सत्यमेव जयते

STUDY ON BEST PRACTICES FOR INSTALLATION AND MAINTENANCE OF AMMONIA/LOW-GWP ALTERNATIVES TECHNOLOGIES IN THE COLD CHAIN INFRASTRUCTURE

OZONE CELL

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

STUDY ON BEST PRACTICES FOR INSTALLATION AND MAINTENANCE OF AMMONIA/LOW-GWP ALTERNATIVES TECHNOLOGIES IN THE COLD CHAIN INFRASTRUCTURE

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OZONE CELL
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(MoEF&CC)

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मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
भारत सरकार

सत्यमेव जयते

भूपेन्द्र यादव
BHUPENDER YADAV

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

MESSAGE

India's cold chain is a rapidly growing sector crucial for preserving temperature-sensitive goods like perishables and pharmaceuticals, driven by the booming food and pharmaceutical sector. It is 'temperature-controlled supply chain for perishable goods' which is driving expansion in storage and transportation infrastructure.

Low Global Warming Potential (GWP) technologies are crucial for the cold chain because they mitigate climate change by reducing greenhouse gas emissions from refrigerants. In addition, compliance under Montreal Protocol is achieved. Promoting use of low GWP alternatives in the cold chain has also been proposed in the implementation framework of the India Cooling Action Plan (ICAP). Developing Standard Operating Procedures (SOPs), for skilled teams in operation and maintenance, ensuring compliance with standards national regulations are the key issues for sustainable cold chain infrastructure.

The study on "Installation and Maintenance of Ammonia/Low Global Warming Potential alternative technologies in Cold Chain" focus on the sustainable practices for setting up and management of cold chain.

I congratulate all those involved in the preparation and consultation of this report.

(Bhupender Yadav)

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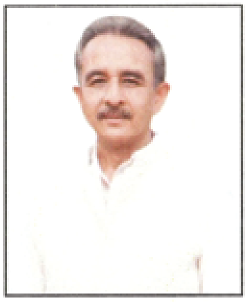

MESSAGE

The cold chain logistics sector in India is experiencing significant growth, driven by the increasing demand for temperature-sensitive products, advancements in technology, and various government initiatives.

The cold chain industry, by focusing on preserving product integrity, reducing food waste, and ensuring regulatory compliance, can significantly contribute to addressing sustainable development goals as well as minimizing environmental impact and improving social and economic benefits. Towards this, there is a need to promote adoption of low global warming potential and energy efficient technologies, capacity building in good servicing practices of the cold chain equipment including effective handling of alternative low global warming potential refrigerants, besides logistics management.

The action points for the Cold Chain thematic area in the India Cooling Action Plan (ICAP) focusses on promoting adoption of energy efficient, non-ozone depleting substances and low global warming potential technologies in different components of cold chain.

The study report on "Best Practices for Installation and Maintenance of Ammonia/Low Global Warming Potential alternative technologies in Cold Chain" would serve as an important resource material and should be disseminated widely amongst all concerned stakeholders. I complement the team associated in bringing out this publication.

(Kirti Vardhan Singh)

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MINISTRY OF ENVIRONMENT, FOREST
AND CLIMATE CHANGE

MESSAGE

Low Global Warming Potential (GWP) technologies in cold chain systems has climate benefits by reducing global warming and make cold chain infrastructure environment friendly. Refrigerants in cold chain act as a heat transfer medium thereby maintaining the critical low temperatures needed to prevent spoilage of food, medicines, and other temperature sensitive products throughout the supply chain including transportation and storage.

International environment agreements like the Montreal Protocol supplemented with domestic policies are encouraging the cold chain sector in transitioning to low-GWP alternatives. Further, implementing advanced temperature monitoring with real-time tracking technologies and developing skilled manpower for managing the cold chain systems will lead to significant growth in cold chain infrastructure.

The Study on "Best Practices for Installation and Maintenance of Ammonia/Low Global Warming Potential alternative technologies in Cold Chain" will be useful for all the stakeholders associated with installation and maintenance of cold chain systems. I compliment the team associated with the preparation of this report.

(Tanmay Kumar)

Place: New Delhi
Dated: September 12, 2025

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Abbreviations	
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AAR	Association of Ammonia Refrigeration
AC	Alternating Current
ASME	The American Society of Mechanical Engineers
BIS	Bureau of Indian Standards
CA	Controlled Atmosphere
COP	Coefficient of Performance
DG	Diesel Generator
EPS	Expanded Polystyrene
GCCA	Global Cold Chain Alliance
GDP	Goods Distribution Practices
GMP	Good Manufacturing Practices
GWP	Global Warming Potential
HDPE	High-Density Polyethylene
HFOs	Hydrofluoroolefins
ICAP	India Cooling Action Plan
IIAR	International Institute of Ammonia Refrigeration
IS	Indian Standard
ISO	International Organization for Standardization
kWh	kilowatt-hour
LFL	Lower Flammability Limits
MoEF&CC	Ministry of Environment, Forest and Climate Change
O&M	Operation and Maintenance
ODP	Ozone Depletion Potential
PIR	Polyisocyanurate
PLC	Programmable Logic Controller
PUF	Polyurethane foam
PVC	Poly Vinyl Chloride
RH	Relative Humidity
SI	International System of Units
TEWI	Total Equivalent Warming Impact
USD	United States Dollar
VCR	Vapor Compression Refrigeration
UPS	Uninterruptible Power Supply
XPS	Extruded Polystyrene

1. INTRODUCTION

1.1: Introduction to Cold Chain Infrastructure

The cold chain is a system that keeps perishable items fresh till the last mile reaching to the end user. The typical cold chain consists of a storage and distribution related activities in which the perishable products are maintained within the predetermined controlled parameters. Perishable products include horticulture produces (fruits, vegetables, flowers) dairy products, meat, vaccines, medicine etc. The main elements of the cold chain involve cooling system, cold storage, cold transport, cold processing and distribution.

Cold chain is one of the thematic areas of the India Cooling Action Plan (ICAP), launched by the Ministry of Environment, Forest and Climate Change (MoEF&CC) in 2019. It is a 20-year roadmap (2017–18 to 2037–38) developed to meet the growing demand for cooling in a sustainable way across multiple sectors, including cold chains. Among its six thematic areas, Cold Chain & Refrigeration plays a crucial role, with emphasis on promoting appliances that use low-global warming potential (GWP) refrigerants without compromising energy efficiency. The goal of ICAP is to reduce refrigerant demand by 25–30% and cooling-related energy requirement by 25–40% of the projected demand by 2037–38. To achieve its goal, ICAP prioritizes capacity building, skill development, and technological innovation, while advocating the adoption of eco-friendly and energy-efficient solutions throughout the cold chain sector.

1.2: Cold Storage System

The cold chain is a temperature-controlled supply chain designed to preserve the shelf life and quality of perishable products from the point of production to final consumption. It functions by maintaining specific temperature levels, relative humidity (RH), and the concentration of certain gases throughout the supply process. The cold chain involves several critical stages, including pre-cooling, sorting, grading, packing, storage, and transportation. Each of these steps plays a vital role in minimizing spoilage and ensuring the product remains safe and fresh until it reaches the end user.

India’s diverse agro-climatic conditions support the cultivation of a wide variety of agricultural products, making it a key contributor to the global food supply chain. However, despite high production levels, the country experiences significant post-harvest losses. These losses, estimated at ₹1.53 trillion (USD 18.5 billion) annually, are primarily due to inadequate cold chain infrastructure, poor handling practices, and inefficiencies in storage and transportation.

1.2.1: Key Challenges in India’s Post-Harvest Sector

India’s agricultural productivity is among the highest globally, but a significant portion of this output is lost after harvesting due to systemic issues. The main challenges are outlined below:

1. Economic Impact

- Annual post-harvest losses are estimated at ₹1.53 trillion (USD 18.5 billion).
- The primary cause is the lack of efficient cold chain infrastructure and supply chain integration.

2. Infrastructure Gaps

- Less than 5% of perishable goods are transported through cold chain systems.
- Inadequate storage, poor logistics, and insufficient pre-cooling facilities contribute to large-scale spoilage.

