Technology and policy roadmap for energy efficient cold storages in India

Sandeep Kachhawa, Kriti Khurana,
Tarun Garg & Gerry George
Alliance for an Energy Efficient Economy (AEEE)
37 Link Road, Ground Floor
Lajpat Nagar III
New Delhi-110024
India
sandeep@aeee.in
kriti@aeee.in
tarun@aeee.in
gerry@aeee.in

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Abstract

Agriculture, one of the most important sectors of the Indian economy, has seen phenomenal growth in the production of perishable commodities, including horticulture produce. Among the horticulture crops, Uttar Pradesh was the largest potato producing state in India, followed by West Bengal, where 13.16 million metric tonne (MMT) of potatoes were produced in 2019–20. However, investments for cold chain development in India and West Bengal, in particular, undermine the importance of a climate-friendly uninterrupted cold chain as an essential requirement for the potato value chain. It provides the critical market linkages for reducing food loss, ensuring food security, and farmers' welfare in India. In this context, the paper focuses on assessing the cold storage industry in West Bengal, emphasizing the potato value chain. A large majority of farmers in West Bengal sell their potato produce to the village traders who store them in the cold storages and sell it in the wholesale markets (mandis) as per the demand. Due to improper handling and storage procedures, more than 25 % of post harvest losses are reported in the supply chain of potatoes in West Bengal, occurring at production, cold storages, wholesale markets, and retail outlets. It is estimated that there is a potential to reduce cold storage losses by up to 75 % if traditional cold storages are retrofitted to modern ones. Detailed energy audits of three different types of cold storage facilities located in the Hooghly district of West Bengal were carried out to understand the potato handling, storage practices, and energy utilization. Energy Efficiency Measures (EEMs) validated with technical and financial data from different industry players have been assessed and proposed to improve the cold storages' overall energy performance while retaining the product quality. It is estimated that around 0.38 MMT of potato losses can be avoided by modernization of cold storages in West Bengal, leading to a monetary benefit of INR ~600 crores (EUR 70 million) per year. A typical 5,000 MT cold storage can save up to INR 60 Lakh (EUR ~70,000) per season through avoided potato losses. Factoring the MIDH subsidy support of INR 95 Lakh (EUR ~111,000) out of the total investment of INR 233 Lakh (EUR ~270,000), the energy savings coupled with the monetary benefits of avoided food losses, present an extremely attractive payback period of just 1.6 years. The State has vast growth potential in the horticulture sector, requiring a shift from cold storages to integrated cold chains to realize its full potential. Retrofitting and modernization of the existing traditional cold storages into multi-purpose cold storages will be the right first step. This will also incentivize diversification of the cropping pattern, bringing new avenues of growth for the farmers. The multiple benefits of modernization, which are generally underestimated worldwide, will significantly outweigh the energy savings considered in isolation. It will help the farmers to realize a greater economic value for their produce and boost their income.

Introduction

Agriculture is one of the most important sectors of the Indian economy. It accounts for approximately 18.3 %[1] of the country's Gross Domestic Product (GDP) for 2020–21 (current prices). Around 54.6 % of India's total workforce still depend on agriculture for their livelihood (Government of India (GoI) 2020a). The majority of landholdings in India – 86 % – are marginal (less than 1 hectare) and small (1–2 hectare) (GoI 2020b). According to National Sample Survey (NSS) data (January–December 2013), the all India average annual total income of an agricultural household was INR 36,972/year (EUR 430/year), i.e. INR 3,081/month (EUR 36/month) in 2013.

India has seen phenomenal growth in the production of perishable commodities, including horticulture produce, dairy, and meat products over the years. It is the world's largest milk producer (22 % of global milk production) and the second-largest producer of fruits and vegetables after China accounting for 9 % of the worldwide production of fruits and 8 % of vegetables (GoI 2018a). A wide range of horticulture crops, including fruits, vegetables, flowers, and spices, are produced in India owing to diverse agro-climatic conditions.

The production of horticulture crops has increased from 221.42 million tonnes in 2010–11 to 290.92 million tonnes in 2019–20, i.e. an increase of 31 %. The area under horticulture production has also increased from 14.87 million hectares to 17.06 million hectares during the same period. In horticulture, Uttar Pradesh is the leading potato producing state followed by West Bengal where 13.16 million metric tonne (MMT) of potatoes were produced in 2019–20. Horticulture is considered a growing sector as it can raise the farmers' income, provide livelihood security, and contribute to the growth through exports (Jha et al., 2018). People's significant economic growth and changing lifestyles are also causing a shift in the food consumption pattern of people away from staple food grains towards high-valued horticulture products. However, with the export of only 1 % of its horticulture produce (fresh fruits and vegetables) to other countries in 2018–19), India's export potential is yet to be fully capitalized.

This paper presents a general overview of the cold chain industry in India, focusing on West Bengal, a significant horticulture state with substantial scope for improvement in the cold chain infrastructure. This is followed by a field assessment of select cold storage facilities in West Bengal, a proposal for modernization of the existing infrastructure, and challenges and way forward for policy and technology for large-scale implementation of the proposed retrofitting and modernization.

