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Nature Protects if She is Protected

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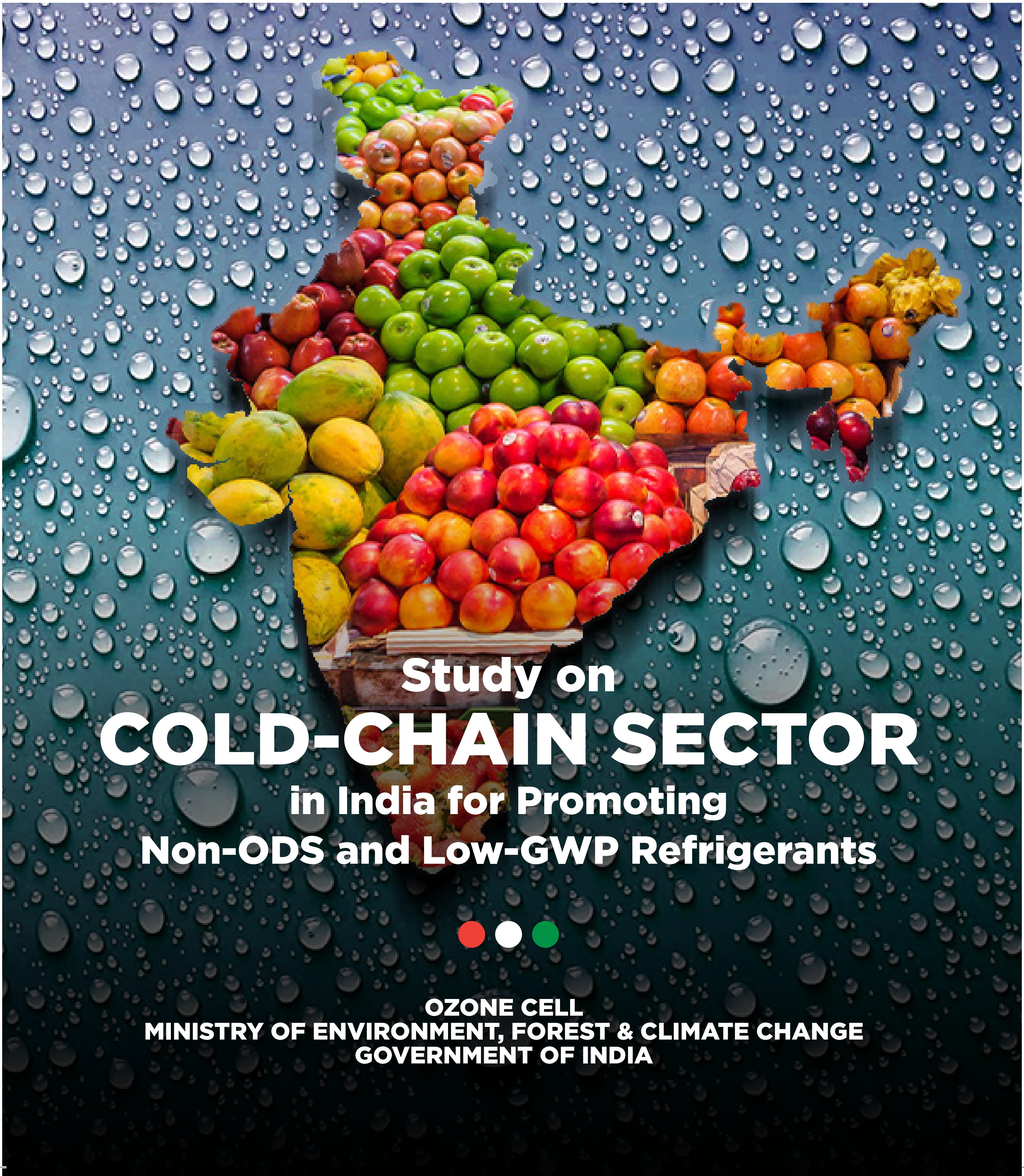

Study on COLD-CHAIN SECTOR in India for Promoting Non-ODS and Low-GWP Refrigerants

OZONE CELL
MINISTRY OF ENVIRONMENT, FOREST & CLIMATE CHANGE
GOVERNMENT OF INDIA

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September 2021

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मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
और
श्रम एवं रोज़गार
भारत सरकार

सत्यमेव जयते

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
AND
LABOUR AND EMPLOYMENT
GOVERNMENT OF INDIA

भूपेन्द्र यादव
BHUPENDER YADAV

MESSAGE

India has been widely known as the agricultural economy and our farmers have always been strength of pillar in the growth and development of the country. The world has recently witnessed the COVID-19 pandemic and major sectors have been impacted by this outbreak. Even in this unprecedented time, our farmers have always been at the forefront to fight and ensured that the country never gets deprived of food and other basic needs.

The Government of India have always focused on improving farmer's life and remunerations. In this regard, the cold-chain plays an important direct linkage between our farmers and the consumers. India's food production including perishable food products has increased multifold over the years and this requires a huge infrastructure of cold-chain to reduce food loss and its nutrition value.

Given the significant role of cold-chain in enhancing farmer's income and reducing food losses, Government of India is extending support in sustainable development of the cold-chain infrastructure through various policies, programmes and schemes. This development in will go long way to help in improving food security and address rural poverty while connecting farmers to markets and generating huge employment opportunities and livelihood. Curtailing food loss throughout the chain will result in reducing GHG emissions leading to reducing climate and environmental impacts.

The growth in the sector will not only lead to significant increase in use of refrigeration technologies and refrigerants but also increased demand of energy., It would call for developing energy efficient and climate friendly cold-chain infrastructure, thus achieving the objectives of the Montreal Protocol on substances that deplete the Ozone Layer.

Recognizing the importance of this sector, Ozone Cell, MoEF&CC in association with UNEP has carried out this "study on the cold-chain in India to promote non-ODS low-GWP and energy efficient technologies. The development of this report has been a multi-stakeholder including line ministries, departments, industry & industry associations think-thanks, academia etc.

I trust that this report would help in addressing key concerns of the stakeholders working to deliver on the sustainable cooling solutions in the sector. I congratulate all those who are part in the preparation of this important report.

With best wishes.

Date: 14.09.2021

(Bhupender Yadav)

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सत्यमेव जयते

आहारशुद्धौ सत्वशुद्धिः

एक कदम स्वच्छता की ओर

राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
उपभोक्ता मामले, खाद्य और सार्वजनिक वितरण
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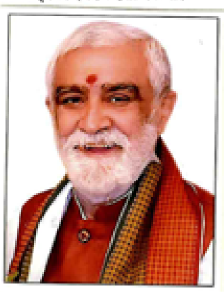

MESSAGE

Cold-chain is an integrated, seamless and resilient network of refrigerated and temperature-controlled pack houses, distribution hubs, and vehicles. Cold-chain helps to reduce the food loss by slowing down the processes of microbial, chemical or enzymatic deterioration of perishables. Cold-chain enhances economic wealth, cash flow and security for farmers and improve food quality, safety and value to the customer.

Given the Government of India's focus on the cold-chain sector, India is looking at a substantial capacity addition in terms of cold storage and transport infrastructure in the coming years. The increase in cold-chain infrastructure will lead to a surge in the cooling and refrigerant demand in the country. Increase in cooling demand will also lead into substantial energy upsurge. India is one of the first countries in the world to develop a comprehensive Cooling Action Plan which has a long-term vision to address the cooling requirement across sectors and lists out actions which can help reduce the cooling demand. The India Cooling Action Plan targets to reduce cooling demand across sectors by 20% to 25% and reduce cooling energy requirements by 25% to 40% by the year 2037-38.

Cold-chain itself is an energy intensive application, often relying on diesel for off-grid and on-vehicle cooling. Given the capacity addition, any indiscriminate use of technology in future deployments can lead to undesired hazards. Future development must harness the use of renewable and sustainable energy resources.

Keeping the vision of ICAP, Ozone Cell, Ministry of Environment, Forest and Climate Change in association with UNEP has conducted this study assessing the prospective sustainable cooling technologies which can possibly be introduced in different components of the cold-chain.. The findings of the report would benefit policy makers, economists, planners, domain consultants and other relevant stakeholders in planning and developing a sustainable cold chain befitting the farmers and consumers.

(Ashwini Kumar Choubey)

।। प्लास्टिक नहीं, कपड़ा सही ।।

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आर पी गुप्ता
R P Gupta

सत्यमेव जयते

MESSAGE

The Indian market is on the cusp of a revolutionary change with the expansion of middle class and affluence coming into the middle classes. The increase in demand for fresh produce, meat and perishable packaged foods is leading to significant growth in the perishables sector. Thus, cold-chain is expected to grow in India during the next few years and therefore a well-defined approach is the need of the hour to address the climate change issues and other environmental impacts associated with the sector.

Refrigerants such as Hydrochlorofluorocarbons (HCFCs), Hydrofluorocarbons (HFCs) and its blends are being used in cold-chain cooling technologies. While HFCs do not contribute to ozone depletion, however they do have significant GWP. Being a signatory to the Montreal Protocol on substances that deplete the Ozone Layer, India is currently implementing stage II of HCFC phase-out management plan (HPMP) as per the accelerated phase out schedule of HCFCs under the Montreal Protocol. Looking at the growth of the sector, actions are required to develop and deploy sustainable cooling solutions in different cold-chain components.

Recognizing this, Ozone cell with key partners is supporting efforts to advance environment friendly technologies and energy-efficient cold-chain in India. This report explores possible application of non-ODS and low-GWP alternatives in cold-chain sector in India. The study makes key recommendations for the development of sustainable cold-chain in India, including promotion of low-GWP and non-ODS based refrigeration systems, retrofitting existing inefficient cold-chain systems with non-ODS, low-GWP, and energy efficient equipment, development of standards and energy efficiency labeling program for refrigeration equipment..

I would like to commend and congratulate the team members from ozone cell and PwC India for carrying out such a comprehensive study and putting together this report. I trust that this study will serve as an important reference for policy makers, manufacturers, association's private sector and other stakeholders working to deliver cleaner and more energy-efficient cold chain while assisting India in meeting its ambitious climate goals. Ozone Cell will continue to promote non- ODS and energy efficient technologies in the country and support efforts and interventions towards sustainable solutions.

[R P Gupta]

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Executive Summary

India is the second largest producer of fruits and vegetables, largest producer of milk and one of the leading producers of meat and fish. Owing to its diverse agro-climatic zones and resources, the production of these commodities extends to a wide variety and quantity. However, India's present share in global farm trade is still very small. A key deterrent to this is the high level of loss across the value chain of key perishables. Cold -chain plays **an important role in reducing this loss** slows down the processes of microbial, chemical or enzymatic deterioration of perishables.

Given the significant role of cold-chain in reducing food losses and promoting India's farm trade globally, Government of India (GoI) is extending support in creation of the cold-chain infrastructure through various agencies such as Ministry of Food Processing Industries (MoFPI), National Horticultural Board (NHB), Agricultural and Processed Food Export Development Authority (APEDA) etc. Given the Government's focus on the cold-chain sector, India is looking at a substantial capacity addition in terms of storage and transport infrastructure in the coming years. The increase in cold-chain infrastructure will lead to a surge in the cooling and refrigerant demand in the country. Increase in cooling demand will also lead into substantial energy upsurge. The energy consumption in the cold-chain sector is likely to double in the next 10 years from 71 Tera Watt hours (TWh) in 2017- 18 to 130 TWh in 2027-28 and increase further by 1.6 times (compared to 2027-28) to 212 TWh by 2037-38. The refrigerant demand consequently is envisaged to increase 5 times and reach ~ 10,000 MT by 2037-38 from 2000 MT in 2017-18[1]

India is currently implementing Stage II of Hydrochlorofluorocarbons (HCFC) Phase-out Management Plan (HPMP) after successful implementation of HPMP stage I under the Montreal Protocol (MP) on Substances that Deplete the Ozone Layer. Under this, the phase out of HCFCs that have Ozone Depletion Potential (ODP) is proceeding as per the set targets and India is expected to achieve complete phase out by 2030. With the recent government approval for the ratification of Kigali amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, the focus now will shift to the Hydrofluorocarbon (HFC), as the Kigali amendment aims for phase-down of HFCs by cutting their consumption and production.

Mostly HCFCs and HFCs have been in use in refrigeration & air-conditioning (RAC), foam manufacturing sectors, aerosol, solvents and fire-fighting applications. Given the envisaged growth in RAC sector, timely interventions are required to promote cooling technologies, which not only have high operational efficiency but use refrigerants with low GWP and zero ozone depleting potential (ODP). The use and promotion of such sustainable technologies is therefore paramount to conform to the Kigali amendment, which will also help in achieving India's Nationally determined contribution (NDC) targets.

