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ASSOCHAM
INDIA

THE ASSOCIATED CHAMBERS OF COMMERCE AND INDUSTRY OF INDIA

D S RAWAT
Secretary General

ACKNOWLEDGEMENT

We are pleased to announce the "National Conference on Cold Chain – Technologies, Convergence and Capacity Building & Awards" on May 30th, 2017, at New Delhi.

The cold chain industry is indeed an emerging and fast growing business sector in India. Considering the current issue of food shortage and food security in India, cold chain facilities will play an important role in the country. Every year fresh produce worth INR 133 billion are thrown away because of the country's lack of adequate cold storage and transport facilities. However, this sector has witnessed a considerable growth in the last decade and is expected to have further improvement in growth rate in the years to come. Various initiatives of the Government of India and other agencies is enabling industry to adopt better and more efficient technologies to ensure year-round availability of perishable food products and reasonable prices to the consumers but also equitable distribution to other parts of the country.

We are confident that the deliberations and suggestions at this conference will benefit all the stakeholders.

ASSOCHAM sincerely thank the Ministry of Food processing Industries, Government of India, Ministry of Agriculture and Farmer's Welfare, APEDA, for their support.

The financial assistance received from Research and Development Fund of National Bank for Agriculture and Rural Development (NABARD) towards publication of journal/printing of proceedings of the Conference is gratefully acknowledged.

We also thank the Sathguru Management Consultants for bringing out a very comprehensive study. This extensively researched publication will highlight challenges in cold chain sector and way forward to create a robust and strong cold chain industry.

We also greatly appreciate the support received from the corporate partners. I also appreciate the efforts put in by team Dr. Om S Tyagi, Sr. Director, ASSOCHAM.

(D S Rawat)

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List of Acronyms:

APEDA	Agricultural And Processed Food Products Export Development Authority
BIS	Bureau of Indian Standards
CA	Controlled Atmosphere
CO2	Carbon Dioxide
COP	Coefficient Of Performance
CPC	Central Processing Center
F&V	Fruits And Vegetables
FDI	Foreign Direct Investments
FEFO	First Expiry First Out
FLW	Food Loss And Waste
FSSAI	Food Safety And Standards Authority Of India
GFCCC	Global Food Cold Chain Council
GHG	Green House Gas
GPS	Global Positioning System
HC	Hydrocarbons
HMNEH	Horticulture Mission For North East And Himalayan States
ICAR	Indian Council Of Agricultural Research
IIR	International Institute Of Refrigeration
IOT	Internet Of Things
IQF	Individually Quick Frozen
ISAM	Integrated Scheme For Agricultural Marketing
LNG	Liquefied Natural Gas
MCE	Magneto Caloric Effect
MCM	Magneto Caloric Materials
MIDH	Mission For Integrated Development Of Horticulture
MoFPI	Ministry Of Food Processing Industries Of India
MRS	Magnetic Refrigeration System
MTPA	Million Tons Per Annum
NABARD	National Bank For Agriculture And Rural Development
NCCD	National Center For Cold-Chain Development
NHB	National Horticulture Board
NHM	National Horticulture Mission
NMFP	National Mission On Food Processing
NO_X	Nitrogen Oxides
PCM	Phase Change Materials
PID	Proportional integral derivative

PPC	Primary Processing Centers
PPP	Public Private Partnership
PSUs	Public Sector Undertakings
PV	Photo Voltaic
RFID	Radio Frequency Identification
ROI	Return On Investment
SFAC	Small Farmer Agri-Business Consortium
TES	Thermal Energy Storage
TFCP	Task Force On Cold-Chain Projects
TFO	Total Financial Outlay
TRU	Transport Refrigeration Unit
TTI	Time Temperature Indicators
VAM	Vapor Absorption Machine
VFDs	Variable Frequency Drives
WDRA	Warehousing Development and Regulatory Authority
WFLO	Word Food Logistic Organization
WSN	Wireless Sensor Networks
ZECC	Zero Energy Cool Chambers

Executive Summary

India is the second largest producer of fruits and vegetables, largest producer of milk and one of the leading producer of meat and fish. Owing to its diverse agro-climatic zones and resources, the production of these commodities not only extends in quantity, but also to a wide variety of them. Despite these merits, India is also one of the leading countries in terms of food loss, even though a sizeable share of the population are suffering from hunger and malnutrition. The farmers in India, even though they are producing the largest quantities of the fore-mentioned agricultural and horticultural produce, their economic situation is not really presenting a happy picture. Compared to developed nations, the Indian agricultural scenario is very complex and so are the reasons leading to this situation. Among all, the important reasons in leading to the high quantities of food loss are poor post-harvest care, highly complex and inefficient supply chains, lack of storage and processing infrastructure.

Cold chain sector is set to play an important role in addressing these problems. Addressing the issue of perishability, Cold chain extends the shelf life and thus usability of the commodity in its best form. Depending on the nature, purpose and the stage where it is employed, the application of cold temperature is divided into Frozen (<-18° C), Chilled (0°C to 10°C), Mild Chilled (10°C to 20°C) and Normal (>20° C) storage. For most of the horticultural produce, cold chain needs to be handled at Chilled and Mild chilled zones, whereas for meat and fish the handling temperature lies between Chilled and Frozen zones. The advantages of employing Cold chain are increasing the availability of produce in lean season, increasing the affordability and accessibility by streamlining the supply chains, improving the quality of the produce, employment generation and improving the economic status of the stakeholders.

Cold chain infrastructure in India is classified into Pack houses, Ripening chambers, Cold storages and Reefer transportation. The importance and need for Pack houses is understood by all the stakeholders after a little delay. At present there are only 250 fully equipped functional Pack houses as against the required number of 70,000. Of the total 812, most of the Ripening chambers are concentrated in the states of Maharashtra, Uttar Pradesh and Andhra Pradesh and being used for ripening of Mangoes. Cold stores in India are concentrated in the states of Uttar Pradesh, West Bengal, Gujarat, Punjab and Andhra Pradesh. Most of the cold storages created before the last decade are suitable for storing single commodity only. The total cold store capacity of the country is about 31.82 million metric tons. Reefer transportation is under severe shortage in India, with about 9000 vehicles in place of the required number of approximately 62,000. The estimated need for investment to bridge the gap in the infrastructure is about Rs. 89,000 Crores.

The Government of India (GoI), understanding the importance of Cold chain, is extending the support in creation of the infrastructure by means of various agencies like Ministry of Food Processing Industries (MoFPI), National Horticultural Board (NHB), Agricultural and Processed Food Export Development Authority (APEDA) and NABARD. GoI, recently made important policy changes to allow 100 % FDI and tax exemptions in Cold chain sector, in order to catalyze the growth of the sector. It is also important to consider the inclusion of cold chain sector and promotion of low cost technologies in the “Vision 2022 - Doubling the farmer’s income”, as it is one of the bridging element in mitigating the losses and streamlining the agricultural supply chains, which are hindering the farmer in realizing the true value of his produce.

Diverse range of technologies are employed depending on the nature of commodity, type and stage of processing and the sophistication of the value chain. Basing on the cooling method employed, the systems can be classified as vapor compression systems, absorption/ adsorption systems, evaporative cooling systems and cooling by use of ice. At a broad level, cooling technologies can be classified as Mechanical and Non- Mechanical and employed in cold chain steps like pre-cooling, cold storage, distribution/ refrigerated transport and retailing. Increased emphasis on energy efficiency, lowering CO_2 foot print and increased demand for cooling requirements have led market to scout for new technologies. In this search, use of solar energy has emerged as an obvious choice. The types of solar based interventions currently under exploration are utilizing the electrical energy from solar cells to run the conventional refrigeration systems and converting solar thermal energy into cooling. Geothermal cooling is also another green technology, which is under exploration. The other upcoming technologies include Liquid air cooling in which liquid nitrogen is used as heat sink to recover cold temperature during LNG regasification, liquid air power cooling, in which liquid air or liquid nitrogen is used in the engines to generate cold temperature, leading high energy efficiency and lower emissions. Magnetic Refrigeration System (MRS) is another future technology, which can be an alternative to vapor compression systems. The advantages of MRS are lack of compressor and refrigerant gas, high COP and lower emissions. Thermal energy storage systems like Phase Change Materials are also finding increased applications in transport and packaging systems and can be used in places where the usage of conventional systems is not feasible.

The cold chain sector in India has not progressed at par with the global developments in the monitoring and control technologies. Even though new entrants in the sector are employing some of these modern technologies, most of the earlier generation cold storages are still dependent on the manual modes of monitoring assisted with conventional measuring systems. The upcoming trends that need to be fully embraced by Indian companies are RFID based systems for unit level measurement, WSN based systems for a local unit, and IoT based monitoring systems for covering the entire supply chain.

In order to grow at a faster pace and further strengthen the sector, some of the recommendations made include development of cluster/ commodity specific supply chains and gradual integration of other minor supply chains in the given region, Utilization of railway network, creation of front end infrastructure for undeveloped markets, promotion of research through public private partnership for commercialization and development of relevant skill development modules.

1. Status and importance of the sector

A. Introduction

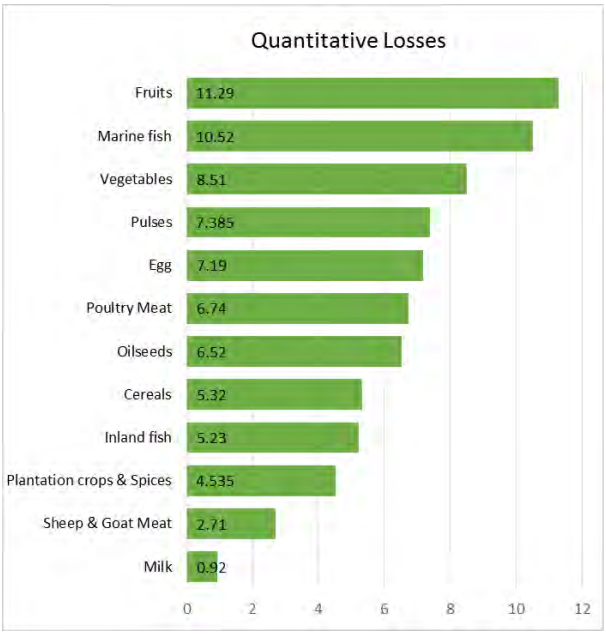

Figure 1: Annual Wastage Percentage in Various Commodities[1]

In a world of finite resources, in order to lead a sustainable life, it is important to produce better and consume intelligently. In India, one-third of horticultural produce especially fruits and vegetables are wasted every year[1]. In today's world though there is enough food for everyone but not everyone eats, owing to the inefficient supply chains and poor processing levels. Millions across the country suffer from malnutrition and die due to hunger. India, with a Global Hunger Index Score 28.5 in 2016, has 15.2% of undernourished population. In such a dire situation where food preservation must be given high priority, the estimated annual value of losses of agri produce is Rs. 92,651 crores. Of these perishable products like fruits and vegetables, meat, fish, and milk account for an estimated loss of Rs. 50,473 crores.[2] Reducing postharvest food losses to at least 15% from the current 30% level could provide 18.3 million tons of fresh foods each year, valued at $3.9 billion.[3] Food losses and their prevention have an impact on the environment, food security, quality, and safety. This in turn also has an impact on socio-economic development as food loss also represents a waste of the labor, water, energy, land and other inputs that go into producing food. The carbon footprint alone of food produced and not eaten is estimated to be 3.3 G tonnes of CO_2 equivalent - in other words, food loss and waste would rank as the third top GHG emitter after USA and China if it were a country[4]. Cold Chain sector holds a key solution to address the problems of food loss, directly by increasing the shelf life of the food and indirectly by increasing the reach of the food to markets and processing facilities.

[1] CIPHET (2015), Report on assessment of quantitative harvest and post-harvest losses.
[2] MOFPI (2016). Opportunities in Cold Chain Sector in India
[3] Kitinoja, L (2014). Exploring the Potential for Cold Chain Development in Emerging and Rapidly Industrializing Economies through Liquid Air Refrigeration Technologies. Postharvest Education Foundation
[4] FAO (2015). Food Wastage Footprint & Climate Change. FAO, Rome

B. Importance of temperature control in food chain:

Fresh foods continue to metabolize and consume their nutrients throughout their shelf life, from harvest or slaughter through packing, distribution, marketing and sale. Processes like respiration, enzymatic breakdown and microbial degradation break down the carbohydrates, proteins and other nutrients into simpler compounds. The degradation processes are highly dependent upon temperature and most of these processes double their rate for each increase of 10^0C (known as the Q10 coefficient). In addition to physiological deterioration, foods are also subject to molds, rots or decays caused by microbes and wilting, shriveling caused by water loss. The rates of microbial growth and water loss increase with temperature increases[5].

In general, food degradation processes increase two or even three-fold with every 10^0C increase in temperature[3]. A perishable food product with a recommended handling temperature of 0^0C will have only one-third to one-half of its maximum shelf life if handled at 10^0C. If the handling temperature jumps to 20^0C, the produce will have one-quarter of its potential shelf life (Table 1). In other words, reducing storage temperatures by 10°C will double the shelf life of perishables.

Table 1: Theoretical relationship between temperature, respiration rate and deterioration rate of a non-chilling sensitive fresh commodity[3].

Temperature °C	Assumed Q10	Relative shelf life	Losses per day (%)
0	-	100%	1
10	2.0 to 3.0	33 to 50%	2 to 3
20	2.0 to 2.5	13 to 25%	7 to 8
30	2.0	7 to 10%	10 to 14
40	1.5	4 to 5%	20 to 25

Cooling provides the following benefits for perishable horticultural foods[3]:

- Reduces respiration: lessens perishability and natural senescence
- Reduces transpiration: lessens water loss, less shriveling
- Reduces ethylene production: slows ripening
- Increases resistance to ethylene action
- Decreases activity of micro-organisms
- Reduces browning and loss of texture, flavor and nutrients

Based on the nature and perishability, the food is handled at different temperatures in the cold chain. The broad classification of Cold chain on the basis of storage temperature is provided in Table 2.

[5] Kitinoja, L (2013). Use of cold chains for reducing food losses in developing countries. PEF White Paper No. 13-03.

Table 2: Categories of cold chain

Category	Temperature	Examples
Frozen	< -18˚C	Frozen ingredients, processed fruits & vegetables, Ice Cream, frozen meats (fish, poultry, livestock), etc.
Chilled	0°C to 10°C	Fresh fruits & vegetables, fresh meats, milk, butter, etc.
Mild chilled	10°C to 20°C	Sub-tropical Fresh fruits & vegetables, chocolates and seeds and some milk products.
Normal	>20°C	Whole Onion, Dehydrated Foods, Pickle, Jams and Oils and extracts.

C. Importance of Cold Chain

There can be various causes of food losses. World Food Logistics Organization (WFLO) project measured postharvest losses for 26 perishable crops in 4 countries, and documented losses from 30 - 80% due to poor quality packages, poor temperature management, and delays in marketing[6]. The International Institute of Refrigeration (IIR) calculated that 23% of perishable foods are lost in developing countries due to the lack of the use of cold chain[3]. Since food loss reduction plays a significant role towards sustainably improving food security, it is important to have economically viable, environmental friendly and socially acceptable solutions. In such a scenario, a well-integrated cold chain is a perfect fit to the problem. The cold chain integrates activities across the value chain. An efficient cold chain is extremely critical to the growth of the agriculture and food industry.

Major benefits of a well-connected cold chain are:

- **Availability:** India has a wide range of climate and physio-geographical conditions which restrict the availability of fruits and vegetables all over the year. An efficient cold chain ensures delivery of produce throughout the year. Agriculture is a seasonal activity which results in surplus production in peak season whereas a lacuna in offseason. The presence of temperature controlled environment facilitates storage of the processed and fresh products, the products are processed/packed in bulk during peak season and stored in the controlled atmosphere so as to supply in the off-season.

  Perishable foods, like fruits, vegetables, meat, poultry and dairy, require an uninterrupted cold chain. Moderating parameters like temperature, humidity, and atmospheric composition, along with utilizing proper handling procedures, cold chain can significantly increase the product life of fresh foods for days, weeks or even months. These services allow fresh products to hold their value longer, increasing their transportability and providing opportunities that expand their market reach.

[6] Kitinoja, L and Al Hassan, HY (2012). Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia: Part 1. Postharvest losses and quality assessments. Acta Hort. 934:31-40.