Overview of cold chain in India

According to NCCD, "cold chain is an environment-controlled logistics chain, ensuring uninterrupted care from source-to-user, consisting only of storage and distribution-related activities in which the inventory is maintained within predetermined ambient parameters". Overall, the cold chain acts as a significant link between the production base (farms) and the consumption centres. Cold chain is a composition of static infrastructure including pack-houses (at/or in proximity to farm gate), cold storage bulk (for storage at the farm gate), cold storage hub (in proximity to market), and ripening chambers (for select produce). Reefer vehicles are used to connect the static infrastructure components of the cold chain. The cold chain does not add any value to the fresh produce and only performs the function of grading, sorting, pre-cooling before packaging, and preconditioning of the produce for travel purposes (Singhal & Saksena, 2018).

In India, the cold chain system started with the first cold storage unit set up in Kolkata in 1892 (NCCD 2015). Thereafter, the Directorate of Marketing & Inspection (DMI), Ministry for Agriculture and Farmers' Welfare, implemented the Central Cold Storage Order in 1964 and later in 1980 in all the states except in Uttar Pradesh, West Bengal, Punjab, and Haryana where the state governments enacted their own Cold Storage Acts. The order was modified by deregulating the refrigerated storage sector in May 1997 under the liberalization policy. This attracted the private sector in the cold storage industry, and in 2017, 95 % of the country's cold storages were owned by private players (GoI, 2017). In 2020, there were 8,186 cold storages in India, having an installed capacity of 37.42 MMT (Figure 1). Cold storages in India have witnessed a Compound Annual Growth Rate (CAGR) of 2.9 %, with the number of cold storages increasing from 6,891 in 2014 to 8,186 in 2020. The average capacity of cold storage in India is around 4,500 MT since 2014.

POLICY LANDSCAPE GOVERNING COLD CHAIN DEVELOPMENT IN INDIA

Primarily, two schemes have been initiated by the GoI to provide financial assistance to set up cold storage units in the country – the Mission for Integrated Development of Horticulture (MIDH) under the Ministry for Agriculture and Farmers' Welfare, and Pradhan Mantri Kisan SAMPADA Yojana (PMKSY) under the Ministry of Food Processing Industries. Financial assistance for the growth and development of the cold chain industry is provided by the Agricultural & Processed Food Products Export Development Authority (APEDA) of the Ministry of Commerce and Industry (MoCI). The National Horticulture Board (NHB) has specified design guidelines for different types of cold storages in India.

The India Cooling Action Plan (ICAP) recommends developing an integrated cold chain infrastructure with proper market linkages and providing appropriate training and up-skilling of farmers and professionals (GoI 2018b). This will improve the farmers' economic status (in alignment with the Doubling Farmer's Income (DFI) initiative) and reduce post-harvest losses. Providing specialized training to the farmers and cold chain professionals is also emphasised both under ICAP and DFI. As per ICAP, the cold chain sector is poised to grow significantly in the near future. The capacity of cold storages is prospected to grow to 44 MMT in 2027–28 and 50 MMT by 2037–38. In 2017, the energy consumption in cold storages in India was estimated to be 4.15 GWh. Projections show that this will increase to 4.77 TWh in 2027 and 4.9 TWh in 2037. The figure also indicates two scenarios for cold storage energy consumption: reference (i.e. current level of effort) and intervention (heightened level of effort), resulting in an energy-saving potential of 300 GWh from 2017–18 to 2037–38. The intervention scenario includes improving the cold storage infrastructure through cooling equipment's energy efficiency and choosing low GWP refrigerant-related servicing practices.

1. Agriculture includes agriculture, forestry and fishing.

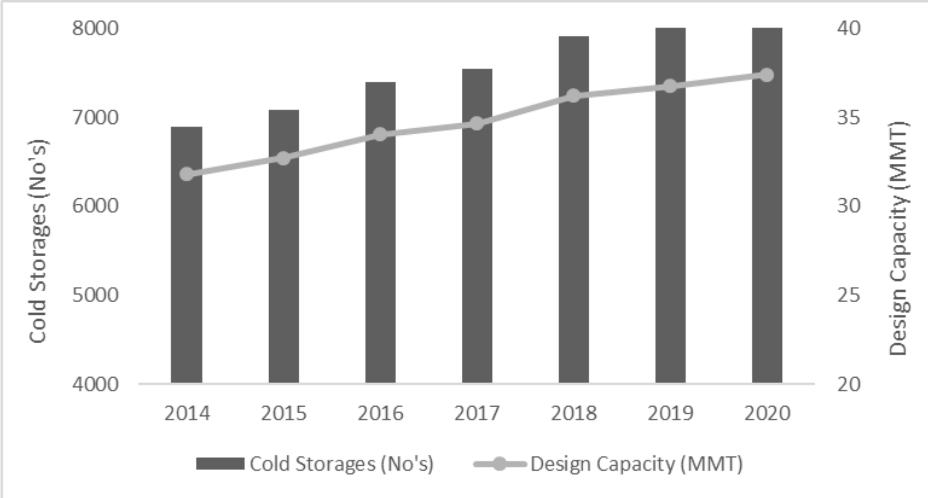

Figure 1. Number of cold storage units and their designed capacity in India.