These interventions provide promotion of sustainable cold-chain development with non-HCFC alternatives maximizing the climate and energy-use benefits in the cold-chain sector. The assignment was undertaken to map the existing technologies in the cold-chain sector and to explore the application of non-ODS and low GWP alternatives. The report provides a comprehensive overview of trends of cold-chain in India. Extensive literature review and desk research was done to delve into emerging trends for cooling technologies (energy efficiency and refrigerant use) and existing policy framework for cold-chain. This activity was parallelly followed by stakeholder consultations and survey questionnaires for expert opinions and bridging any gaps in data. Opinions of diverse stakeholder groups (Govt. agencies, manufacturers and consultants) were taken to gather multidimensional views for this sector.

[1] Indian Cooling Action Plan (2019)

The inputs / feedback from diverse stakeholder groups made sure that all dimensions were captured and suitably addressed.

Chapter 1 starts with importance of cold-chain for India and provides insights on various Government policy/programs for the sector. This section also details the envisaged capacity addition in terms of cooling capacity and refrigerant demand in the coming decades.

Chapter 2 provides an overview of various cold-chain components, their infrastructure requirements and gaps.

Chapter 3 details various construction requirements and applicable standards which govern energy efficiency in the Cold- chain sector such as the National Building Code of India 2016 (NBC 2016), Guidelines & Minimum System Standards for Implementation in Cold – chain Components and ISO-2370:2014.

Chapter 4 and 5 assess the existing technologies used across the various components of the Cold-chain, presents a list of commercially available and prospective clean technologies which can be introduced in the different components of the Cold-chain.

Chapter 6 highlights the O&M practices which can improve the overall operational energy efficiency and promote a robust maintenance framework.

Chapter 7 lists recommendations for promoting sustainable technologies in the sector.

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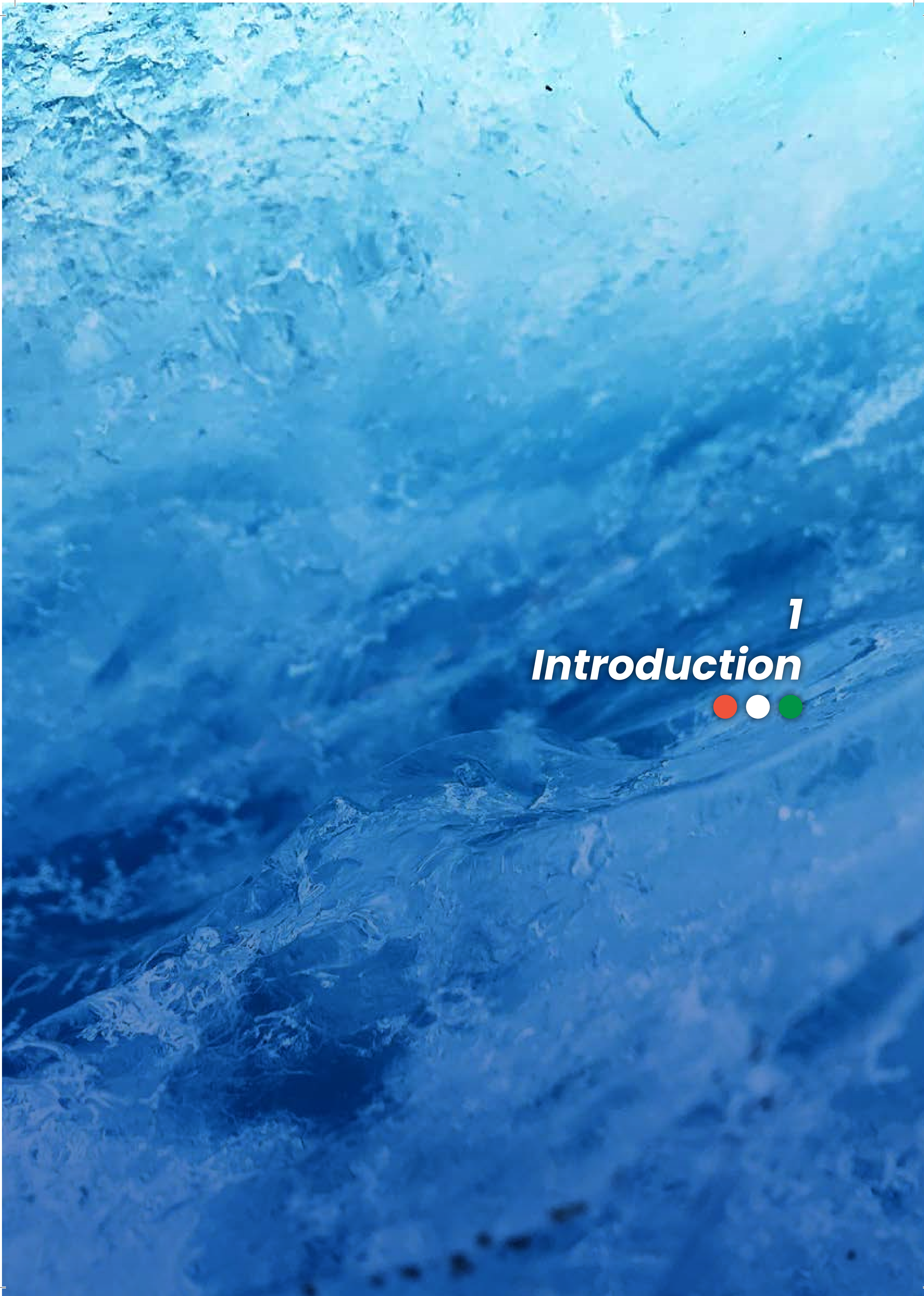
Abbreviations

APEDA	Agricultural and Processed Food Products Export Development Authority
BEE	Bureau of Energy Efficiency
CAGR	Compound Annual Growth Rate
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HPMP	HCFC Phase-out Management Plan
ICAP	India Cooling Action Plan
IoT	Internet of Things
MIDH	Mission for Integrated Development of Horticulture
MoFPI	Ministry of Food Processing Industries
MoEF&CC	Ministry of Environment, Forest & Climate Change
MT	Metric Tonne
Mn	Million
NCCD	National Centre for Cold-Chain Development
NHB	National Horticulture Board
NHM	National Horticulture Mission
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substances
OEM	Original Equipment Manufacturer
PCM	Phase change materials
VFD	Variable Frequency Drive



1
Introduction

1.1 COLD-CHAIN : IMPORTANCE

India has seen a phenomenal growth in production of perishables such as horticulture (fruits & Vegetables), dairy, fish and meat products over the last decade. According to the Yes bank report on Cold-chain opportunities in India published in year 2018, India occupies a top position in production of a host of perishables such as:[2]

- India is the second largest producer of fruits and vegetables in the world with a production of 277 Million Metric tonne (Mn MT)
- India is the world's largest producer and consumer of milk and dairy products, with 20% share in global milk production
- India is also the second largest fish producing nation in the world valued at around USD 15 Billion
- The total meat production in India currently stands at about 7.4 Mn MT (2016-17) and ranks 5^{th} in the world. India is the largest buffalo meat exporting country with small amount of sheep meat[3].

However, India's present share in global farm trade is still very small. A key deterrent to this is the high level of wastage across the value chain of key perishables. Due to their perishable nature, fruits, vegetables, meats and dairy products require controlled environment (temperature, RH%) facilities for storage and onward travel in the supply chain. Controlled environment slows down the processes of microbial, chemical or enzymatic deterioration. These controlled environment infrastructure from farm (or production source) till the last point (consumer) is known as **cold-chain.**

There is significant opportunity for India to build cold-chain infrastructure to utilize the full potential of perishable produce. A seamless cold-chain will ensure the following benefits:

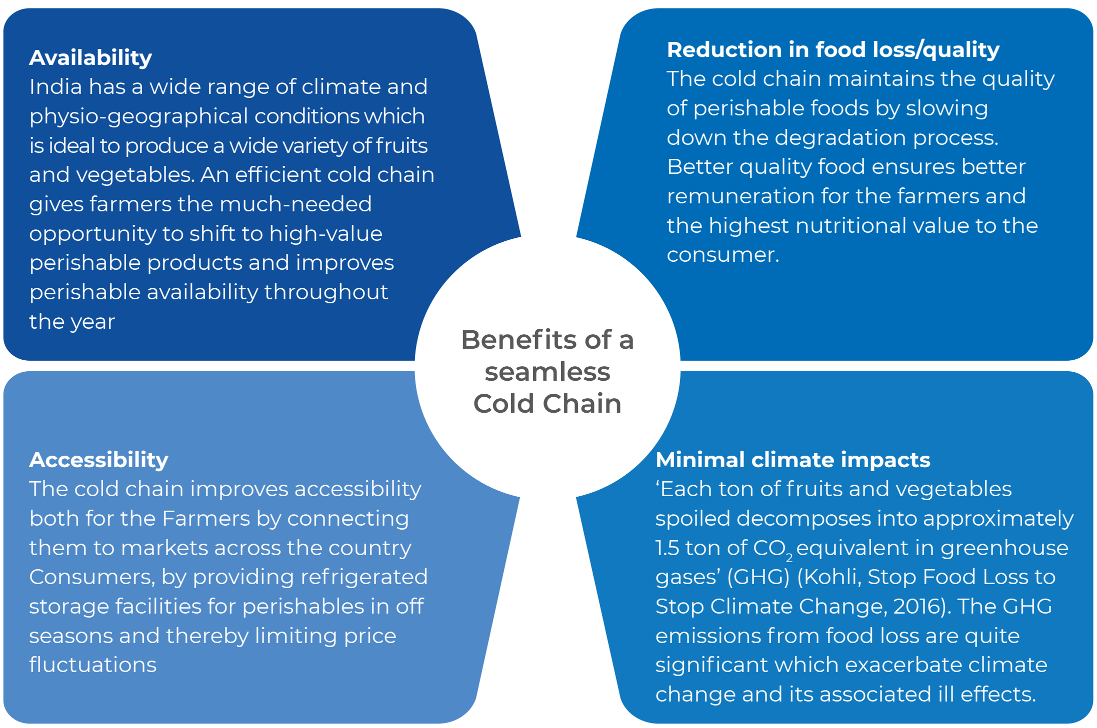


Figure 1: Benefits of cold-chain

[2] Cold -chain Opportunities in India: Yes bank report 2018
[3] Indian meat industry: Red Meat Manual-APEDA

All the factors listed above strengthen country's food safety and food security and at the same time strengthening Government of India's vision on Doubling farmers income (DFI).

1.2. MAPPING OF THE EXISTING GOVERNMENT POLICIES AND PROGRAMS FOR COLD-CHAIN

Given the benefits, Government of India has introduced various policies and programs to boost the cold-chain sector. Some of the key policies and programs are as follows –

1. **Support in the form of financial assistance, subsidies, grants for setting up of cold-chain infrastructure through various government agencies are mentioned in table 1**

Table 1 : Financial assistance / subsidies for cold-chain infrastructure

Ministry	Concerned body / Scheme	Cold-chain Component	Incentive/ Subsidy
Ministry of Agriculture and Farmers Welfare	National Horticulture Board (NHB) NHB is a sub-scheme of Mission for Integrated Development of Horticulture (MIDH). MIDH is a Centrally Sponsored Scheme for the holistic growth of the horticulture sector covering fruits and vegetables)	Pack-house, Reefer Van, Ripening Chamber etc. (applicable for all states and Union Territories focusing on commercial horticulture)	Credit linked back ended subsidy at 35% of cost per project in general areas 50% of cost per project in north-east (NE) and hilly areas[4]
		Cold storage - 5001 Metric tonne (MT) to 10000 MT	Credit linked back ended subsidy at 35% of project in general areas 50% per project in NE and hilly areas[5]
		Pack-houses, logistics facilities, primary processing centers, ripening chambers	INR 1,00,000 crores will be provided for financing agriculture, infrastructure projects at farm gate and aggregation points through Aatmanirbhar Bharat Abhiyan[6]
	National Horticulture Mission (NHM) and Horticulture Mission for North East & Himalayan States (HMNEH) are a sub-scheme of MIDH	Pack-house, Reefer Van, Ripening Chamber etc. (applicable for selected districts of 18 states and 6 Union Territories)	Credit linked back ended subsidy at 35% of cost per project in general areas 50% of cost per project in NE and hilly areas[7]
		Cold storage (long term storage and distribution hubs) – upto 5000 MT capacity	Credit linked back ended subsidy at 35% of project in general areas 50% per project in NE and hilly areas[8]

4 http://nhb.gov.in/guideline/113.pdf
5 http://nhb.gov.in/guideline/12.pdf
6 http://nhb.gov.in/
7 https://midh.gov.in/PDF/Annexure-V.pdf
8 https://midh.gov.in/PDF/Annexure-V.pdf
9 https://apeda.gov.in/apedawebsite/Announcements/SchemeGuidelinesMTEF27042018.pdf

Ministry	Concerned body / Scheme	Cold-chain Component	Incentive/ Subsidy
Ministry of Commerce and Industry	Agricultural and Processed Food Products Export Development Authority (APEDA)	Pack-houses, reefer transport, and cold storages	Up to 40% of the total cost subject to a ceiling of INR100 lakhs[9]
Ministry of Food Processing Industries	Pradhan Mantri Sampada Kisan Yojana	Mega Food Park Scheme: facilitate establishment of a strong food processing industry backed by an efficient supply chain Collection Centers, Primary Processing Centers (PPC), Central Processing Center (CPC) and Cold-chain infrastructure	50% grant in aid of the project cost for general areas 75% of the project cost for difficult area subject to a maximum of INR 50 crore per project[10]
		Integrated food chain and Value Addition Infrastructure: Pack-houses, pre-cooling units, ripening chamber and transport infrastructure	For storage infrastructure 35% grant-in-aid for general areas and 50% for north-east states, himalayan States, ITDP areas & islands, of the total cost of plant & machinery and technical civil works. For value addition and processing infrastructure grant-in-aid at 50% for general areas and at 75% for north-east states, himalayan states, ITDP areas & islands.[11]

2. Various policies and reforms in the agricultural sector to promote the farmers for diversifying to high value perishables

Table 2 : Policies and reforms for promotion of cold-chain

Policy and reform	Description
The Farmers produce and Commerce (Promotion and Facilitation) Act, 2020[12]	As per the Agricultural Produce Market Committee (APMC) Act, 2003 Yards/Mandis in the market area regulated the notified agricultural produce and livestock. The Promotion and Facilitation Act, 2020 is meant to allow farmers to bypass the APMC regulated markets. This act aims at opening up agricultural sale and marketing outside the notified mandis for farmers, removes barriers to inter-state trade and provides a framework for electronic trading of agricultural produce. A new initiative called E-NAM (National Agriculture Market) has been undertaken to encourage states to adopt e-trading platform for agricultural commodities.