- **Affordability:** Vegetable and fruits production in the country has increased over the years but still the prices are not normal across the country. Normalizing price of the crops throughout the year and locations is possible through the holistic development of integrated cold-chain. It holds the key to reducing post-harvest losses, ensuring uninterrupted supply and thereby minimizing food inflation.

- **Accessibility:** Availability across various parts of the country can be guaranteed if the crop produced can be supplied to areas where it is not cultivated. The cold-chain will considerably help farmers to reach far away markets. It empowers them with the ability to capture a larger buyer base and helps to bring their harvest to more valuable end use. Also, the consumer will now have access to the products of his choice and at desirable time and place. In the proposed Vision 2022 "for doubling farmers income, the components to strengthen agricultural supply chains is an important aspect. Extending the cold chain network is one of the key solutions to bridge the existing gap and strengthen these supply chains.

- **Quality**: Cold chain maintains the quality of perishable foods by slowing down the respiration rate, reducing transpiration, lowering microbial activity etc.

- **Social importance:** A major part of an efficient cold chain lies in having an equivalently good backward integration. This, in turn, is a potential source of generating growth opportunities in rural areas, improve living standards and reducing migration to urban areas. It will also substantially increase the employability in the rural areas offering tremendous opportunities for both men and women in this sector.

D. Benefits of Investments in Cold Chain

Investing in cold chain in developing countries could produce major economic gains. The return on investment (ROI) for any specific cold chain operation will depend largely upon the market value of the food commodities being cooled and stored and the use efficiency of the facility (i.e. whether operated at full capacity or not).

Investment in the cold chain, specifically in pre-cooling and transport refrigeration equipment, can reduce food loss by 76 percent and CO_2 equivalent emissions by 16% in India. These are the results obtained from a pilot study on kinnow, conducted by the Indian School of Business under the direction of the National Center for Cold-chain Development (NCCD) of India and funded by Carrier Transicold India.[7] The study demonstrates that the kinnow aggregator's profit margin jumped 20% from out-of-season sales and access to distant markets; distributors and retailers margins also improved significantly. The payback for pre-cooling equipment was around 2.3 years, while it takes 4 years to pay back refrigerated trucks. This pilot study succeeded in:

[7] Sodhi, MMS et al., 2016. Cold Chain Development for Fruits & Vegetables in India. Kinnow cold chain study. ISB Report.

i) Demonstrating the benefits from deploying a cold chain that is integrated all the way from the farmer to the retailer. Therefore, any incentives/ subsidies should be designed, considering a supply chain perspective.
ii) Demonstrating value for all stakeholders along the supply chain - growers, aggregators, transporters, distributors, and retailers.
iii) The study also provides a general framework for aggregators and distributors to analyze profitability for any crop when using the cold chain.

The study also compared the CO_2 equivalent emissions of the kinnow supply chain with and without refrigeration and concluded that the cold chain can have a net decrease in overall carbon footprint when compared with the carbon emissions of kinnow that is lost or wasted. A similar study by the Global Food Cold Chain Council (GFCCC) in 2015[8] highlighted the importance of refrigeration technology in reducing greenhouse gas emissions associated with current food waste due to the lack of, or inefficiencies in cold chains. According to the findings of the study, the total amount of food wastage in 2011 has generated about 1 G tonnes of CO_2 equivalent, an amount comparable to the total GHG emissions of road transportation in the EU (0.9 G t). The study concludes that expansion of the food cold chain in developing countries could reduce net food waste greenhouse gas emissions by 180-550 million tons of CO_2 equivalent/ year between now and 2050, representing more than a 50% reduction in the carbon footprint of food waste currently due to the lack and/or inefficiencies of cold chains. In all modelling scenarios, the decrease of food loss and waste (FLW) carbon footprint from cold chain expansion clearly outbalances the newly created emissions, by a factor of 10 to 1.

Investments in low cost technologies like zero energy cool chambers (ZECC) at the backend will help to reduce the food loss in the subsequent stages and generate better returns to the farmer. The fresh produce stored in the ZECC lost lower moisture compared to that stored in ambient temperature, as demonstrated in a study conducted in India. ZECC of 1 MT capacity yielded a return on investment in about 8 usage cycles[9]. In the field case study by Kitinoja (2012), employing low cost walk-in coolers (Coolbot) of 6 MT capacity at farm level in Ghana resulted in reduced losses of onions from 30% to 5% and fetched a better value. The produce fetched at least 4 times the value to the farmer on selling in offseason compared to selling immediately after harvest. Investments in such low cost technologies/ infrastructure will result in increasing the efficiency of the supply chain while generating better returns.

[8] GFCCC (2015). Assessing the potential of the cold chain sector to reduce GHG emissions through food loss and waste reduction. Report by GFCCC & UTC.
[9] Kitinoja, L (2012). Appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia - Part 2. Field trial results and identification of research needs for selected crops Proc. XXVIIIth IHC - IS on Postharvest Technology in the Global Market Eds.: M.I. Cantwell and D.P.F. Almeida, Acta Hort. 934, ISHS

2. Components of Cold Chain across value chain

A. Constituents of Cold Chain

A typical cold chain starts at the farm gate level or the production center. The primary stage of cold chain is sorting, grading and pre-cooling; subsequently, the products pass through various processing, storage phases, and other infrastructure to reach the end consumer. Various components involved in the integrated cold chain are:

- Packing and cooling fresh food products (immediately after harvest or collection),
- Food processing (i.e. ripening, chilling or freezing of processed foods),
- Refrigerated transportation (cold transport and temporary warehousing under temperature controlled conditions)
- Cold storage (short or long term warehousing of chilled or frozen foods),
- Retail (refrigerated or freezer storage and displays at wholesale markets, retail markets and foodservice outlets)

Packing & Pre-cooling:

Pack-houses are facilities where established systems for sorting, grading, washing, drying, weighing, packaging, pre-cooling and staging are present. Pre-cooling refers to reducing the field temperature of fresh horticultural produce soon after harvest and the target temperature depends upon the type of produce. Modern pack-houses are the first step in organized post-harvest management for horticulture and are in effect the first mile sourcing points for this sector.[10] They are used to prepare and pre-condition the fresh farm produce for subsequent logistics connectivity in the cold-chain. The activities at pack house depend on the type of produce and market. Nearby markets generally need only sorting and packing, while for distant markets, additional operations are needed. When immediate transport is available, storage may not be necessary.

Food processing:

Cold chain processing plays a significant role in increasing the shelf life, henceforth utility of the product. Processing can be done through ripening, chilling and freezing of the produce having its own implications on the shelf life.

Ripening Chambers are enclosures engineered to simulate ripening process without altering the taste or freshness of fruits. A ripening chamber comprises of following components:

- Air tight room with insulation
- Temperature control for cooling and heating
- Air circulation and ventilation system

[10] NCCD (2016): Report on Cold-chain (rationalizing concept & requirements).

- Humidity control system
- Electric control system
- Ethylene gas injection system

Chilled products: The temperature range required for storing chilled products could be from 0 to 10°C extending the shelf life of the products from 2 - 10 days.

Frozen products: Freezing is the drastic reduction of processed food temperature to below -18°C with the conversion of water into ice. Blast freezing speeds freezing by rapidly passing cold air over packages as they move through a tunnel or when they are stacked on racks in cold rooms. The freezing process can be sped up even further by using a free flow freezing process to achieve individually quick frozen (IQF) product pieces. Methods that produce quick freezing (IQF via immersion or liquid nitrogen sprays) result in better quality food products than do methods that provide slow freezing (traditional freezer room racking).

Refrigerated transportation:

Refrigerated transport plays a key role in a seamless cold chain ensuring smooth movement of the materials to various locations. Transportation between farm to processing units and processing units to the retailer is very essential to maintain an unbroken cold chain. Vehicles equipped with active refrigeration designed for environment controlled carriage of products can be broadly classified as:

i) Reefer Trucks: The refrigeration trucks are powered by integrated diesel driven motors, independent of the main truck engine, acting as cold rooms on wheels. Smaller vehicles can also be used to serve the same purpose, by utilizing direct drive systems that are linked to the vehicle engine or battery powered refrigeration units. New age reefer trucks are also incorporated with GPS based location tracking system and data logging temperature and humidity sensors that help in continuous monitoring.

ii) Reefer Containers: Reefer containers are multi-modal containers with integrated refrigeration equipment, normally used for multi-modal activities where rail-road-sea-air movements are involved in the logistics chain. It sources electric power from a separate generator (power-pack) which is independent of the reefer container. It has temperature control range of -25 to +20°C.

iii) Reefer Vessels/Ships: Cargo vessel specializing in carriage of goods which are required to be maintained at below ambient temperatures. Each cargo carrying space is lined by layers of insulation material. Furthermore, the floor is double skinned to allow even circulation of the cooling air. Usually, perforated wooden/plastic gratings are utilized so as to allow uniform percolation of the cold air. Reefer vessels can carry any frozen or cooled cargo including fruits, vegetables, meat, and fish. Depending on the type of cargo a temperature range of -30 to +12°C can be maintained.

Cold storage:

Cold Stores are buildings or chambers that achieve controlled storage environment using appropriate thermal insulation and an efficient refrigeration system. Its objective is to properly handle and store fresh produce under appropriate temperature and humidity conditions for maintaining quality and extending shelf life. Fresh produce cold stores are designed to control respiration and prevent discoloration, sprouting, dehydration and decay. The cold stores/warehouses can be classified as follows:

i) Bulk Cold Stores: Environment controlled warehousing space intended for the bulk storage of perishable produce are known as bulk cold stores. It is designed for long duration storage of produce so as to build an inventory buffer which will serve to smoothen the episodic production by stabilizing & sustaining the supply lines. These are normally constructed in areas close to producing areas (farm-gate) to facilitate quick access to producers for a selective set of crops only. Generally used for storage of a single commodity, which mostly operates on a seasonal basis e.g. stores for Potato, Chilies, and Apples etc.

ii) Multipurpose Cold Stores: Warehousing space with multiple temperature zones for functioning as a distribution hub. It is designed for short-term handling of products so as to serve as a distribution logistics platform for market ready packaged produce and ready to retail products. They are designed for storage of a variety of commodities which operate, round the year. The products stored in these types of cold stores are seasonal fruits, vegetables, dry fruits, spices, pulses, milk products etc.

iii) Small cold stores with precooling facilities for fresh fruits and vegetables, mainly, for export oriented items like Grapes etc. The major concentration of these units is in Maharashtra but the trend is now picking up in other states like Karnataka, Andhra, and Gujarat etc.

iv) Frozen food stores with or without processing and freezing facility for fish, meat, poultry, dairy products and processed fruits and vegetables. These units have helped the promotion and the growth of frozen foods sector, both in the domestic and the export markets.

v) Controlled Atmosphere (CA) Stores**:** These are cold store fitted with technology that can alter the atmospheric gaseous contents, in addition to controlling the temperature. For certain fruits/ vegetables like apples, pears, cherries.

vi) Mini units / Walk-in cold stores located at hotels, restaurants, malls, supermarkets etc.

Figure 2 describes different stages of product value chain and the losses incurred at each stage.

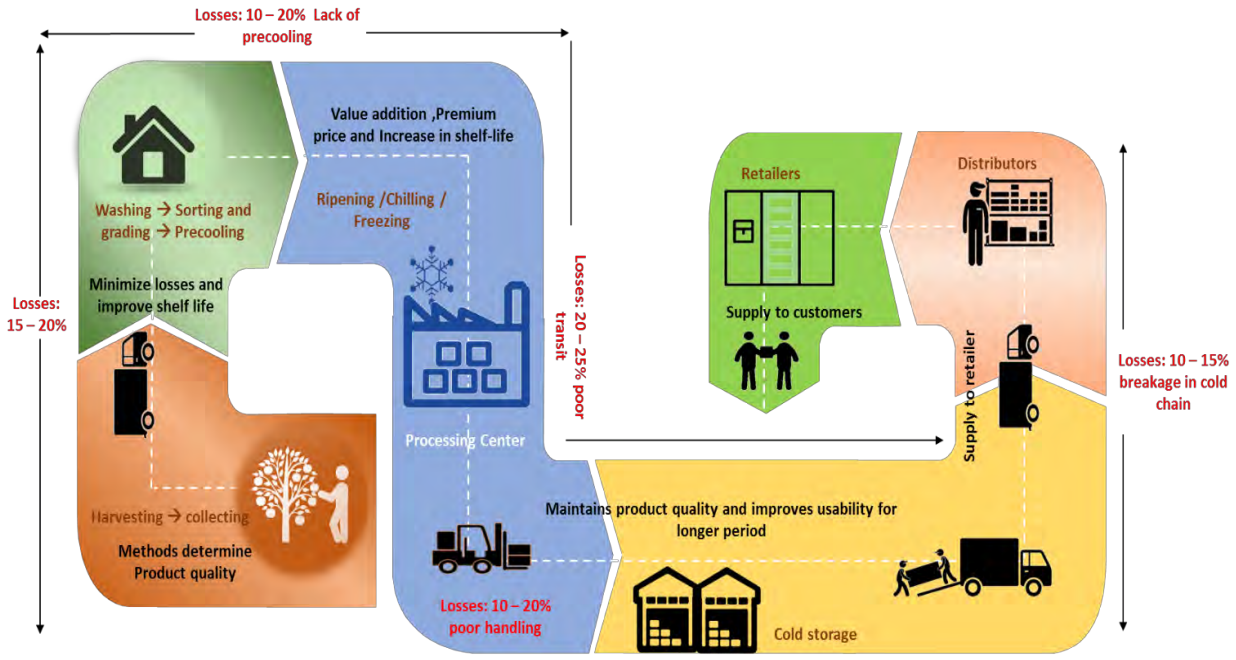

Figure 2: Different stages of product value chain and losses incurred at each stage

B. Stakeholders and their roles in Cold Chain

The stakeholders in cold chain based on their roles and functions in the chain, include growers associations, farmers producer organizations and co-operatives and association of retailers to companies engaged in manufacture and installation of refrigeration equipment, associations of cold chain owners, chambers of trade, industry and commerce, regulatory and development agencies (NCCD, MoFPI, NHB, WDRA, FSSAI, BIS), PSUs, skill development academic and resource institutions.

- **Producers/Grower Associations and Consolidators**: Farmers in India are small by land holding, yield, volume of crop and are highly fragmented across geographical areas. Typically a farmer handles cultivation, harvesting and preliminary packaging and transportation to the local mandi or consolidator. Some local entrepreneurs/consolidators provide the collected produce at the predetermined quantity and quality to the traders or processors and responsible for transportation of the produce from field/farmer storage to the trader/processor. The consolidator is accountable for the physical transfer of the product in good quality without injury. In a cold chain both these actors play a crucial role as, the produce is most susceptible to damage after first few hours of harvesting.

- **Traders & Processors:** Small producers with very small orchards take their harvested produce to the market yard and sell it to traders, who in turn will sell them to processor after performing basic pack

house operations. Traders are mostly owners of primary collection centers where the fresh produce is stored initially. Usually, they perform both trading and pack house, storage and in some cases ripening activities. They buy the produce from multiple farmers after performing suitable operations sell it to either wholesaler or the retailer. Some traders/ pack houses apart from trading, offer their operations as services and charge a fixed price for each activity performed.

- **3rd party reefer transporter:** Currently major part of transportation is through roadways via trucks. The products are carried from farm to trader or mandi either in tempo/vans, in case of larger consignment trucks, which are unrefrigerated. Reefer transportation is employed only in the organized trade after surpassing two to three stages in the value chain. Third party reefer transporters are employed mostly by organized retail marts, food processing companies to meet the shortage of own reefer transportation.

- **Technology Providers:** Technology providers in cold chain sectors comprises companies working in the areas of refrigeration technologies, packaging technologies, IT infrastructure, Post-harvest care, monitoring and control technologies for real time acquisition and reporting data. They play an important role in modernizing the infrastructure by engaging in research and development to improve the efficiency of the cold chain by working on the aspects like energy efficiency, cost reduction, increasing the reach and reducing the environmental impact.

- **Cold Chain Associations:** Various cold chain associations at national and state levels are active in voicing out for necessary policy support. They act as pivotal agents for the sector to collaborate and network with each other for sharing knowledge, lobbying and liaising for government support.

- **Government agencies:** Government agencies play the lead role in designing policies, infrastructure creation, and framing regulations. Agencies like MoFPI, NHB, and APEDA extend their support in infrastructure creation. National Center for Cold Chain Development (NCCD) is an autonomous agency under the Department of Agriculture, Cooperation and Farmer Welfare, established to promote cold chain sector for the perishables in collaboration with Industry and other stakeholders. It plays a vital role in promoting research, formulation of suitable technical standards and protocols, development of human resources for cold chain infrastructure in the country[11].

