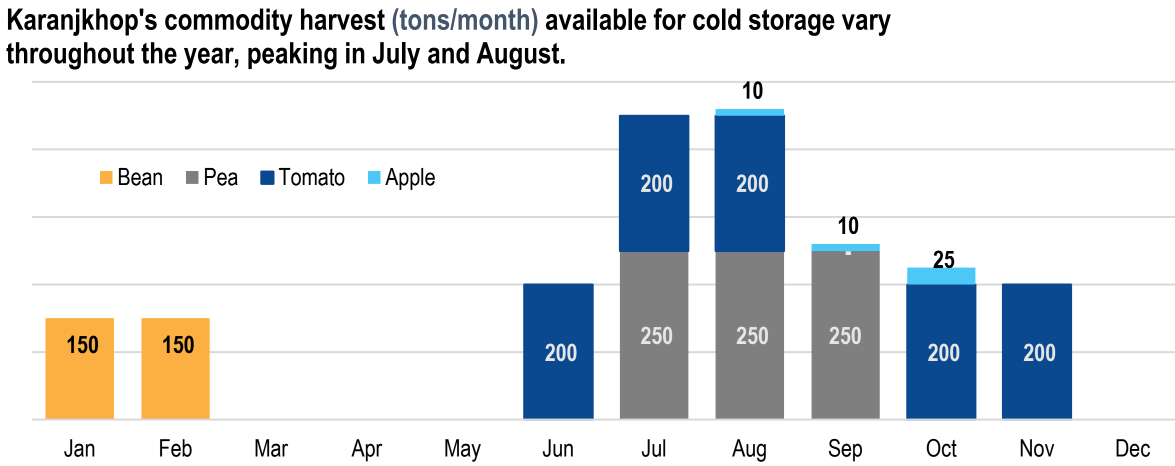

Figure 3: Karanjkhop has four commodities harvested throughout the year that could be stored in the refrigeration unit. Even though farmers do not harvest crops during four months of the year, commodities can be stored for weeks after harvest. Due to the availability of four commodifies for storage in Karanjkhop, the pilot project focused on storage of a single village's crops. EPA obtained monthly and annual production for each commodity from farmers during the site visit in 2021.

2.1.4 Commodity Prices

On- and off-season pricing, as shown in Figure 4, was determined through mandi (market) public information and in consultation with farmers and stakeholders. These values were used in the financial model to determine the range of prices that could be charged by the cold storage facility operators to make the storage system financially feasible.

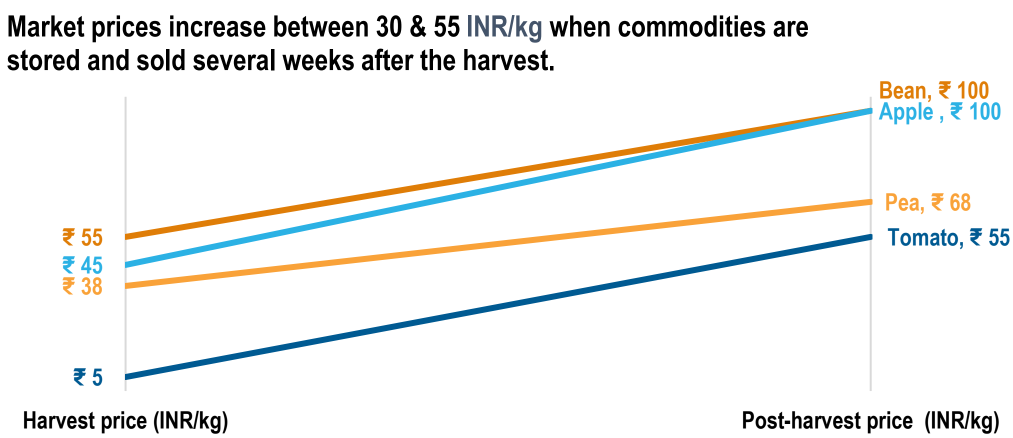

Figure 4: The difference in market price per kilogram during and after the harvest period range between 30 and 55 INR depending on the commodity. Tomatoes and beans can be stored for 2 - 4 weeks post-harvest. Peas and custard apples can be stored between 1 - 2 weeks. EPA obtained pricing information during 2021 site visits. Lal Basediya et al., 2013 provided storage length data for each commodity.