[10] https://mofpi.nic.in/Schemes/mega-food-parks/pattern-assistance
[11] https://mofpi.nic.in/Schemes/Cold-chain/pattern-assistance-0
[12] https://egazette.nic.in/WriteReadData/2020/222039.pdf
[13] https://dmi.gov.in/Documents/Final_GrAM_Guidelines_final_03012019.pdf

Policy and reform	Description
Gramin Agricultural Markets (GrAMs)[13]	Another significant Initiative of GOI is to develop 22,000 Gramin Agricultural Markets (GrAMs) as announced in the 2018-19 budget. These will be kept outside the ambit of APMC act. The GrAMs will serve 2 purposes -1) help farmers operate markets privately and sell their produce locally and to bulk purchasers and 2) act as aggregation and pooling centers for movement of produce to distant markets. These GrAM's will essentially be designed with pack-houses to stage and dispatch produce.
Promoting producer alliances for small and marginal farmers[14]	Small Farmers Agribusiness Consortium (SFAC) and National Bank for Agriculture and Rural Development (NABARD) are promoting Farmers Producers Organizations (FPO) to pool resources which will help small and marginal farmers in the country to leverage scale factor, bargaining strength and market connectivity.

3. Tax rebates and incentives

Tax rebates and incentives such as GST exemption on activities such as preconditioning, pre-cooling, packaging in cold-chain components

4. Other initiatives

100% FDI participation under the automatic route for E-commerce companies in the food and beverage segment, Cash & Carry, Wholesale Trading (including sourcing from MSEs)

Given the government push on the cold-chain sector, India is looking at a substantial capacity addition in terms of storage and transport infrastructure in the coming years. According to the **India Cooling Action Plan (ICAP)**, different components of cold-chain infrastructure will witness substantial growth by 2037-2038.

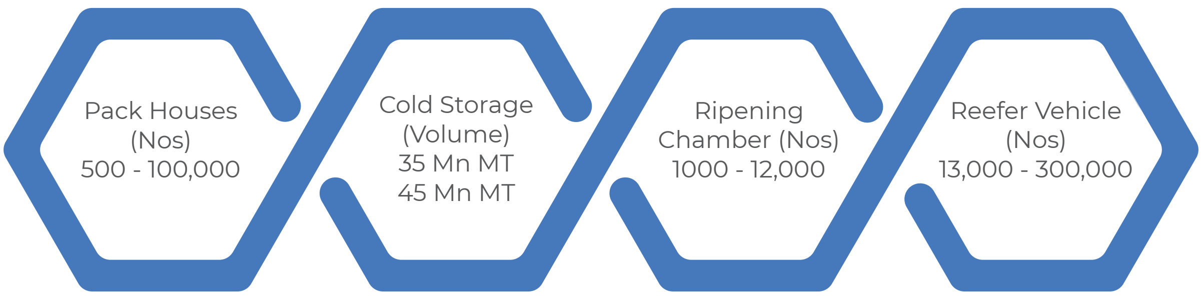


Figure 2 Envisaged growth in cold-chain infrastructure from 2017-18 to 2037-38

The increased infrastructure will eventually result in substantial capacity addition in cooling requirement and upsurge in refrigerant demand, as most of the cooling demand will be met with technologies that are compression based[15]:

[14] http://sfacindia.com/UploadFile/Statistics/Strategy-Paper-on-Promotion-of-10,000-FPOs.pdf
[15] Indian Cooling Action Plan

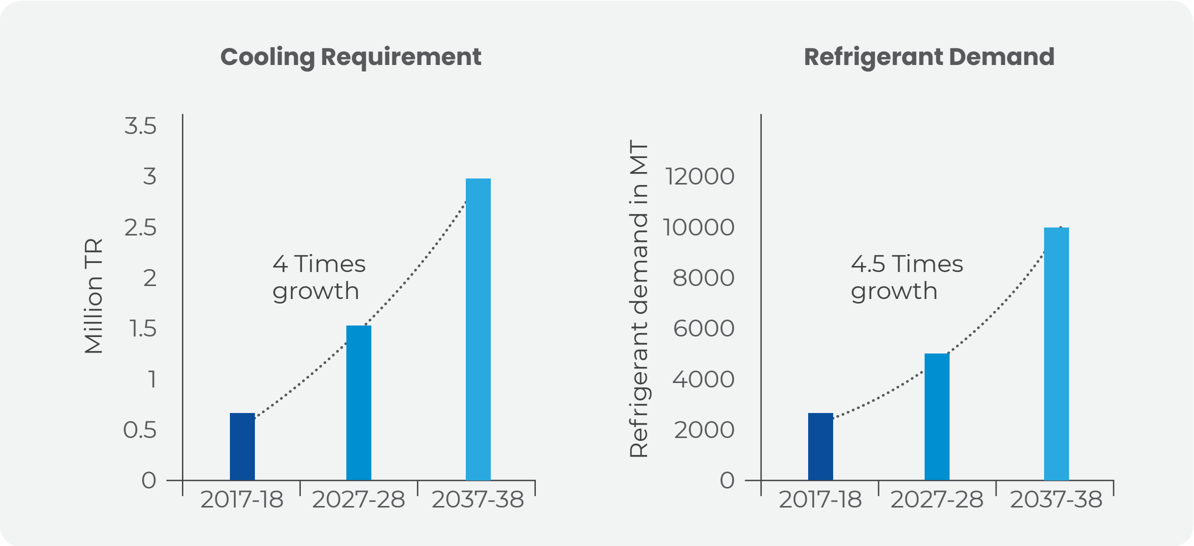
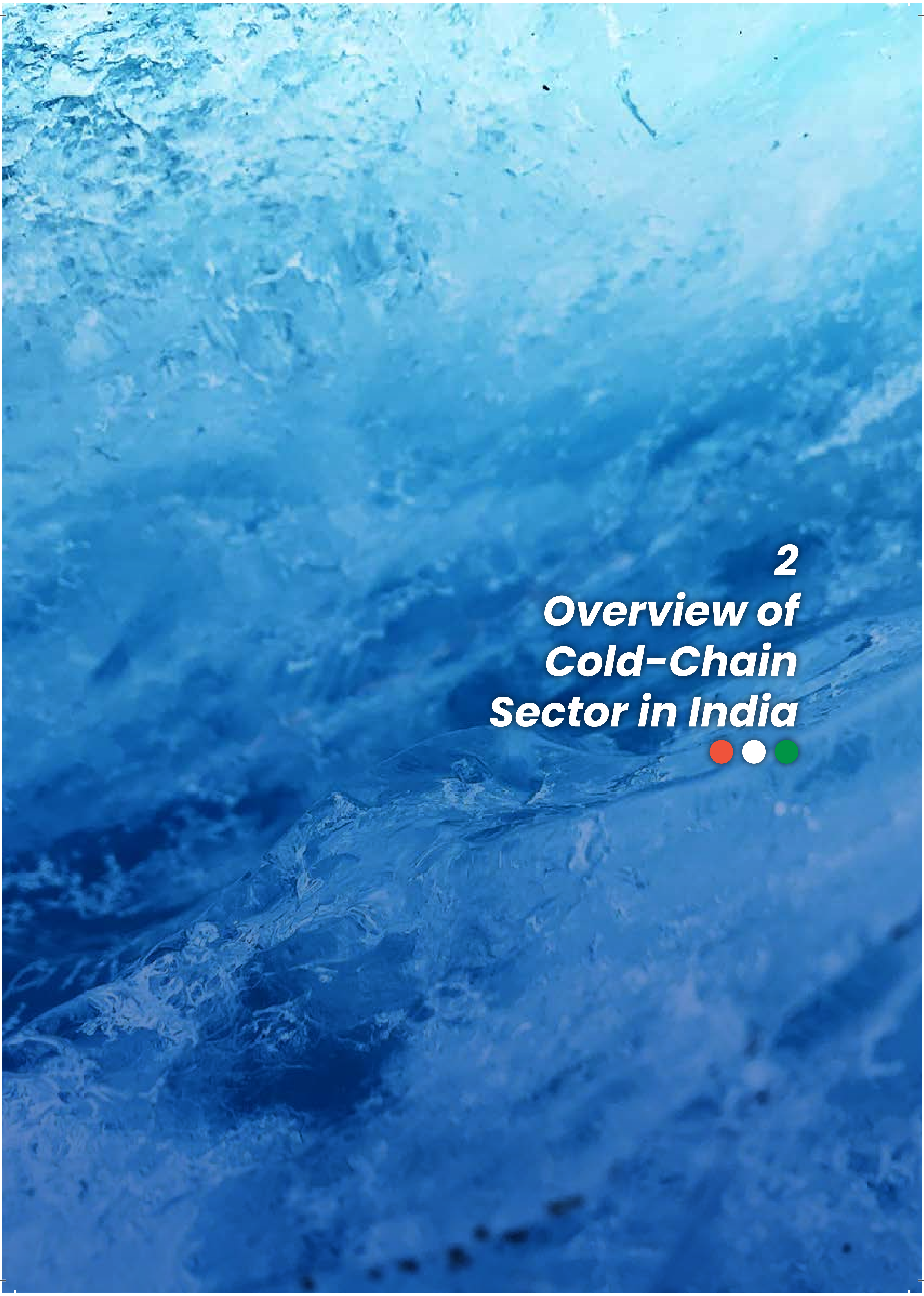


Figure 3: Growth in cooling requirement and refrigerant demand for cold-chain

Refrigerants such as Hydrochlorofluorocarbons (HCFCs), Hydrofluorocarbons (HFCs) and its blends are being used in cold-chain cooling technologies. HCFCs are ozone depleting substances (ODS) and they do have global warming potential (GWP). While HFCs do not contribute to ozone depletion, however they do have significant GWP. Being a signatory to the Montreal Protocol on Substances that Deplete the Ozone Layer, India is currently implementing stage II of HCFC Phase-out Management Plan (HPMP). Given the envisaged growth in cold-chain sector, timely interventions are required to promote cooling technologies, which not only have high operational efficiency but also use refrigerants with low GWP and zero ODP.

This also presents an opportunity to explore clean technologies which have high operational efficiencies and use low GWP and non-ODS based refrigerants. As per stakeholder consultations and inputs from various experts, there is a potential to improve energy efficiency up to ~ 30% in this sector through prudent choice of cooling technologies. The report maps the cooling technologies currently in use at various cold-chain components and presents a list of clean technologies, which can help phase-out HCFCs and lower the dependence on high GWP based HFCs to promote sustainability in the sector.



2 Overview of Cold-Chain Sector in India

2.1. COLD-CHAIN COMPONENTS

Cold-chain is a controlled environment 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[16]. Cold-chain does not alter the essential characteristics of the produce or product handled. Cold-chain is particularly deployed for perishable products such as:

- Horticulture produce (fruits, vegetables, flowers)
- Dairy products
- Meats
- Vaccines (the supply chain for vaccines is completely different from agricultural and processed food. Thus, it is not covered in this report)

A basic schematic of a typical cold-chain through which perishable products go through before reaching the end consumer is depicted in figure 4.