Against the backdrop of the Kigali Amendment to the Montreal Protocol, India has agreed to reduce its HCFC production and consumption by 10 % in 2015 over the 2009–10 baseline, 35 % by 2020, 67.5 % by 2025, and 97.5 % by 2030. Currently, the majority of the cold storages in India deploy Ammonia (R717) as a refrigerant. The refrigerant mix in the cold storages segment in India is around 75 % R-717, 10 % R-404a, 10 % R-22 and 5 % R-134a (Kumar et al., 2018). The sector is already on track to phase-out HCFCs, and an aggressive phase-down of HFCs with increased adoption of natural refrigerants such as R-717 may be explored in the future.

The total carbon emission from cold storages was around 3.7 mtCO_2e in 2017, increasing up to 4 mtCO_2e in the next decade (Kumar et al., 2018). The indirect emissions dominate over the direct emissions primarily due to the adoption of R717 (zero GWP) refrigerant in the future stock. Although R-717 is toxic, the trend still exists as there is minimal human exposure to cold storages.

LOSSES REPORTED IN THE AGRICULTURAL SUPPLY CHAIN

Fruits and vegetables are highly nutritious agricultural produce and require good care and proper harvest handling practices to minimize their quality deterioration. Gaps in cold chain infrastructure, including pack-houses, refrigerated transport, and traditional designed cold storages, are the most significant contributors to India's food loss. The Indian Council of Agricultural Research (ICAR) estimates that the average range of fruits and vegetable losses is 4.58 % to 15.88 % in the entire supply chain. According to the Central Institute of Post Harvest Engineering and Technology (CIPHET), 30 % of fruits and vegetables go to waste because of the lack of adequate storage facilities, transport, handling, and processing. Farm to consumer losses occurs due to improper threshers, delay in harvesting, and lack of proper storage facilities. However, an efficient and integrated cold chain infrastructure can significantly address food loss during post-harvest and before it reaches the consumers. Focused government intervention and pronounced actions by all the stakeholders are necessary to reduce the post-harvest losses in the cold chain sector.

It is touted that the cold chain industry will bring in the second wave of green revolution in India (NCCD, 2015). A well-functioning cold chain industry will reduce food losses and price volatility and improve the quality of end-consumed products.

Agricultural landscape in West Bengal

West Bengal is predominantly an agricultural economy occupying 2.7 % of India's geographical land and supports 7.6 % of its population. Around 72.03 % of the State's population lives in rural areas, which is much higher than the national average of 68.8 % (Census 2011). Based on its diverse topography, terrain, and climate, the State has three agro-climatic zones, namely, Eastern Himalayan Region (Zone II), Lower Gangetic Plain Region (Zone III), and Eastern Plateau and Hilly Region (Zone VIII), which supports a wide variety of crops. West Bengal ranks first in paddy production in India and second in potato production. Around 96 % of the operational holdings in West Bengal are either marginal (less than 1 hectare) or small (1–2 hectare). Marginal operational holding in West Bengal (less than 1 hectare) accounts for 88.8 % of the total operational holdings against 69.8 % at all India levels (NABCONS 2009).

Around 44 % of the State's workforce is engaged in the agriculture sector as primary cultivators or agricultural labourers. Many agricultural commodities are produced in West Bengal due to its varied agro-climatic conditions and diverse natural resources. Yet, the agrarian households' income in West Bengal is one of the lowest in India due to the average land endowment (Mandal et al., 2017). According to the NSS data (January–December 2013), the average annual farm income of an agricultural household in West Bengal in 2013 was INR 11,748/year (EUR 137/year), i.e. INR 979/month (EUR 11/month), which is much lower than the all India annual income of an agricultural household of INR 3,081/month (EUR 36/month). The net cropped area in West Bengal is 5.52 million hectares which is 92 % of its arable land. In Triennium Ending (TE) 2018–19, around 17 % of the total cropped area was under the horticulture crops (fruits and vegetables) in West Bengal. It was the second biggest horticulture producing State in India in 2017–18 (GoI 2018a). Among the horticulture crops, potato plays a vital role in the agricultural economy of West Bengal. West Bengal is a Rabi potato producing state where the sowing period is from mid-September to November, and the crop is harvested from December to March (GoI 2020c). Majorly three varieties of potatoes, i.e., Kufri Jyoti, Kufri Pukhraj, and Kufri Chandramukhi, are grown in West Bengal according to their needs and seed availability (Pradel et al., 2019 million hectares of land and contributed to 27 % of India's total potato production in TE 2018–19. The production of potatoes in West Bengal has increased from 9.72 MMT in 2011–12 to 14.93 MMT in 2017–18. The area under potato cultivation has increased from 3.8 lakh hectare in 2011–12 to 5 lakh hectares in 2016–17.

Potatoes produced by the farmers are not directly sold in the wholesale markets; instead, it follows a specific supply chain elaborated in the next section.

The supply chain of potatoes in West Bengal

According to a study by Mitra et al. (2018), a large majority of farmers in West Bengal sell their potato crop (more than 90 % potatoes) to the village traders located either in the village or near the wholesale markets. Farmers do not sell their produce directly to wholesale buyers. The village traders directly sell some of the produce in wholesale markets (mandis) and store the remaining produce in the cold storages, which are sold to the wholesalers as per the market demand. From these wholesalers, the potatoes are purchased by the traders from the city markets and neighbouring states that are ultimately sold to the consumers in the retail markets (Figure 2).