3. Financial Pre-Feasibility Analysis

The financial pre-feasibility analysis sought to determine if the biogas and cold storage systems can operate at a break-even or profitable level by using tools developed by GMI to estimate the internal rate of return (IRR). The IRR estimates the annual effective compounded return rate and is used to determine the profitability of an investment. A target IRR for infrastructure projects may range between 9 and 15 percent; however, with the support of the Panchayat, these community systems are not necessarily required to generate large profits. Stakeholders from BAIF noted that while the IRR is a useful financial metric, it is not always a major selling point for community projects. The actual implementation and proof of concept on the ground may be more important in driving widespread adoption.

EPA conducted separate financial pre-feasibility assessments for 1) the anaerobic digestion facility to produce biogas and 2) the cold storage facility to enable the adaptive cooling process through the purchase of the biogas generated by the anaerobic digestion system. In actuality, the two facilities are likely to be co-located and operate as a single business entity. To scale up deployment of similar systems EPA determined it could be beneficial to demonstrate potential profits from small-scale biogas-powered cold storage systems.

The financial analysis of the anerobic digestion system is focused on a pilot project in Karanjkhop due to the availability of livestock manure and commodities available for storage. Continued access to adequate feedstock ensures that a biogas-powered cooling system can function reliably. Though subsidies may be available for small scale biogas-powered cooling system projects in Randullabad and Karanjkhop, the financial model only considered subsidies when determining financial feasibility of the cold storage system, not the anaerobic digestion system. Additional assumptions used in both analyses are listed in Appendix B: Economic Assumptions.

3.1 Anaerobic Digestion System Assumptions and Results

The Organics Economics (OrganEcs) – Anaerobic Digestion tool[1] was used to generate initial expense and revenue estimates of the anaerobic digestion system and calculate the expected IRR based on a facility lifespan of 15 years. OrganEcs requires data on AD system feedstocks, facility information, and economic inputs to generate results. Based on the estimated biogas requirements of the cold storage system, the AD system produces least 50 m^3 per day (1,500 m^3 per month) and has a feedstock capacity of 1,525 kg of livestock manure per day.

[1] OrganEcs was developed by EPA under the auspices of the Global Methane Initiative and in support of the Climate and Clean Air Coalition. OrganEcs is a tool for estimating the costs associated with organic waste management projects, including AD. Model outputs should be viewed as preliminary results that can be used for planning purposes and estimates should be verified through detailed feasibility studies prior to project development, or through the solicitation of bids from qualified firms.

Based on the key assumptions listed below and in Appendix B: Economic Assumptions, OrganEcs estimated an IRR of 3.3 percent for the AD system. The results can be used by project proponents to move the pilot project forward to a full, detailed feasibility study. Based on initial assumptions, which did not include available Government of India subsidies, an AD system is financially feasible in the village. The full OrganEcs model includes initial estimates of the capital expenditure (CAPEX) and total operations and maintenance (O&M) expenses for year one and can be viewed on the GMI resources page alongside the report.

3.1.1 Assumptions

Facility and economic expense assumptions used in the tool are listed in Table 3-1 and identify the key capital and operating expenses of the biogas system to utilize 1,525 kg of livestock manure per day to produce 50 m^3 of biogas per day needed for the cold storage facility. The capital costs and labor requirements were provided by in-country partners based on similarly sized systems. The feedstock purchase price may vary between 0.4 to 1 INR per kg. For the final model, a feedstock purchase price of 1 INR/kg was used to reflect the high end of the range. The sensitivity analysis below considers both 1 INR/kg and 0.7 INR/kg to procure manure as a feedstock.