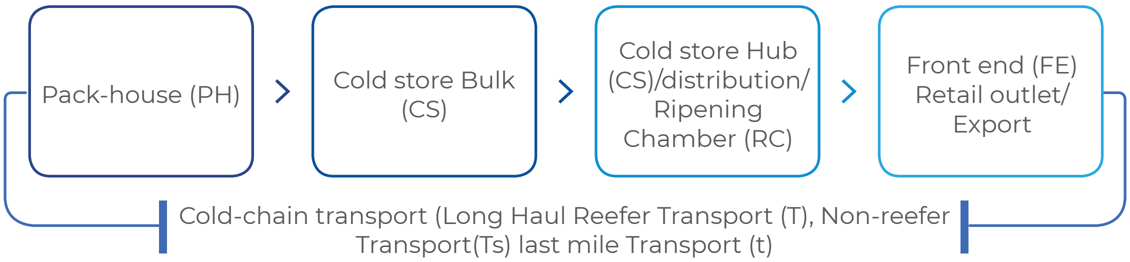


Figure 4 Different components of cold-chain

2.2. CURRENT INFRASTRUCTURE AND OWNERSHIP PATTERN

- **Pack-house:** Most of the pack-houses i.e. ~ 60% (207 numbers) are APEDA registered (as on January 2021)[17]. These are mostly located in **Maharashtra (~ 75%) and owned/operated by exporters**.
  - » Over 50% of total pack house cater to **pomegranates and mangoes**.
  - » Other products which require pack-houses are Grapes, Okra, Bitter Gourd, Chilly, Herbs

- **Cold storage:** The cold storages in India might look enough, but most of the development in India has happened in the single commodity cold storages for potatoes and chillies. Majority of cold storages are in Uttar Pradesh, West Bengal and Gujarat.

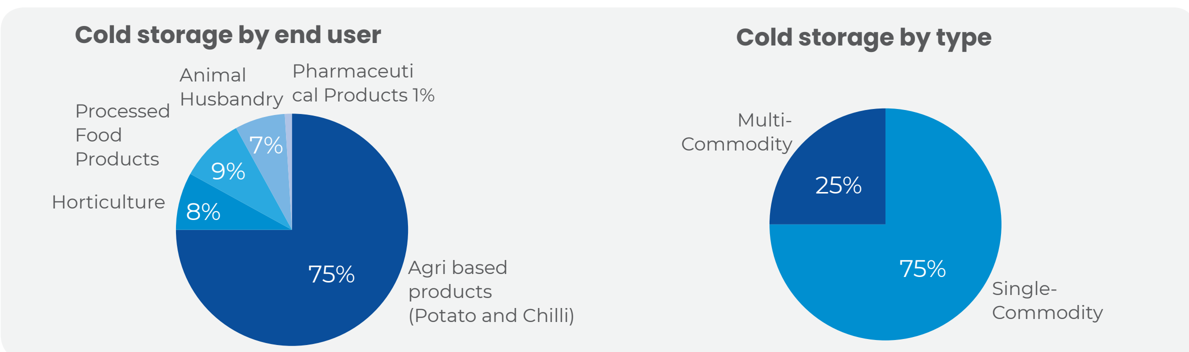


Figure 5: Cold Storage by type and end use[18]

[16] All India Cold-chain Infrastructure capacity 2015 – National Centre for Cold-chain Development (NCCD)
[17] http://apeda.gov.in/apedawebsite/Announcements/Active_Pack_House_list_jan_2021.pdf
[18] Cold -chain Technologies: Transforming food supply chains

Currently, 95% of the cold storages are owned by **the private sector**, 3% by cooperatives and the remaining 2% by the public sector undertakings (Balmer Lawrie & Co Ltd, Container corporation of India)

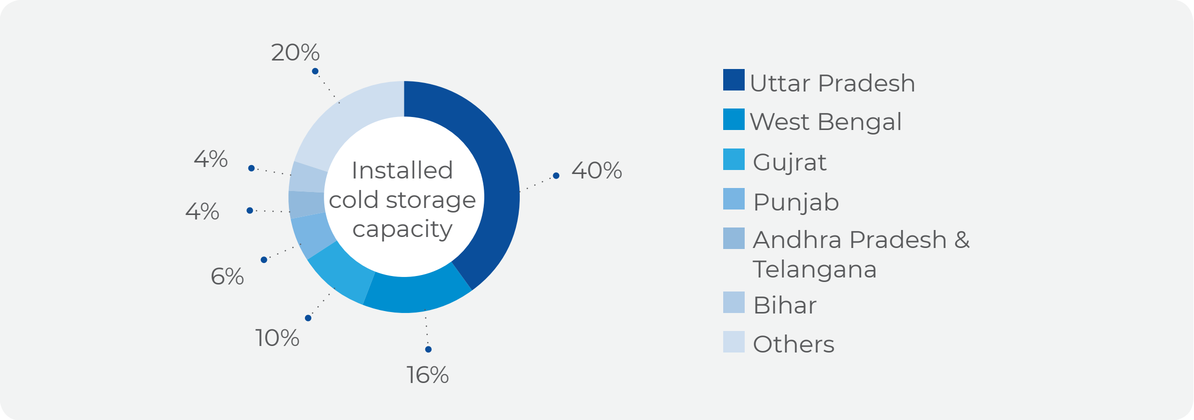


Figure 6: State wise cold storage capacity[19]

- **Reefer Transport**: As per National Centre for Cold Chain Development (NCCD), 97.4% of fruits and vegetables produced in India moves on roadways and only 2.6% moves through rail network. Refrigerated transport is mainly deployed for meats and dairy products, while majority of the horticulture produce still is transported in diesel trucks. This sector is highly fragmented and dominated by third party logistic players.

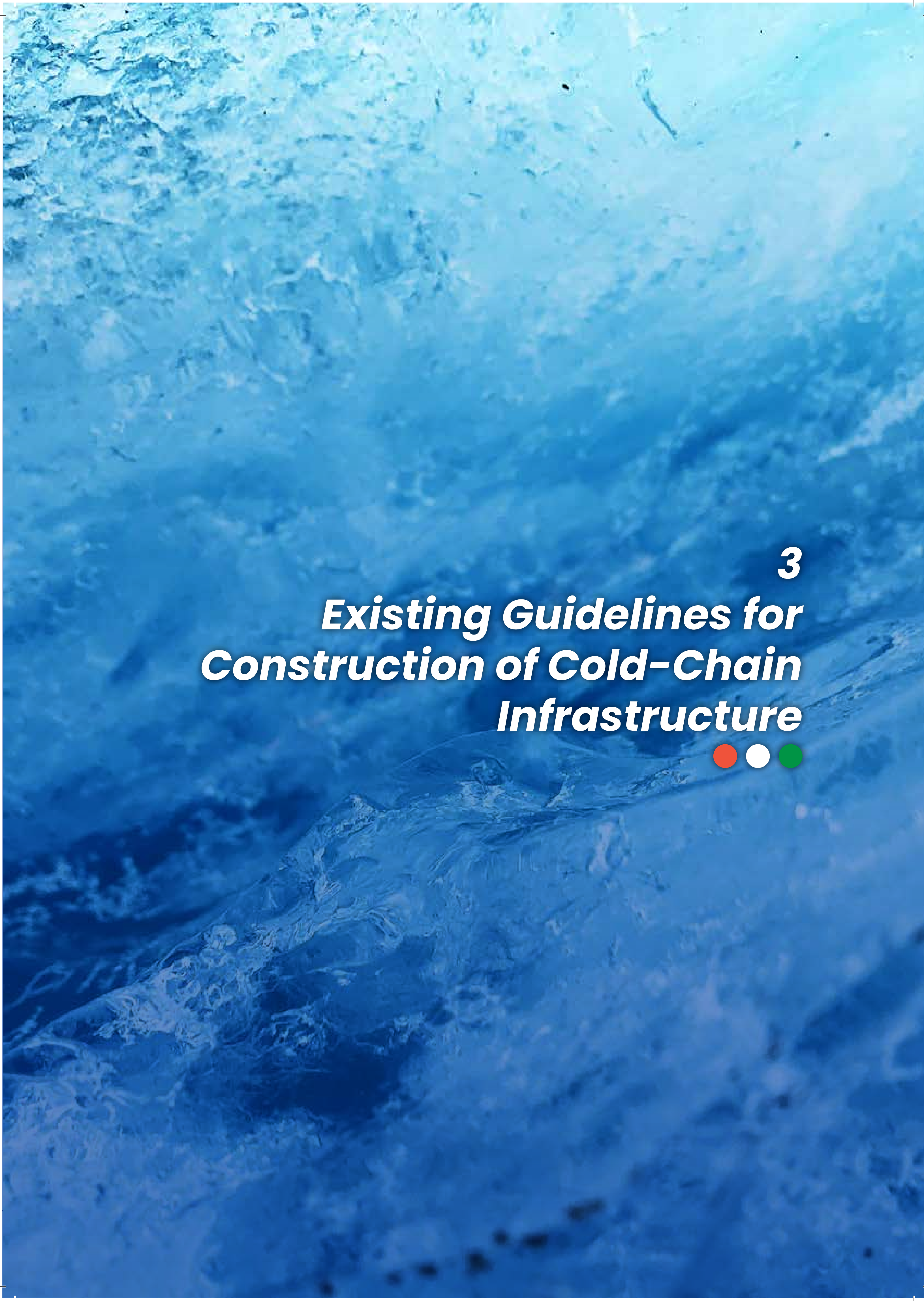
The table 3 shows the required and existing infrastructure of cold-chain components in India –

Table 3 : Cold-chain Infrastructure in India in 2020

Component	Requirement*	Existing	Gap
Pack-house (Nos.)	82,372	207[20] *(APEDA Registered)*	99.7%
Cold storage (Bulk) and cold Storage hub (MT)	41,257,132	37,425,097[21]	9%
Reefer transport (Nos.)	72,670	12,700[22]	82.5%

*While the existing numbers have been taken from the Govt. websites as reference, the following methodology has been applied to estimate the requirements. As per report “All India cold-chain infrastructure capacity (2015)-NCCD and Ministry Agriculture and Farmers Welfare, capacity addition in cold storage has happened at a CAGR (from 2014 to 2020) of 2.73%. Same growth rate has been applied to other components to work out the requirements in 2020.

[19] https://pib.gov.in/PressReleasePage.aspx?PRID=1658114
[20] http://apeda.gov.in/apedawebsite/Announcements/Active_Pack_House_list_jan_2021.pdf
[21] https://pib.gov.in/PressReleasePage.aspx?PRID=1658114
[22] FnBnews.com- Pavenexh Kohli-CEO, NCCD



3
Existing Guidelines for Construction of Cold-Chain Infrastructure

3.1. NATIONAL BUILDING CODE OF INDIA (NBC 2016)

The National Building Code of India (NBC 2016) of India provides guidelines for regulating the building construction activities across the country. It serves as a model code for adoption by all agencies involved in building construction. The code contains administrative regulations, development control rules, and general building requirements (including fire safety and facility management). While no benchmarks or threshold values has been specified for energy efficiency related aspects for cold storages, the clause 9 'Refrigeration of cold stores' of Part 8 of NBC 2016 provides general guidelines on following:

1. Refrigeration heat load considerations

For calculation of heat load, the NBC 2016 specifies taking into consideration thermal transmission or U-values as prescribed in international standards such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers standards ASHRAE 90.1 and inclusion of the following loads for arriving at the total cooling load and sizing of the refrigeration system

- Transmission load: Heat transmitted into the refrigerated space through its surface;
- Product load: Heat removed to bring products to a storage temperature and heat generated by products in storage;
- Internal load: Heat produced by internal sources;
- Infiltration air load: Heat gain associated with air entering the refrigerated space; and
- Equipment related load: Heat gain by refrigeration equipment

2. Temperature sensing and monitoring

Accurate and constant temperature monitoring is paramount for a cold storage since the food products are adversely affected by temperature fluctuations. Temperature monitoring is dependent on factors such as placement, resolution, accuracy etc. of measuring instruments. The NBC 2016 specifies the following for temperature monitoring:

- Temperature sensors and thermometers should be placed at multiple locations in cold storage and their values should be displayed accordingly at the central control location;
- Products requiring considerably different temp. requirements should be zoned separately; and
- The accuracy of the probe that can be inserted in the food should be at least ±0.5°C

3. Installation and maintenance of cold room

NBC 2016 recommends the use of Polyurethane foam (PUF) Panels as insulation material foamed between 2 sheet metal skins compared to conventional insulation materials such as fiberglass, mineral wool on walls and ceilings. NBC 2016 refers to IS 661:2000 'Code of practice for thermal insulation for cold storage (third revision)' for selection and design of panels for thermal insulation.

4. Cold room safety

The NBC 2016 specifies safety guidelines for firefighting equipment, safe handling of refrigerant leaks, safety device, controls and alarm systems, emergency lighting in the cold chambers, first aid kit, emergency assembly points and water shower in ammonia plants.

3.2. "GUIDELINES & MINIMUM SYSTEM STANDARDS FOR IMPLEMENTATION IN COLD – CHAIN COMPONENTS"

"Guidelines & Minimum System Standards for Implementation in Cold-chain Components" (Published by NCCD, 2015) provides standard definitions and description of cold-chain components supported under Mission for Integrated Development of Horticulture (MIDH) and allied agencies. The document incorporates the minimum norms as per the MIDH guidelines that enable the users to leverage financial and other assistances available under government schemes and programs.

For both new and old projects, the document provides standard templates and technical data sheets for various equipment and components. These must be included in the Detailed Project Report (DPR) and complied for the purpose of availing loan, subsidies and other form of financial assistance.