3. Commodity-Specific Losses

- Fruits and Vegetables: 5% to 13% losses occur between harvesting and consumption.
- Livestock Products (eggs, fish, meat): Losses can reach up to 22%.
- Cereals: Face average losses of around 10%.

The cold chain is expected to play a crucial role in overcoming these challenges. By reducing perishability, cold storage significantly extends the shelf life of commodities, ensuring they remain in optimal condition for longer use and distribution.

1.2.2: Cold Storage in India

India's cold storage infrastructure plays a vital role in preserving perishable goods and reducing post-harvest losses. As of 2023, there are approximately 9,000 operational cold storage units across the country, offering a total capacity of around 150 million metric tons. These facilities ensure the quality and longevity of fruits, vegetables, dairy, and meat products. With an average energy usage of 0.02 kWh per metric ton, the estimated annual energy consumption reaches nearly 3 million kWh. This network contributes significantly to food security, price stabilization, and supply chain efficiency. State-wise cold storage capacity is illustrated in Figure 1.1.

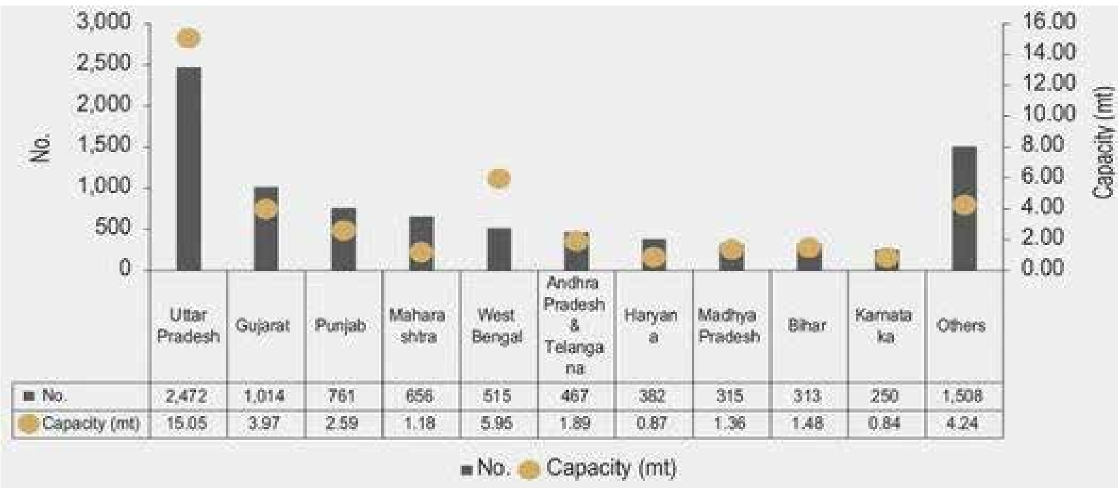


Figure 1.1: An overview of cold storage capacity in India (Source: National Horticulture Board, Ministry of Agriculture and Farmer Welfare)

Figure 1.2 illustrates the zone-wise distribution of cold storage facilities across India, highlighting regional variations in both the number of units and their storage capacities. It also presents the commodity-wise installed capacity, showing how storage space is allocated among different types of perishable goods

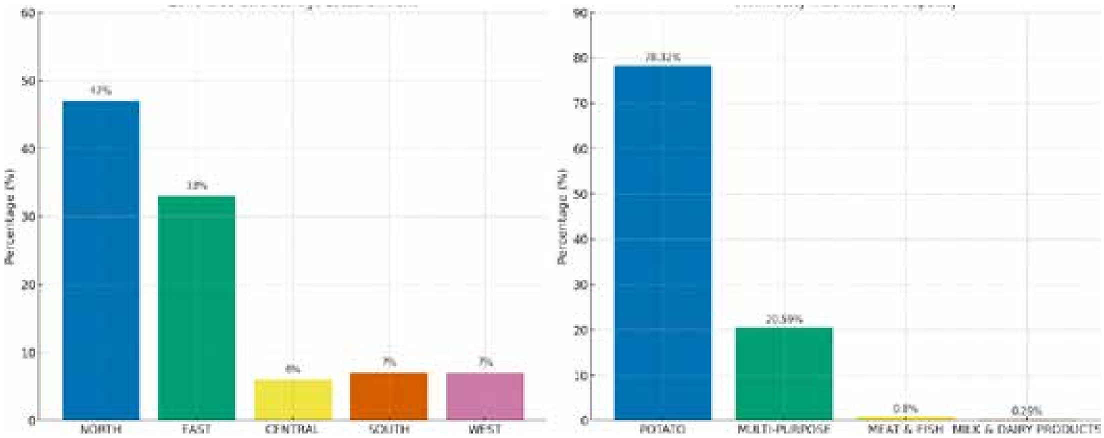


Figure 1.2: Zone-wise establishment and commodity-wise installed capacity of Cold Storages in India. (Source: National Horticulture Board, Ministry of Agriculture and Farmer Welfare)

1.2.3: Global Scenario of Cold Chain:

According to the 2020 report by the Global Cold Chain Alliance (GCCA), the global cold storage capacity reached approximately 719 million cubic meters across 51 countries, showing a 16.7% increase since 2018. The United States, India, and China emerged as the top contributors with capacities of 156, 150, and 131 million m³, respectively (Figure 1.3). Countries like Canada and the Netherlands reported the largest average cold storage warehouse sizes, often exceeding 100,000 m³ per facility. However, per capita availability remains uneven across regions, with the global average standing at 0.15 m³ per urban resident. The report highlights a pressing need for cold chain expansion and modernization, particularly in developing nations, to improve food preservation and reduce post-harvest losses.

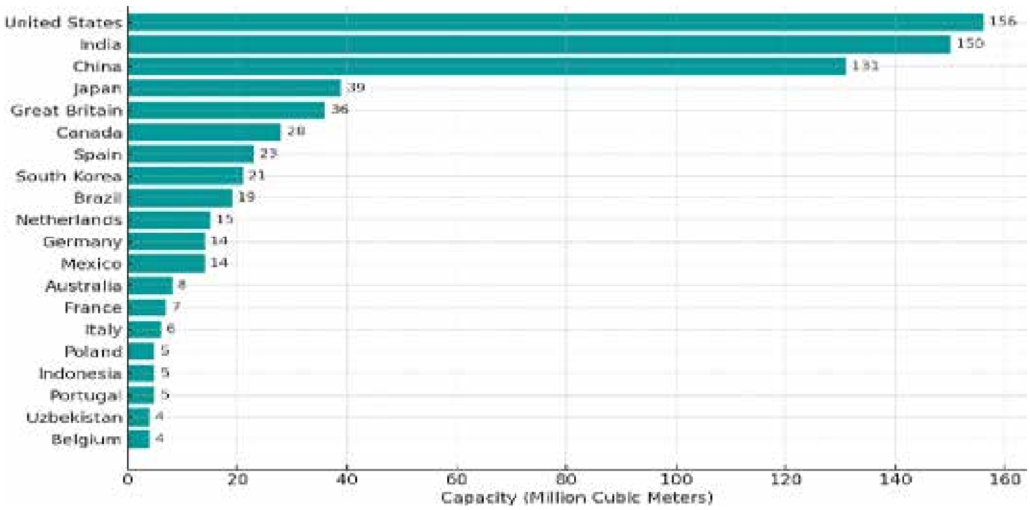


Figure 1.3: An overview of cold storage capacity (Source:2020 Global Cold Storage Capacity Report: Global Cold Chain Alliance (GCCA)

1.2.4: Type of Cold Storage

India, recognized as the world's largest fruit producer and often referred to as a global fruit basket, benefits from its diverse agro-climatic zones and wide range of fertile soils. This allows the country to grow a vast variety of fruits and vegetables such as apples, mangoes, guavas, grapes, papayas, bananas, oranges, potatoes, tomatoes, cauliflower, chilies, and ginger. In addition, India's extensive coastline supports high marine produce generation.

a. **Bulk Cold Storage:** These are large, climate-controlled storage units primarily used for long-term storage of single horticultural commodities such as potatoes, apples, and chilies. Located near production zones, they help stabilize supply by creating a buffer stock during periods of seasonal surplus. The photograph shown in Figure 1.4 depicts a bulk storage system, which is typically employed for large-scale storage and handling of materials.