Table 3-1: Key Anaerobic Digester System Expense Assumptions

Assumption	Value	Source and additional notes
Anaerobic digestion equipment and site development costs	2,200,000 INR	Project developers and sector experts
De-watering equipment	300,000 INR	Project developers and sector experts
Feedstock purchase price	1,000 INR/tonne	Project developers and sector experts, converted from 1 INR/kg
Employees	2 full time at 10,000 INR/month	Project developers and sector experts

Facility revenue assumptions used in the tool are listed in Table 3-2 showing the sales of biogas to the cold storage facility as well as sales of solid digestate and liquid slurry digestate to farmers. The biogas and digestate sale prices may vary based on market conditions. The selected values for the final model reflect the high end of the ranges. The sensitivity analysis below considers a range of prices for the biogas and solid digestate sales price.

Table 3-2: Key Anaerobic Digester System Revenue Assumptions

Assumption	Value	Source and additional notes
Biogas sale price	25 INR/m^3	Project developers & BAIF
Digestate (solid) sale price	4,000 INR/tonne	BAIF, converted from 4 INR/kg
Liquid effluent sale price	454 INR/tonne	BAIF, converted from 0.5 INR/liter

3.1.2 Sensitivity Analysis

The first sensitivity analysis considers a range of biogas sales and solid digestate sale prices using the model's feedstock procurement cost of 1 INR/kg, the final model assumption. In Table 3-3 below, the yellow box is the IRR from the final model assumptions. The blue box indicates an approximate breakeven point where biogas can be sold for 20 INR/m^3 and solid digestate for 4.5 INR/kg.

Table 3-3: Sensitivity Analysis of the anaerobic digestion system using 1 ING/kg as a feedstock cost and variable biogas and digestate sale prices.

	Digestate Sale Price (INR per kg)				
Biogas Purchase Price (INR/m3)	**₹ 3.0**	**₹ 3.5**	**₹ 4.0**	**₹ 4.5**	**₹ 5.0**
₹ 8.0	-15.0%	-14.4%	-13.4%	-12.4%	-11.2%
₹ 10.0	-12.7%	-11.7%	-10.7%	-9.6%	-8.3%
₹ 15.0	-7.4%	-6.3%	-5.2%	-4.0%	-2.7%
₹ 20.0	-3.1%	-2.0%	-0.8%	0.6%	2.0%
₹ 25.0	0.7%	1.9%	3.3%	4.8%	6.4%
₹ 28.0	2.9%	4.2%	5.7%	7.3%	9.1%

The analysis below considers the same range of biogas and solid digestate sale prices using a lower feedstock procurement cost of 0.7 INR/kg.

Table 3-4: Sensitivity Analysis of the anaerobic digestion system using 0.7 ING/kg as a feedstock cost and variable biogas and digestate sale prices.

	Digestate Sale Price (INR per kg)				
Biogas Purchase Price (INR/m3)	**₹ 3.0**	**₹ 3.5**	**₹ 4.0**	**₹ 4.5**	**₹ 5.0**
₹ 8.0	-11.7%	-10.4%	-9.0%	-7.5%	-5.7%
₹ 10.0	-8.9%	-7.6%	-6.2%	-4.6%	-2.8%
₹ 15.0	-3.3%	-1.9%	-0.4%	1.4%	3.3%
₹ 20.0	1.4%	2.9%	4.6%	6.6%	8.7%
₹ 25.0	5.7%	7.5%	9.4%	11.7%	14.2%
₹ 28.0	8.3%	10.2%	12.4%	14.8%	17.6%

3.2 Cold Storage System Assumptions and Results

A financial analysis based on the OrganEcs' data fields and calculations was created in Microsoft Excel to generate initial expense and revenue estimates of the biogas-powered cold storage system and calculate the expected IRR based on a facility lifespan of 10 years. The financial inputs such as capital and operating expenses reflect a technology like New Leaf's GREENCHILL system. Based on the estimated biogas requirements of the cold storage system of 50 m^3 per day (1,500 m^3 per month) and a maximum storage capacity of 20,000 kg at a time. This storage capacity represents the highest storage capacity of the GREENCHILL systems, which range from 10,000, 15,000 and 20,000 kg.