The cold storage owners are an essential link in the potato industry business. They act as service providers where they rent the storage capacity in cold storage to the local traders or farmers to store their potato produce.

COLD STORAGE INDUSTRY IN WEST BENGAL

With 514 cold storages, West Bengal stands fifth in terms of the number of cold storages in India and second in storage capacity, which has remained at around 5.9 MMT from 2014 onwards (Figure 3).

Approximately 90 % of the cold storages in West Bengal cater to potatoes and have an average capacity of around 11,000 metric tonnes (MT). The storage rates in West Bengal fluctuate on a weekly, monthly, and yearly basis and currently, the storage rate is prevailing at INR 157/quintal per season (i.e. nine months, March-November). This means a farmer or trader pays INR 0.17/kg to store their potato produce in cold storage for a month. Demand for raising the cold storage rent to INR 180/quintal has been raised due to a rise in input cost and capital cost for cold storage (Munshi, S 2021).

The loading of potatoes in cold storages starts towards the end of February and closes by March-end. The unloading, driven by the market demand, typically starts from May/June onwards and continues till the end of the storage season in November. From December onwards, most cold storages are shut for annual maintenance. During the peak season, 100 % of the capacity is utilized for storing potatoes, but as the unloading starts from May/June onwards, the cold storages capacity utilization also starts decreasing. During the storage process, temperature, humidity, and air movement can affect the quality of the stored potatoes. Potatoes not appropriately stored are prone to tuber losses due to fungal and bacterial infection.

LOSSES REPORTED IN POTATOES POST-HARVEST MANAGEMENT IN WEST BENGAL

During the loading and unloading process in the cold storage, improper handling and baggage system increases potatoes' losses at the wholesale and retail level. Overall, 27–30 % of losses are reported in the supply chain of potatoes in West Bengal. Around 5 % of losses occur at the farm level, 9.5–10 % of losses occur during the storage process, leading to 12–15 % of losses together at the wholesale and retail level (Figure 4). Several storage inefficiencies and poor handling processes are the operational cause of waste in the supply chain (Negi & Anand, 2016).

Field assessment

West Bengal's government requested Energy Efficiency Services Limited (EESL) to conduct detailed energy audits at select cold storage facilities and prepare state-level policy documents to bring energy efficiency and sustainability to the State's

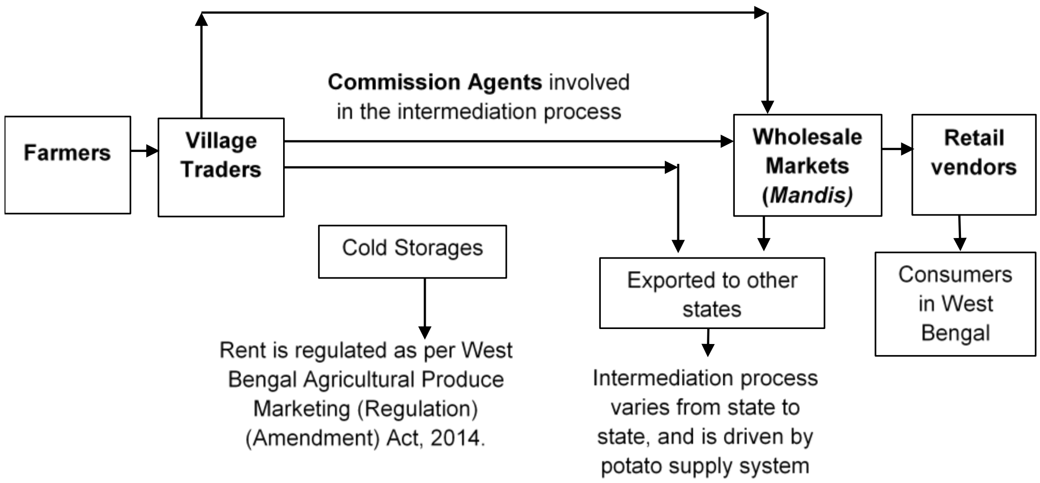

Figure 2. Supply chain of potatoes in West Bengal.

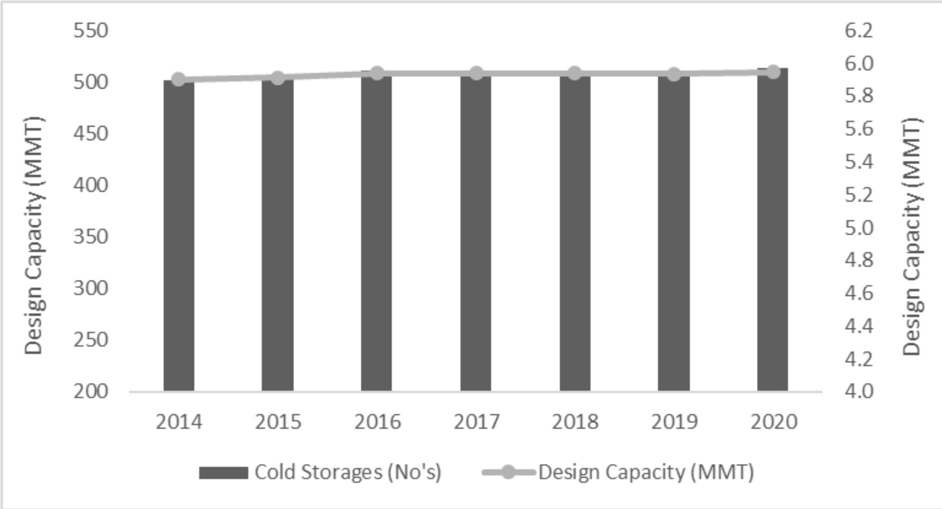

Figure 3. Number of cold storage units and their designed capacity in West Bengal.