For new installations, this specifies compliance with standards such as BIS, ISO and EN as specified in tables 4,5 and 6 which indirectly drives equipment level energy efficiency.

For old and existing installations, this specifies three broad areas for improving the energy efficiency, these are:

1. Modernization of refrigeration systems in cold storage

This component refers to modernizing of refrigeration system in existing cold storages to reduce the carbon footprint, power consumption and enhance safety for existing cold storages. The components may include:

» Upgradation of evaporators
» Upgradation of compressors
» Replacement of refrigeration valves including electronic expansion valves
» Automation with PLC/ microprocessor-based monitoring and controls

To qualify for subsidy and other financial assistance under this area, the reference data sheets of old and new equipment must substantiate reduction in energy consumption by 5%. In addition, the refrigerant GWP and ODP must be in compliance with the **Montreal Protocol on Substances that Deplete the Ozone Layer.** The cost norm applicable is 50% of incurred cost with maximum admissible cost of INR 100 Lakhs but not more than INR 2500 per MT (Metric tonnes) of the cold store capacity.

This component will typically manifest into upgradation of open tube evaporators to more energy efficient evaporators and low efficiency compressors to higher energy efficiency compressors with the capability of full and partial operating load. The modern refrigeration systems must comply with important standards mentioned in table 4.

Table 4 : Reference standards for modernization of refrigeration equipment [23]

Code and Reference	
Eurovent	European standards for evaporators/ Air-coolers
ARI/EU	Manufacturing and Testing standards for refrigeration compressors
ASME Sec VIII Div. 1	Code of Pressure vales
IS 16656: 2017/ ISO 817: 2014	Refrigerants — Designation and Safety Classification

[23] Guidelines & Minimum System Standards for Implementation in Cold – chain Components – NCCD report 2015)

Code and Reference	
IS16678 (Part 2): 2018 / ISO 5149 Pt 2:2014	Refrigerating Systems and Heat Pumps — Safety and Environmental Requirements Part 2 Design, Construction, Testing, Marking and Documentation
IS16678 (Part 3) : 2018/ ISO 5149-3: 2014	Refrigerating Systems and Heat Pumps — Safety and Environmental Requirements Part 3 Installation Site
IS16678 (Part 4) : 2018/ ISO 5149-4: 2014	Refrigerating Systems and Heat Pumps — Safety and Environmental Requirements Part 4 Operation, Maintenance, Repair and Recovery

2. Non-ODS blowing agents for insulation:
This applies to modernizing the insulating medium resulting in superior thermal barrier which in turn results in reduction in energy loss. **The modern insulation be CFC free and preferably HCFC free material, resulting in reduction of energy consumption by at least 5%.** The reference data sheet to substantiate old versus new performance includes details of insulating material and thickness, U-value, density, thermal diffusivity etc. The cost norm applicable is 50% of incurred cost with maximum admissible cost of INR 100 Lakhs but not more than INR 1500 per MT of the cold store capacity.

The insulation must comply with important standards mentioned in table 5.

Table 5 : Standards for modernization of insulation[24]

Code and Reference	
IS 661	Code of practice for thermal insulation of Cold Storages
IS 12436-1988	Specification for Preformed Rigid Polyurethane (PUR) and Polyisocyanurate (PIR) foams for thermal insulation'
DIN 55928	Specifications for galvanised steed cladding
ASTM D 1622	Density
ASTM C 177-97	Thermal Conductivity
The National Building Regulations and Building Standards Amendment Act No. 103 of 1977	Building Standards
AISC-2005	Design Code
IBC-2006	Building Code

3. Alternate energy options:
Various alternative energy options such as renewable energy source, thermal energy banks or other non-conventional technologies have been listed in the document to promote lower carbon footprint. Under MIDH norms, a beneficiary may apply for a maximum cost of **INR 35 Lakhs for listed items and combination of them**. The items under the subsidy component include:

- Solar PV systems
- Solar Thermal systems
- Thermal Banks
- Vapour Absorption Refrigeration

[24] Guidelines & Minimum System Standards for Implementation in Cold – chain Components – NCCD report 2015)

[25] Guidelines & Minimum System Standards for Implementation in Cold – chain Components – NCCD report 2015)

The compliance requirements for the above-mentioned alternate energy options have been specified in the guidelines. Some of the key standards applicable for use of alternate energy options are mentioned in table 6.

Table 6 : Standards for alternate energy options[25]

Code and Reference	
IEC 61215/ IS14286/IEC 61646	Thin film/ crystalline silicon terrestrial PV modules
IEC 62108	Concentrator PV modules & Assemblies
IEC 61730	Part 1: requirements for construction & part 2: requirements for testing, for safety qualification or equivalent IS.
IP 54	General requirements for junction boxes/ enclosures for inverters/ Charge Controllers/Luminaries
Flat plate collector	ISI mark
Outer cladding & Frames	Al/SS/FRP or GI powder coated. MS may also be used with special anti-corrosive protective offering.
Thermal insulation of tanks & Hot water piping	Minimum 50 mm thick with CFC free PUF having density tanks & hot water piping of 28-32 kg per cum.
Valves, cold water tank	ISI mark or standard make
IEC 60947 part I, II, III	General requirements, connector safety, A.C/D.C (switches, circuit breakers, connectors)

3.3. WALK IN COLD ROOMS– IS 2370: 2014

Bureau of Indian Standards (BIS) is the National Standard Body of India, responsible for the standardization, marking and quality certification of various appliances. BIS published standard no. IS 2370 in 2014 for walk in cold rooms. IS 2370 prescribes the constructional and performance requirements of walk in cold rooms of 5 to 20 kiloliter gross volume capacity that are operated by an electrically driven refrigerating machine of the vapor compression type. The document prescribes guidelines pertaining to materials, sound level, safety features and rating of motors.

While no benchmarks or threshold values has been specified for energy efficiency related aspects, the standard illustrates various methods of testing the cooling capacity and the test conditions such as indoor and outdoor temperature and RH%. The standard also mandates the following tests for compliance requirements:

Production routine tests (Conducted at manufacturer works)	Type tests (conducted at accreditated Labs)	Acceptance tests
• Pressure Running Test • Vaccum Test • Electrical Test • General Running Test	• Door seal test • Thermal Insulation • Measurement of Air flow • Capacity rating test • Power Consumption test • Maximum operating condition test	• On request of purchaser, production routine tests can be repeated))

3.4. FREIGHT CONTAINERS: SPECIFICATION AND TESTING- IS 13288 PART-2 (THERMAL CONTAINERS)

IS 13288 (Part 2) prescribes specifications and testing requirements for thermal containers which are suitable for export of goods (including perishable goods like meat, fruits and vegetables) by road, rail and sea. These containers are used in the refrigerated transport component of the Cold-chain. The standard classifies the allowable heat leakage rates and design temperatures for various types of containers such as: thermal container, insulated container, refrigerated container, mechanically refrigerated container etc. Some of the tests that the standard mandates for compliance requirements are:

- Strength test: To prove the ability of the thermal container to withstand forces
- Weather proofness: To prove no water has leaked into the thermal container
- Heat leakage test: To establish the heat leakage of the thermal container
- Performance test: To establish the ability of the thermal container, fitted with a mechanical refrigeration unit, to maintain a given inside temperature.

4
Cooling Technologies in Cold-Chain

India produces a wide variety of fruits & vegetables given its diverse agro-climatic zones. The storage requirement (temperature and RH) of these perishables is different based on their properties and shelf life. Temperature requirements of common perishables in India are given in the table 7.

Table 7 : Cold-chain flow and temperature. requirement for common Indian perishables[26]

S.No.	Products	Logistics Flow	Temperature requirement
1	Apple, Kiwi	CS – PH – T – CH - t - FE	Chill (0 to 10 Deg.C)
2	Grapes, Orange, Strawberry	PH – T – CH - t – FE	
3	Potato	CS – Ts – FE	
4	Tomato, Cauliflower, Okra	PH – T – CH - t – FE	
5	Carrot, Cabbage	CS – PH – T – CH - t - FE	
6	Onion	SS - Ts – FE	Normal (20 Deg.C to 30 Deg.C)
7	Mango, Banana, Papaya	PH – T – CH – RC - t - FE	Mid Chill (10 to 20 Deg.C)
8	Processed food products, Meat & dairy products	PU – T – CH - t – FE	Frozen (Below – 18 Deg.C)

PH - Pack-house; T - Long Haul Reefer Transport; Ts – Non-reefer Transport; CS - Cold Storage Bulk; CH - Cold Storage Hub; RC - Ripening Chamber; FE - Front-end merchandising; SS – Storage Structure; PU - Food Processing Unit or Allied; t – last mile Transport

The wide range of temperature requirement (-18 Deg.C to 30 Deg.C) and produce properties result in use of various cooling technologies in this sector.

4.1. CLASSIFICATION BASIS PRINCIPLE

Cooling technology options fall into 4 broad categories basis principle of operation. The suitability (in terms of food products and ambient conditions) and controllability (temperature and RH) determines its application as depicted below in table 8.

Table 8 : Cooling methods in cold-chain[27]

Cooling Method	Principal Applicability				Operating Energy	Refrigerant use
	Food Products	Temperature Range	Cold-chain Steps	Other		
Vapor Compression	All food products	Full Temperature Range	Entire cold-chain		Electrical	Halogenated or natural refrigerants
Sorption	All food products	Full Temperature Range	Entire cold-chain but limited applicability in transport		Thermal	Natural refrigerants
Ice Making	Non chilling sensitive produce only (fish and meat)	Temperatures around 0℃	Fish and meat		Electrical or thermal	Halogenated or natural refrigerant
Evaporative cooling	Chilling sensitive fruit & vegetables	Temperatures of above 10℃	Mainly bulk storage	Climatic limitations (low humidity)	Electrical	Water

[26] All India Cold-chain Infrastructure Capacity Assessment of Status & Gap. New Delhi: NCCD, (2015)
[27] Cold -chain Technologies: Transforming Food Supply Chains, ASSOCHAM

4.2. VAPOUR COMPRESSION TECHNOLOGIES

Vapour compression-based cooling technologies dominate different components of cold-chain (pack-houses, cold stores, transport refrigeration, and retail outlets) and account for ~ 95% of the cooling requirement. This can be attributed to their ability to work under varying ambient conditions and wide temperature range catering to a variety of products. This cooling technology can be broadly classified into 2 categories basis their refrigerant use-

- Ammonia based;
- Fluorocarbon (HCFC/HFC) based

According to the various original equipment manufacturers (OEMs), the cooling technologies are also segregated based on the temperature requirement as shown in the figure 7.

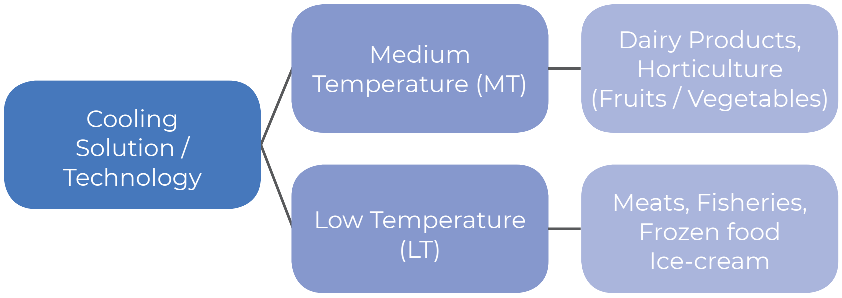


Figure 7: Cooling technology classification basis temperature

There are no standards which define temperature values for Medium temperature (MT) and Low temperature (LT). But as per the industry players, the range for LT and MT is -30^0 to -5 ^{0}and -5^0 to 10^0 respectively.

4.2.1. Classification of compression-based technologies basis refrigerant

1. Ammonia based chillers

Ammonia based chillers mostly find application in large capacity i.e. bulk cold storages. These are centralized type of systems consisting of a compressor, condenser, evaporators and expansion valves. Main compressor is located in the plant room connected with multiple cooling towers, evaporators and condensers as per the design of the system.

Ammonia based systems are **dominated by the unorganised players (80-85%[28]),** where different components such as (compressors, evaporators, condensers, controls etc.) are procured from different vendors and are assembled at site.

Compressors and evaporators in ammonia based systems are mostly imported, whereas control valves, condensers and cooling towers are source locally. For bulk cold storage facilities, ammonia has become refrigerant of choice since it produces greatest net refrigerating effect (Btu/lb).

Ammonia is a natural refrigerant with a GWP of 0 and has significantly lower climate impacts. The main challenging factor is the toxicity of ammonia with the large quantities of gas used in conventional systems. Due to safety concerns, ammonia-based systems are used in cold storages located outside the city limits.

[28] Cold-chain Opportunities in India

Figure 8: Ammonia based chiller Image source: http://www.ashrae4greenville.com/resources/ Newsletter/2014/Intro-to-Ammoni-Refrigeration.pdf

2. HCFC/HFC based systems

HCFC/HCF based systems mostly find application in small cold storages (Hubs) and modular cold storages. This is mostly catered by India's leading HVAC companies. These fall into 2 broad categories as shown in the figure 9.