- **Consumers/Markets:** The premium pricing offered by the consumers for the quality products will determine the demand for quality products in the country which in turn will boost the cold chain sector, encouraging more players to adapt it.

[11] NCCD (2015). All India Cold-chain Infrastructure Capacity (Assessment of Status & Gap).

3. Current status of Cold Chain in India

A. Cold-Chain Infrastructure: Status

Over the years India has seen a gradual increase in production of perishable products like fruits, vegetables, meat and poultry products etc. It ranks first in dairy production, second in fruits and vegetables and 6th in chicken and meat production in the world. Unfortunately, cold-chain infrastructure development has not met this demand, which resulted in absence of mechanisms, for safe handling and storage, transportation of perishable products to markets. A resultant demand supply gap has emerged across these agricultural commodities, frequently contributing to widespread price fluctuations and inflation. This shortage of farm-to-market logistics, also contributed to high food losses in case of perishable foods, further adding to inflationary pressures.

According to ICAR study on post-harvest losses of major agricultural and horticultural crops as well as livestock products, the losses in selected fruits and vegetables were found to be in the range of 5.8% - 18.0%, losses in inland and marine fisheries were estimated to be 5.23% and 10.52%, respectively. On board losses were not recorded in case of marine fisheries. The assessed loss in milk sector was only 0.92% whereas losses in meat and poultry sectors were 2.71% and 6.74%, respectively.[12] To a great extent, these losses could be reduced by utilizing basic cold chain infrastructure. A brief snapshot of the current status of various infrastructure in Indian cold chain is presented below.

a) Pack houses & Ripening Chambers

- Pack-houses and refrigerated transport are important to initiate the vital link of logistics chain from villages to city or distribution hubs (in case of fresh produce).
- As per the NCCD (2015) report, at present the country has about 250 fully equipped functional pack-houses, whereas to fulfil current consumption of urban clusters, India needs about 70,000 pack-houses, each equipped with a pre-cooler and dispatch room for onwards transport links.
- Backward integration in a cold chain has been completley neglected until recent past when the focus has been shifted from building just cold stores to holistic development of integrated cold chain.
- A small concentration of packhouses in Maharashtra has brought global momentum to India's grape sector. Maharashtra is also a leading state in terms of number of packhouses for Mango and Pomengranate, followed by Andhra Pradesh.
- In Uttaranchal customised packhouses have been created to cater to the need of exporting Litchi.
- Another constraint in this sector is that most of the packhouses in India are primarily focused on fruits, there is very little emphasis on vegetable sector. Only few categories of exotic vegetables are handled propoerly and not much care is extended to others.
- Most of the packhouses created provide only basic operations of grading sorting and are not equiped with latest technology to carry out further value addition.

[12]CIPHET (2015), Report on assessment of quantitative harvest and post-harvest losses.

- Most of the pack houses are established by government. Lack of active partcipation from private companies is hindering the growth and innovations.

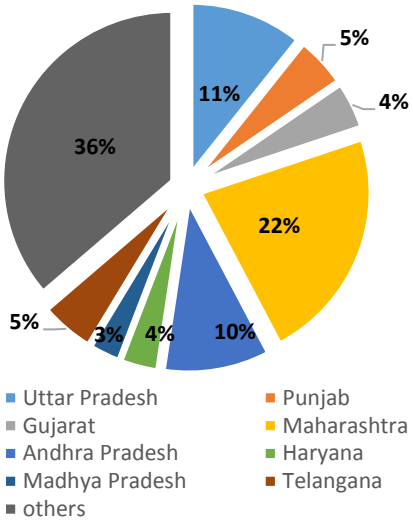

Figure 3: State-Wise Distribution of Ripening Chambers created under various government schemes [11]

Ripening Chambers

- Generally, ripening can be carried out for fruits like Mangoes, Papayas, Pears, Apricots, Guava, Citrus, Melons, and for reddening of Tomatoes, Green Chilies, but in India ripening chambers are predominantly used only for Mango and Banana.[13]

- Maharashtra and UP are hub of ripening chambers in India. Andhra Pradesh stands 3rd in the country. Majority of the ripening chambers are used for ripening of Mangoes in these states.

b) Cold Storages

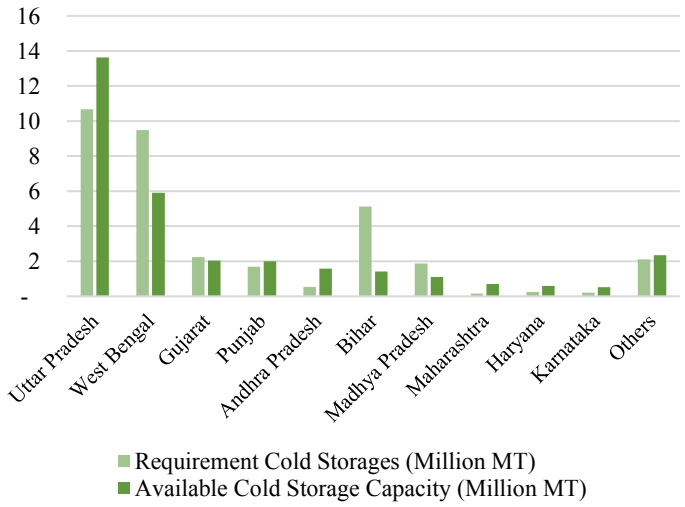

Figure 4: State Wise Cold Storage Distribution in India: 2014-15 [11]

- The Task Force on Cold-chain Projects (TFCP-2014) reported that 31.82 million metric tons of cold stores have been created in the country, out of these, a total of 10.58 million tons in cold storage size were created in the last decade, through Central Government Assistance.
- Top 5 states in terms of total installed capacity are
  - Uttar Pradesh (13.6 million MT)
  - West Bengal (5.9 million MT)
  - Gujarat (2.3 million MT)
  - Punjab (2.0 million MT)
  - Andhra Pradesh (1.6 million MT)

[13] www.nhb.gov.in

- It can be observed from Figure 4 that the growth of cold storages in India is not uniform. Some states like UP Andhra Pradesh, Punjab etc. have excess capacity whereas others like Bihar, MP have insufficient facilities.
- In UP and West Bengal, majority of cold stores are single purpose storages which are utilized to store potatoes and in case of AP, they are used for storing chilies.
- States like West Bengal, UP have high storage capacity with an average storage capacity more than 6000 MT, whereas Karnataka and Maharashtra, though have a high number of cold storages, average storage capacity is less than 2000 MT.
- Since the majority of cold stores in India are single purpose warehouses due to the seasonality of produce they remain idle for almost 6 months.

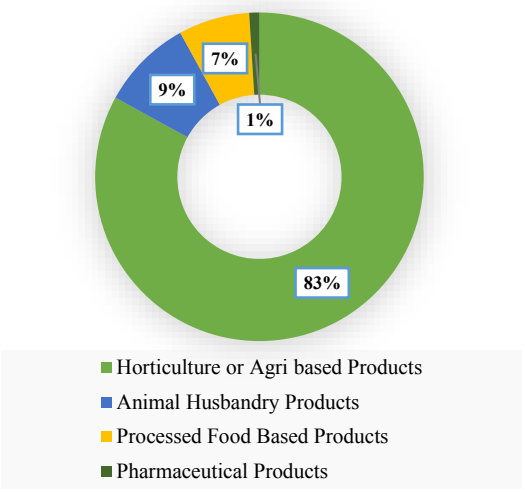

Figure 5: Product wise Cold Storage Distribution [11]

- It has also been observed in the NCCD study (2015), that only 75% of installed cold stores is being utilized.
- Majority of the warehouses in India are under private ownership. In states like Gujarat, Haryana, UP a number of cold storages are owned on partnership basis, whereas storages in AP are predominantly owned by private limited companies. In states like Karnataka, proprietorship basis is also prevalent.

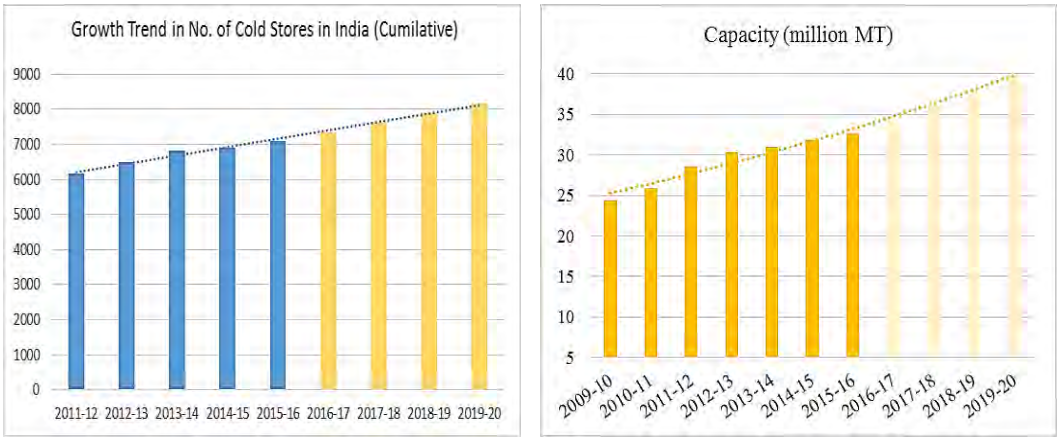

Figure 6: Growth rate of cold storages; Number and Capacity[11, 13]

c) Reefer Transport

- In cold chain, it is very essential to maintain the link and ensure that the chain is not broken. One crucial aspect to ensure this is to have a seamless refrigerated transportation network.
- Currently, this sector is ignored in the industry as very few players are equipped to provide the temperature controlled logistics service. This sector is highly fragmented and dominated by the private players.
- Indian market comprises of around 250 major and minor reefer transport service providers with ~ 9000 controlled temperature vans having a capacity of 4.2 million tons.
- Figure 7 shows state wise refrigerated transport infrastructure created under various government schemes. Though almost every state is facing shortage in terms of reefer transport, it is evident from the pie chart that Maharashtra, Gujrat, and Haryana are better off.

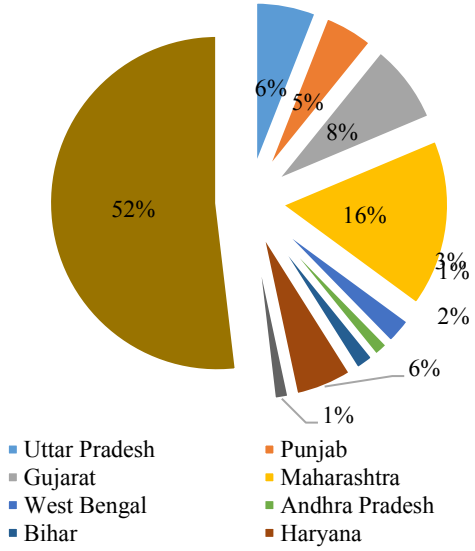

Figure 7: State-Wise number of Reefer Vehicles provided under various schemes [11]

- Most of the infrastructure sponsored under the current schemes consist of reefer vehicles with large capacities of approx. 20 tons, which do not cater to the need of transportation at farm end.
- The states like UP, West Bengal and Punjab are leading in terms of number of cold stores, but they are considerably lagging behind in transportation network.
- NCCD in collaboration with Mahindra Logistics has come up with a unique service proposition of Reefer Vehicle Call-in Center. It is 24/7 call-in facility for registered transport drivers to help them with on-road concerns regarding extortion, transit bottlenecks or any other issues.

B. Gaps and challenges:

a) Gaps in Indian Cold Chain infrastructure

As per a recent study by NCCD[11], there is a shortfall of almost 70,000 pack houses in the country. The gap of 70,000 pack houses indicates an average need for one between for every 10 villages. This evaluation indicates that the cold-chain backend is underdeveloped and large investment needs to flow into rural India, at grass roots level. The optimal requirement of cold stores in the form of bulk stores and distribution hubs is 35.1 million tons in capacity, as against the existing cold stores capacity of 32.86 million tons from about 7129 units. As per a recent baseline census undertaken[14], 1219 cold stores of estimated 5 million tons in size, were found permanently closed/not available. The total number of functional cold stores is 5367 amounting to a total storage capacity of 26.85 million tons.

[14] NHB (2015). All India Cold storage Capacity and Technology Baseline Survey

Table 3: Gap Analysis of Cold-chain Infrastructure in India[11]

Infrastructure Type	Infrastructure Requirement (A)	Infrastructure Created (B)	All India Gap (A-B)	% share of Gap to Required
Pack house	70,080	249	69,831 nos.	99.60%
Reefer Vehicle	61,826	9,000	52,826 nos.	85%
Cold Storage (Bulk)	341,64,411 MT	318,23,700 MT	32,76,962 MT	10%
Cold Storage (Hub)	9,36,251 MT			
Ripening Chamber	9,131	812	8,319 nos.	91%

According to the NCCD study, there is an associated requirement of about 62,000 refrigerated transport units (of carrying capacity of 10 tons each) in the form of vehicles or multi-modal containers. Most of the current capacity (actively refrigerated trucks) is deployed for frozen processed foods, pharmaceutical sector, and imported foods; and not for the domestic supply of fruits and vegetables. This is largely because the shortfall of pack houses does not introduce fruits and vegetables into the cold chain in the first place. Although most of the cold storages facilitate transportation of commodities, 79% don't own any transportation facility and there are very few modern pack houses to originate produce into cold-chain. An additional 30-40,000 vehicles (non-refrigerated/ Insulated) are estimated to be in use for transporting milk and fresh fish.

The NCCD study also indicates a need to develop an additional 8000 ripening chambers, large numbers of temperature controlled retail cabinets and city delivery vehicles. The Table 3 shows that India has done reasonably well in terms of creating capacity for cold stores but it significantly lags behind in terms of creation of pack houses, reefer vehicles, and ripening chambers.

b) Investments needed for meeting the gaps:

Approximately, 4000 projects are funded through various schemes in India constituting a total subsidy sanctioned of Rs. 3022.5 crores primarily focusing on bulk store capacity development with limited attention on linking other infrastructural components of cold chain which includes pack houses, reefer capacity, ripening chambers, mini storage hubs etc. Further focus needs to be given in supporting development and implementation of upcoming technologies and improvement of cold chain from farm to fork in order to cater the rising demand for quality and quantity, predominantly from urban markets. The table below estimates the total investments required to fulfil the current infrastructural gaps in the cold chain[15].

[15] NCCD (2016). Strategy document.

Table 4: Investment requirement for fulfilling the infrastructural gaps in the cold chain

Item	Components	Gaps All India	Unit Cost	Investments	Remarks
		Units	Rs. Lakhs	Rs. Crores	
1	Integrated Pack Houses	69,831	95	66339.45	For preconditioning 16 tons a day for cold-chain transit. Includes a pre-cooler and staging cold room with dispatch area for trucks. Facility will handle larger volume of incoming goods to segregate for non-refrigerated local market.
2	Reefer Transport	52,826	30	15847.8	Cost considered for 30 foot vehicles. Vehicle is insulated and refrigerated, capable of full range of temperature (-25 to +15°C).
3	Cold storage Bulk	650	400	2600	Cold store (Bulk) with large chambers for long term storing of certain produce, for periodic sale to markets over months. Average size of 5000 tons is considered.
4	Cold Storage Hub	360	350	1260	Cold store (Hub) with chambers of less than 250 tons each with multiple docks and doors, racking and forklift systems. Average size of 2500 tons is considered.
5	Ripening Chambers	8,319	40	3327.6	Ripening units with daily handling of 10 tons after a 4-day ripening cycle.
Total Investment				89374.85	in Rs Crores

Unit costs taken are as per the normative costs assessed under the MIDH guidelines. Additionally for modernizing retail end in cold-chain (for fruits, vegetables, and processed foods), an investment of Rs. 10,000 - 15,000 crores can be estimated at last mile. The estimation is made assessing the overall storage, processing and transportation connectivity along with consumption centers store hubs required for overall produce handholding.