Figure 4. Traditional post-harvest losses in West Bengal.

cold storage infrastructure. Alliance for an Energy Efficient Economy (AEEE) has collaborated with EESL to assess the cold storage infrastructure in West Bengal and prepared the report- ”Analysis of potato value chain in West Bengal: Roadmap for retrofitting-cum-modernizing existing cold storages”. AEEE hired Development Environergy Services Ltd. (DESL) for conducting the Detailed Energy Audit at three cold storages in the Hooghly district of West Bengal. The field studies' findings were discussed with different stakeholders in West Bengal to estimate the state-wide cold storage scenario.

OBJECTIVE

Detailed energy audits of three cold storage facilities in the eastern Indian state of West Bengal were carried out to understand the net utilization, produce handling practices, storage conditions (temperature, relative humidity, and air circulation) maintained, thermal integrity of the building envelope, historical electricity and diesel bills, design and operational energy performance of the refrigeration system, and establish the energy use intensity of cold storages.

KEY FINDINGS

The basic details of the three cold storages in the Hooghly district of West Bengal, where the energy audits were conducted, are presented in Table 1. Cold storage owners & operators, cold storage industry associations, state government officials in the agricultural marketing, food processing, and horticulture departments, academia, and national and global cold chain industry experts, were among the key stakeholders consulted during the study.

Building design

The majority of West Bengal's cold storages catering to a single commodity, i.e., table potatoes, representing 95 % of the total 514 nos., are designed in traditional style with mezzanine floors like Facility #1. However, the audited Facilities #2 and #3 are designed with multi-chambers for storing multiple commodities. As per the National Horticulture Board (NHB) guidelines, a 5,000 MT cold storage should have four chambers with a capacity of 1,250 MT each. Even cold storage dedicated to a single commodity such as potato should follow this design. Multi-chamber cold storages, providing the ability to store other high-value horticulture produce, will open up new revenue streams for cold storage owners

Building envelope

The thermal integrity of the building envelope is not appropriately maintained in all the three facilities audited. The thermal performance of walling and roofing material is inadequate, and on top of that, air leakages are happening due to cracks in walls and roofs. The leakages lead to condensation problems inside the cold storages. Leakages from the cold room doors are also common as they are kept open for long durations during loading and unloading. There are no provisions for strip curtains or air curtains with the doors whose insulating properties are also inadequate.

Thermocol, i.e., Expanded Polystyrene (EPS), is the most common insulation material used for walls. And either Fibre Glass or EPS is used for roof insulation. In the absence of a proper vapour barrier and natural contraction of EPS over time, most of these cold storages lose their insulation properties to a significant extent due to moisture ingress and other wear and tear. EPS is also susceptible to being eaten up by rodents and requires continuous maintenance and patchwork.

Produce handling practices and storage conditions

Potato handling for sorting/grading (wherever applicable), loading, and unloading is done manually, leading to damages to the potatoes. During the holding and unloading season, the potato bags are manually shifted/flipped in a sequential man-

Table 1. Basic details of the three cold storages studied in West Bengal.

	Facility #1	Facility #2	Facility #3
Year of establishment (age in 2020)	1987 (33 years)	1986 (34 years)	2010 (10 years)
Location (Climatic Zone)	Hooghly district of West Bengal (Warm and Humid)		
Cold storage capacity	9,500 MT*	15,673 MT	16,200 MT
Commodity stored	Single commodity: Table Potatoes (Jyoti and Chandramukhi)	Multi-commodity: Table Potatoes (Jyoti and Chandramukhi), Processing Potatoes (for chips manufacturing), Maize, Chilli and Ground-nut	Multi-commodity: Table Potatoes (Jyoti and Chandramukhi), Processing Potatoes (for chips manufacturing), Chilli and Dhania
No. of chambers	2	14	14
Refrigeration plant	Reciprocating Ammonia compressors with gravity flooded system	Reciprocating Ammonia compressors with gravity flooded system	Reciprocating Ammonia compressors with gravity flooded system
No. of compressors (capacity)	7 (110TR X 2,100TR X 2, 80TR X 2, 65 TR)	7 (110TR X 2,100TR, 80TR X 2, 65 TR, NA)	5 (110TR X 2, 80TR X 2, 60 TR)
Evaporator	Traditional bunker coil	Hybrid of traditional bunker coil and modern Air Cooling Units (ACUs)	Modern ACUs
Ammonia flow control	Manual	Manual	Manual
Condenser	Atmospheric	Atmospheric	Atmospheric
Diesel Generator (DG) sets	2 Nos. (70 kVA and 110 kVA)	3 Nos. (63 kVA, 110 kVA and 250 kVA)	3 Nos. (15 kVA, 110 kVA and 250 kVA)
On-site Solar Photovoltaic	None	Rooftop PV of capacity 300 kWp with net metering	None
Automated material handling system	None	None	None
Strip curtain and Air curtain	None	None	None
Wall insulation	Chamber 1: Fibre Glass; Chamber 2: Thermocol (EPS**)	Varies from chamber to chamber: Thermocol (EPS) or PUF**	Varies from chamber to chamber: Thermocol (EPS) or Fibreglass or PUF
Roof insulation	Thermocol (EPS)	Fibre Glass	Fibre Glass
Door insulation	PUF	Thermocol (EPS)	Thermocol (EPS)