- **Condensing and evaporating units**: These systems have standard size evaporators and condensers units along with inbuilt control systems for various applications.

Figure 9: Condensing and evaporating units

- **Rack type systems:** This type of system features a number of compressors working together which allows variable cooling instead of simple turning on and off. When cooling requirement is less, some compressors can be turned off while others are kept in operation. This method is applicable when a system has several evaporators running at similar temperatures that are required to meet varying refrigeration loads. Typically, this method uses from three to nine compressors of unequal sizes. The compressor rack is connected to the evaporator coils by a common refrigerant supply and return line through connection lines as per their individual capacities. The rack refrigeration system can be of 3 types:
  - **Remote type refrigeration system**: All compressors are combined at a single location while condensers are fixated on roof tops.
  - **Refrigeration rack system with multiple outdoor condensing units**: It has multiple compressor each dedicated with its own condenser. The compressors with condensers are located outdoors.
  - **Refrigeration rack system with common outdoor condenser**: It has multiple compressors sharing a common condenser assembly. These are located outdoors

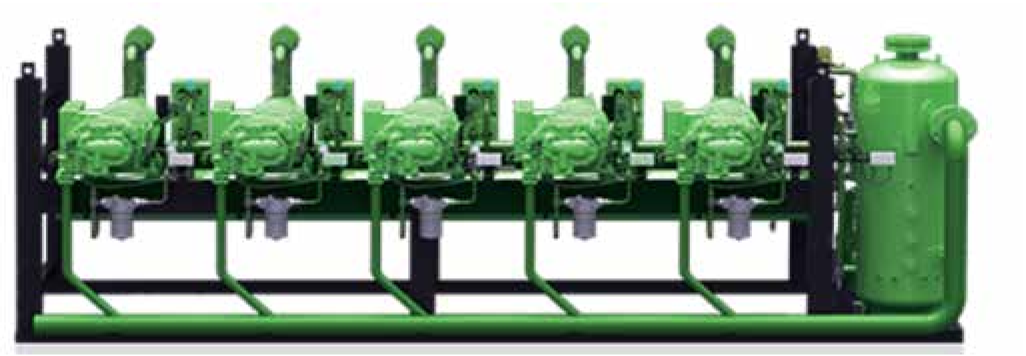


Figure 10: Rack Type systems Image source: https://www.bitzer.de/au/en/products/engineered-packages/multiple-compressor-systems/parallel-racks/screw-rack/

The finer details of the HCFC/HFC based systems are presented in the table 9 -

Table 9 : Common application and refrigerant type used in HCFC/HFC based systems

Capacity	**Compressor**	**Refrigerant**	GWP) [29]/ODP	**Application**
Low Temperature Condensing Units				
Up to 20 kW	Hermetic/ Reciprocating/ Scroll/ Semi-Hermetic/ Rotary/Scroll	R-404A	ODP-0 GWP-3922	Ice-cream, Fisheries, Vaccines, Frozen food, Restaurants with small cold storage, supermarket
		R-407F / R-407A	ODP-0 GWP of R-407F 1825 GWP of R-407A 2107	
		R-22	ODP-0.055 GWP-1810	
Medium Temperature Condensing Units				
Up to 70 kW	Hermetic Reciprocating/ Scroll	R-22	ODP-0.055 GWP-1810	Dairy, Pharma, Fruits & Vegetables, Horticulture, Convenience stores
		R-404A	ODP-0 GWP-3922	
		R-407F / R-407A	ODP-0 GWP of R-407F 1825 GWP of R-407A 2107	
Medium Temperature Parallel Racks				
100 ~1200 kW	Screw Compressor	R-404A	ODP-0 GWP-3922	Vegetables, fruits, meat fish
		R-134a	ODP-0 GWP-1430	
		R-507A	ODP-0 GWP-3985	
		R-22	ODP-0.055 GWP-1810	

[29] UNEP Ozone Secretariat

Capacity	Compressor	Refrigerant	GWP)[29]/ODP	Application
Low Temperature Parallel Racks				
60~600 kW	Screw Compressor	R-404A	ODP-0 GWP-3943	Seafood, meat, ice cream
		R-134a	ODP-0 GWP-1430	
		R-507A	ODP-0 GWP-3985	
		R-22	ODP-0.055 GWP-1810	

- Due to absence of standards, the capacity and efficiency figures for these systems can be misleading. However, as per inputs from OEMs, the standalone condensing and evaporating units have a COP of up to 2.4. Parallel rack systems that employ multiple compressors have a higher COP than standalone systems.

4.3. COOLING TECHNOLOGIES FOR REFRIGERATED TRANSPORT SECTOR

Refrigerated transport is vital as it connects different links of the cold-chain and ensures supply of best quality produce from farm to the consumer. In India, 95% of the perishables are transported through road by trucks or trailers powered by diesel engines.

- According to industry experts and OEMs, majority of horticulture (fruits / vegetables) are **transported in non-refrigerated vehicles leading to a significant loss in produce and quality**. Refrigerated transport is used only for select perishable and exotic produce, which are majorly exported.

- Refrigerated transport is majorly used for dairy products and meats. The refrigerated transport in this segment uses **diesel powered refrigeration system**, which not only results in higher GHG emissions but also leads to air pollution releasing pollutants such as nitrogen oxides, carbon monoxides etc.

The refrigerated transport sector is dominated by 3rd party logistic providers. Based on inputs from various logistic providers, the refrigerated trucks and trailers are assembled at site by sourcing various components and accessories (such as refrigeration units, controllers, temperature loggers, insulated chamber body etc.) on a truck chassis. There are some OEMs which supply complete refrigerated trucks and trailers but these are scanty in numbers owing to associated high costs.

The cooling technologies for refrigerated transport types in India can be broadly classified as follows –

Type

- Trailers - Have large containers (40ft.) and suitable for long hauls. Typically single door opening
- Trucks - Have medium (20ft.) to large (40ft.) containers and multiple door openings suitable for distribution purposes
- Light commercial vehicles (LCV) - Have small to medium containers. Suitable for last mile and intercity applications
- Refer containers - These containers have their own refrigeration systems and can be mounted on railways, ships, trailers etc. These are plug and play type powered by external sources (generators, alternators, grid electricity). These are not common in India

Technology

- Engine driven - the refrigeration system is powered by a secondary engine
- Alternator driven - alternator coupled with vehicle engine supports power required for refrigeration system
- Battery operated - battery supports power required for refrigeration system

Temperature

- Mono - Single temperature is maintained inside the container
- Multi - Multiple temp. zones are mantained inside the container

- The common **refrigerants** used in the transport refrigeration are **R-134A, R-404A and R-22**.

As mentioned above, 95% of the perishables in India are transported through road by trucks or trailers powered by diesel engines which leads to higher emissions of GHGs and air pollutants. Use of railway network for transportation of perishables can possibly mitigate this issue to some extent. Indian railways undertook a strategic initiative through setting up Container Corporation of India Ltd. (CONCOR), which provides inland transportation by rail for containers. Indian railways has also introduced multi-commodity 'Kisan Rail' train service that will carry and transport vegetables and fruits. CONCOR and railway networks can be leveraged to provide refrigerated **transport and storage at economical prices through strategic tie ups** for **providing refrigerated container technologies and financial assistance for building handling terminals.**

5
Sustainable Cooling Technologies for Cold-Chain

The increase in cold-chain infrastructure will surge the cooling and refrigerant demand in the country as indicated in section 1.2. Consequently, the energy consumption in the cold-chain sector is likely to double in the next 10 years and increase further by 1.6 times (compared to 2027-28) in the next decade as depicted in figure 11.

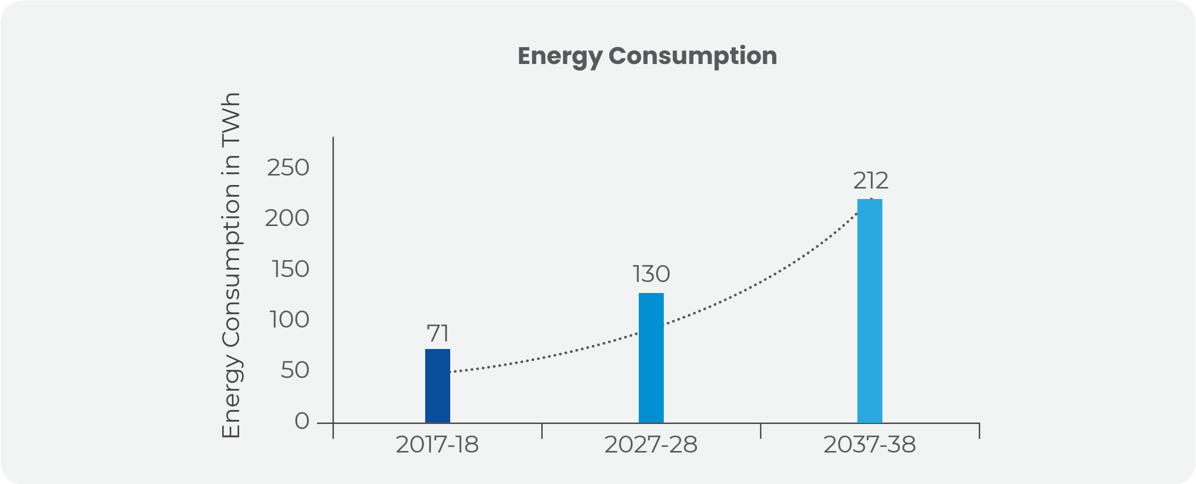


Figure 11: Energy consumption in cold-chain

There is a potential to decrease the energy consumption by ~ 30% and minimize the associated climate impacts through the following measures:

- Sustainable building envelope design to optimize the cooling load
- Prudent selection of efficient and low GWP and non-ODS refrigerant based technologies
- Better operation and service practices to minimize refrigerant leaks and optimize operational efficiency

Better choice of technologies, which use low GWP and non-ODS refrigerants, optimize the refrigerant demand and have better operational efficiency which will play a pivotal role in sustainable development of this sector. This will also strengthen country's commitment to the international agreements (such as Montreal Protocol) and help in achieving the NDC targets. The aspects related to sustainable building design have already been discussed in section 3 of the report. The subsequent sections discuss a list of sustainable technologies and prudent operation / maintenance practices which can enhance the sustainability of this sector and minimize the climate impacts.

5.1. COMMERCIALLY AVAILABLE SUSTAINABLE COOLING TECHNOLOGIES

Low charge ammonia systems with VFD controllers and advanced controls

Figure 12: Low Charge Ammonia System Image Source: https://www.mayekawa.com.au/products/newton-low-charge-ammonia-nh3co2-cooling-system/

Description: Though ammonia is a natural refrigerant with zero GWP, its toxicity at volumes restricts its use. However, low-charge ammonia systems are commercially available that handle smaller quantities and use sensors, valves and electronic controls to detect leaks, mitigating the hazards of handling large volumes of ammonia. About 10–25% savings on energy consumption can be achieved by the use of AC drives which optimize the capacity control of refrigeration compressors, condensers and evaporators.

- **Refrigerant**: Ammonia
- **Energy Efficiency:** 40% more efficient than a baseline R-507A chiller[30]
- **Application:** Cold storage

Solar based pack houses and cold storages

Figure 13 Solar based cold storage

Description: This technology uses a combination of Eutectic plates and solar PV powered condensing units. During the day, the cooling is provided by the condensing unit powered by PV panels and during non-sun hours via charged eutectic plates. The system has a holding time of **30 hours** reducing dependency on generator or battery storage. This solution provides cooling requirement of 4 to 10℃ and maintains the humidity range of 65-95%.

- **Refrigerant:** R-407F
- **Energy Efficiency:** The average CoP at 35℃ is 2 but the efficiency varies as there are no set standards. The payback period is 3-4 years.
- **Application:** Pack house at farm gates

Case Study:

A smaller number of companies offer economically attractive standard solutions for small solar powered cold storage for the first part of the cold-chain close to the farmers. Examples are Solar Cooling Technologies[31] and Cold Hubs[32] for small size solutions. The deployment of thousands of standardized huts based on solar power combined with battery backup or phase changing cooling storage could be a key product in the pack houses. This could enable the shift towards higher value products such as fruits and vegetables instead of cereals. These can be leased to farmers as per seasonal requirements or can be operated by private / public sector charged on pay per use models.

[30] https://ammonia21.com/articles/9857/ultra_low_chargeand_ammonia_chiller_boosts_efficiency_40_for_sake_producer
[31] solar-cooling-technologies.com
[32] coldhubs.com

Figure 14: ColdHubs storage for fruit and vegetables based on photo voltaic and battery backup for cooling at night

Cascade refrigeration systems

Figure 15: Cascade systems Image source: UNIDO

Description: Cascade refrigeration system uses two or more kinds of refrigerants with their own vapor-compression cycles for cooling. The refrigerants are selected basis their ability to work efficiently in a particular temperature range. The evaporation and condensation temperatures of each cycle has some overlap which gives the desired temperature drop.