As discussed above, the system assumes a fixed pay-as-you-store charge to farmers per kg per week. The model assumes the annual production (kg/year) for tomato, bean, and peas are divided equally among the months of harvest. The model assumes custard apple harvest varies by month, based on information provided by farmers during the site visit. When commodities are harvested, a set number of commodities are held and sent for cold storage; this amount is based on the storage capacity of the GREENCHILL technology. Half is stored in the month of harvest; the other half is stored in the subsequent month due to allow for variability in harvest times each month and the storage time (either 1-2 or 2-4 weeks for each commodity). Table 3-5 shows the total maximum storage capacity for each commodity assuming that the single commodity is being stored in the chiller at a time.

Table 3-5: Total storage potential by week and month based on the density of the commodity type.

Type of commodity	Maximum storage capacity (Kg/ batch)	Maximum No. of Batches	Total maximum storage capacity (kg/month)
Tomato	14,500	4	58,000
Bean	9,000	4	36,000
Pea	9,000	4	36,000
Custard apple (Sitaphal)	9,000	4	36,000

Based on the key assumptions listed below and in Appendix B: Economic Assumptions the cold storage model generated an IRR of 7.9 percent. Based on initial assumptions, which include land provided at no charge and did include available Government of India subsidies, a biogas-powered cold storage system is financially feasible in the village. The full model includes initial estimates of the capital expenditure (CAPEX) and total operations and maintenance (O&M) expenses for year one and can be viewed GMI resources page alongside the report.

3.2.1 Assumptions

Facility and economic expense assumptions used in the tool are listed in Table 3-6 and identify the key capital and operating expenses of the cold storage system to 50 m^3 of biogas per day purchased from the digester.

Table 3-6: Key Cold Storage System Expense Assumptions

Assumption	Value	Source and additional notes
Facility lifespan	10 years	Project developers and sector experts
Equipment and site development costs	2,000,000 INR	Project developers and sector experts
Biogas purchase price	25 INR/m^3	Project developers and sector experts
Employees	1 full time at 10,000 INR/month	Project developers and sector experts

The total revenue for the cold storage system was calculated by multiplying the monthly commodity storage potential for each commodity by the fixed storage fee of 3 INR per kg per week. The estimated monthly commodity stored in the system and total revenue from the storage cost paid by farmers is shown in Table 3-7. The total amount stored remains within the maximum capacity of the cold storage system of 20,000 kg at any given time because the total monthly storage is split between 1-2 or 2-4 weeks depending on the commodity.

Table 3-7: Cold Storage Commodities and Total Revenue

Month	Type of commodities stored	Total available for storage (kg/month)	Total revenue (INR/month)
January	Bean	18,000	₹ 54,000.0
February	Bean	36,000	₹ 108,000.0
March	Bean	18,000	₹ 54,000.0
April	(None available)	-	₹ 0.0
May	(None available)	-	₹ 0.0
June	Tomato	29,000	₹ 87,000.0
July	Tomato and pea	23,500	₹ 70,500.0
August	Tomato, pea, and apple	23,500	₹ 70,500.0
September	Tomato, pea, and apple	23,500	₹ 70,500.0
October	Tomato, pea, and apple	23,500	₹ 70,500.0
November	Tomato and apple	23,500	₹ 70,500.0
December	Tomato	29,000	₹ 87,000.0
	Total	**247,500**	**₹ 742,500.0**

3.2.2 Sensitivity Analysis

The cold storage system sensitivity analysis considers the same range of biogas prices as the previous analysis as well as fixed pay-as-you-store prices per kg per week. In Table 3-7 below, the yellow box is the IRR from the final model assumptions. The blue box indicates an approximate breakeven point.