Figure 1.4: Bulk cold storage system, and Multi-purpose cold storage

b. **Multi-purpose Cold Storage**: Designed for the short-term storage and distribution of multiple commodities (as shown in Figure 1.4) – such as dairy products, fruits, vegetables, spices, and dry fruits—these facilities feature different temperature zones. Located near consumption centres, they serve as key distribution hubs throughout the year.

c. **Small Cold Stores**: Used mainly for export-quality fresh produce like grapes, these cold stores include pre-cooling chambers to minimize quality loss. Suitable for small-scale producers, they may use mechanical refrigeration, chilled water, or icing systems, depending on cost and efficiency requirements.

d. **Frozen Food Stores**: Specialized for deep freezing and long-term storage of meat, fish, poultry, dairy, and processed fruits and vegetables. These stores maintain a standard temperature of -18°C to ensure food safety and prevent structural or chemical degradation. Figure 1.5 depicts a cold storage facility for frozen food.

e. **Mini Units / Walk-in Cold Stores**: Commonly located in supermarkets, malls, hotels, and hospitals, these units store a wide range of items like dairy, beverages, food products, cosmetics, and pharmaceuticals that require low temperatures.

f. **Controlled Atmosphere (CA) Stores**: These facilities use a non-chemical method involving regulated levels of oxygen, carbon dioxide, and nitrogen to extend the shelf life of fresh produce like apples, kiwis, and pears. The controlled atmosphere storage as depicted in Figure 1.5 is ideal for long-term preservation of seasonal and high-respiration fruits and vegetables.

g. **Ripening Chambers**: Designed for the controlled ripening of fruits such as bananas, mangoes, papayas, and guavas using ethylene gas. These chambers help ensure uniform ripening while preserving the quality of the produce.

Figure 1.5: Frozen food store, and Controlled atmosphere (CA) store

1.3: Use of ammonia and low-GWP based refrigeration system in cold storage

Refrigerants: Role, Relevance & Considerations:

The primary working fluid in a refrigeration system is the refrigerant, which absorbs heat at a low temperature and pressure and releases it at a higher temperature and pressure. It typically undergoes phase changes, such as evaporation and condensation, to transfer heat effectively. While many fluids can technically function as refrigerants, the focus is mainly on those used in Vapor Compression Refrigeration (VCR) systems due to their efficiency and wide application. In some systems, like air-cycle refrigeration, even air can serve as a refrigerant, although it does not undergo a phase change in the process.

Refrigerants play a crucial role in determining the thermodynamic efficiency of a refrigeration system, as their performance is closely linked to the operating temperature. The choice of refrigerant also directly impacts key design parameters such as system size, cost, safety, reliability, and ease of maintenance. Moreover, refrigerants have significant environmental implications, including their potential to cause ozone depletion and contribute to global warming. Selecting the right refrigerant is therefore essential not only for optimal system performance but also for meeting environmental standards and regulatory compliance.

Selection criteria for refrigerants:

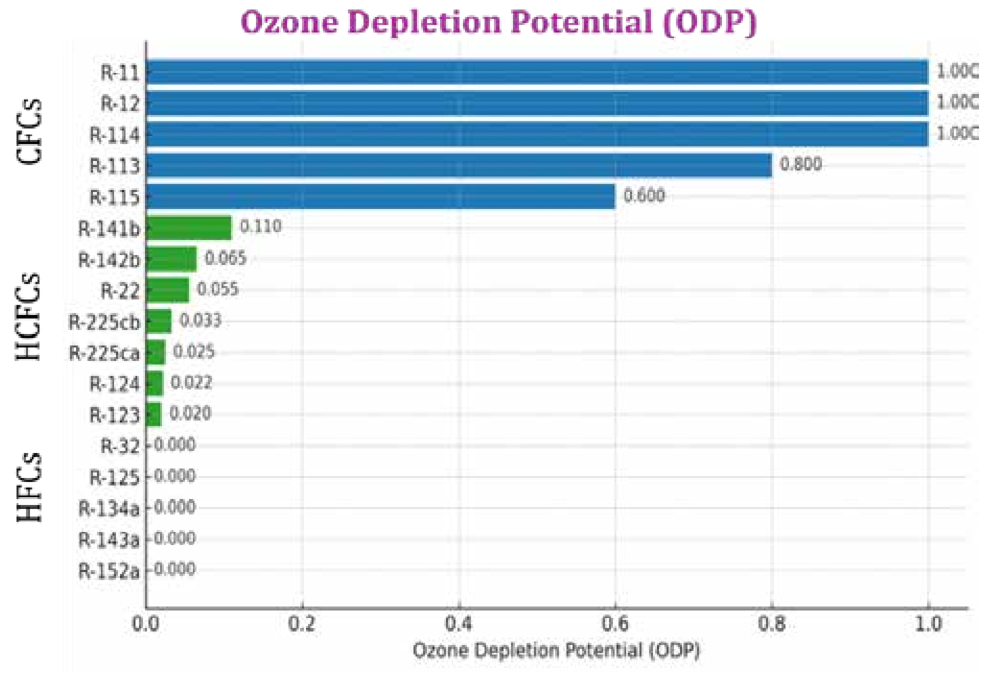
a. **Thermodynamic and Thermo-Physical Properties:** Several key thermophysical properties of a refrigerant significantly influence the overall performance and design of a refrigeration system. A higher latent heat of vaporization enhances the Coefficient of Performance (COP), making the system more energy-efficient. The refrigerant's operating pressures must align with the system's design to ensure safe and optimal functioning. Volumetric cooling capacity is another critical factor, as it determines the compressor size required for effective operation.

b. **Economic Factors:** Economic considerations play a crucial role in refrigerant selection and system design. The initial cost of the refrigerant itself can impact the overall system investment, especially for large-scale applications. Additionally, operating costs—which encompass both energy efficiency and maintenance requirements—must be carefully evaluated. A refrigerant that enables high energy efficiency and requires minimal upkeep contributes to lower long-term operational expenses, making the system more cost-effective over its lifecycle.

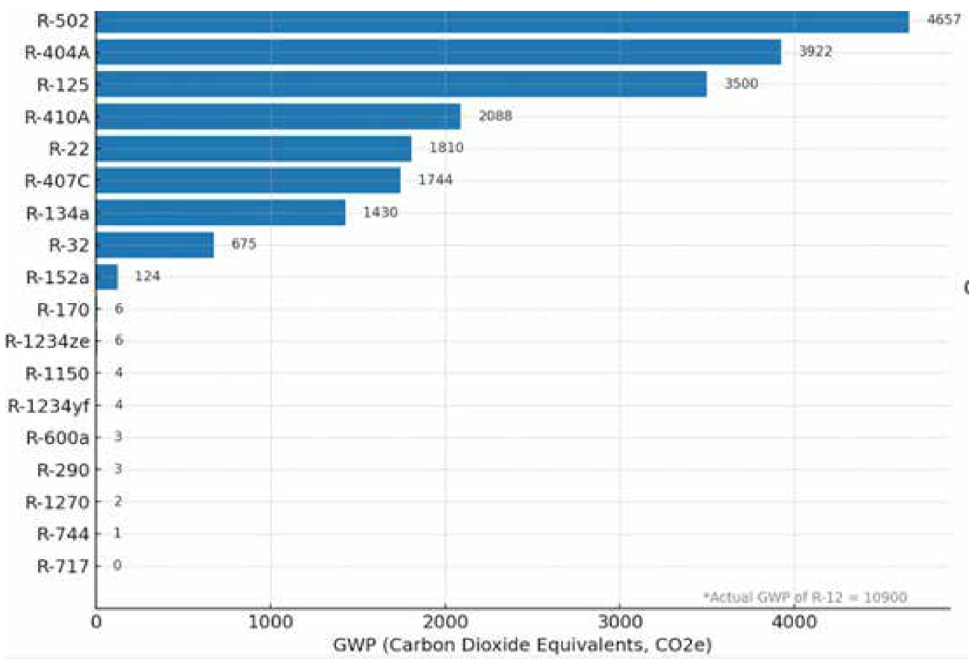
c. **Environmental and Safety Properties:** Environmental and safety considerations are critical in refrigerant selection. Ideally, refrigerants should have zero Ozone Depletion Potential (ODP) and a low Global Warming Potential (GWP) to minimize their environmental footprint. The Total Equivalent Warming Impact (TEWI) should also be low, accounting for both direct emissions through leakage and indirect emissions due to energy consumption. Toxicity must be minimal to ensure safety, and refrigerants should preferably be non-flammable. If flammable, they must comply with ASHRAE safety classifications (A1 to B3) and require appropriate mitigation measures. Chemical stability is essential for reliable performance during system operation. Additionally, compatibility with system materials, good lubricant miscibility, high dielectric strength, and ease of leak detection are necessary to ensure safe, efficient, and long-lasting operation**.**

Environmental Impact of Refrigerants: Ozone Depletion Potential (ODP) & Global Warming Potential (GWP)

Figure 1.6 illustrates the global impact of various refrigerants, focusing on their ozone-depleting potential and global warming potential. It compares the contributions of different refrigerants to environmental issues, including ozone layer damage and climate change.