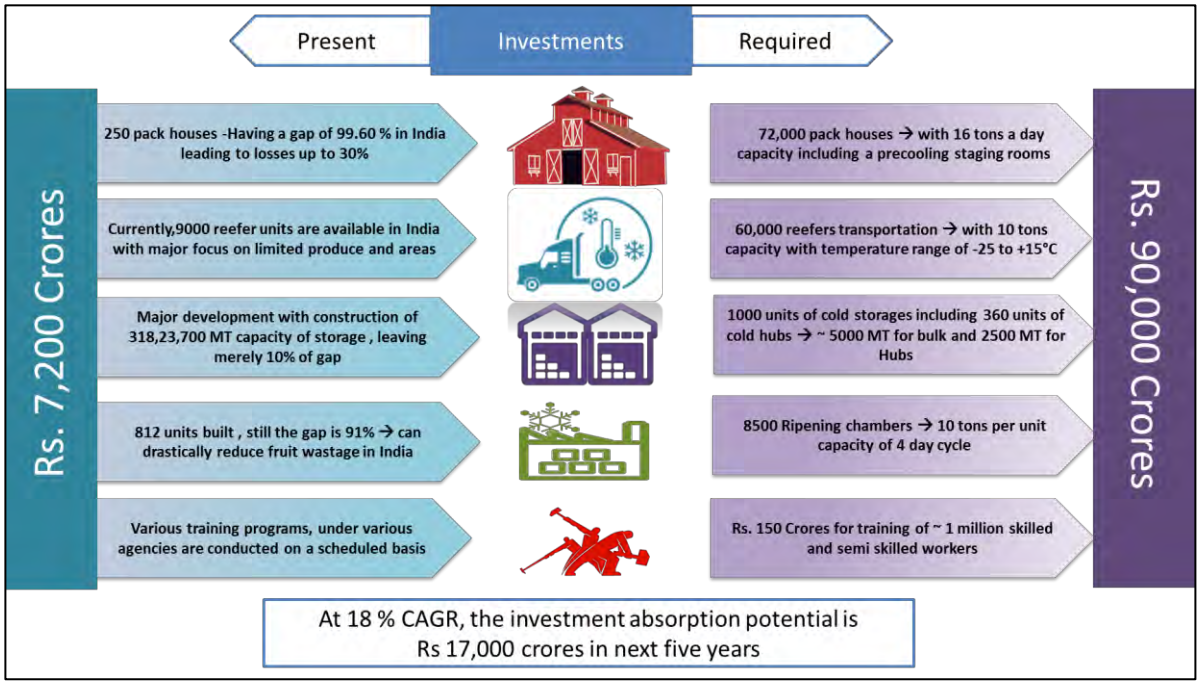

Figure 8: Infrastructure requirement in cold chain; present to future and investment requirements[11, 13] (Sathguru analysis).

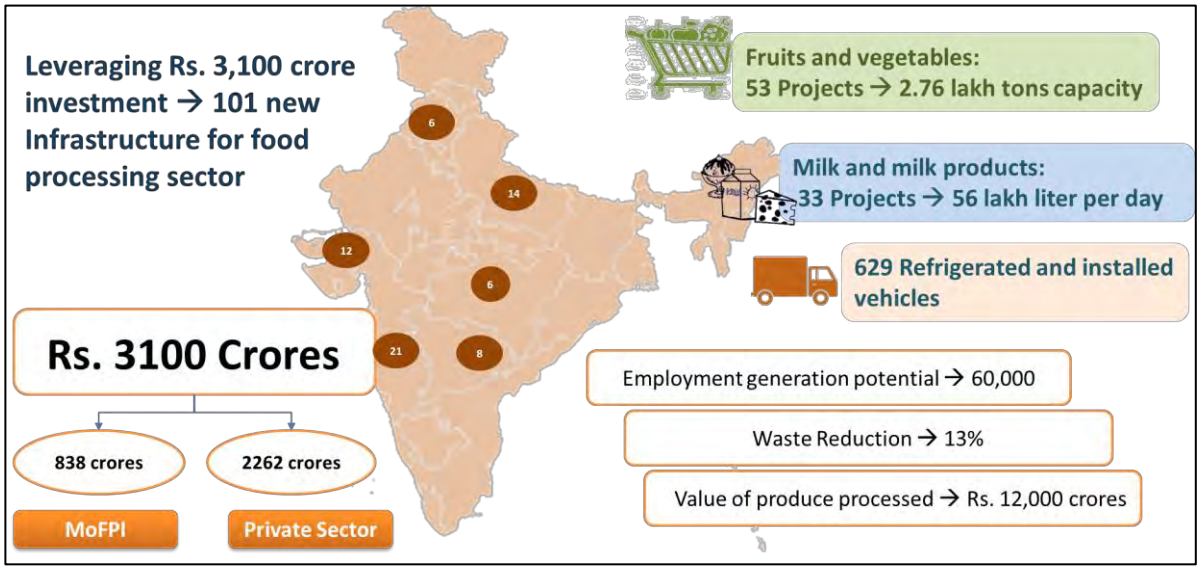

Figure 9: Investments in Cold Chain infrastructure by MoFPI in 2017.

c) Challenges in Indian Cold Chain infrastructure

Operational Challenges:

- **High lifecycle cost**: High real estate prices with an increase of more than 280% in last decade adds up significantly to the total cost, as for building a cold storage with 1 million cubic feet of space which requires an acre of land. Interstate barriers, intercity and state taxes, and bad roads etc. are other factors contributing to the rise in project and operational costs. In the country like the USA, the similar scale of installation cost less than half of the investment required in India

- **Quality cold warehouse infrastructure:** Nearly 75% of the cold storage infrastructure created in the past is suitable only to store single commodity, rendering them of no use for utilizing for the multi temperature and multi commodity storage.

- **Standards and protocols in construction and operation of facility:** Technical standards followed in India are mostly unsuitable for Indian conditions, which results in poor performance of a standard refrigerated system

- **Uneven distribution of cold storage:** Storage facility throughout the supply chain is another major challenge. Majority of cold storage facilities are located at the point of production, creating a lack of efficient supply chain to the downstream operations/ markets.

- **Low awareness**: Cold chain industry consists of multiple players, of which are 85% of unorganized players who are unable to invest much in the technology required to build high quality cold storages along with reefer trucks. 36% of the total players are small players with capacity less than 1000MT and their lower margins further limit their ability to maintain quality standards and invest in growth.

- **Generic schemes on pan India basis:** Approximately, 4000 projects are funded through various schemes in India constituting a total investment of INR 3022.5 crores. These schemes are basically volume driven nearly based on parallel parameters throughout the country. Lack of focus can be seen on technologies, capacity variance and customization of policies depending on geographical area requirements

Availability and supply of electricity through-out the country: India currently faces about 9% of peak power deficit, which enforces the use of fuel based operations leading to a marked increase in operating costs. The majority of electricity deficiency and unavailability could be found in the major agrarian states of the country, having a significant percentage of cold storages.

Table 5: Electricity deficiency and number of cold storage in major agrarian states[16]

State / Region	Total cold storage capacity	Surplus(+)/ Deficit (-) of electricity as %	
	MT	Energy	Peak
Tamil Nadu	238536	11.2	4.8
Andhra Pradesh	900606	-7.6	-13.8
Maharashtra	546748	7.4	0.7
Bihar	1147041	- 25.2	-18.4
Karnataka	407165	4.6	- 11.2
Gujarat	1267304	4.2	4.2
West Bengal	5682000	- 13.7	- 3.6
Uttar Pradesh	10118000	- 6.4	- 9.7
Odisha	291039	2.2	4
Kerala	58105	4.5	- 6

Laxity in refer transportation and development of rail and air mode to cold transport:

There is a marginal lag of proportionality between storage to the reefer capacity, leading to 85% shortage of refers in India. Supplementary attention needs to be given to air and rail reefer modes. Rail reefer transport, despite wide coverage of railway network, is still at the nascent stage and calls for a need for drawing better strategy.

Major challenges to reefer transportation are:

- Dearth of adequate in-house facilities for holding consignments.
- Lack of proper handling facilities at intermediator stations.
- Multi temperature and chamber support system for air and rail refers.
- Cost optimization for transit.
- Skilled workforce to understand the product standards.
- Backup support for detaining of refers increasing perishability chances.
  No financial coverage for the losses incurred during vehicle malfunctioning.
- Lack of specific guidelines that set the standard or protocols which need to be maintained for refrigerated transports.

[16] Central Electricity Authority. Load generation and balance report, 2016-17.

C. Government schemes and support for cold chain infrastructure

Table 6: Support to Cold Chain sector from various government agencies

Agency	Component	Incentive
MoFPI	For storage infrastructure including pack house and pre-cooling unit, ripening chamber and transport infrastructure	Grant in aid of 35% of the project cost for general areas and 50% of the project cost for difficult areas.
	Value addition and processing infrastructure including frozen storage/deep freezers associated and integral to the processing	Financial assistance (grant-in-aid) of 50% the total cost of plant and machinery and technical civil works in General areas and 75% for difficult areas, subject to a maximum of Rs.10 crore.
	Mega Food Park Scheme: to facilitate the establishment of a strong food processing industry backed by an efficient supply chain, which includes Collection Centers, Primary Processing Centers (PPC), Central Processing Center (CPC) and Cold Chain infrastructure.	A onetime capital assistance of 50% of the project cost (excluding land cost) subject to a maximum of Rs. 50 crore in general areas and 75% of the project cost (excluding land cost)subject to a ceiling of Rs. 50 crore in difficult and hilly areas
National Horticulture Board (NHB)	Capital Investment subsidy for construction/ expansion/ modernization of cold storage for Horticulture Products	Setting up of cold storage (of capacity above 5000 MT and up to 10000 MT) and their modernization are eligible for assistance of 40% of capital cost of project limited Rs. 30.00 lakhs per project in general area and 50% limited to Rs. 37.50 lakhs per project in case of NE, Hilly and areas.
Small Farmer Agri-Business Consortium (SFAC)	Integrated Scheme for Agricultural Marketing (ISAM)	Setting up of cold storage as a part of an integrated value chain project are eligible for subsidy provided the cold storage component is not more than 75% of TFO (Total Financial Outlay). The scale of assistance as subsidy to projects is at 25% of capital cost and maximum ceiling to Rs 2.25 crores in general area and 33.33% and maximum ceiling up to Rs 4 crores in case of NE, Hilly & Scheduled areas.
National Mission on Food Processing (NMFP)	The State Governments have been allowed to sanction cold chain projects for non-horticulture sector under the NMFP for Dairy, Meat, Poultry, Fish, etc.	Financial assistance is provided up to Rs.5.00 Crore per project in form of grant-in-aid and interest subsidy at 6%, subject to maximum Rs.2.00 Crore.
	Primary Processing Center/Collection Centers (PPC/CC) for both horticulture and non-horticultural produces:	Financial assistance is provided at 50% eligible project cost limited to a maximum of Rs.2.50 Crore.

	Reefer Vehicles for carrying horticultural/food products:	Back ended grant in aid of Rs.50 Lakh.
Agricultural and Processed Food Products Export Development Authority (APEDA):	For setting up infrastructure including specialized pack-houses, reefer transport, and cold stores as perishable cargo centers for promoting exports.	Financial assistance of 25% of project cost to private companies aimed at exports.
NABARD	For setting up of warehouse for agricultural produce	Low interest loan through food processing and infrastructure fund.

MoFPI has recently announced a converged assistance scheme called SAMPADA (Scheme for Agro-Marine Processing and Development of Agro Processing Clusters), the existing programs of Integrated Cold Chains and Value Addition Infrastructure will be implemented under this new scheme.

Foreign direct investments (FDI) in cold chain:

Foreign Direct Investment (FDI) is allowed under automatic route in cold storage. External Commercial Borrowing (ECB) can be raised for creation of cold storages, cold room including farm level pre-cooling for preservation or storage of agriculture/horticulture produce. For facilitating the growth of cold chain infrastructure in the sector, following additional support components are considered.

- Reduced excise duty on refrigerated containers, from 12.5% to 6%.
- Reduction of customs duty from 10% to basic 5%, on imports for cold storage, cold chamber and cold chains including pre-cooling unit, pack house, sorting and grading lines and ripening chambers.
- Service tax exemption on the operations like pre-conditioning, pre-cooling, packaging, and transportation of milk.
  Service tax exemption on construction, erection, commissioning or installation of post-harvest storage infrastructure/cold storages

Other Tax incentives:

- Section 80-IB of the Income Tax Act provides deductions in respect of profits from Industrial undertakings related to Cold Chain. For the first 5 years, the deductions are at 100% and then at 25 % for next 5 years.
- Under Section 35-AD of the Income-tax Act 1961, deduction @ 150% is permitted for expenditure incurred on capital investment in setting up a cold chain facility.
- Concessional rate of customs duty @ 5% on imported equipment for cold chain facility under the project import benefits.
- Under Section 35-AD of the Income-tax Act 1961, deduction for expenditure incurred on investment is allowed, if this investment is wholly and exclusively for the purpose of any specified

business which are explained below . However, this deduction is allowed only for the investment made in the previous year and prior to the commencement of its operations.

- Businesses allowed 150% deduction (provided the taxpayer has commenced business on or after 01.04.2012).
- Setting up and operating a cold chain facility.
- Setting up and operating warehousing facility for storage of agricultural produce.

- Refrigeration machinery and parts used for installation of cold storage, cold room or refrigerated vehicle, exempt from Excise Duty.
- Cold Chain services of preconditioning, pre-cooling, ripening, waxing, retail packing, labeling of fruits and vegetables exempted from service tax.

Current Status of Various schemes

Table 7: Agency Wise Cold Chain Infrastructure Assisted under the Schemes of Government of India[13]

Agency	No. of Project(s)	Total Subsidy Sanctioned (In lakhs)
MIDH	1249	93346.26
NHB	2496	112327.8
MOFPI	135	60349.58
APEDA	81	35569.26
NCDC	23	657.1
Compiled as on April 2017		

D. Vision 2022 and Cold Chain

Government has time and again emphasized the impact importance of farmer's in our economy. The vision statement of niti ayog states clearly the one of the main objective of the present government is to double the farmer's income by 2022. Primary source of income for a farming household is through cultivation and sale of crops. Other important ancillary sources are rearing livestock and wages earned by farm or casual labor. In order to achieve this goal, the action plan outlines a strong program for agricultural transformation. It includes numerous measures to raise farm productivity, fetch remunerative prices to farmers and increase productivity of farm land. Better price realization for farmers can be ensured through competitive markets, value chains and improved linkages between field and fork. Many recommendations have been submitted covering all the aspects and are grouped into[17] –

[17] Indian Council for Food and Agriculture (2016), Report on doubling farmers Income by 2022- Farm crisis and farmer's distress.

- Increasing incomes by improving productivity
- Water and Agri-Input policies
- Integrated Farming Systems
- Better market price realization
- Special Policy Measures

Under infrastructure creation and market connectivity elements, importance needs to be given to Cold Chain Sector. It is an integral part of the agri-business sector and is an enabling mechanism that connects producing areas with consumption centers. Cold-chain has prodigious socio-economic impact as it empowers the farmers to directly connect with multiple markets, across geographies. Without facilitation of Cold Chain, the average farmer is forced to sell his produce immediately after the harvest, as there is no counter to address the perishability. An efficient and affordable cold chain will encourage farmers to sell the produce at distant markets which in turn will facilitate them to earn better profits. Also cold chain will ensure better quality of produce it will fetch premium pricing for the produce.

Currently it is estimated that only 70% of the crop produced by the farmer reaches the end consumer. With inclusion of cold chain elements like pack houses, reefer vehicles and storages in the policy support, the loss in perishables can be significantly reduced. As a result the farmer will have better volumes of crop to offer for sale which will further their revenue. The provision of mini cold stores/ low cost walk in coolers will help the farmers in storing the produce for longer time and selling in the market during lean time to earn better margins.

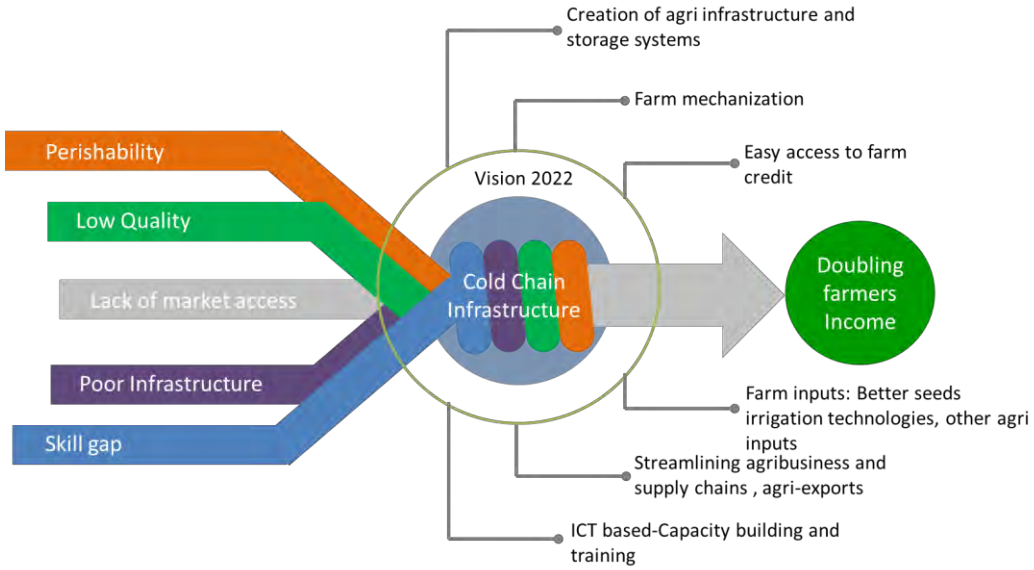

Figure 10: Causes for low farmer income and suggested elements in Vision 2022.