Table 3-8: Sensitivity Analysis of the cold storage system based on changing the biogas purchase price and cold storage charge.

	Cold storage charge (INR per kg per week)			
Biogas Purchase Price (INR/m3)	**₹ 2.0**	**₹ 2.5**	**₹ 3.0**	**₹ 3.5**
₹ 8.0	5.3%	12.3%	18.5%	24.3%
₹ 10.0	3.9%	11.0%	17.4%	23.2%
₹ 15.0	-0.1%	7.7%	14.4%	20.4%
₹ 20.0	-4.7%	4.1%	11.2%	17.5%
₹ 25.0	-10.2%	0.1%	7.9%	14.6%
₹ 28.0	-14.4%	-2.5%	5.8%	12.7%

3.3 Emissions Reductions Analysis

The project feedstocks and baseline manure management were entered into the Global Methane Initiative's Anaerobic Digestion Screening Tool[2] to determine the emissions reductions from the Karanjkhop pilot, as shown in Figure 5. The baseline management system assumes that manure is left to cure in an unmanaged pile for approximately eight months.

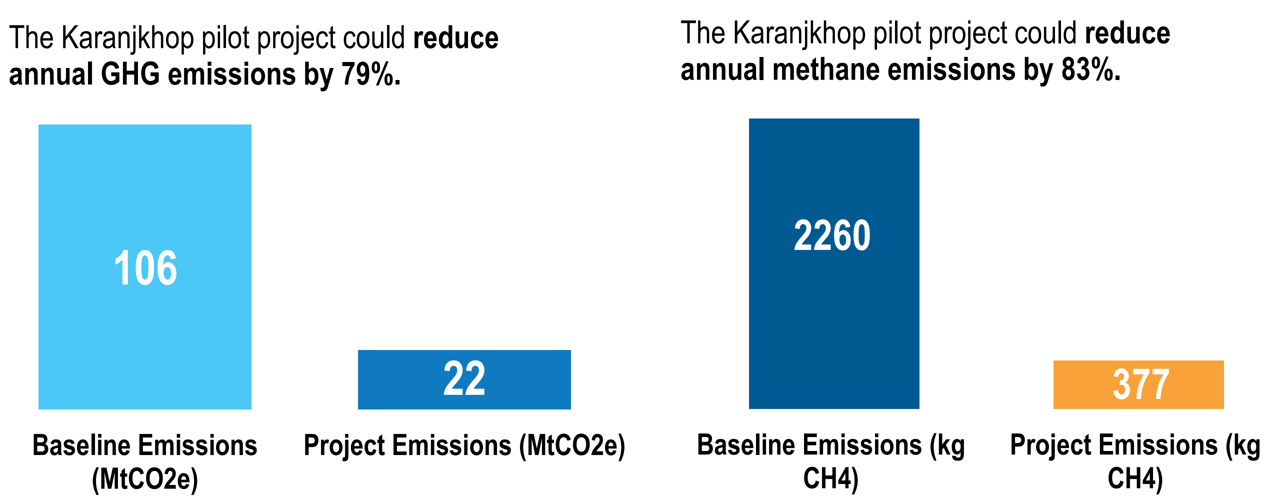

Figure 5: Estimated emissions reductions were calculated using the Anaerobic Digestion Screening Tool. The graph on the left shows estimated baseline and project emissions in metric tons of carbon dioxide equivalent (MtCO$_2$e), which represents an amount of a GHG whose atmospheric impact has been standardized to that of one unit mass of carbon dioxide (CO_2), based on the global warming potential of the gas. The graph on the right shows baseline and project emissions in kg of methane (CH_4).

[2] Anaerobic Digestion (AD) Screening Tool was developed by EPA under the auspices of the Global Methane Initiative and in support of the Climate and Clean Air Coalition. The AD Screening Tool enables users to conduct pre-feasibility analyses to evaluate AD opportunities for a variety of feedstocks, including organic municipal solid waste, livestock manure, agricultural residues, and wastewater.