(a)



(b)

Figure 1.6: Effect of different refrigerants on a) ozone depletion potential (ODP)[1,2] and b) global warming potential (GWP) (Source: Ref. [1])

[1]Use of CFCs has been phased out

[2]Use of HCFCs in new manufacturing has been phased out from 1 January 2025, however use for servicing is allowed until 2040

1.4: Thermodynamic and performance properties of refrigerants

The thermodynamic and performance properties of refrigerants play a vital role in determining power consumption, pressure ratio, and the Coefficient of Performance (COP) of a cooling system. Refrigerants with higher latent heat and optimal pressure characteristics can minimize energy usage while ensuring efficient operation. Table 1.1 presents the COP values and corresponding power consumption for various refrigerants.

Table 1.1: COP values and corresponding power consumption for various refrigerants [Ref. 1]

Refrigerant	NBP[3] (°C)	Pressure Ratio	Discharge Temp. (°C)	Power Consumption (kW/TR)	COP
R113	47.59	7.71	30	0.703	4.81
R123	27.82	6.81	33	0.717	4.9
R11	23.71	6.25	43	0.693	5.02
R600a	-11.67	4.58	30	0.756	4.62
R152a	-24.02	4.64	46.7	0.72	4.78
R134a	-26.07	4.71	37	0.76	4.6
R12	-29.75	4.1	38	0.746	4.7
Ammonia	-33.33	4.76	39	0.739	4.76
R22	-40.81	4.66	53	0.753	4.66
R290	-42.09	4.5	36	0.767	4.5
R407C	-43.63	4.5	48	0.781	4.5
R502	-45.17	4.4	38	0.802	4.38
R404A	-46.22	4.21	36	0.833	4.21
R410A	-51.44	4.41	51	0.781	4.41

Ammonia as a Refrigerant:

Ammonia is a naturally occurring compound produced by both humans and animals as part of metabolic processes. In the human body, it is primarily generated during the breakdown of proteins. On average, a person produces around 17 grams of ammonia each day.

Globally, ammonia is produced in vast quantities from both natural and industrial sources. Natural processes generate approximately 3,000 million tons of ammonia per year, primarily through biological activity in humans, animals, and the environment. In contrast, industrial production accounts for about 225 million tons annually, supporting a wide range of applications. Of this, around 6 million tons are specifically utilized in refrigeration systems, highlighting ammonia's significance as an efficient and eco-friendly refrigerant in the cooling industry. The photograph in the figure 1.7 depicts a field visit to a facility where ammonia is stored.

[3] *NBP- Normal boiling point Temperature*

Figure 1.7: Ammonia storage facility in cold storage with all safety measures

Advantages:

Key advantages of using ammonia as a refrigerant in cold storage systems as shown in Figure 1.8.

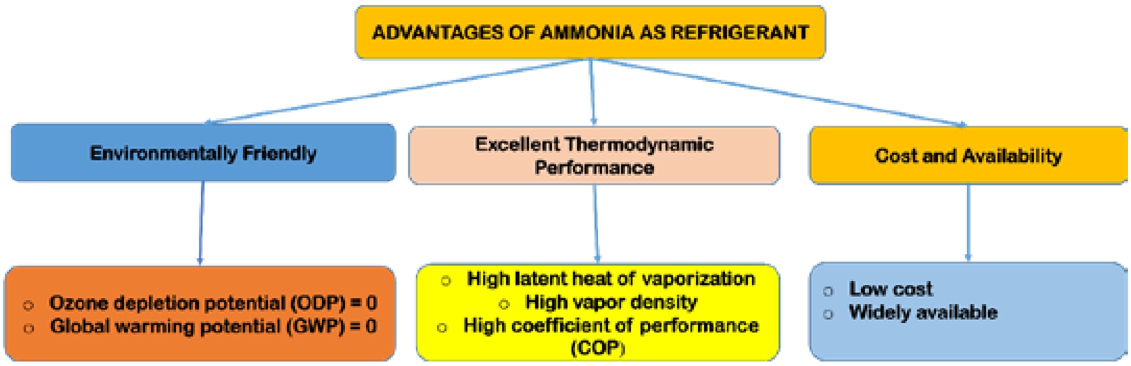


Figure 1.8: Flow chart showing advantages of Ammonia as refrigerant

Disadvantages:

Health Hazard:

- Irritation starts at concentrations of 25 ppm
- Becomes dangerous at levels above 500 ppm

Flammability:

- Flammable when the concentration in air is between 16% and 25%

Material Compatibility:

- Incompatible with copper
- Requires stainless steel or other compatible materials

High Discharge Temperature:

- Leads to increased stress on the compressor

Safety Guidelines for Ammonia-Based Refrigeration Systems:

Hazards Associated with Ammonia:

Anhydrous ammonia is a hazardous substance that can cause serious health effects. It acts as a strong irritant to the skin, eyes, and respiratory system, and at high concentrations, it can lead to painful irritation and even severe chemical burns. A key safety feature of ammonia is its sharp, pungent odor, which allows for early detection of leaks. Apart from health risks, ammonia also poses a fire and explosion hazard, as it can form flammable mixtures in air when its concentration ranges between 16% and 25% by volume. Proper safety practices are essential to handling ammonia safely.

Safety Measures to be Followed:

For the safe handling and storage of ammonia, it is essential to follow the guidelines outlined in IS 4544:2025, which apply to both filled and empty cylinders. Preventive measures should also be in place as per the same standard to minimize the risk of leaks or accidents. In the event of exposure, the affected person should be immediately moved to fresh air, and any contact with the eyes or skin should be treated by flushing with plenty of running water. Cleaning and repair activities involving ammonia systems must strictly adhere to the procedures specified in IS 4544:2025. Additionally, waste disposal must be carried out following local, state, and central pollution control regulations to ensure environmental safety.

2. CODE OF PRACTICES FOR COLD CHAINS

Standards and codes are vital for cold chains to ensure product quality and safety, reduce massive post-harvest losses of food and medicines, facilitate global trade, meet regulatory requirements, and promote economic growth by linking farmers to markets. They provide a common framework for managing temperature-controlled logistics, ensuring consistency from farm to consumer and protecting public health.

2.1 Existing guidelines, national standards, and code of practices for Cold Chain storage given by the Bureau of Energy Efficiency (BEE) and the Bureau of Indian Standards (BIS):

The Codes and the standards comprising practices and guidelines issued by the Bureau of Indian Standards (BIS) and other international organizations are applicable to the design and construction of cold stores, pack houses, ripening chambers, food processing facilities, and related infrastructure. These standards serve as valuable references for practicing engineers in determining appropriate test methods, performance ratings, requirements, and limits for the design, construction, and equipment used. In cases where an Indian Standard (IS) code is not available, the corresponding standards / practices / guidelines of ASME, ASHRAE, IIAR, or other recognized international bodies shall be referred. In all instances, the latest revisions of the relevant codes and standards shall be applied.

In the development of cold infrastructure facilities, the electrical, mechanical, and building standards prescribed by BIS are to be followed. In contrast, for food preservation, the guidelines established by ASHRAE must be adhered to. The applicable standards are summarized in Table 2.1-2.4.

Table 2.1: Standards prescribed by Bureau of Indian Standards (BIS) for electric items.