4. Cold Chain Technologies

A. Current technologies across the value chain

Various options and technologies, varying from simple and inexpensive to complex and sophisticated, are available to produce cold conditions for food handling, processing, storage and transport (tables 8, 9 & 10). The suitability of these options will depend upon the food products being handled and the level of sophistication of the value chain. According to the cooling method applied, systems can be described as vapour compression systems, absorption/adsorption systems, evaporative cooling systems, and cooling through the use of ice. These technologies differ with regards to key performance and operational characteristics, such as output temperature range, energy and refrigerant use and primary areas of application[18].

Table 8: Key characteristics of different cooling technologies [18]

Cooling method	Principal Applicability				Operating energy	Refrigerant use
	Food products	Temperature range	Cold chain steps	Other		
Vapor compression cycle	All food products	Full temp range (including freezing)	Entire cold chain		Electric	Halogenated or natural refrigerants
Sorption	All food products	Full temp range (including freezing)	Entire cold chain, but limited applicability in transport		Thermal	Natural refrigerants
Evaporative cooling	Chilling sensitive fruit & vegetables	Temperatures of above 10^0C	Mainly bulk storage, household refrigeration	Climatic limitations (low humidity)	Thermal (passive)	Water
Ice making	Non-chilling sensitive produce only (fish & meat)	Temperatures around 0^0C	Entire cold chain		Electric or thermal	Halogenated or natural refrigerants

In general, the highest cost will be for mechanical refrigeration systems using electricity or diesel fuel in the tropical regions with high temperatures. However, the benefits of using cold chain technologies can still outweigh costs, since it is in these regions where food losses due to lack of temperature management are the highest[5] .Tropical fruit crops and tomatoes require handling temperatures of 12-18^{0}C for longer shelf life. Non-mechanical cooling practices can often achieve these moderately cool temperatures at very low cost. The evaporative cooling systems work well only in dry regions or during the dry seasons when the relative humidity is low.

[18] Lange, B et al., 2016. Promoting Food Security and Safety via Cold Chains. GIZ, GmbH.

Table 9: Mechanical technologies available for cooling/freezing at small and large scale[3]

Cold chain steps	Small scale	Large scale
Packing and cooling (Pre-cooling systems)	• Portable forced air cooling systems (can be set up inside a cold room) • Use of ice	• Vacuum cooling • Forced air cold walls • Hydro-cooling
Processing - chilling or freezing	• Convection freezing • "Direct expansion" chilling of bulk milk	• "Instant" chilling of milk • Blast freezing • Immersion freezing • IQF (individual quick frozen) • Vacuum cooling of packaged meats • Freeze drying
Cold Storage	• Walk-in cold rooms • CoolBot™ equipped cold rooms	• Large cold rooms • Refrigerated warehouses
Distribution/ Refrigerated transport	• USDA Porta-cooler (trailer mounted pre-cooler) • Use of gel packs (phase change materials that can be chilled or frozen) • "Pack-n-Cool" trailers • Refrigerated cargo van Reefer (12ft length insulated box truck)	• Reefer trailers (20, 40 or 53ft length) • Refrigerated marine containers • Refrigerated intermodal containers (for road, rail and sea shipping)
Marketing	• Misting during display • Use of ice	• Refrigerated/frozen display cases

Table 10: Non-mechanical technologies available for cooling at small and large scale[5].

Cold chain steps	Small scale	Large scale
Pre-cooling systems	• Portable evaporative forced air cooling systems	• Slurry ice
Cold Storage	• Zero energy cool chambers (ZECC) • Evaporative cooled cool rooms (charcoal coolers) • Underground storage (root cellars) • Night air ventilation • High altitude storage • Radiant cooling • Solar chillers	• Evaporative cooled warehouses • Underground storage (caves) • High altitude storage • Radiant cooling
Processing - chilling and freezing	• None available	• None available
Refrigerated transport	• Evaporative cooled insulated transport boxes or trailers	• Passive cooling (insulated pallet covers)

B. Drivers for new technologies:

The cold chain places a significant burden on the environment since refrigeration is energy intensive and is a source of greenhouse gases. The food cold chain currently consumes about 20% of global hydrofluorocarbons usage currently, and energy consumption by the technology is an important factor in its overall GHG contribution (GFCCC). The emissions from cold chain are of two types: direct emissions caused by the leakage of refrigerants, and the indirect emissions from the energy used to operate the refrigeration systems; with indirect emissions making up more than two-thirds of the total emission of greenhouse gases.

Currently, 90 percent of India's cooling capacity and annual refrigeration and air-conditioning (RAC) is based on hydrofluorocarbons (HFCs) and Hydrochlorofluorocarbons (HCFC) refrigerants, about 10 percent is based on naturals[19]. Prioritizing naturals will result in direct emissions saving of 50 million tonnes of CO2 per year by 2030. Fortunately, in India, more than 95% of all cold storages are based on ammonia, making this the world's largest collection of users of natural refrigerant. However, investment in India's cold chains is going to increase in the coming years, which will be dominated by highly polluting diesel-powered Transport Refrigeration Units (TRU). TRUs not only consume up to 20% of the truck's fuel but also emit 29 times as much particulate matter (PM) and six times as much nitrogen oxide (NOx) as a modern propulsion engine[20]. It is crucial to develop cold chains to reduce food loss and the consequent waste of water, energy, and labor used to produce the food lost. But doing so with conventional technologies would only swap one set of environmental problems for another. Replacing each diesel-powered TRU with sustainable cooling technologies will significantly reduce gas emissions.

There are significant opportunities for reducing greenhouse gas emissions from cold chain sector by expanding the cold chain in developing countries, improving the energy efficiency of the equipment being utilized, and transitioning from high global warming potential (GWP) HFCs to low GWP compounds and technologies, including Hydrofluoroolefins (HFOs), carbon dioxide, hydrocarbons and ammonia. The recent negotiations around the HFC phase-down amendment to the Montreal Protocol have made the alternatives to HFCs crucial in many countries.

The drivers for new technologies can be summarized as:

- Increased demand for cooling requirements
- Increased focus on energy efficiencies
- Reduction in CO_2 footprint and other pollutants like No_X and PM
- Transition to lower GWP refrigerants
- New technological developments in the market

[19] Bhushan, C (2016). Prioritizing Natural Refrigerants in India. Centre for Science and Environment, New Delhi.
[20] Birmingham Energy Institute (2014). The prospects for liquid air cold chains in India.

C. Improving energy efficiency of cooling systems:

The energy consumption of cooling systems depends on several factors that may lead to higher or lower energy efficiency. Over recent years, several efficient technologies have evolved that include optimized compressor design, Variable Frequency Drives (VFDs) to control compressor and fan motors, advanced heat exchanger design, etc. Appropriate use of these technologies can significantly improve the energy efficiency of standard systems[18].

The heat load directly affects the size of the refrigeration system, the amount of refrigerant used and the energy consumption. LED lighting in cold units do not generate heat and thereby can reduce the load of the refrigeration. Effective insulation is an important barrier to heat load and technologies that hasten operations and minimize breaks in thermal integrity like dock shelters can reduce energy consumption. Various thermal barriers, automation and efficient facility designs also reduce energy requirement. The efficiency of a system also depends on the refrigerant and its thermos-physical properties. Some refrigerants are more suited for some applications and climate zones than others and therefore lead to higher efficiencies. Hydrocarbons (HC) for example have very good properties and systems with HC refrigerants are usually more efficient than the same units with fluorinated refrigerants. CO_2 is an excellent refrigerant in ambient temperatures below 30°C, but for now less efficient in hotter climates[18]. An audit of cold storage facilities showed average potential energy reductions of 28% could be achieved by behavior change, improved maintenance and off-the-shelf technologies only[21].

Danfoss India and Sabharwal Food Industries have set up India's first green cold storage at Sonipat, Haryana in 2015. Danfoss has installed energy efficient technologies ranging from variable frequency drives (VFDs) to compressors, valves and electronic controllers which are expected to result in energy savings of 15-25%.

[21] Evans JA et al., (2014). Assessment of methods to reduce the energy consumption of food cold stores. Applied Thermal Engineering. 62:697-705.

D. Renewable Energy Options for Cold Chain:

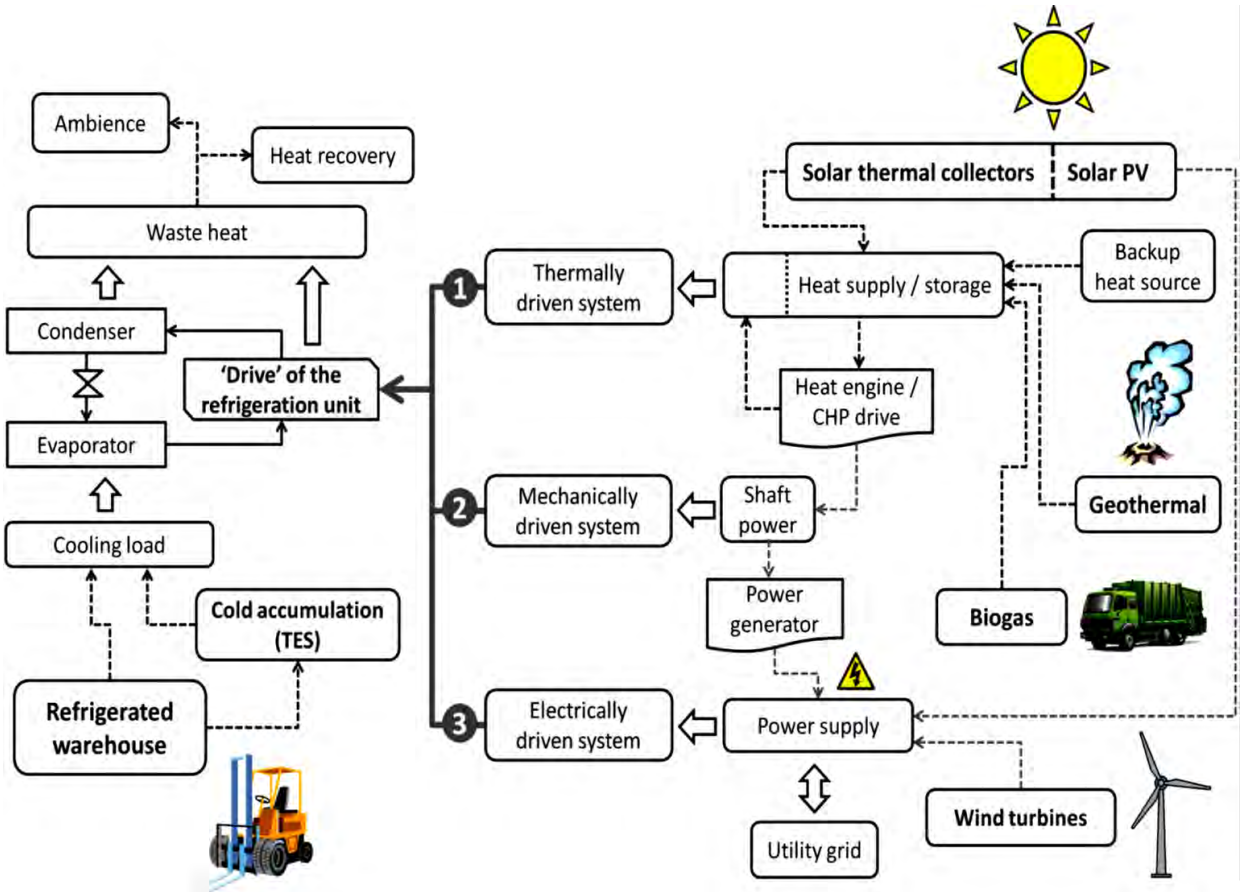

Figure 11: Various options to integrate renewable sources in the energy supply of refrigeration systems[22]

Electrical energy is a major running cost to maintain the cold storage facility in India, accounting for about 30 percent of total expenses in cold storage. Moreover, the grid power supply in the rural areas is very poor with respect to its quantity and quality. Renewable energy resources like solar energy are available in abundance in India and can be used to power existing or new technologies through electricity generation or cooling through solar-driven absorption. The alternate energy sources only replace the energy source and cannot reduce the energy requirement.

Integration of renewable sources in the energy supply of cold storage facilities can be achieved in several ways[22]. Solar photovoltaic cells can be used for on-site power generation, while solar thermal collectors, geothermal sources and biogas combustion can serve as a heat source for thermally driven refrigeration systems. The thermal sources can be used to drive cogeneration or trigeneration systems, thereby simultaneously producing electricity, heating and refrigerating output. Thermal energy storage (TES) for

[22] Gaspar, PD and da Silva, PD (2015). Handbook of research on advances and applications in refrigeration systems and technologies. Engineering Science Reference.

heat and cold accumulation can be integrated into the system to shift energy supply and/or demand as to permit better overall utilization of renewable energy[22]. The renewable energy source generated power can be fed to the utility grid via proper interaction established between the cold store and the grid. This, along with the inclusion of thermal energy storage systems can overcome a major challenge of many renewable energy source technologies, i.e. the intermittent energy supply due to the fluctuations in the availability of the energy.

a) Solar photovoltaic systems to generate power for cooling:

The following solar photovoltaic energy options are available or demonstrated in India[23]:

i. Solar Photovoltaic Power Pack:

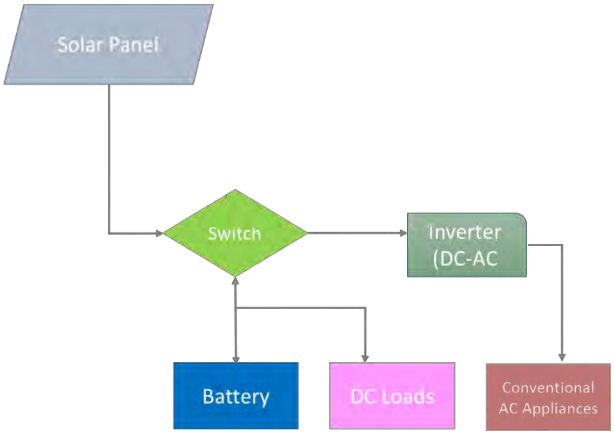

Figure 12: Solar Photovoltaic Power Pack[23]

- Power Pack systems are used to generate electricity for locations where the grid is unreachable or the access is expensive.
- It is a PV based solar energy system, where solar energy is converted into electrical energy and used for refrigeration much like conventional methods.
- These Solar Power Pack Systems as illustrated in can also be used in combination with existing grid for uninterrupted supply of electricity.

ii. Solar PV System + Diesel Gen-Set Hybrid

- A solar PV can be coupled with existing DG set to supply electricity for base load & minimum reefer load.
- During the non-availability of the grid power, the electrical units generated by solar PV can be utilized hence minimizing the energy cost.

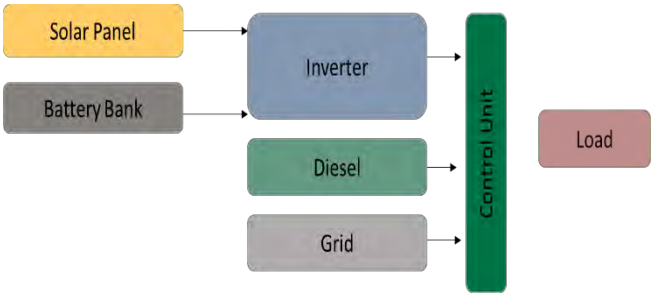

Figure 13: Solar PV + Diesel Hybrid [23]

- Projects are operational at various locations so as to hedge the cost of diesel with the help of smart controlling and prolonged temperature maintenance.