4. Next Steps

The results of this pre-feasibility analysis indicate that a pilot project for small scale biogas-powered cold storage is potentially financially feasible in Karanjkhop. A full-scale feasibility analysis should be conducted by a project developer prior to project implementation. An additional cold storage facility in Randullabad or an expansion of the Karanjkhop facility to include commodities from both villages could be explored after analyzing the results from the pilot project.

The analysis determined that a lack of available commodities in April and May means that the cold storage system was not required for two months of the year (April and May). This will require project developers to find alternative uses for biogas, such as:

- Supply biogas via pipelines to the nearby households for cooking purposes
- Supply biogas to schools for use cooking midday meals
- Utilize biogas to generate off-grid electricity for street lighting and drinking water pumping, or to run an irrigation pump in the village
- Alternatively, the Karanjkhop facility could allow storage of commodities from surrounding agricultural villages.

Following the financial pre-feasibility analysis, project partners could work with the local community Gram Panchayat, NGOs, and other development groups to identify options for funding project development, such as government grants, CSR funds, or private financing. Additional uses for biogas during months without cold storage would be determined for the application. As noted in the financial models, construction for both facilities should take less than one year. After successful demonstration of the pilot project, the project team would assess predicted versus actual revenue and expenses and develop lessons learned to assist other rural areas. Using pilot project information, a strategy for scaling biogas-powered cold storage could be prepared for use in agricultural villages in states to be selected with input from MNRE. Development of additional projects would be done in consultation with the state agencies, village leaders, agricultural departments, farmers, technology providers, and other stakeholders.

Additional Resources

The following resources may be helpful for developing and operating AD projects

- Initial Project Checklist | US EPA
- EPA Biogas Toolkit
- AgSTAR Anaerobic Digester Project Development Handbook
- AgSTAR Anaerobic Digester/Biogas System Operator Guidebook
- Anaerobic Digestion Screening Tool
- Organics Economics (OrganEcs) Screening Tool – Anaerobic Digestion

Appendix A: Relevant Programs in India

India has invested in a national strategy to increase biogas production while reducing methane emissions, which includes policy initiatives, capacity-building, and public-private partnerships. This section describes various current policies and initiatives that help promote biogas development in India that may be relevant for the development of biogas-powered cold storage in rural areas. In addition to the climate benefits of biogas project development, the benefits of this strategy support India's sustainable development goals, which include providing affordable clean energy (GMI, 2020).

4.1.1 Galvanizing Organic Bio-Agro Resources – DHAN

India has undertaken the Swachh Bharat Mission (Clean India Mission), which is aimed at improving sanitation and cleaning India's cities, towns, and rural areas. The effort in rural areas, among addressing other issues, includes efforts to productively use agricultural waste and crop residues to generate biogas. The Galvanizing Organic Bio-Agro Resources (GOBAR)-DHAN scheme, led by the Ministry of Drinking Water and Sanitation, is an extension of the Swachh Bharat Mission. The program aims to improve management of biowaste, including animal waste, kitchen scraps, agricultural residue, market waste, and human waste. Livestock waste management in India can result in air pollution and associated health impacts when cattle manure is dried and used as a cooking fuel. Poor sanitation practices from manure discarded in open spaces results in land and water pollution and health impacts due to pathogens. GOBAR-DHAN is an effort to create clean villages and provide energy in India by using livestock manure and solid agricultural waste to produce biogas or bio-compressed natural gas (bio-CNG) (GMI, 2020).

States can choose to develop as many viable projects as possible to achieve effective biowaste management in their villages. Funding under the initiative will be based on the number of households in each Gram Panchayat, village, or small town with local government and the chosen model of operation. Villages cannot receive GOBAR-DHAN funding if they have used funding for other solid and liquid waste management projects under the Swachh Bharat Mission.