S. NO.	Title	Reference
1.	PVC Insulated cables (light duty) for working voltage up to 1100 volts	IS 694-1977 Part I & II
2.	PVC Insulated cables (heavy duty) for working voltage up to 1100 volts	IS 1554-1976 Part-I
3.	PVC Insulated cables for voltage 3.3 KV to 11 KV	IS 1554- 1976 Part-II
4.	Specification of Polyurethane insulated PVC sheeted heavy duty electrical cables, voltage not exceeding 1100V	IS 5959- 1970 Part-I
5.	Specification of Polyurethane insulated PVC sheeted heavy duty electrical cables, voltage 3.3 KV to 11 KV	IS 5959- 1970 Part-II
6.	Guide for making of insulated conductors	IS 5578-1970
7.	Code of practice for installation and maintenance of paper insulated power cables	IS 1255-1967
8.	Code of practice for earthing	IS 3043-1966
9.	Guide of practice for installation and maintenance of induction motors	IS 5216-1969
10.	Code of practice for installation and maintenance of AC induction motor starters	IS 5214-1969

S. NO.	Title	Reference
11.	Code of practice for installation and maintenance of AC induction motors	IS 900-1965
12.	Code of practice for installation and maintenance of switchgears	IS 372-1975
13.	Code of practice for installation and maintenance of transformers	IS 1886-1967
14.	Code of practice for electrical wiring installation, voltage not exceeding 650 V	IS 732-1963
15.	Code of practice for electrical wiring installation (system voltage exceeding 650 V)	IS 2274-1963
16.	Guide for testing three-phase induction Motor	IS 4029-1967
17.	Three Phase induction Motors	IS 325
18.	Electrical measuring instruments and their accessories	IS 248
19.	Current transformers	IS 2705
20	Dimensions of slide rails of electric motors	IS 2968
21.	Flexible Steel conduits for electric wiring Air-Break Switches	IS 3480
22.	Motor Starters for voltage not exceeding 1000 Volts Conduits for electrical installation	IS 4064
23.	Selection, installation & maintenance of Transformers	IS 8544
24.	Selection, installation & maintenance of switch gear and control gear National Electrical Codes	IS 9537
25.	Flexible Steel conduits for electric wiring Air-Break Switches	IS 10028
26.	Selection, installation & maintenance of switch gear and control gear National Electrical Codes	IS 10118
27.	Selection, installation & maintenance of switch gear and control gear National Electrical Codes	SP: 30
28.	Household and Similar Electrical Appliances-Safety-Particular Requirements for Commercial Refrigerating Appliances and Ice-Makers with an Incorporated or Remote Refrigerant Unit or Motor- Compressor (IEC 60335-2-89: 2019, MOD)	IS 18689:2024
29.	Safety of Household and Similar Electrical Appliances Part 2 Particular Requirements Sec 40 Electrical Heat Pumps, Air- Conditioners and Dehumidifiers (IEC 60335-2-40 : 2022, MOD)	IS 302 (Part 2/ Sec 40):2025

Table 2.2: Standards prescribed by Bureau of Indian Standards (BIS) for mechanical device.

S.NO.	Title	Reference
1	Safety codes for Mechanical Refrigeration	IS 660
2	Code of practice for thermal insulation of cold storages	IS 661
3	Code of practice for application of polyurethane insulation by in-situ pouring method	IS 13205

S.NO.	Title	Reference
4	Rigid phenolic foams for thermal insulation	IS 13204
5	Application for spray applied insulation code of practice – Polyurethane / Poly-isocyanate	IS 12432 Part-III
6	Specifications for preformed rigid polyurethane (PUR) and polyisocyanurate (PIR) foams for thermal insulation	IS 12436
7	Expanded polystyrene for thermal insulation	IS 4671
8	Code for practice for fire safety of industrial buildings: General Storage and warehousing including cold storage	IS 3594
9	Anhydrous ammonia	IS 662
10	Industrial Bitumen	IS 702
11	Gunmetal gate, globe and check valve for general purpose	IS 778
12	Ball Valves including floats for water supply purposes	IS 1703
13	Mild Steel Tubes, tubular and other wrought steel pipes fittings	IS 1239
14	Steel Plates for pressure vessels used at moderate and low temperature	IS 2041
15	Color code for identification of pipe lines	IS 2379
16	V- belts for industrial purposes	IS 2494
17	Hot dip galvanizing of iron and steel	IS 2629
18	Code for unfired pressure vessels	IS 2825
19.	Glossary of terms for safety and relief valves	IS 3233
20	Steel for pressure vessels and welded structures	IS 3503
21.	Steel tubes for mechanical and general engineering purposes	IS 3601
22.	Steel for general structural purposes	IS 2062
23.	Steel tubes for structural purposes	IS 1161
24.	Specifications for steel doors, windows and ventilators	IS 1038
25.	Code of practice for design loads (other than earthquake) for building and structures	IS 875 Part I to V
26.	Criteria for earthquake resistant design of Structures	IS 1893
27.	Specifications for cold formed light gauge structural steel sections	IS 811
28.	Code of practice for use of Steel Tubes in general building construction	IS 806
29.	Code of practice for use of cold form light gauge steel structural members in general building construction	IS 801
30.	Code of practice for general construction in steel	IS 800
31.	Glossary of terms used in refrigeration and air-conditioning	IS 3615
32.	Pressure and vacuum gauges	IS 3624
33.	Safety Codes for scaffolds and ladders	IS 3696
34.	Formed ends for tanks and pressure vessels	IS 4049
35.	Shell an tube type heat exchangers	IS 4503
36.	Ammonia-Code of safety (Second Revision)	IS 4544:2025
37.	Expanded polystyrene for thermal insulation purposes	IS 4671

S.NO.	Title	Reference
38.	Hot-dip Zinc coating on steel tubes	IS 4736
39.	Units and symbol for refrigeration	IS 4831
40.	HDPE pipes for potable water supplies, sewage and industrial effluents	IS 4984
41.	Gauge glasses	IS 5428
42.	Specification for sprayed aluminum and zinc coating on iron and steel surfaces	IS 5905
43.	Steel Pipe flanges	IS 6392
44.	Injection molded HDPE fittings for portable water supplies	IS 8008
45.	Vertical steel ladders	IS 8172
46.	Treatment of water for industrial cooling systems	IS 8188
47.	Nominal sizes of valves	IS 9520
48.	Selection, use and maintenance of respiratory protective devices	IS 9623
49.	Polythene floats for ball valves	IS 9762
50.	General purpose ball valves	IS 9890
51.	SI units	IS 10005
52.	Recommendations for general pipeline welding	IS 10234
53.	Ammonia valves	IS 11132
54.	Finned type heat exchanger for room air conditioner	IS 11329
57.	Specification for metal air duct	IS 655
58.	Specification for galvanized steel sheet	IS 227
59.	Specifications for Performed Rigid Polyurethane	IS 12436-1988
60.	Glossary of Terms used in Refrigeration& Air conditioning	IS 3615: 2007
61.	Code of Practice for Fire Safety of Ware housing including cold storages IS specification As per Relevant	IS specification As per Relevant
62	Food Hygiene – General Principle – Code of Practice	IS 2491-1998
63	Self-blasted lamps for general lighting service	IS 15111 Part 1 and 2
64	Refrigerants-Designation and safety classification	IS 16656: 2017 / ISO 817: 2014
65	Refrigerating systems and heat pumps-Safety and environmental requirements	IS 16678 (Part 1 to 4) / ISO 5149-1 to 4
66	Closed-Circuit Ammonia Refrigeration System - Code of Practice for Design and Installation	IS 17773: 2022
67	Refrigerating systems and heat pumps-Competence of personnel	IS 18847:2024 / ISO 22712: 2023

Table 2.3: Publication by International Societies and Associations for pre-engineering building

S.NO.	Title	Reference
1	Building Code Design Code Tolerance Code Purlin Code Welding Code	IBC 2006
2	Wind Load & Seismic Load	AISC 2005
3	Building Code Design Code Tolerance Code Purlin Code Welding Code	MBMA 2002
4	Wind Load & Seismic Load	AISI 2001
5	Building Code Design Code Tolerance Code Purlin Code Welding Code	ANS 2006
6	Wind Load & Seismic Load	IS 875 & IS A893-2002