[23] Sinha, V and Tripathi, A (2014). Integrating renewable energy to cold chain: Prospering rural India. IPCBEE. 76: 99-104

iii. Solar PV + PCM:

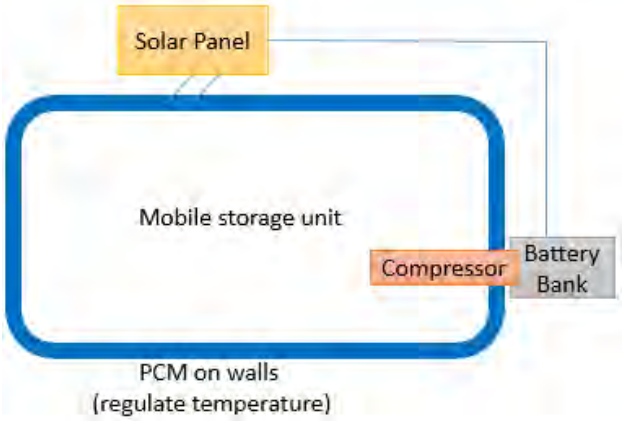

Figure 14: Solar PV Power Pack To Power the Compressor[23]

- These systems are used to generate electricity through solar PV to drive the compressor and also maintain the required temperature with the help of Phase Change Material (PVM) so as to minimize the load on the compressor.

iv. Biomass Gasifier:

- Existing generators are fed with gas from biomass to produce electricity.
- Biomass Gasifier based electricity generating systems are a viable option for decentralized electricity production especially in village areas where the grid is not available and biomass is readily available.
- This setup can provide cold storages with electricity even in standalone mode.

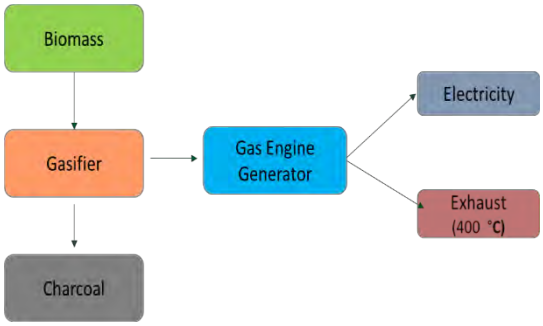

Figure 15: Biomass Gasifier driving the generator supporting the cold storage[23]

b) Solar thermal refrigeration system:

In solar thermal refrigeration system, the refrigerant is directly heated by a solar collector instead of using solar electric power. Sorption technology is utilized in thermal refrigeration techniques; wherein the cooling effect is obtained from the chemical or physical changes between the sorbent and the refrigerant. Vapour Absorption Machines (VAMs) operating on solar thermal technologies are finding good acceptance in the country. Solar thermal systems make sense and are a viable solution where there is no electricity available all the time or it is very expensive[24].

[24] Singhal, AK (2014). Status and Scope of Solar Cooling in India. Sun Focus. 4: 6-8

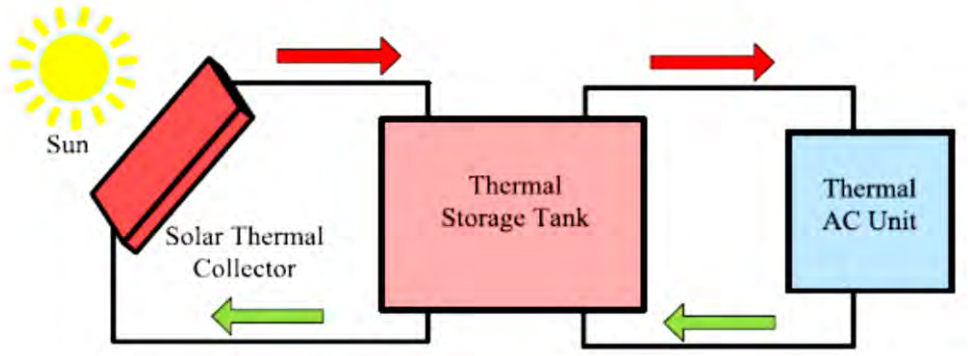

Figure 16: A schematic diagram of a solar thermal cooling system[24]

Solar Energy Centre (SEC), Gurgaon, in collaboration with Thermax (cold storage component) and TERI (gasifier component), have developed and demonstrated a solar - biomass hybrid absorption cooling system operating on thermal energy.

Solar/Biomass Co-generation (Power and Cooling):

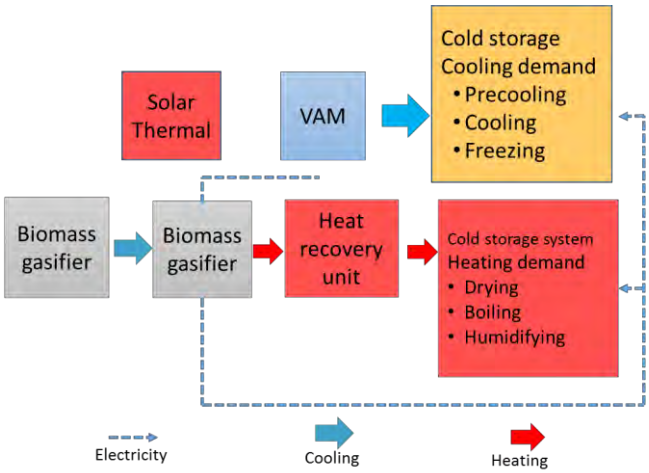

Figure 17: Solar Thermal and Biomass COGEN Plant[23]

- In this system producer gas from Biomass Gasifier drives gas engine to produce the electricity required to drive the system.
- A Vapor Absorption Machine (VAM) is driven by the engine waste heat.
- The solar thermal collectors supplement the heat to the vapour absorption system during day time.
- The balance heat available from the engine can be utilized for drying, humidifying, sanitizing needs of the cold storage.

This hybrid system thus not only meets both electricity and cold storage needs but also optimizes the use of biomass. Indian Government through the Ministry of New and Renewable Energy (MNRE) has funded academic and commercial establishments for developing products based on these technologies. The MNRE has extended the subsidy scheme that it currently offers for most solar power installations to solar powered cold storages as well. The government offers a 30% subsidy for solar installations for both rooftop and large scale projects under its various programs.

Geothermal cooling:

Geothermal cooling systems use the ground as a heat sink, as the earth's temperature at certain depth is lower than that of the atmosphere temperatures. With lower ground temperature available to the cooling systems, their efficiency increases significantly. Where feasible, such systems can replace or augment existing refrigeration systems, leading to significant energy savings. MNRE has been supporting R&D on exploration activities for harnessing the geothermal energy in the country.

Green India Building Systems and Services (GIBSS), an Indian company, has developed geothermal based technology for air-conditioning and cooling in buildings that can save up to 35% energy consumption.

E. New and emerging technologies

a) Liquid air cooling

Natural gas is liquefied by cooling it (at -162^{0}C) for the purpose of reducing volume in shipping. At receiving terminal, the Liquefied Natural Gas (LNG) undergoes regasification (reheating) process before supplying to customers and in the process, vast amounts of cold are lost to the environment. There is great opportunity to harness the wasted/ stranded cold at the LNG terminals to produce liquid air and provide zero-emission cooling and power in a wide range of applications, static as well as mobile. This energy re-cycling at LNG terminals can develop dedicated gateways for perishable foods in the region. Currently, India has four regasification plants with a total capacity of 25 million tons per annum (MTPA) and the rating agency ICRA has projected India's LNG regasification capacity to double by 2025. The LNG import terminals could in future form the hubs of extensive import-export cold chains. The waste cold from India's projected LNG imports in 2022 could fuel over half a million liquid air refrigeration units or fuel 1 million auto-rickshaws[20].

Cryogenic liquids like liquid nitrogen have been produced in bulk for industrial purposes and blast freezing for several years now. With recent developments, liquid nitrogen can be used as an energy vector or store of power and cooling. Liquid nitrogen is widely available in India and the industry has 3,500 tonnes per day of spare production capacity. This would be enough to cool around 17,000 refrigerated vehicles, twice the size of India's refrigerated truck fleet[20].

NCCD is pursuing the potential of clean energy from liquid air based cold chains by recovering stranded cold from LNG re-gasification. A study by E4tech, conducted on behalf of India's NCCD, shows that a typical LNG terminal re-gasifying 7,100 tons of LNG/day can produce 2,600 tons of liquid nitrogen, enough

to provide the cooling for almost 1,100 chilled and frozen refrigerated trucks operating around the clock; and peak time cooling (three hours a day) for 7.5 million cubic meters of chilled and frozen buildings, both at the port and at inland warehouses[20].

Indian industry has also taken a lead in harnessing waste cold, with Petronet LNG recently inviting expressions of interest from players to help it develop an integrated cold store facility at its LNG import terminal at Dahej, Gujarat[25] .

Unlike other alternative refrigeration technologies, liquid air can cater to full range of cold chain services - from pre-cooling of produce to warehouse cold storage and long distance vehicle refrigeration. It can also supply the cold for blast freezing and other forms of food processing. Liquid air can find applications beyond agriculture like back-up power and air-conditioning in buildings.

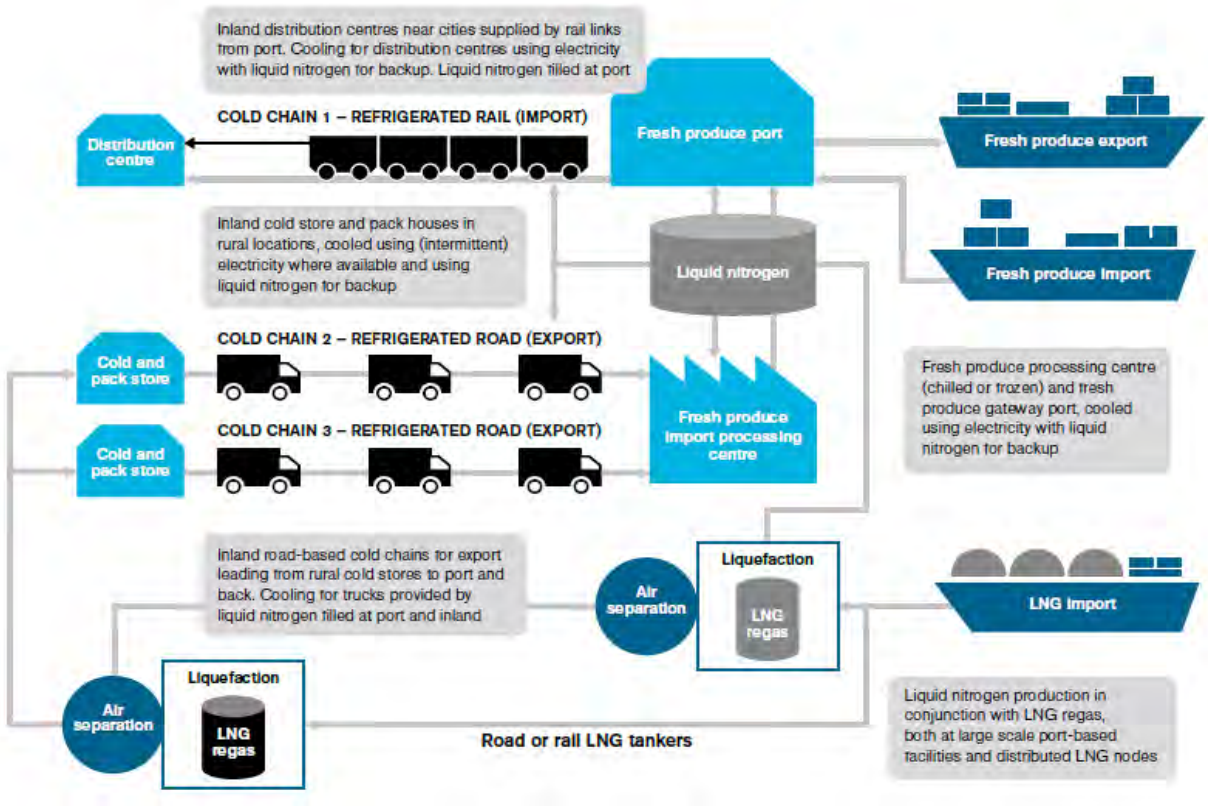

Figure 18: How waste cold from LNG re-gasification could power the cold chain industry in India (Source: E4tech)

[25] https://www.petronetlng.com

Economic feasibility of liquid air refrigeration

The economics of liquid air refrigerated transport in India look promising, even without the help of waste LNG cold. According to a report by Kitinoja (2014)[3], there is a strong case for urban delivery using liquid air equipped reefer vans. It was found that for a 1 tonne reefer van, liquid air refrigeration could be 20 - 35% cheaper per kg of cargo than diesel truck and for a 0.5 tonne vehicle 23 - 33% cheaper than diesel.

Table 11: Estimated comparative costs for refrigerated transport in India[3].

	1 tonne capacity (small reefer van) Load market value $1000	**0.5 tonne capacity (very small reefer van) Load market value $500**		
Reefer target temperature	Diesel/ICE 5kW engine	Liquid Air/ cryogenic engine	Diesel/ICE 5kW engine	Liquid Air/ cryogenic engine
2^0C	$25 to maintain temperature (21 L) $0.025/kg	$20 to maintain temperature (112 kg) $0.02/kg	$13 to maintain temperature (11 L) $0.013/kg	$10 to maintain temperature (56 kg) $0.01/kg
12^0C	$23 to maintain temperature (20 L) $0.023/kg	$15 to maintain temperature (84 kg) $0.015/kg	$12 to maintain temperature (10 L) $0.012/kg	$8 to maintain temperature (42 kg) $0.008/kg

b) Liquid air power and cooling

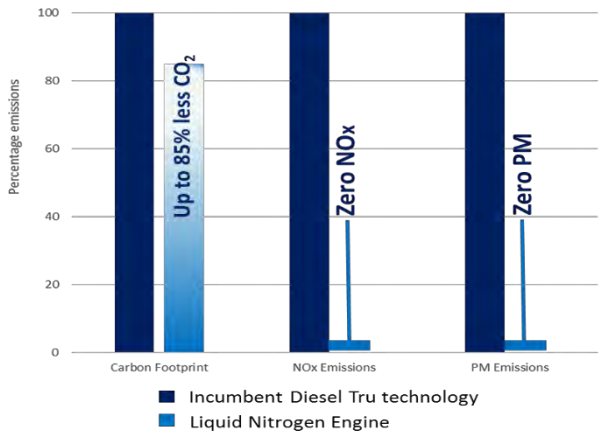

Figure 19: Zero Emissions from Liquid Nitrogen Engine (Source - Dearman)

Dearman, a UK-based technology company, has developed a family of engines that uses liquid air/ liquid nitrogen to deliver zero-emission power and cooling. The Dearman engine is a novel piston engine powered by the phase-change expansion of liquid air or liquid nitrogen. The only exhaust is cold air[26]. The Dearman engine can be highly efficient Transport Refrigeration Unit (TRU) for 'reefers', because it extracts both shaft power and cold from the same unit of liquid air or nitrogen, and replaces the traditional diesel engine used to chill the vehicle. This technology will reduce fuel costs (refrigeration alone consumes as much as 20% of truck's fuel) and will eliminate all emissions associated with refrigeration.

[26] http://dearman.co.uk

Market readiness of liquid air or liquid nitrogen engine technology

Sainsbury in the UK has become the first company in the world to introduce a refrigerated delivery truck cooled by a liquid nitrogen powered engine[26]. Dearman is in discussion with leading Indian companies in engine manufacturing and the industrial gas industry.

c) Magnetic Refrigeration System

Magnetic Refrigeration System (MRS) is another potential low carbon technology that is being considered as an alternative to conventional vapor compression. Magnetic refrigeration is based on the Magneto caloric Effect (MCE). The temperature of Magneto caloric Materials (MCM) increases when they are exposed to a magnetic field and decreases when they are removed from it; the effect is reversible and almost instantaneous. MRS offers the following advantages over compressor-based refrigeration systems:

- High Coefficient of Performance (COP): reduces energy consumption by up to 40%
- No compressor/refrigerant gas used, instead water-based coolant liquid used: eliminates harmful emissions
- No gas leakage: reinforced safety and eliminates CO2 emissions
- Less noise and vibrations

MRS can be easily integrated into refrigeration display cases replacing compressors in refrigeration (Figure 20). In the magneto-caloric heat pump, heat is transferred from the cold interior of the refrigerator to the warm external air by circulating a water-based coolant through the magneto-caloric materials as they cycle in and out of the magnetic field.