** MT: Metric Ton; ** EPS: Expanded Polystyrene; *** PUF: Polyurethane Foam.*

ner. Each potato bag changes its position at least twice during the season. This inefficient practice carried out to minimize the possible potato spoilage due to compression of bottom bags as well as inadequate air circulation, ends up damaging the potatoes due to physical shocks by improper manual handling of bags, as well as adds up additional heat load due to working staff and lighting operation. Modern cold storage, which can maintain the desired temperature, relative humidity, and air circulation levels, obviates the need for flipping of bags, thus minimizing handling and the associated damages.

With traditional bunker coil systems and single chamber designs (mezzanine floors), the desired air circulation, temperature, and humidity conditions are difficult to maintain. The storage and stacking pattern should accommodate space for adequate air circulation. Hot pockets are created due to potato respiration, adversely impacting the potato quality. Due to the mezzanine floor design, there is temperature asymmetry across different floors. The lower floors are often susceptible to inadequate air circulation leading to heat built up, thus damaging the potatoes. For most traditional cold storages catering to Table variety potato, ventilation requirements are met by opening a window on the roof and doors on the ground floor for 1–2 hours at 3–4 am early morning. This leads to massive heat gains due to infiltration, thus adversely impacting the refrigeration system's performance. CO_2 extractors/scrubbers are only installed in cold storages catering to processing potatoes.

Refrigeration system and controls

Ammonia-based gravity flooded refrigeration system is the most common refrigeration plant configuration observed in West Bengal. It is the preferred refrigeration system owing to the cost-effectiveness, low maintenance expenditure, and easy availability of maintenance technicians. The refrigeration plant is typically run (operated manually) for only 4–6 hours per day, leading to suffocation of stored produce and deteriorating its quality. Redundant compressor capacity is observed in many of the cold storages audited. The overall refrigeration system is generally designed based on non-standard engineering practices. Traditional bunker coil system with manual ammonia flow control is the most common evaporator configuration. A thick layer of ice gets accumulated over the tubes, thus hindering heat transfer. Many cold storages have started to replace bunker tubes with finned coil tubes, which is an improvement as it increases heat transfer area. However, the overall system remains non-standard, whose performance cannot be scientifically assessed. With a traditional bunker coil type of evaporator, it is impossible to precisely maintain desired temperature, relative humidity, and air circulation levels. However, Facility #2 (partially) and Facility #3, which are multi-commodity cold storages, have standard fin-coiled evaporators, also called air cooling units (ACUs). Automatic temperature-based ammonia flow regulation and isolation valves are not present in any of the facilities audited.

Moreover, ammonia safety control valves are absent. All three facilities have atmospheric condensers. The Total Dissolved Solids (TDS) level of condenser water is high, and there are algae deposits in the condenser water tank. Blowdown is conducted only once or twice a season, leading to both high TDS and algae formations.

Analog temperature and relative humidity (RH) meters are generally installed in a few areas in cold storage. The operators manually regulate the ammonia flow based upon the temperature conditions maintained. None of the audited facilities have any CO_2 meters to check for any unwanted accumulation of CO_2 levels. It is recommended to have one sensor per 100 MT of storage (NHB 2010).

Energy consumption

Table 2 shows the three facilities' annual energy consumption and expenditure for 2018–19 and 2019–20. The average unit rate of electricity purchased from the grid varies from INR 7 to 8 per kWh among the audited facilities, compared to the average unit rate for DG generation, ranging from INR 18 to 33 per kWh depending upon the specific energy generation of the DG sets. More than 90 % of the energy expenditure is attributed to the electricity grid. One of the audited facilities also has a grid-interactive rooftop photovoltaic (PV) plant of 300 kWp capacity with a net metering facility. Around 10 cold storages in the states have rooftop solar with net metering.

Energy Efficiency Measures (EEM) for modernization of the existing cold storages

The Energy Efficiency Measures (EEMs) have been worked out for a standard 5,000 MT cold storage having four chambers of capacity 1,250 MT each. The EEMs fall under two main categories: 1) Improving the thermal performance of the building envelope; 2) Optimizing the overall refrigeration system performance to match product load and seasonal variations. Both the broad EEM categories go hand in hand to improve the

Table 2. Annual energy consumption and expenditure for the three facilities for 2018–19.