4.1.2 Indian Ministry of New and Renewable Energy Programs

The Ministry of New and Renewable Energy (MNRE) is the nodal Ministry of the Government of India for all matters related to new and renewable energy. MNRE aims to develop and deploy new and renewable energy projects, including biogas, to help meet the energy requirements of the country (Government of India, 2021a). In addition to the Waste-to-Energy Program and New National Biogas and Organic Manure Program detailed below, MNRE also leads the Biogas Power Generation (off-grid) and Thermal Energy Application Program.

Waste-to-Energy Program

MNRE promotes the waste-to-energy program, a national program to spur the recovery of energy from urban, industrial, and agricultural wastes through waste-to-energy projects. The program focuses on converting municipal solid waste and agricultural waste into fuel for heating and cooking, combined heat and power, and bio-CNG. MNRE has proposed financial incentives to encourage participation in these projects (EAI, 2017), including:

- Financial assistance through interest subsidies for commercial projects, capital cost for innovative demonstration projects that generate power from municipal or industrial waste and sewage treatment plants, and conducting studies on waste-to-energy projects and covering the full cost of such studies
- Incentives to the state nodal agencies for promotion, coordination, and monitoring of waste-to-energy projects
- Promotional activities including research and development, resources assessments, technology upgradation, and performance evaluations

While there are no limitations on size of the projects, based on the capital subsidy cap for individual projects, projects are typically in the range of 1,200 to 36,000 m^3 biogas/day. In July 2018, MNRE announced the continuation of the program to promote energy from urban, industrial, and agricultural waste and central financial assistance for three fiscal years (2017–2018, 2018–2019, and 2019–2020). The central financial assistance includes a capital subsidy of INR 1.0 crore (approximately US $150,000) per 12,000 m^3 biogas/day for biogas projects and INR 4.0 crore (US $600,000) per 4,800 kgs of bio-CNG/day generated from 12,000 m^3 biogas/day.

Bioenergy Schemes

MNRE promotes installation of biogas plants by implementing two bioenergy schemes for under off-grid/distributed and decentralized renewable power (Government of India, 2021b). Under both schemes, central financial assistance is available depending on the biogas generating capacity.

- New National Biogas and Organic Manure Programme, for biogas plant size ranging from 1 to 25 m^3 per day. Small biogas plants are eligible if the beneficiary has their own land, about 50 to 60 m^2, to install the biogas plant, has available manure for the feedstock, has an available water supply, and has the financial capacity for investing their own money (Government of India, 2021b).
- Biogas Power Generation (Off-grid) and Thermal Energy Application Programme, for setting up biogas plants in the size range of 30 m^3 to 2,500 m^3 per day, for corresponding power generation capacity range of 3 kW to 250 kW from biogas or raw biogas for thermal energy / cooling applications (PEDA, 2021).

Appendix B: Economic Assumptions

The table below shows the economic assumptions used in the financial analysis for both the anaerobic digestion and cold storage facilities.

Assumption	Value	Source and additional notes
Cost of land	0 INR	Under the GOBAR-DHAN scheme, land for a pilot project could be provided by the Gram Panchayat at no charge. In other cases, land would be purchased or leased
Government subsidy	0 INR	It could be possible for a project to obtain public funding, however this value was no included to determine if the project was feasible independent of public funding.
Labor cost per employee	120,000 INR/year	Project developers and sector experts
Annual interest rate	5.8%	National Bank for Agriculture and Rural Development (NABARD)
Annual inflation rate	4.91%	India CPI inflation rate
Tax levied on profits	0%	Profits are tax exempt
Goods and services tax levied on equipment	12%	Project developers and sector experts

References

Agarwal, M., S. Agarwal, S. Ahmad, R. Singh, and K. M. Jayahari. 2021. Food Loss and Waste in India: The Knowns and the Unknowns. Working Paper. Mumbai: World Resources Institute India. Available online at: http://www.wri.org/publication/food-loss-and-waste-in-india.

Bharatiya Agro Industries Foundation (BAIF). 2019. Vision and Mission. Available online at: https://baif.org.in/who-we-are/vision-and-mission/.