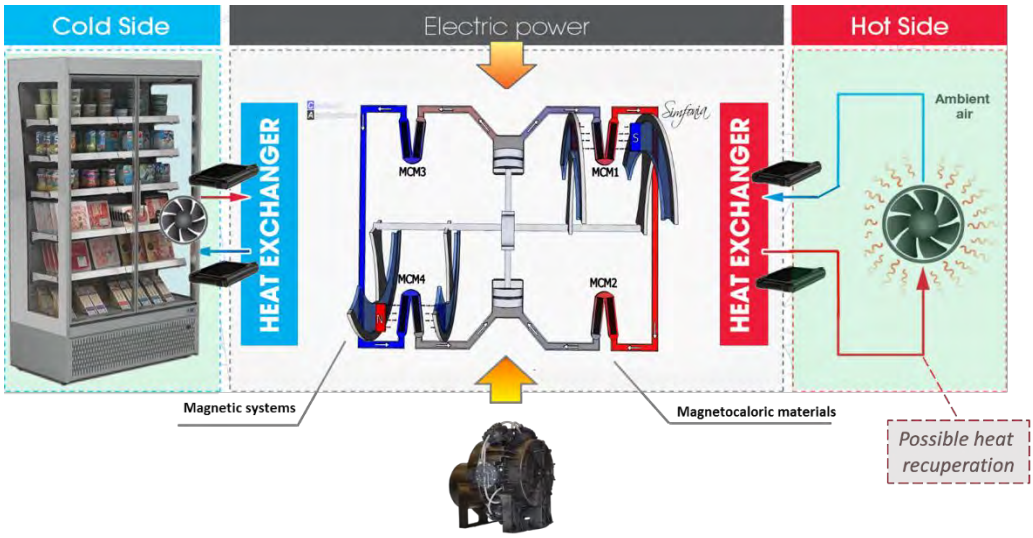

Figure 20: General functioning of the Cooltech's Magnetic Refrigeration System integrated into a refrigerated display cabinet[27]

[27] http://www.cooltech-applications.com

Cooltech Applications, a French company, has launched the first magnetic cooling system for commercial refrigeration. Initial applications of magnetic cooling have been targeted at refrigeration markets. With cooling powers between 200W and 700W, the MRS product line is optimized for a wide range of products in commercial refrigeration like display cabinets, beverage dispensers, store plugins, medical refrigerators etc. Cooltech has partnered with several display case manufacturers and leading supermarket chain like Carrefour[27]. This magnetic cooling can also be adapted to other applications, such as transport refrigeration, air conditioning, and cryogenics or in heating systems. Cooltech is adopting both compact as well as scalable versions for the development of the magneto-caloric technology and gradual penetration into the potential markets (Figure 21).

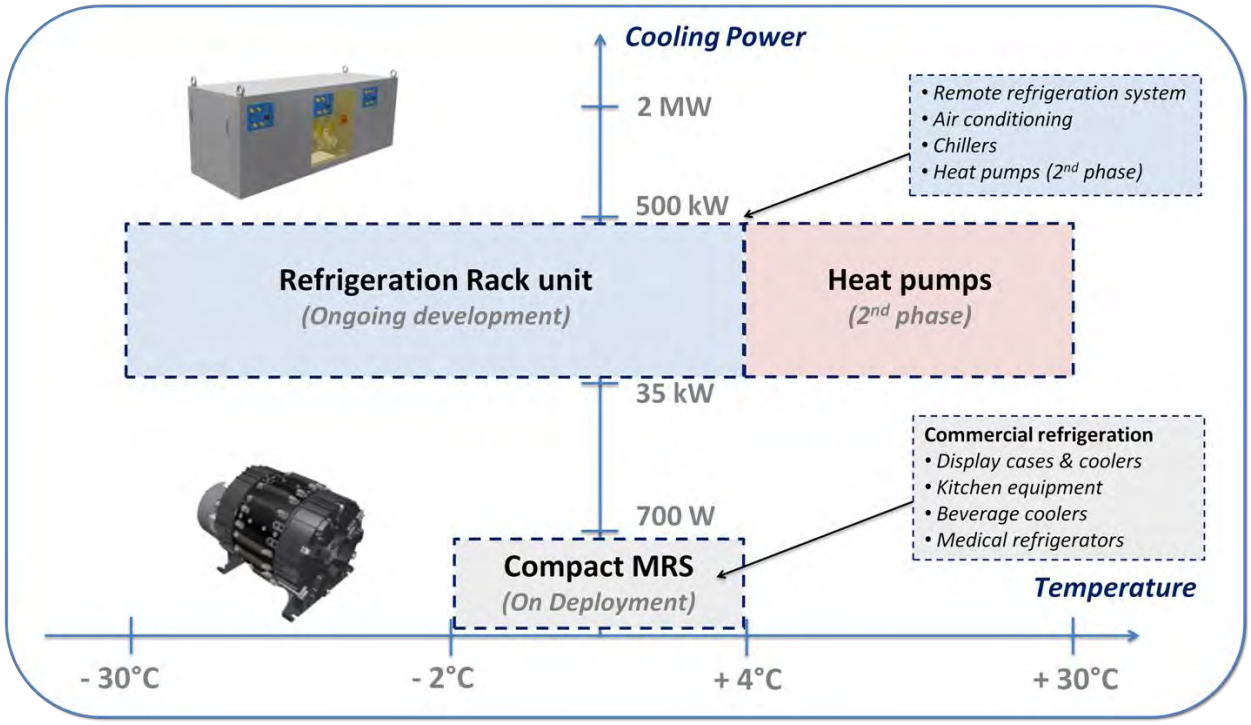

Figure 21: Cooltech's approach to gradually penetrate the potential markets with MRS[27].

According to Markets and Markets report of 2015, Magnetic Refrigeration would reach $315.7 Million by 2022. Some other players in the magnetic cooling market include Astronautics Corporation America (USA), Camfridge Ltd (UK), General Electric (USA), Whirlpool Corporation (USA) etc. BASF is currently working on developing innovative materials and functional components for magnetic cooling[28].

d) Alternatives for energy storage

Thermal energy storage (TES) systems allow the storage of heat or cold for later use. TES is useful for applications where there is a mismatch between supply and demand of energy. Latent heat storage using

[28] www.basf.com

phase change materials is one of the efficient methods to store thermal energy. Phase change materials (PCMs) are substances that undergo a phase transition (e.g. liquid to solid) at a specific temperature and, as a result of which they are able to absorb and release latent heat with a very small variation in temperature. PCMs can be used during transport, storage and distribution stages to maintain the cold chain of solid food, beverages, pharmaceutical & biomedical products, electronic circuits etc[29].

Application of PCM in transport containers was one of the first commercial PCM applications as PCMs could maintain the desired temperature. The conventional refrigeration unit in a reefer truck needs constant running of the diesel engine to maintain the temperature of the product. The PCM systems are engine-independent, so result in lower operating costs and fuel consumption and are environment friendly. Most importantly, the PCM system makes it possible to have different temperature profiles on the same vehicle and conventional refer trucks are not needed. The PCM based truck can be charged for about 4-5 hours using a 3-phase power source consuming. PCM based refrigeration trucks are being manufactured by TESSOL in India and the shift from usage of a diesel generator to PCM can reduce the overall transportation cost by up to 50% for the end user. Pluss Polymers is a leading Indian player in the field of PCMs designed to cater to a wide range of temperatures between -33 to $+89^0$C.

The PCM solution can also be applied to stationary applications given the low grid reliability in India - both at rural and urban levels. This solution is being further extended to cold storages combined with renewable technologies like solar. As per NHB guidelines, PCM technology based products are eligible for a 100% subsidy up to INR 35 Lakhs.

Sure Chill, a UK based company, has developed a fridge that keeps its contents cool at a steady 4^0C for days or weeks without power through a natural energy storage system based only on ice and water[30]. This means it works particularly well with solar panels or in countries with erratic grid electricity. Sure Chill was announced as "the most innovative new cold chain technology of the year" at the Global Cold Chain Forum in Boston, USA in 2016.

[29] Oró et al., (2012). Review on phase change materials (PCMs) for cold thermal energy storage applications. Applied Energy. 99, 513-533.

[30]http://www.surechill.com

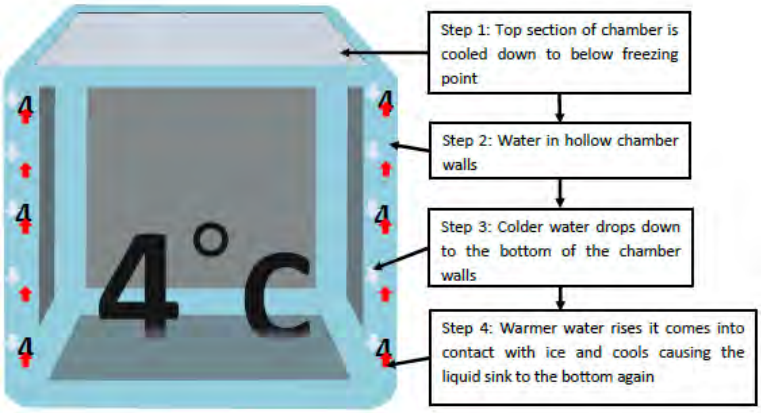

Figure 22: Schematic showing basic working principle of the Sure Chill cooling technology[31]

e) Trends in monitoring of cold chains

Creation of low temperature is the core of the cold chain systems and the challenge lies in maintaining effective temperature across the cold chain from farm to the end market, particularly in the case of perishables like fruits, vegetables, meat, poultry, and seafood[32]. The disruption in the set parameters leads to not only to qualitative and quantitative food loss but also to compounded loss of resources like energy, packaging material and man hours, food safety issues and environmental impact. Hence, monitoring and control of basic parameters like temperature and humidity is one of the critical elements in the cold chain. In the advanced systems like CA/ MA, this extends to other parameters like gas concentration in addition to the basic parameters. The issue became a concern for the industry and topic of interest for research.[33]

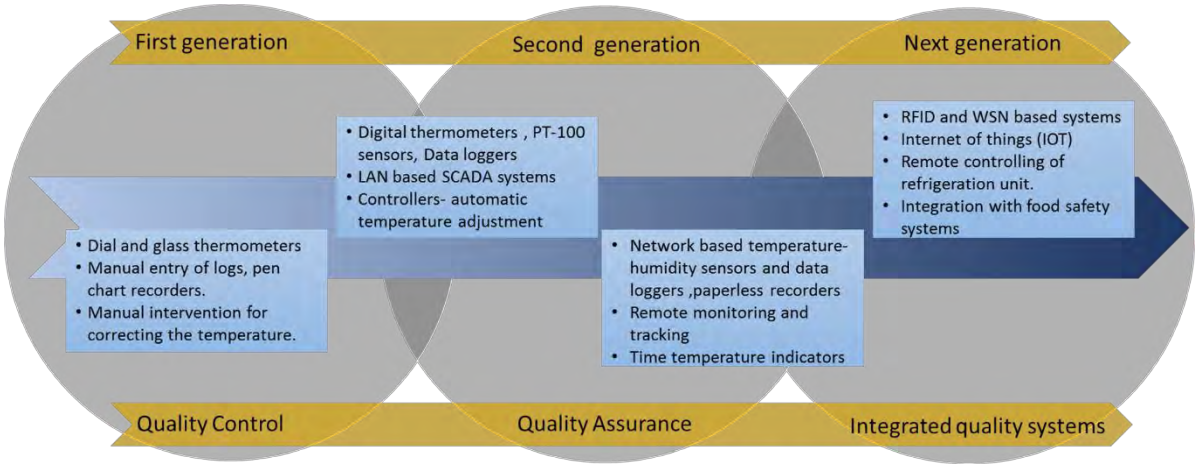

Figure 23: Evolution of monitoring and control systems in India (Sathguru Analysis)

[31] Source: http://www.sirach.org.uk
[32] Aung, MM and Chang, YS (2014). Temperature management for the quality assurance of a perishable food supply chain. Food Control. 40: 198-207.
[33] Xiaohong, X et al., (2010). Identification of critical control points of the food cold chain logistic process. In Intl' Conference on Logistics Systems and Intelligent Management, Beijing, China. 1: pp. 164e168.

The progress of cold chain monitoring systems in India has been good in the recent past but still lags behind when compared with developed countries and our peers like China and Brazil. In India, a major fraction of the infrastructure created in the states of West Bengal, Uttar Pradesh, and Andhra Pradesh during the decade of 1990 is of single commodity type, with outdated technology. In most of these older units, even maintaining of proper daily temperature logs is a not a standard practice.[34] The main challenges in relation to monitoring and control of cold chain systems in India are-

- Outdated technologies and single commodity stores.
- Non-integrated services, leading to lack of ownership among the stakeholders.
- Lack of trained manpower and a general callous attitude.
- Poor integration between the monitoring and quality & food safety systems.
- Lack of drive from the front end.

Some of these factors are applicable at a greater magnitude in case of advanced systems like CA/ MA storages. The current scenario and relative importance of temperature monitoring and other parameters across the value chain for perishable commodities are presented in the below Figure 24.

[34] Kumar, A. (2014). Left out in the cold: The case of potato cold stores in West Bengal, The IUP journal of supply chain management, 11(2).

	Monitoring stages in the cold chain	Current scenario
 Farm	• Required during precooling of the produce and on- farm storage of the produce after harvesting	• Precooling is not practiced at any visible scale in the country. • On-farm storage , almost is at ambient temperature. • Followed in dairy, meat and fisheries- but effective monitoring is not followed. • No control at the farmer end.
 Farm transport	• Since, the prior steps are not temperature controlled, in most cases monitoring during transportation is not employed.	• Temperature control during transportation in followed only in dairy, meat and fisheries in the perishables. • Active monitoring of temperature is not practiced during the transit in most cases.
 Cold storage	• Monitoring of temperature and other parameters are required all through the time. • For most of the perishables, need for the cold chain monitoring starts from this stage.	• Single commodity storages form major chunk of the storage. Temperature set points are maintained, but not well monitored and calibrated. • Cold storages for RM/FG in private enterprises- well monitored. • Recent infrastructure-well monitored and automated control units.
 Cold chain transport	• Monitoring of temperature and other parameters are required through out the stage	• Severe shortage of reefer trucks, particularly for multi commodity transport. • Temperature monitoring is built into the refrigeration unit. • Additional monitoring units like data loggers are deployed. • Advanced systems like RFID and WSN are still at a nascent stage. • The transport personnel are unskilled about the temperature control and nature of the commodity. • Very few service providers offering integrated services.
 Retail	• Temperature controlled storage is adopted during in-store cold room storage, in visi-coolers and display units. • Monitoring of temperature and other parameters are required through out the stage	• Proper infrastructure is available only in modern retail outlets. • Monitoring is carried out in only in large retail chains. • No proper correlation/ understanding about quality and food safety implications to the store manpower. • Lack of history of handling in the prior steps.

Figure 24: Temperature monitoring across the value chain (perishables)

To achieve visibility and controllability of every link in a cold chain, real-time data should be communicated to customers and suppliers. Visibility of product throughout its lifecycle can be ensured with the help of advanced technologies such as sensors, Radio Frequency Identification (RFID) and wireless networks. Cold chains with advanced analytics and modelling based on food science and safety guidelines will help in assisting managers with complex decisions.[32,35]

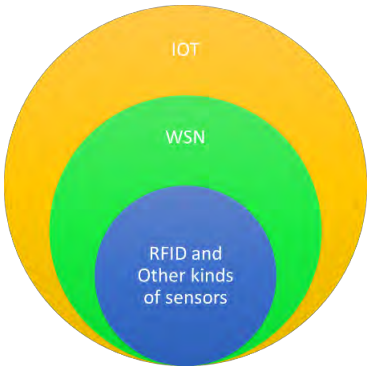

Figure 25: Interrelation between different monitoring systems.

Temperature monitoring systems: The older generation systems are still employed across the value chain in yesteryear infrastructure. These include Dial thermometers (no data logging capability), Pen chart recorders (daily/ weekly logs), and PID control units with no data logging capability. Portable data loggers are also employed for recording the temperature and humidity data for a specific period of time, however, they are limited to show one data point at a time and real time trend cannot be obtained. Some of the modern temperature monitoring systems that are discussed here are being widely used in the developed markets and are gaining popularity in the present day cold chain infrastructure. These monitoring systems are interdependent and can be integrated to achieve a full-fledged monitoring and control system.