S. No	Particulars	Unit	Facility #1		Facility #2		Facility #3	
			2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
	Energy Consumption							
1	Annual Energy Purchased & Consumed from Grid	kWh	585,712	441,249	815,685	762,920	474,255	646,150
2	Annual Energy Generated (by DG Sets) & Consumed	kWh	16,933	12,687	16,236	5,904	4,360	12,644
3	Annual Energy Consumed from Solar PV System	kWh	NA	NA	113,575	181,441	NA	NA
4	Total Annual Energy Consumption	kWh	602,645	453,937	945,496	950,265	478,615	658,794
	Energy Expenditure							
5	Cost of Electricity Purchased from Grid	Lakh INR	40.6	32.1	62.2	55.0	34.7	48.3
6	Unit Rate of Electricity Purchased from Grid	INR/kWh	6.9	7.3	7.6	7.2	7.3	7.5
7	High Speed Diesel (HSD) Purchased & Consumed	Litre	5,799	4,345	4,400	1,600	2,000	5,800
8	Cost of HSD purchased & Consumed	Lakh INR	4.0	2.9	3.0	1.2	1.4	4.2
9	Unit Rate of HSD Purchased & Consumed	INR/Litre	68.1	67.8	68.0	73.0	68.0	73.0
		INR/kWh	23	23	18	20	31	33
10	Total Annual Energy Expenditure	Lakh INR	44.6	35.0	65.2	56.2	36.1	52.6
11		EUR (@ INR 86/ EUR)	51,803	40,750	75,756	65,337	41,977	61,105
	Energy Use Intensity							
12	Design Capacity	MT	9,500	9,500	15,673	15,673	16,200	16,200
13	Energy Use Intensity	kWh/MT	63	48	60	61	30	41

cold storages' overall energy performance while retaining the product quality. The EEMs have been arrived at through detailed consultations with national and international cold chain industry experts in order to reflect the global best practices.

The energy efficiency impact and the applicability of the government of India's subsidy support under Mission for Integrated Development of Horticulture (MIDH) have been mapped for individual EEMs. The investment requirement and energy-saving potential are calculated for individual EEMs based upon technical data and financial information received by different industry representatives. It should be noted that the individual EEM saving estimates are calculated over the refrigeration system energy usage, which constitutes the bulk of the overall energy consumption. The overall investment required for the modernization of a standard 5,000 MT cold storage is estimated at INR 233 Lakh (EUR ~270,000), which can be partly paid for by the MIDH subsidy. MIDH subsidy support of 50 % is available for select EEMs as marked in Table 3, adding up to INR 95 Lakh (EUR ~111,000). Overall energy-saving potential of 20–25 % over total cold storage energy consumption is possible with all the proposed EEMs.

To improve the traditionally designed and operated cold storages' energy performance, equipment replacement alone may not be of much help. Modernization of the entire cold storage in terms of the refrigeration system's design and operation is the need of the hour. The benefits of modernization will significantly outweigh the energy savings considered in isolation. Modernization will reduce food losses (weight losses and spoilage) and open up new revenue streams for the cold storage owners. A modern multi-chamber cold storage can store multiple fruits, vegetables, and spices, among other food products, as per the market demand. While the benefits to cold storage owners through diversification of products handled and better net capacity utilization are difficult to estimate. The authors have estimated the avoided food (potato) loss through the modernization of cold storages. As per the authors' assessment validated through stakeholder consultations, the spoilage (up to 5 %) happening due to poor handling and inadequate storage conditions could be completely avoided in modern cold storages. Additionally, the evaporative weight losses could also be reduced from 5 % in traditional cold storage to 2.5 % in modern ones. Thus 7.5 % out of the 10 % potato losses happening in traditional cold storages can be avoided through modernization. A typical 5,000 MT cold storage can save up to INR 60 Lakh (Euro ~70,000) per season through avoided potato losses. 75 % of the total potato losses happening in West Bengal (i.e. 0.38 MMT of the total 0.51 MMT loss) can be avoided if traditional cold storages are retrofitted to modern ones, thereby yielding monetary benefits of INR ~600 Crores (EUR 70 million) at a wholesale potato price of ~INR 15/kg (EUR ~0.17/kg) in 2020. Factoring the MIDH subsidy support of INR 95 Lakh (EUR ~111,000) out of the total investment of INR 233 Lakh (Euro ~270,000), the energy savings coupled with the monetary benefits of avoided food losses, present an extremely attractive payback period of just 1.6 years.

Challenges and way forward for policy and technology

Fruits and vegetables are highly nutritious agricultural produce but have a short shelf life due to their delicate nature. They require good care and proper post-harvest handling practices in cold chains to minimize the quality deterioration while extending their shelf life. Gaps in cold chain infrastructure, including pack-houses and refrigerated transport, coupled with traditional design and operation of cold storages, are the most significant contributor to food loss in India. While the cold storages infrastructure has been created to some extent, the gaps in other cold chain linkages are incredibly high – 99 % for pack-houses, 85 % for reefer vehicles, and 91 % for ripening chambers (NCCD 2015). Controlling food loss is a broader problem and is beyond individual farmers and consumers' scope. Reduction of post-harvest food loss requires focused government intervention and pronounced action by all stakeholders in the cold chain sector.