Bagai, A. 2020. Keeping Rural Harvests Cool: India Pilots Solution to Food Loss and Waste. Available online at: https://coolcoalition.org/keeping-rural-harvests-cool-india-pilots-solution-to-food-loss-and-waste/.

Lal Basediya, A., D. V. Samuel, and V. Beera. 2013. Evaporative cooling system for storage of fruits and vegetables – a review. *Journal of Food Science and Technology* 50(3) 429–442. https://doi.org/10.1007/s13197-011-0311-6.

EAI. 2017. Indian Government Support for Waste to Energy Projects. Latest News for Energy Efficiency, Solar, Wind, Biomass Power, Biofuels, Waste to Energy. Energy Alternatives India. Available online at: http://www.eai.in/ref/ae/wte/pol/policies.html.

Food and Agriculture Organization of the United Nations. 2021. Technical Platform on the Measurement and Reduction of Food Loss and Waste. Available online at: https://www.fao.org/platform-food-loss-waste/food-loss/introduction/en/.

Flammini, A., S. Bracco, R. Sims, J. Cooke, and A. Elia. 2018. Costs and Benefits of Clean Energy Technologies in the Milk, Vegetable, and Rice Value Chains. Food and Agriculture Organization of the United Nations. Available online at: https://www.fao.org/3/i8017en/I8017EN.pdf.

GMI. 2013. Successful Applications of Anaerobic Digestion from Across the World. Global Methane Initiative, U.S. Environmental Protection Agency. Available online at: https://www.globalmethane.org/documents/GMI%20Benefits%20Report.pdf

GMI. 2020. Market Opportunities for Anaerobic Digestion of Livestock and Agro-Industrial Waste in India. Global Methane Initiative, U.S. Environmental Protection Agency. Available online at: https://www.globalmethane.org/documents/Market%20Opportunities%20for%20AD%20in%20India.pdf.

Government of India, Ministry of Home Affairs. 2011. Census Data – 2011. Available online at: https://censusindia.gov.in/2011-Common/Archive.html.

Government of India, Ministry of New and Renewable Energy. 2021a. WTE Schemes. Programme on Energy from Urban, Industrial, Agricultural Waste/Residues and Municipal Solid Waste. Available online at: https://mnre.gov.in/waste-to-energy/schemes.

Government of India, Ministry of New and Renewable Energy. 2021b. New National Biogas and Organic Manure Programme (NNBOMP). Available online at: https://biogas.mnre.gov.in/about-the-programmes.

Ideas to Impact. n.d. Off-grid Cold Storage Business Models. Available online at: https://storage.googleapis.com/leap-assets/OGCCC-Business-Models.pdf.

PEDA. 2021. Biogas Power Generation (Off-grid) and Thermal application Programme (BPGTP). Punjab Energy Development Agency. Available online at: https://www.peda.gov.in/biogas-power-generation.

Peters, T., Dey, S., Negpal, C., Patankar, M., Yehuda, R.U., Chattbar, C., Deshpande, S., Prem, I., and Lobo, S. 2019. Promoting Clean and Energy Efficient Cold-Chain in India. University of Birmingham, EN Systems Advisory Pvt. Ltd., and Shakti Sustainable Energy Foundation. Available online at: https://shaktifoundation.in/wp-content/uploads/2019/04/Cold-chain-in-India-Executive-Summary-for-web.pdf.

Sumon Rashid, T.H.M., A. H. M. Iftekharul Ferdous, A. Shobug Md, E. Khan Md., S. Arefin Md. 2018. Feasibility Study of an Off-Grid Biogas Solar Hybrid System for a Dairy Hub at Pabna Zone in Bangladesh. *International Journal of Scientific Engineering and Science* 2(7) 28-33. Available online at: http://ijses.com/wp-content/uploads/2018/08/188-IJSES-V2N7.pdf.

Timperley, J. 2019. The Carbon Brief Profile: India. Carbon Brief. Available online at: https://www.carbonbrief.org/the-carbon-brief-profile-india.