Table 2.4: ISO standard for different food preservation

(Source: American Society of Heating, Refrigeration and Air Condition Engineers, Inc ASHRAE Refer to REFRIGERATION-Systems and applications, book Chapter-51 Codes and Standards, International Standard (ISO) Standard and/or project)

S.NO.	Title	References
1	Peaches -- Guide to cold storage	ISO 873:1980
2	Fresh fruits and vegetables -- Sampling	ISO 874:1980
3	Green bananas -- Guide to storage and transport	ISO 931:1980
4	Cauliflowers -- Guide to cold storage and refrigerated transport	ISO 949:1987
5	Pears -- Cold storage	ISO 1134:1993
6	Apples -- Cold storage	ISO 1212:1995
7	Onions -- Guide to storage	ISO 1673:1991
8	Fresh pineapples -- Storage and transport	ISO 1838:1993
9	Fruits and vegetables -- Morphological and structural terminology	ISO 1956-1:1982
10	Fruits and vegetables -- Morphological and structural terminology	ISO 1956-2:1989
11	Fruits -- Nomenclature -- First list	ISO 1990-1:1982
12	Fruits -- Nomenclature -- Second list	ISO 1990-2:1985
13	Vegetables -- Nomenclature -- First list	ISO 1991-1:1982
14	Vegetables -- Nomenclature -- Part 2: Second list	ISO 1991-2:1995
15	Ware potatoes -- Guide to storage	ISO 2165:1974
16	Carrots -- Guide to storage	ISO 2166:1981
17	Round-headed cabbage -- Guide to cold storage and refrigerated transport	ISO 2167:1991
18	Table grapes -- Guide to cold storage	ISO 2168:1974

S.NO.	Title	References
19	Fruits and vegetables -- Physical conditions in cold stores -- Definitions and measurement	ISO 2169:1981
20	Avocados -- Guide for storage and transport	ISO 2295:1974
21	Apricots -- Guide to cold storage	ISO 2826:1974
22	Citrus fruits -- Guide to storage	ISO 3631:1978
23	Fruits and vegetables -- Ripening after cold storage	ISO 3659:1977
24	Green bananas -- Ripening conditions	ISO 3959:1977
25	Dry fruits and dried fruits -- Definitions and nomenclature	ISO 4125:1991
26	Asparagus -- Guide to storage	ISO 4186:1980
27	Horse-radish -- Guide to storage	ISO 4187:1980
28	Tomatoes -- Guide to cold storage and refrigerated transport	ISO 5524:1991
29	Potatoes -- Storage in the open (in clamps)	ISO 5525:1986
30	Round-headed cabbage -- Storage in the open	ISO 6000:1981
31	Cashew kernels -- Specification	ISO 6477:1988
32	Peanuts -- Specification	ISO 6478:1990
33	Shelled sweet kernels of apricots -- Specification	ISO 6479:1984
34	Sweet pepper -- Guide to refrigerated storage and transport	ISO6479:1984/ Cor 1:1999
35	Mangoes -- Cold storage	ISO 6659:1981
36	Fresh fruits and vegetables -- Arrangement of parallelepipedic packages in land transport vehicles	ISO 6661:1983
37	Plums -- Guide to cold storage	ISO 6662:1983
38	Garlic -- Cold storage	ISO 6663:1995
39	Bilberries and blueberries -- Guide to cold storage	ISO 6664:1983
40	Strawberries -- Guide to cold storage	ISO 6665:1983
41	Dried sour cherries -- Specification	ISO 6755:2001
42	Decorticated stone pine nuts -- Specification	ISO 6756:1984
43	Decorticated kernels of mahaleb cherries -- Specification	ISO 6757:1984
44	Potatoes, root vegetables and round-headed cabbages -- Guide to storage in silos using forced ventilation	ISO 6822:1984
45	Asparagus -- Guide to refrigerated transport	ISO 6882:1981
46	Fruits and vegetables -- Principles and techniques of the controlled atmosphere method of storage	ISO 6949:1988
47	Guide to the pre packing of fruits and vegetables	ISO 7558:1988
48	Cucumbers -- Storage and refrigerated transport	ISO 7560:1995
49	Cultivated mushrooms -- Guide to cold storage and refrigerated transport	ISO 7561:1984
50	Potatoes -- Guidelines for storage in artificially ventilated stores	ISO 7562:1990
51	Fresh fruits and vegetables -- Vocabulary	ISO 7563:1998

S.NO.	Title	References
52	Dried apples -- Specification and test methods	ISO 7701:1994
53	Dried pears -- Specification and test methods	ISO 7702:1995
54	Dried peaches -- Specification and test methods	ISO7702:1995/ Cor 1:2001
55	Carob -- Specification	ISO7703:1995/ Cor 1:2001 ISO 7907:1987
56	Dried sweet cherries -- Specification	ISO 7908:1991
57	Dried mulberries -- Specification	ISO 7910:1991
58	Unshelled pine nuts -- Specification	ISO 7911:1991
59	Sweet cherries and sour cherries -- Guide to cold storage and refrigerated transport	ISO 7920:1984
60	Leeks -- Guide to cold storage and refrigerated transport	ISO 7922:1985
61	Apples -- Storage in controlled atmospheres	ISO 8682:1987
62	Lettuce -- Guide to pre-cooling and refrigerated transport	ISO 8683:1988
63	Early potatoes -- Guide to cooling and refrigerated transport	ISO 9376:1988
64	Root vegetables -- Cold storage and refrigerated transport	ISO 9719:1995
65	Melons -- Cold storage and refrigerated transport	ISO 9833:1993
66	Green beans -- Storage and refrigerated transport	ISO 9930:1993
67	Dried rosehips -- Specification and test methods	ISO 23391:2006
68	Fresh and quick-frozen maize and peas -- Determination of alcohol- insoluble solids content	ISO 23392:2006
69	Pomegranate fruit -- Specification and test methods	ISO 23393:2006
70	Dried oleaster -- Specification and test methods	ISO 23394:2006

2.2: An overview of national and international practices for integrating ammonia and low GWP refrigerants in cold storage:

The selection of an alternative refrigerant is guided by multiple criteria, including performance, material compatibility, environmental impact, safety, and cost. From a performance standpoint, two key parameters are considered: the coefficient of performance (COP) and the volumetric capacity (Qv). COP, defined as the ratio of the refrigeration effect produced to the energy consumed, is directly related to operating costs. Qv, an inverse measure of the required compressor size, influences the equipment cost.

Refrigerant performance evaluation typically begins with preliminary estimates, progresses to models of varying technical complexity, and culminates in laboratory testing of prototypes. These tests are often complemented by advanced simulations to optimize equipment design based on refrigerant properties.

Lower-GWP HFC/HFO blends and non-halocarbon refrigerants—such as R-290 (propane), R-600a (isobutane), R-744 (CO_2), and R-717 (ammonia)—have emerged as the most promising replacements for HFC-134a and R-404A, with several already in successful global use. Transitioning from high-GWP HFCs to low-GWP alternatives presents an opportunity to innovate system architectures that use less refrigerant, operate more efficiently, are simpler to install, easier to maintain, and less susceptible to leaks.