RFID: RFID is the generic name for technologies that use radio waves to identify items and gather data on items without human intervention or data entry. RFID sensors/ labels can be equipped with additional sensors like temperature, humidity and gas sensors; these can be commonly used for spatial temperature profiling during transport of perishable foods. Temperature sensors combined with RFID offer the possibility to map the temperature history across the supply chain. Earlier studies of comparing RFID temperature data loggers to traditional temperature data loggers revealed that RFID temperature tags are comparable with regards to the accuracy of the conventional methods, but offers superior performance because of facilitation to quick instrumentation and data recovery and the possibility of accessing the sensor program and data at any point of the supply chain. This helps in efficient inspection and decision making process for better inventory management with fewer batch rejections[36].

Wireless sensor networks (WSN) and **Internet of Things (IoT):** WSN is a combination of sensors, micro controllers, and RF handsets. These components communicate with each other at a local location. A wide array of WSN are connected through the Internet to act as sensory organs for IoT. IoT refers to the network which follows conventional protocols of network and connects various objects via the internet to transmit information for the purpose of object locating, tracking, monitoring, and management, with supports of radio frequency identification (RFID) tags, sensors, actuators, and other control systems (Components of WSN). Owing to its advantages like better connectivity and level of automation, IoT is an ideal platform for remotely monitoring and controlling the real-time status of perishable goods across the cold chain with very less human intervention and combining it with models of food safety and microbial growth enables to manage the First expiry first out (FEFO) system. IOT can help in remote management of complex storage

35 Terreri, A (2009). Cold chain management: monitoring each link in the chain. Food Logistics.
36 Turcu, C (2010). Sustainable Radio Frequency Identification Solutions., Intech pub, ISBN: 978-953-7619-74-9

systems comprising of multi commodity and CA/ MA systems, where monitoring and control of multiple complex parameters like gas concentration, temperature and humidity can be achieved through automation. IOT also enables integration of food safety systems and regulatory requirements and support specific report generation (as programmed in the algorithm).

Time temperature indicators (TTI):

TTI's are simple and inexpensive devices, which indicate the time-temperature history of the product when they are applied to them. The labels can indicate temperature abuse by mean o color change and indicate the accumulated time-temperature history from production till it reaches consumers. TTI's can be specially modulated to indicate and correlate a specific food product safety and quality status at any point in the supply chain, thus providing an effective decision tool. These can act as important monitoring agents in smaller SKU's and where the cold temperature is being maintained by means of medium like dry ice, PCM etc. and access to power will be difficult.

In adopting the latest monitoring, control mechanisms and automation in data capturing, Indian cold chain sector has a long way to go. The key to transforming this aspect is to localizing the technologies to suit the scale of Indian industries and by creating flexibility in the system to accommodate and modify the elements of complex supply chains on need basis.

5. Employment Generation & Capacity Building

A. Employment Generation

The cold chain sector has tremendous employment generation potential. Government has taken several steps to encourage the participation of private and non-profit agencies in this sector. NGOs and skill development agencies are playing significant role in targeting unemployed poor and providing skill training in order to equip them and provide them a source of living.

Cold chain can create employment opportunities at various levels. First and foremost it helps in encouraging farmers to get better income and in turn leads to more and more people to be actively engaged in agriculture. Another major component of a cold chain is a pack house, any average pack house employs around 20 direct and indirect workers. Creation of new facilities to meet the deficit of around 78 thousand integrated pack houses (pack houses + ripening chambers) across the country, will create 1 million jobs. Pack houses are necessarily established at the farm end. Creation of these integrated pack houses will not only encourage farmers but also promote entrepreneurship among the locals. This will result in significant increase in farmer's standard of living and in turn in rural development.

Reefer transportation is another major subsector in cold chain which has great potential to create employment. There is a dire need for almost 53 thousand reefer vehicles to facilitate smooth transportation of perishable produce. This is directly proportional to the need of skilled drivers and helpers. Also this will promote establishment of more 3rd party logistic companies which will further create jobs. Skilled workers and technicians are also needed for provision of services and maintenance to these vehicles. In addition to this reefer vehicle redressal call-centers (RVRC) are being created which have potential to absorb many people.

Table 12: Job creation potential from Cold chain sector (Sathguru analysis)

Infrastructure Type	All India Gap (no's)	Direct and Indirect manpower requirement (per unit)	Total Job creation potential
Integrated Pack house	78150	20	15 Lakhs
Reefer Vehicle	52826	4	2 Lakhs
Cold Storages	328	75	25 Thousand

Beside these manufacturing suitable infrastructure plays a crucial role in absorbing unemployed people. Since cold chain is at nascent stage in India, this sector has the potential to provide employment to many people by 2022 at the manufacturing side. Over the years, there would be high demand for labor to work in industries manufacturing infrastructure for cold chain. Technology providers will also play crucial role in the sector.

Since it's an emerging sector there exists a demand for more number of training sessions to be organized so as to bring a larger number of beneficiaries into the fold, which will further add on to the jobs for trained professionals.

B. Capacity Building & Skill Development

The operation of cold chains requires knowledge and skills in several areas, including knowledge of the effects of temperature on food products, product specific storage requirements, good practices in the handling & packaging of food products and cold chain management, skills required for the operation of cooling technologies, supply chain management, and logistics. Considering the rapid expansion of cold chains in next few years in the country, lack of adequate & relevant trained manpower to manage and operate these cold chain systems will pose a big challenge. Addressing the current skill gaps through extensive capacity building and training is necessary to promote the proper functioning of cold chains.

The skilled manpower requirement would be in the two major areas:

(i) Handling and post-harvest care of fresh produce including appropriate temperature & humidity control
(ii) Cold chain equipment related - Technicians for installation, maintenance etc.

For the handling and post-harvest care, the training should focus on:

- Identifying the causes and sources of losses
- Processes along the cold chain (like postharvest handling, precooling, cold storage, cold transport, food processing etc.)
- Basic practices for reducing losses for perishable foods intended for cold storage
- Logistics
- Food safety issues due to poor post-harvest practices.
- Energy efficiency.

Traders, middlemen, and transporters have a large impact on temperature management during handling and transport, and therefore on the final quality of foods. Hence they should also be trained on the importance of temperature maintenance.

For technicians, the training should focus on:

- Practices for reducing losses for perishable foods intended for cold storage,
- Engineering including design, repairs, maintenance of cold technologies
- Energy efficiency
- Technical training is required for the proper handling of the refrigerants and other environmental issues
- Food safety

Since training and capacity building needs will shift over time as changes occur in agricultural value chains and cold chains, continual formative evaluation to improve programs is needed to ensure capacity building efforts continue to meet the needs of target audiences.

Capacity building in food safety modules:

Even though the actors in the supply chain, particularly in the logistics and retail end, are aware of various technicalities in maintaining the cold chain, there is a serious lack of knowledge pertaining to the food safety aspects of the frozen/ chilled/ temperature sensitive foods. In order to bridge this gap, there is a need to develop simplified modules of training to address-

- Criticality of temperature in food safety
- Probable food safety risks of cold chain failure
- Integration and monitoring of HACCP into cold chain
- Risk mitigation and corrective actions during cold chain failure.

Training on these aspects will help in effective decision making by the stakeholders during crisis times and ensure food safety to the consumers.

6. Recommendations and Way forward

The nature and the dynamics of the agricultural and food supply chains in the country, even for the same commodity/product, are very complex and there is no single point solution to this. In addition to this, the problems and challenges hindering the development of the cold chain sector are interdependent on diverse aspects. The need for creation of integrated solutions is the need of the hour to address the problems like colossal food wastage despite high production, increasing competition in agri-exports from other countries marring the growth of forex and importantly, improvement of local supply chains to benefit the stakeholders from farmers to consumers.

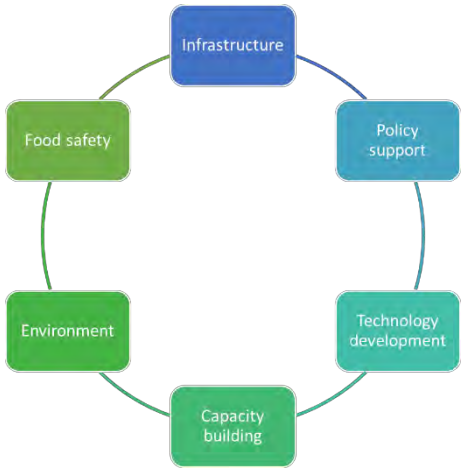

Figure 26: Integrated approach for cold chain development

A. Infrastructure creation and management:

Infrastructure creation in the cold sector has been identified as an important factor for growth by various actors and receiving a fair amount of support from the government. As pointed from the earlier studies there is still a long gap in bridging the actual requirements and further to that there is an increased need for optimizing the infrastructure type addressing the specific shortages at different stages of the supply chain. A holistic approach to addressing all the stages of the supply chain needs to be considered.

- Commodity/ Cluster specific infrastructure plans: Identification of key commodity producing clusters and designing of infrastructure to create an integrated model should be taken up. The developed primary infrastructure should be extended to accommodate other suitable commodities in the region by creating sub-infrastructure by creating smaller cold rooms/ IQF plants. This leads to the creation of a network in the region and extends the usage of the infrastructure.

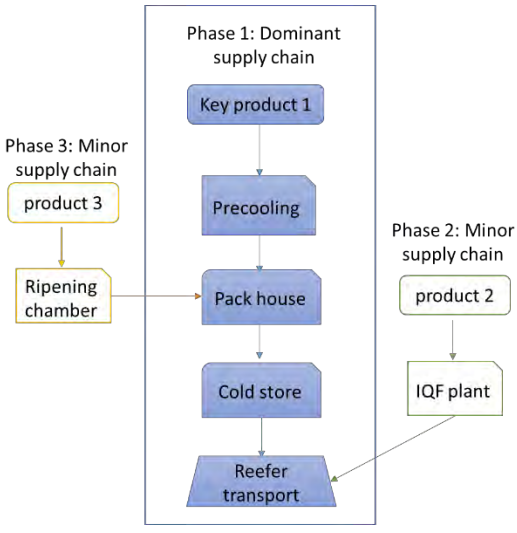

Figure 27: Schematic plan for the development of infrastructure for key supply chains in the region.

- Utilization of railway network:
  India has a well-connected railway network, with a fair share of it, covered under stable power grid. This can be used for increasing the connectivity of the reefer transportation. The key intentions required to make this actionable are-
    a. Development of more perishable cargo centers in the key localities,
    b. Making available enough reefer containers with grid connectivity and
    c. Relative importance in clearing the trains carrying perishable cargo.

- Development of common infrastructure for multi-commodity storage:
  In order to give unrestricted access to small farmers, development of smaller common multi-commodity storages should be taken up by pooling two or three nearby villages.

- Creation of infrastructure at the front end:
  Even though serious emphasis is being paid on creation of back-end infrastructure, it is equally important to create front-end infrastructure in the markets to make a meaningful impact and gain the benefit of cold chain. Currently, only a small portion of the produce is handled through organized retail where cold chain is maintained till the consumer end and there is a serious gap in the unorganized sector. This creates an uneven level playing field as small vendors cannot afford the high capex requirements. Smaller units for handling perishables should be provided at low cost to local vendors, through whom the majority of the trade happens.

Figure 28: Example of small-scale retail cart for perishables[37]

B. Technology development:

Technologically, the Indian cold chain infrastructure is still lagging behind to catch up with latest global developments. Even though recent companies are instrumental in adopting the latest technologies, the fragmented supply chain with the lack of prior data about produce is hindering in realizing the advantage of cold chain completely. On technology front the following aspects are to be taken up:

- Promotion of research and development of low cost technologies to address the problems of local supply chains.

[37] http://www.knidsgreen.in

- Development of commodity specific packaging and temperature models representing the local supply chains.
- India has a still long way to go in adapting efficient monitoring and tracking tools. Developing monitoring and tracking models with technologies like WSN and IoT, representing the local conditions is to be taken up.
- Low cost and small capacity reefer trucks with technology like PCM's are to be developed to connect the difficult areas.
- As countries are in transition from the use of ozone depleting substances (ODS) and high global warming potential (GWP) HFCs, there is increasing need of adopting climate-friendly alternative technologies.
- Transfer of technology should be aided by small and large scale demonstration projects and fiscal incentives.
- Manufacturing industry should be supported to introduce price competitive technologies in the market.

C. Policy Implementation:

Currently, cold chain sector is one of the sectors receiving the best policy support from multiple agencies like MoFPI, NHB, APEDA, State governments etc. Fine tuning of support is required on the following aspects-

- The absence of well-balanced supply chains is one of the main reasons that is hindering the farmers from earning better prices for their produce. Creation of a well-integrated cold chain infrastructure, designed considering the limitations and needs of the small scale farmers and rural communities should be taken up under the "Vision 2022- to double the farmer's income", in order to strengthen the agricultural supply chains.
- Clear demarcation for funding of research projects aiming at fundamental research and research for commercialization. Agencies like MOFPI should give prominence to projects aimed at commercializing the technologies.
- Support should be extended to local companies in the development of technologies like RFID, WSN, and IoT, as this will lead to reduction of cost and better adaptability.
- Promotion and subsidizing of farm level and village level small scale units with conventional and alternate energy sources for better connectivity.
- Incentivizing the front end infrastructure for small players.
- Drawing a policy to address commodity specific food loss- by Identification of key loss making commodities and regions, by identifying the underlying reasons and justifying the need for cold chain and drawing a phase wise plan to reduce the loss.
- Public Private Partnerships should be promoted to undertake research for advancing the emerging technologies towards commercialization.

D. Food safety:

Product and storage standards are clearly laid for frozen foods and other temperature sensitive foods by FSSAI. But there is no clear understanding about the food safety risks of frozen or temperature sensitive foods to the actors in the supply chain. There is a need for developing product/ product group specific guidelines and importantly, risk mitigation plans for food safety hazards arising from supply chain failures.

E. Environment:

The recent negotiations around the HFC phase-down amendment to the Montreal Protocol have made it imperative to assess the alternatives to HFCs. A transition to these alternatives and other clean technologies would minimize costs and maximize energy and emissions savings. However, this would require enabling regulations, updating safety standards and market incentives for commercializing the technologies.

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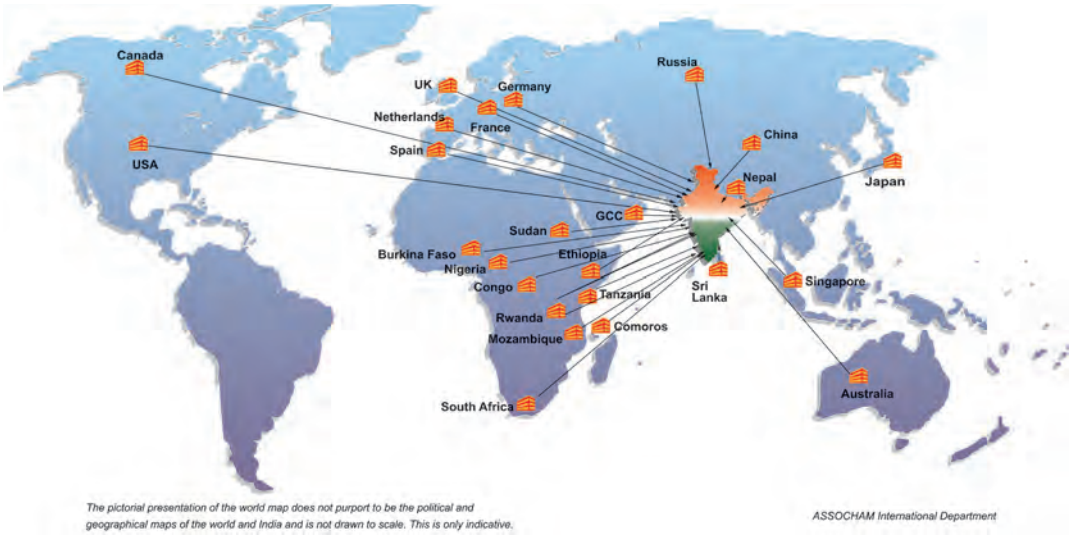

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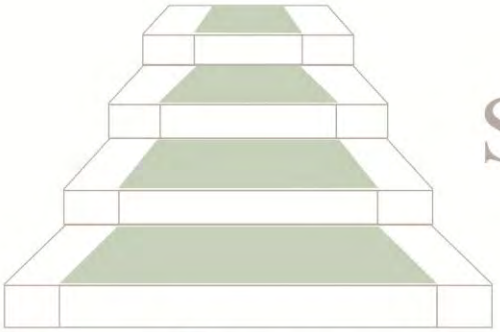

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