In West Bengal, where 44 % of the population is dependent on agriculture for livelihood, it is essential to invest in the cold chain infrastructure facilities. Cold storages play a vital role in the post-harvest management functions, including the storage and distribution of perishable commodities and food products as per the market demand. Food loss at the storage level has several implications in West Bengal, where more than 95 % of the farmers are either marginal or small. Food losses lead to increased food prices for the consumers and mean lost income for the small farmers. Poor cold storage infrastructure affects the freshness and quality of the produce, leading to food losses and below-par price realization.

The cold storage system in West Bengal is working in a controlled environment due to restrictive policies and regulations by West Bengal's government. At all India level, West Bengal stands second in terms of cold storage capacity (5.9 MMT), 90 % of which is utilized for storing potatoes. The majority of the cold storages in West Bengal are designed with a traditional single chamber with multiple mezzanine floors that do not provide the flexibility to store multiple products that are already grown or grown/sold in West Bengal. Different product requires different storage conditions in terms of temperature and humidity levels. As a result, storage for other fruits and vegetables continues to face significant shortages. The lack of multi-commodity cold storages in a way disincentivizes farmers to diversify their cropping pattern.

Multi-commodity cold storage facilities can take care of various commodities such as fruits, vegetables, spices, etc., throughout the year. Modern multi-commodity cold storages will help the farmers diversify their horticulture crops, suitable as per the agro-climatic conditions in West Bengal. With separate chambers operating at different temperatures, these cold storages save cost, space and deliver high profitability with greater net capacity utilization. Considering the high capital costs associated with setting up modern cold storages, retrofitting and modernization of the existing cold storages is the most cost-effective solution to reap multiple benefits of better net-capacity utilization, lower capital and operational expenditure, better storage quality (lower losses), and higher price realization.

The latest produce handling, energy management, automation, and control technologies in the modern multi-purpose cold storages can help maintain the product's quality and minimize the losses due to human negligence. To conclude, retrofitting and modernization of the existing cold storages into multipurpose ones will stretch the marketable time of potatoes for a longer duration and allow servicing a more diversified farmer's crop production. Modern cold storages can have transformative impacts on small and marginal farmers of West Bengal

Table 3. Energy Efficiency Measures (EEM) for modernization of the existing cold storages.

S. No.	Identified Intervention Areas	Proposed EEM	MIDH Subsidy	Investment	Energy Saving Potential			Simple Payback	Simple Payback w/ MIDH
				(Lakh INR)	(%)	(kWh)	(Lakh INR)*	(years)	(years)
1	***Improving the thermal performance of the building envelope***								
1.1	Wall and roof insulation	Replacement of existing EPS insulation with 100 mm PUF insulation panels with galvanized iron (GI) cladding on one side and aluminium foil on another side for a reduction in thermal transmittance load from the building envelope	Yes	110	31 %	154,060	12.3	10.2	5.1
1.2	Reducing infiltration load	Replacement of existing hinged doors with airtight horizontal insulated doors with air curtains (20 Doors) for a reduction in heat transfer and air leakage through doors	Yes	16					
2	***Optimizing the overall refrigeration system performance to match product load and seasonal variations***								
2.1	Compressor	Installation of Variable Frequency Drive (VFD) drive on reciprocating compressor for more efficient part-load energy performance	No	8	7 %	24,179	1.9	4.1	4.1
2.2	Atmospheric condenser	Replacement of atmospheric condenser with an evaporative condenser with stainless steel (SS) coils including condenser pressure control valves for a reduction in energy and water consumption, i.e. lower drift losses	Yes	12	34 %	19,393	1.6	7.7	3.9
2.3	Bunker coil	Replacement of existing bunker coils with SS fin coil evaporator including energy-efficient (EE) VFD fan and evaporator pressure control valves for better air circulation, better product quality, and lower ammonia leakages	Yes	42	–**	–	–	–	–
2.4	Gravity flooded system	Replacement of gravity flooded system with pump recirculation (overfeed) system with ammonia pumps and flow regulating valves and controls for better flow regulation thus lower compressor run time	No	24	9 %	44,431	3.6	6.8	6.8
2.5	Programmable Logic Controller (PLC) controller	Installation of PLC controller for temperature/relative humidity (T/RH) management and optimizing the refrigeration plant performance for varying load conditions	Yes	10	4.5 %	22,215	1.8	5.6	2.8
2.6	Subcooling with Plate Heat Exchanger (PHE)	Installation of economizer for subcooling for improve the evaporation efficiency	No	2.5	5.5 %	27,152	2.2	1.2	1.2
2.7	Suction line insulation	Improving the suction line insulation through Armaflex/PUF to reduce the superheat, thus improving the overall system efficiency	No	8	3 %	14,810	1.2	6.8	6.8
	Overall system efficiency			**233 (EUR ~270,000)**	**20 to 25 %**	**306,240**	**24 (EUR 30,000)**		

** @ INR 8/kWh; ** Energy savings from replacing existing bunker coils with modern air cooling units (ACU) have not been estimated.*

through enhanced market connectivity. It will help them realize a more significant economic value for their produce, and even the consumer may have to pay less due to the lower supply chain post-harvest losses. The modernization of cold storages will boost the farmers' income in West Bengal and incentivize them to use modern equipment for agricultural production- a win-win situation for the farmers and the consumers.

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