Table 2.5: List of refrigerants (Source: International Institute of Refrigeration (IIR) 2022)

Refrigerant	GWP	Safety Class	Basic System			System with ll/sl-hx[a]			Evaporator Glide[b] (°C)	NBP (°C)
			$\frac{COP}{COP_{HFC2134a}}$	$\frac{Q_v}{Q_{v,\,HFC2134a}}$	$\frac{P_D}{P_S}$	$\frac{COP}{COP_{HFC2134a}}$	$\frac{Q_v}{Q_{v,\,HFC2134a}}$	$\frac{P_D}{P_S}$		
HFC-134a	*1430*	*A1*	*1*	*1*	*5.1*	*1.035*	*1.03*	*5.0*	*−1.0*	*−26.1*
R-290	3	A3	1.039	1.48	3.8	1.078	1.52	3.7	−0.5	−42.1
HFO-1234yf	4	A2L	0.947	0.95	4.8	1.002	1.00	4.6	−0.8	−29.5
HFO-	7	A2L	0.965	0.72	5.5	1.017	0.75	5.3	−1.1	−19.0
R-516A	142	A2L	0.970	1.00	4.7	1.022	1.04	4.6	−0.5	−29.6
HFC-152a	124	A2	1.046	0.96	4.9	1.065	0.97	4.8	−1.3	−24.0
R-515B	293	A1	0.958	0.70	5.5	1.013	0.74	5.3	−1.2	−19.0
R-450A	605	A1	0.980	0.85	5.2	1.023	0.88	5.1	−0.6	−23.6
R-513A	632	A1	0.966	1.02	4.8	1.016	1.07	4.7	−1.1	−29.6
R-717	0		1.29	1.94	4.76	--	--	--	--	-33.3

Table 2.5 outlines commonly considered alternatives to HFC-134a for such cooling applications, showing their estimated performance in both a basic refrigeration cycle and a cycle equipped with a liquid-line/suction-line heat exchanger. Among single-compound fluids with single-digit GWP, R-290 demonstrates a higher COP than HFC-134a in the basic cycle. HFO-1234yf offers higher volumetric capacity than HFO-1234ze(E), providing an application advantage. HFC-152a delivers strong performance but becomes less attractive than R-290 once flammability safety measures are factored in. Non-flammable options such as R-515B, R-450A, and R-513A provide meaningful GWP reductions and may serve as short-term solutions, with R-515B potentially being viable for longer-term use. Overall, the refrigerants with the lowest GWP generally exhibit at least mild flammability, with safety classifications of A2L, A2, or A3.

3. ADOPTION OF AMMONIA AND LOW GWP REFRIGERANTS

Different low-GWP options are available for cold chain infrastructure which broadly categorized into ammonia-based chillers and vapor compression / refrigeration system for bulk cold storage facilities. Ammonia is the refrigerant of choice since it produces the greatest net refrigerating effect. Other low-GWP technologies in the cold chain include natural refrigerants like hydrocarbons (e.g., propane), carbon dioxide (CO_2), and ammonia, along with newer hydrofluoroolefins (HFOs) like R-1234ze and R-1234yf. Technologies like solar-powered refrigeration, and energy-efficient green building designs for cold storage facilities are also crucial for a sustainable cold chain.

3.1: Types of Cooling Technologies:

Various types of refrigeration systems can be employed in cold rooms, as refrigeration requirements depend on several factors that directly influence the preservation and maintenance of stored products. Key considerations include the cold room's dimensions, frequency of door openings, cooling load, specific requirements of the stored products, and the type of construction materials used in the cold room structure.

The main cooling systems are:

- **Direct refrigeration systems**: In this system, the compressed and condensed refrigerant gas exits the refrigeration unit and is directly supplied to remote evaporators. Such systems are commonly used in smaller, commercial applications, as industry regulations limit the allowable refrigerant charge.

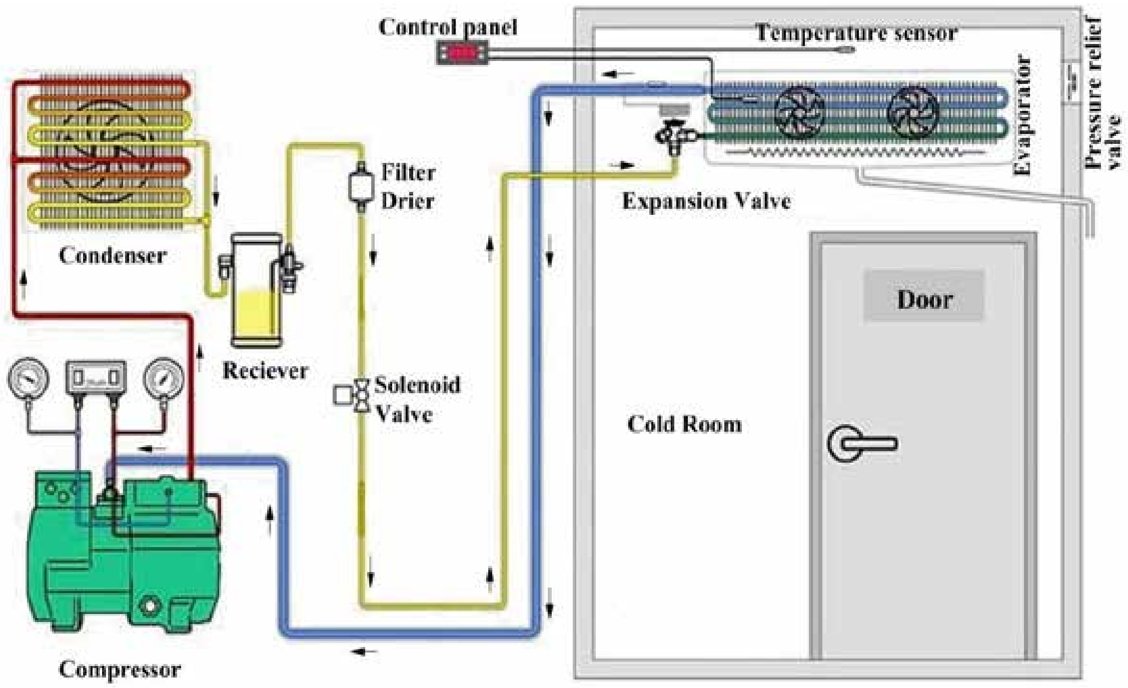


Figure 3.1: Basic components of a direct refrigeration system

- **Indirect refrigeration systems**: In this system, the refrigerant gas remains confined within the cooling generation zone, where its cooling capacity is transferred to a secondary fluid—such as water, glycol, or brine—through a heat exchanger. This chilled secondary fluid is then circulated by a pumping system to final components like air coolers, heat exchangers, or tank coils. Indirect systems are primarily used in large-scale and industrial applications, as employing a secondary fluid significantly reduces refrigerant charge costs

3.2: Components and Equipment Used in the Cold Chain:

The cold chain consists of several key components that work together to keep perishable items safe and fresh until they are delivered to the end user. The main components of the cold chain include:

Pre-cooling Systems: Pre-cooling rapidly lowers the temperature of freshly harvested produce such as fruits and vegetables. This process removes the field heat absorbed during harvesting. By reducing temperature quickly, it significantly slows down the rate of spoilage. As a result, the freshness and quality of the produce are better preserved during storage and transportation.

Cold Storage Units: Cold storage maintains items at a controlled temperature for short or long-term preservation. Common types include cold rooms and refrigerate warehouses. This setup helps extend the shelf life of perishable items. It ensures products remain fresh before transport, processing, or sale.

Refrigerated Transportation: Cold transportation involves moving perishable goods in temperature-controlled vehicles. Examples include refrigerated trucks/reefer van, cold containers for ships, and refrigerated rail wagons. These systems maintain the required conditions throughout the journey. This prevents spoilage and ensures product quality during transit.

A reefer van is a self-powered vehicle fitted with an integrated refrigeration unit, designed to transport temperature-sensitive products such as food, pharmaceuticals, and flowers while maintaining precise temperature control during transit. These specialized vehicles are insulated with materials like PUF panels and are equipped with temperature recorders to ensure consistent product quality across both local and long-distance supply chains.

Basic Components of a Reefer Van:

The essential components of a reefer van include:

- **High-Grade Insulation:** The walls are lined with premium insulation materials that act as non-conductive barriers, minimizing heat transfer.
- **Cooling System:** Refrigeration may be powered either by the vehicle's engine or an external source to maintain the required temperature.
- **Precise Temperature Control:** Allows setting and maintaining exact temperatures for different types of products.
- **Durable Construction:** Built to withstand heavy loads while ensuring maximum efficiency.
- **Optimized Interiors:** Designed to provide ample storage space without compromising cooling performance.

Types of Reefers Vans:

- **Small Refrigerated Trucks:** Ideal for urban deliveries, as they can easily navigate narrow streets while transporting perishable goods within cities.
- **Medium Refrigerated Trucks:** Suitable for intercity transport, offering a balance between load capacity and maneuverability.
- **Refrigerated Container Trucks:** Larger units with detachable containers, designed for bulk transport over long distances.