- **Refrigerant**: Carbon di-oxide, ammonia or R-134a
- **Energy Efficiency:** A CO_2 / NH_3 cascade system uses less energy per tonnes of refrigeration when compared to other refrigeration systems at full load[33]
- **Application:** Cold storage

Vapor absorption machine supported by solar thermal system

Description: Vapor absorption refrigerant system is an alternative to the conventional and more common vapor compression refrigeration technology. The absorption systems are free from high GWP based refrigerant such as **HCFC and HFC** and their application is viable in places where there is a waste steam source or gas used for producing steam is available at subsidised rates. Absorption systems can be combined with solar thermal collectors as depicted in figure 16 to provide steam. This can further increase the working efficiency of the VAM.

[33] https://stellarfoodforthought.net/six-reasons-to-consider-a-co2nh3-cascade-refrigeration-system/#:~:text=A%20CO2%2FNH3%20cascade%20system,F%20to%20%2D60oF.&text=2

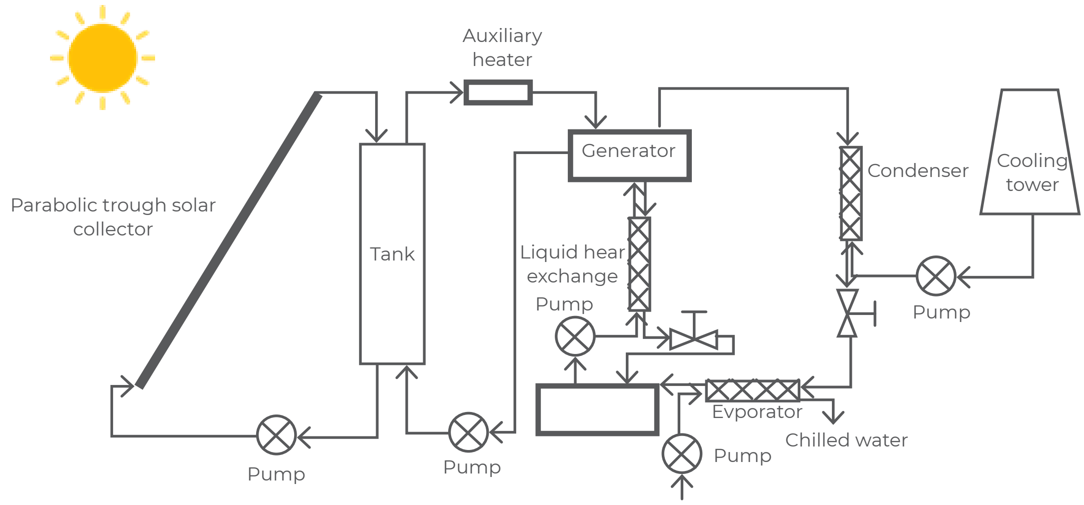


Figure 16: VAM supported by solar thermal collector Image Source: Renewable Energy and Energy Efficiency Group, The University of Melbourne

- **Refrigerant:** Ammonia-Water - Ammonia is the refrigerant, and water is the absorbent.
- **Energy Efficiency:** The efficiency achievable in case of solar based VAM could be as low as ~ 0.58[34] KW/TR
- **Application**: Large cold storages

Reefer Trucks with Eutectic plates

Figure 17: Reefer truck with eutectic plates

Description: Use of Phase change material (PCM) as a thermal energy storage (TES) enables the transportation of goods at a constant temperature while minimizing the dependency on diesel/petrol or any other conventional fuel for continuous running of cooling units in the reefer trucks. The term eutectic plates refer to phase change material solution encapsulated in a metal/plastic plate. The PCM filled encapsulation units, which are mounted in the insulated containers, are charged using electricity during the non-operational hours. This system is ideal for inter-city transportation and short hauls services as their holding time is **14 to 16 hours**.

- **PCM range can broadly be arranged into three categories**: Eutectics, salt hydrates, organic material[35]
- **Cost efficiency:** PCM offers up to 80% savings in operating cost by virtue of the elimination of use of diesel to run the AC[36]
- **Application**: Refrigerated transport

34 https://www.e3s-conferences.org/articles/e3sconf/pdf/2020/30/e3sconf_evf2020_02011.pdf
35 https://www.pcmproducts.net/
36 https://www.process-worldwide.com/pluss-polymers-introduces-pcm-solution-for-Cold-chain-transport-a-425312/

Internet of Things

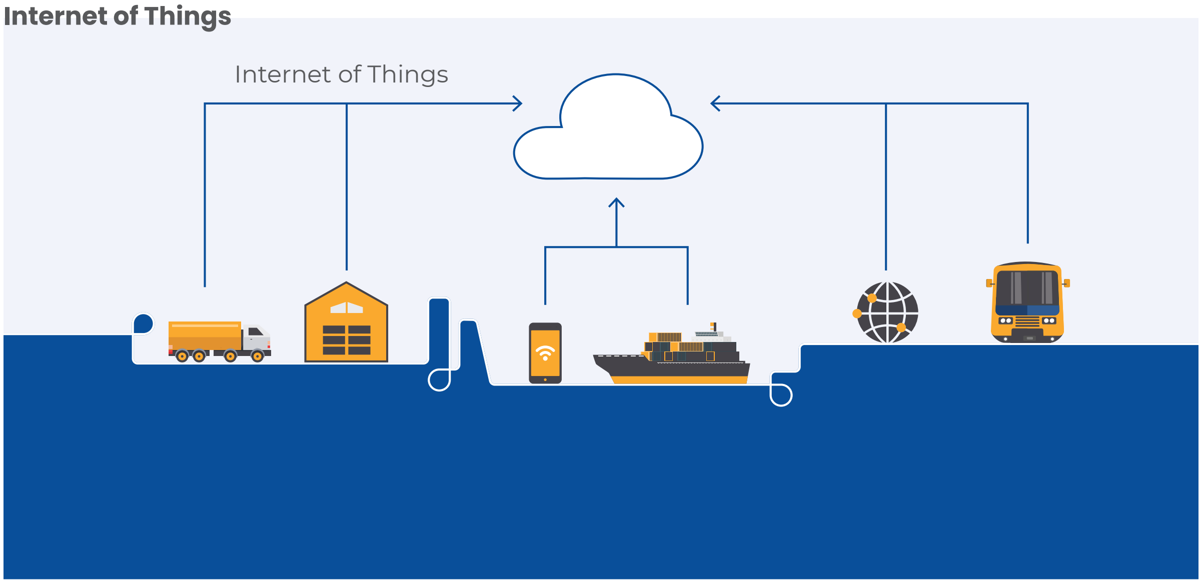


Figure 18: IoT

Description: The use of IoT in cold-chain logistics can ensure that food, perishable products, and medicines are maintained at desired temperatures to ensure the best quality.

The use of Radio frequency identification (RFID) along with temperature sensors map the temperature history along the entire supply chain. Retailers and suppliers can ensure the quality of fresh foods in transit by monitoring real time temperature, RH value, moisture, temperature fluctuations, frequency of door openings etc. which can further help in removing the inefficiency in the supply chain.

IOT can help in remote management of cold storages, where monitoring and control of multiple complex parameters like gas concentration, temperature and humidity can be achieved through automation.

- **Application:** Transportation and cold storage

5.2. PROSPECTIVE SUSTAINABLE COOLING TECHNOLOGIES

Liquid nitrogen-based cooling

India is importing increasing volumes of Liquid Natural Gas (LNG) by tankers. LNG is then evaporated for further distribution. This evaporation produces large amounts of **low cost, zero-emission cooling,** which can be stored in the form of liquid nitrogen. The nitrogen can then be used as a cooling source in cold-chain applications such as on lorries or in remote areas, where electric refrigeration is difficult. The infrastructure requirements for liquid nitrogen cooling at LNG terminals is provided in the figure 19

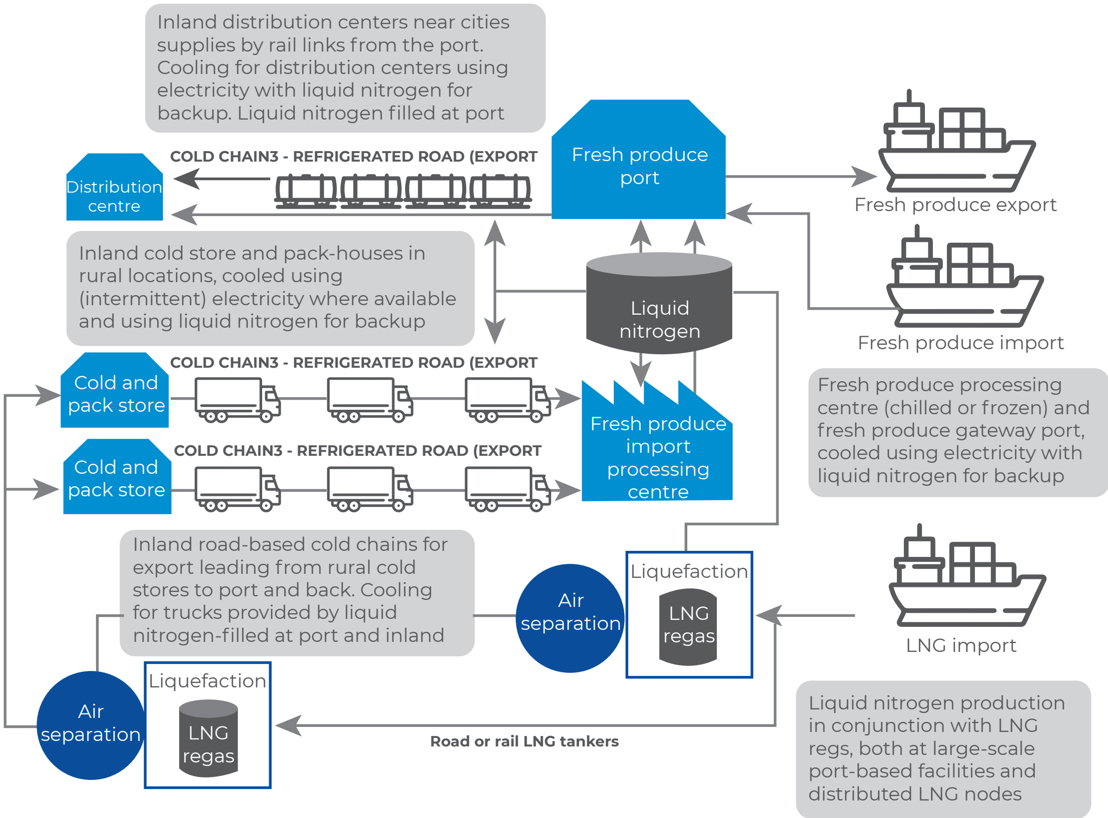


Figure 19: Example of LNG evaporation cooling system Image source: The University of Birmingham

Refrigerated transport units that use liquid nitrogen as a fuel source (instead of diesel / petrol) and also provide cooling are becoming popular in Europe, because of their **Zero emissions**. One such technology is **Dearman's Engine which produces power and cooling** from liquid nitrogen.

A study by E4tech for India's National Centre for Cold-chain Development (NCCD) shows that a typical LNG terminal re-gasifying 7,100 tonnes of LNG per day could produce 2,600 tonnes of liquid nitrogen, enough to provide the cooling for almost 1,100 chilled and frozen refrigerated trucks operating around the clock. India has four LNG import terminals with an annual capacity of 25 million tonnes, expected to expand to 32 million tonnes, and a further 18 terminals have been proposed. The refrigerated vehicles based on liquid nitrogen will have zero-emission and would also reduce well-to-wheel carbon emissions between 18% and 56% depending on duty cycle (chilled or frozen)[37].

Condensing units with HFO/HFC-HFO blends based refrigerants

These systems work similar to HCFC/HFC based refrigeration systems but use HFO / HFC-HFO blends which have low GWP. However, their use is limited due to high costs[38]. HFO-1234yf, HFO-1234ze can be utilized in cold storages and pack houses as an alternative to high GWP refrigerants. Blends such as R-455A which is a blend of an HFO (R-1234yf), HFC (R-32) and CO2 having a GWP of 146 is also a good alternative to HFCs.

[37] https://cleanleap.com/clean-transport-refrigeration-and-cold-economy/Cold-chains-powered-lng-waste-cold
[38] Promoting clean and energy efficient Cold-chain in India

Solar Biomass Co-generation (Power and cooling)

Solar Energy Centre (SEC), Gurgaon, in collaboration with Thermax and TERI have developed and demonstrated a solar-biomass hybrid absorption cooling system operating on thermal energy[39]. This system produces gas from biomass gasifier, drives a gas engine to produce the electricity. The waste heat and electricity are used to run a Vapor Absorption Machine (VAM), which provides cooling.

The solar thermal collectors supplement the heat to the vapour absorption system during daytime which is much cheaper than large scale electrical batteries. The balance heat available from the engine can be utilized for drying, humidifying, sanitizing needs of the cold storage[40]. This system can be used for community based local pack-houses in rural areas that could potentially supply both power and cooling.

Reefer containers with integrated refrigeration systems

These types of container have an integral refrigeration unit for controlling the temperature inside the container. The refrigeration unit is arranged in such a way that the external dimensions of the container meet ISO standards. The presence of an integral refrigeration unit entails a loss of internal volume and payload. When being transported by ship, integral units have to be connected to the on-board power supply system. The number of refrigerated containers which may be connected depends on the capacity of the ship's power supply system. If the aforesaid capacity is too low for the refrigerated containers to be transported these are powered through diesel generators. When at the terminal, the containers are connected to the terminal's power supply system. For transport by road and rail, most integral unit refrigeration units are operated by a generator set (genset).

The use of such containers (reefers) in Indian Railways could reduce the cost of transportation significantly, given the vast network connectivity of Railways. This will also reduce the emissions emanating from the refrigerated transport sector. CONCOR (a subsidiary of Indian Railways) is boosting the Indian cold-chain by developing ICDs in various locations. These kinds of containers have the potential to boost the cold-chain sector, since refrigerated transport is the backbone of the sector.

[39] Cold-chain Technologies: Transforming food supply chains
[40] Integrated Renewable Energy to Coldchain: Prospering Rural India

6
Operation & Maintenance Practices for Cold-Chain Components

Good operation and maintenance (O&M) practices help in maintaining proper functioning and upkeep of cold-chain infrastructure and refrigeration equipment.

Better O&M practices help in improving energy efficiency and reduce refrigerant leaks. Inadequate maintenance can be a cause of energy wastage as well as refrigerant leakage which will lead to higher direct and indirect GHG emissions. The energy usage is a major cost head in the cooling industry as it directly impacts the environmental sustainability of the entire set up. Energy losses from air leaks, uninsulated lines, maladjusted or inoperable controls, and other losses from poor maintenance are often considerable. Good maintenance practices can generate substantial energy savings and avoid losses. This helps in facilitating compliance with legislation such as the Clean Air Act and the Clean Water Act.

O&M practices increase the safety of operator/technician/customer and conform the design life expectancy of equipment is achieved. Safety aspects are critical in terms of handling flammable and toxic refrigerants. Utmost measures should be undertaken to avoid any mishap.

O&M basically involves following but is not limited to

- Actions focused on scheduling, procedures, and work/systems control and optimization; and
- Performance of routine, preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety.

A competent O&M program requires the participation of staff from five well-defined O&M Best Practices. Five well-defined elements of an effective O&M program are **Operations, Maintenance, Engineering, Training, and Administration**. These elements form the basis for a solid O&M organization, the key lies in the well-defined functions each brings and the linkages between organizations. A subset of the roles and responsibilities for each of the elements is presented below.

Operations

- Administration – To ensure effective implementation and control of operation activities.
- Conduct operations – To ensure efficient, safe, and reliable process operations.
- Equipment status control – To be cognizant of status of all equipment.
- Operator knowledge and performance – To ensure that operator knowledge and performance will support safe and reliable plant operation.

Maintenance

- Administration – To ensure effective implementation and control of maintenance activities.
- Work control system – To control the performance of maintenance in an efficient and safe manner such that economical, safe, and reliable plant operation is optimized.
- Conduct of maintenance – To conduct maintenance in a safe and efficient manner.
- Preventive maintenance – To contribute to optimum performance and reliability of plant systems and equipment.
- Maintenance procedures and documentation – To provide directions, when appropriate, for the performance of work and to ensure that maintenance is performed safely and efficiently.

Engineering Support

- Engineering support organization and administration – To ensure effective implementation and control of technical support.
- Equipment modifications – To ensure proper design, review, control, implementation, and documentation of equipment design changes in a timely manner.

- Equipment performance monitoring – To perform monitoring activities that optimize equipment reliability and efficiency.
- Engineering support procedures and documentation – To ensure that engineer support procedures and documents provide appropriate direction and that they support the efficiency and safe operations of the equipment.

Training

- Administration – To ensure effective implementation and control of training activities.
- General employee training – To ensure that plant personnel have a basic understanding of their responsibilities and safe work practices and have the knowledge and practical abilities necessary to operate the plant safely and reliably.
- Training facilities and equipment – To ensure the training facilities, equipment, and materials effectively support training activities.
- Operator training and certification – To develop and improve the knowledge and skills necessary to perform assigned job functions.
- Maintenance training – To develop and improve the knowledge and skills necessary to perform assigned job functions

Administration

- Organization and administration – To establish and ensure effective implementation of policies and the planning and control of equipment activities.
- Management objectives – To formulate and utilize formal management objectives to improve equipment performance.
- Management assessment – To monitor and assess station activities to improve all aspects of equipment performance.
- Personnel planning and qualification – To ensure that positions are filled with highly qualified individuals.
- Industrial safety – To achieve a high degree of personnel and public safety

O&M of cold-chain infrastructure requires knowledge and skills in several areas. This includes knowledge of the effects of temperature on food products, product specific storage requirements, operation of cooling technologies, including handling and storage of refrigerants, refrigerants recovery and charging, leak and pressure testing, safety measures to handle flammable and toxic refrigerants etc. Adequate training and capacity building is required to develop the required skilled work force.

7 Recommendations

The development of cold-chain components will help in improving food safety and curtailing significant food loss across the country. Curtailing food loss and waste throughout the chain will result in reduced climate and environmental impacts of agriculture and improved income and livelihood of the actors. It will also address rural poverty while connecting farmers to markets and generating huge employment opportunities.

While there is a huge opportunity for the cold-chain sector in India, this growth prospect comes with basic energy and environmental challenges resulting from increased energy and refrigerant consumption. However, these challenges can be converted into valuable opportunities through development of sustainable cold-chain infrastructure in India. This section presents a set of actions or recommendations required to develop sustainable cold-chain infrastructure in India.

The following are the broad recommendations of the study

Short-term recommendations:

1. Promote use of low GWP and non-ODS based refrigeration systems

Refrigeration system is the core of all cold-chain components and the choice of refrigerant is an important factor considering the high GWP of the currently used refrigerants such as HCFCs and HFCs, which are controlled substances under the Montreal Protocol on Substances that Deplete the Ozone Layer. As discussed in chapter 5, alternatives with low GWP and non-ODS have been introduced in different cold-chain components and this creates an opportunity for India to use these alternatives in new cold-chain infrastructure.

Ammonia has been used in the bulk cold storages for last many decades in India and it is preferably a good choice of refrigerant in medium and large sized cold storages. The main issue associated with the ammonia-based system is the toxicity of ammonia and large volume of gas used in conventional systems. Low charge ammonia systems with VFD controllers and advanced controls are being introduced to mitigate this issue. To address the safety aspects of ammonia-based systems, BIS is working on drafting a document named 'Closed-circuit Ammonia Refrigeration System - Code of Practice for Design and Installation' . This is envisaged to be published in the near future.

Alternative with low GWP such as HFO/HFC-HFO blends have been introduced in many applications of cold-chain particularly in pack houses and cold storages. Though these are expensive at present but have potential to replace HCFC and HFC based systems.

2. Enhance skills through capacity building and training for system operators, engineers, technicians consultants and policy makers to promote sustainable cold-chain

Extensive capacity building and training is critical for effective promotion and deployment of sustainable cold-chain and associated energy efficient and climate friendly cooling technologies. These trainings and capacity buildings should include farmers, cold-chain component operators (such as pack house, cold storage, reefer transport operators etc.), design engineers, service technicians, consultants and potential funding organizations. Training and capacity building should cover aspects such as economic impacts and benefits of sustainable cold-chain, innovative business models, temperature requirement of produce and monitoring, installation and maintenance/repair of refrigeration systems, energy efficient and safe operation, passive design, management and recycling of equipment and refrigerant etc. Skill-enhancement programmes such as "Pradhan Mantri Kaushal Vikas Yojana" could also be used to develop these required skills. Industry leaders, associations (such as ISHRAE), practitioners, construction professionals and academics could work together to develop relevant training programmes. The International Organization for Standardization (ISO) is preparing a guiding document 'Refrigerating systems and heat pumps — Competence of personnel' which could be referred for training and capacity building.

3. Promote use of renewable and alternate energy solutions

Renewable and alternate energy technologies being used in different cold-chain components such as pack houses, cold storages and reefer transports. Cooling options based on renewable energy and alternate technologies include - solar PV, solar thermal system, solar-biomass hybrid systems, use of phase change materials for thermal storage etc. Deployment of these technologies not only reduce GHG emissions but also mitigate the risks associated with the weak grid connectivity.

4. Implement pilot projects for sustainable cold-chain components

There is a need to set up pilot pack-houses, ripening chambers in specific fruit and vegetable belts in the country. Sustainable cooling technologies along with relevant business models which will allow the farmers to leverage cold-chain infrastructure is the need of the hour. Probable business propositions such as solar based packhouses[41] and community-based pack houses / ripening chambers where farmers can store their commodities on CaaS (Cooling as a Service), Pay as you go, leasing model or PPP model for setting up modern packhouses / ripening chambers can be evaluated. These approaches would provide the farmers with affordable and sustainable cooling by removing burdens on them to acquire cost and maintenance intensive cooling and other assets under the cold-chain component. The pilot projects with such business propositions will also help in creating awareness for farmers and private stakeholders who are willing to invest in sustainable cold-chain components.

5. Legislation / policy to make standards for perishable handling, temperature monitoring/ logging mandatory

BIS has various standards (such as IS 7192, IS 7730, IS 9304, IS 7252) which prescribe temperature, RH and in some cases gaseous concentrations for storage of fruits and vegetables. There is a need for stricter enforcement of these standards and protocols across all cold-chain components, possibly through certain legislations / policies This will not only help in enhancing skills and awareness for handling temperature sensitive products but also improve food safety and curtail food loss across the country. A single repository can be developed where all the applicable standards are available.

6. Development of standards and comparative labelling program for refrigeration equipment

Performance benchmarking through standards and labelling (S&L) programmes have helped achieve energy efficiency in various consumer products / appliances. BEE has developed S&L programmes for more than 26 appliances. Such S&L programme can be expanded to include all compression-based cooling technologies used in cold-chain components. This would not only spur efficiency improvements also lead to innovations in this segment and make the market more competitive. Technologies such as hybrid and passive cooling technologies can be promoted through endorsement labels.

7. Promote multi commodity cold storages

Multi-commodity cold storages are now available commercially and it can cater to wide range products including meat & poultry, seafood, dairy products, fruits & vegetables and pharmaceuticals. Majority of cold stores (~75%) in India is for storage of single commodity such as potatoes. It is recommended that all upcoming cold storages need to be designed for storing multiple commodities. It can also be explored to convert existing single commodity cold storages to multi commodity storages.

[41] Ecozen have a community business model wherein they lease the solar cold storage to a community to be used in mandi wherein farmers pay on per Kg basis for the use.

Medium-term recommendations:

8. Retrofitting existing inefficient cold-chain systems with low-GWP, non-ODS and energy efficient equipment

The current state of the existing cold-chain infrastructure, especially the cold storages provides an opportunity to improve energy efficiency, use of low GWP and non-ODS refrigerant based systems and reduce refrigerant demand and cooling load through judicious design practices. Retrofitting inefficient cold-chain systems with energy efficient and climate friendly solutions can possibly ensure better price realization to farmers by reducing operating costs and retain produce quality over longer periods. Implementation of retrofitting and replacement programs for inefficient refrigeration system can be promoted. In addition, adequate measures should be deployed on recovery and reclaiming the refrigerant and recylcing and proposer disposal of old systems so that it does not add to the environmental damage. Demand side management (DSM) programmes like DISCOM's AC replacement program and EESL's super-efficient AC programmes can be implemented in order to eliminate the in-efficiencies in cold-chain sector.

9. Increase share of railways in refrigerated transport

High cost of refrigerated transport is a deterrent for the farmers selling their produce in far off markets. As per NCCD report, 97% volume of the fruits and vegetables moves on roads and is dominated by 3rd party logistic companies. On the other hand, food grains and hardy produce use railways for long haul transport.

Indian railways with their vast network and connectivity can provide affordable and convenient mode of transportation for perishables. Building dedicated cold-chain components for railways - such as dedicated aggregation / collection centres, cold storage warehousing, multimodal containers and refrigerated vans for last mile transport can be instrumental for reducing the costs associated with refrigerated transport. According to the NCCD report[42], there is a perennial flow of apples and potatoes from north to south, while banana, chicken, lettuce is routed from south to north. Such long-haul perennial produce can easily be routed at a lesser rate (than reefer transport). Similar strategies for other products which can leverage railways for transport can be identified and investment accordingly should be made to boost farmer confidence and give an overall impetus to the sector.

10. Integration of IoT and automation system in cold-chain components

IoT and other automation system needs to be integrated in all components of cold-chain, specifically in clod-chain logistics. Use of IoT will help in remote management of cold storages and other components, where monitoring and control of multiple complex parameters like gas concentration, temperature and humidity can be achieved through automation. The automation of components can help in reducing cooling losses.

[42] "Railways mode of Transport for Cross-regional Trade of Perishable Agri-produce"

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