The details of different types of technologies, refrigerants, cooling systems, and their respective limitations for various kinds of reefer vans are outlined below:

Type of Vehicle	Type of Technology	Types of Refrigerants	Types of Cooling	Limitation
Medium & Large Reefer Trucks	Diesel Engine/ Crankshaft Drive	R-404A	Engine-driven mechanical cooling	High greenhouse gas emissions; High dependence on diesel fuel; Noise and particulate pollution; Regulatory risk due to phase-out of R-404A
Medium & Large Reefer Trucks	Diesel Engine/ Crankshaft Drive	R-452A	Engine-driven mechanical cooling	Still relatively high GWP refrigerant; High fuel consumption; Limited infrastructure for maintenance outside metros
Small Reefer Vans	Battery/ Electric (DC compressor)	R-134a / R-1234yf	Battery-powered compressor cooling	Short operating range due to limited battery capacity; High upfront cost; Grid dependency (often coal-based) reduces sustainability impact; Lack of charging infrastructure
Electric Heavy Trucks (Pilot Fleets)	Battery-Electric with Auxiliary Cooling Pack	CO_2 (R-744)	Fully electric compressor system	Very high upfront cost; Specialized maintenance required; Limited pilot adoption; Charging downtime reduces efficiency
Hybrid Vans	Dual Power Refrigeration (Engine + Battery)	R-290 (Propane) / R-452A	Switchable engine or battery-powered cooling	Complex system increases maintenance cost; Safety concerns with hydrocarbon refrigerants; High capital cost; Limited adoption and technician expertise
Large Reefer Trucks (10T+)	Diesel + Standalone Generator Units	R-404A / R-452A	Independent diesel genset-powered cooling unit	Excessive fuel consumption; High emissions; Maintenance intensive; Regulatory non-compliance risk for refrigerants

Distribution to Retailers and Consumers: The final step in the supply chain is delivering products to shops or customers. This usually needs last-mile delivery services that keep the right temperature. It is important to keep the products fresh during this stage. This helps maintain their quality until they are sold or used.

Equipment Used in the Cold Storage:

It includes key components such as compressors, condensers, evaporators, and expansion devices essential for maintaining controlled temperatures.

1. Compressors

Compressors are the heart of refrigeration systems. They compress the refrigerant, increasing its pressure and temperature, enabling heat rejection in the condenser. In cold storage systems, reciprocating and screw compressors are commonly used due to their suitability for refrigerants like R-12, R-22, R-404a, and ammonia, which condense at relatively high pressures. Small facilities often use hermetic compressors for their low cost and power needs, while medium to large facilities prefer semi-hermetic types. Hermetic compressors have the motor and compressor on the same shaft within the sealed system, eliminating the need for a shaft seal and reducing refrigerant leakage.

Figure 3.2: Compressor used in ammonia-based refrigerant in the cold storage system

2. Condensers

Condensers remove heat from the refrigerant, converting it from a gas to a liquid. The condenser in a cold chain system converts vapor refrigerant into liquid by transferring heat to a cooling medium. Common types include air-cooled, water-cooled (shell and tube), and evaporative cooled (cooling tower) condensers. Air-cooled condensers are typically used in small-capacity plants or areas with limited water supply. To enhance performance, finned tubes are often used to improve heat dissipation.

3. Evaporators and fan system

Evaporators absorb heat from the product or air inside the storage space, causing the refrigerant to evaporate and lowering the temperature. In a cold storage facility, the evaporator—commonly known as the cooling coil—operates on a low-temperature, low-pressure line to absorb heat from the refrigerated space, causing the liquid refrigerant to evaporate. Finned cooling coils with axial or centrifugal fans are widely used to circulate air and enhance cooling. Fan-coil units are typically of draw-through or blow-through types, where air passes over the cooling coil either before or after the fan. Blow-through units provide air closer in temperature to the refrigerant and help minimize room heat from the fan motor. Regardless of the setup, fan motor heat is considered in the total room heat load.

4. Expansion Valves

The expansion valve in a cold chain system reduces the refrigerant pressure from the condenser to the evaporator level, thereby lowering its temperature and regulating its flow. Different types of expansion valves are used for this purpose, such as thermostatic, automatic, and capillary tube types. Some systems also use high-pressure, low-pressure, or manually operated valves. In this study, a thermostatic expansion valve is employed for precise control.

5. Cold Storage Chambers

These are insulated rooms or warehouses designed to maintain specific temperatures for storing perishable goods. They vary in size and temperature range (chillers or freezers).

6. Receiver

A receiver is a storage container used to hold excess refrigerant that is not currently in circulation. It becomes essential during heat load fluctuations, allowing the system to store surplus refrigerant when operating under reduced load conditions.

7. Filter Drier

A filter drier removes moisture and foreign particles from the refrigeration system to prevent damage. Moisture can freeze at the expansion valve or corrode metal parts, potentially causing compressor failure. Desiccants like silica gel, molecular sieve, or activated alumina inside the filter drier absorb moisture and ensure clean refrigerant flow.

8. Solenoid Valve

A solenoid valve is an electrically operated device used to control the flow of refrigerant. When energized, it opens to allow flow; when de-energized, it closes via spring or gravity. It offers fast, reliable operation and is commonly used to regulate refrigerant feeding to the evaporator.

9. Blast Freezers/Chillers

These are high-capacity cooling units used for rapid chilling or freezing of perishable products like meat, seafood, and dairy, helping maintain product quality and shelf life.

10. Refrigerated Transport Vehicles

These include reefer trucks and containers equipped with refrigeration units to maintain the cold chain during transportation from farms to markets or retail outlets.

11. Temperature & Humidity Sensors

Sensors monitor real-time temperature and humidity conditions to ensure storage requirements are met. Data loggers help maintain records for audit and safety compliance.

12. Backup Power Systems

Diesel generators (DG sets) and uninterruptible power supply (UPS) systems are installed to provide backup power, ensuring consistent refrigeration during power outages.

13. Safety and Control Equipment

This includes pressure relief valves, ammonia detectors, ventilation systems, and control panels to ensure safe and efficient operation of the refrigeration system.

Figure 3.3: Safety equipment used in the cold storage system.

These include clearance from the municipal body for land use and construction, approval from the electricity distribution authority for power safety and load requirements, and authorization from relevant agencies for mechanical and building standards in accordance with BIS. Environmental approvals may be required to ensure compliance with sustainability and pollution control regulations, while fire safety clearance from the fire department is mandatory for safe operation. For food preservation and storage activities, adherence to ASHRAE guidelines. Additional permissions may also be required for water usage, waste management, and the integration of renewable energy. Collectively, these approvals ensure that the facility is legally compliant, environmentally sustainable, and technically sound for reliable operation.

3.3: Insulation systems in cold storage:

Thermal energy naturally flows from warmer substances to colder ones. While all materials—including good conductors like metals—offer some resistance to heat flow, insulation materials provide a much higher level of resistance, making them essential for controlling energy transfer.

A wide range of materials can be used for insulation, each with distinct properties. Selecting the right insulation is a critical construction decision, requiring a balance between affordability and suitability for the intended application. While cost is important, performance characteristics-such as the R-value (thermal resistance), moisture resistance, and durability-should take priority. The chosen material should ideally be odourless, vermin-proof, non-flammable, and moisture-proof.

Insulation selection is significant not only because it greatly affects energy efficiency but also because it represents a considerable share of total construction costs. Both the type of insulation material and its thickness are crucial to achieving desired performance. Well-designed insulation ensures that storage facilities, such as cold rooms, maintain temperature effectively with minimal energy use. An airtight, well-insulated structure keeps stored products cooler for longer periods and reduces operational costs.

Moisture control is equally important. Unchecked moisture penetration can lead to water or ice accumulation within the insulation, compromising both its effectiveness and the integrity of the structure. To prevent this, cold storage facilities are built using various insulation methods, including insulated structural panels, mechanically applied insulation, adhesive systems, and spray-applied foam systems.

PUF Thermal Insulation Panel   EPS Thermal insulation Panel   XPS Thermal insulation panel

Figure 3.4: Different insulation panel used in cold storage

Economic assessment

The cost of insulation must be evaluated carefully, as it represents a significant portion of the total installation cost of cold storage facilities. While increasing insulation thickness raises initial material and installation expenses, it simultaneously reduces refrigeration operating costs. Type and thickness of insulation should be chosen to achieve the lowest total life cycle cost, considering both the initial investment and the operational expenses over the facility's expected 25-year lifespan.

Minimum insulation thickness:

Common insulating materials for cold storage applications include expanded polystyrene (EPS), polyurethane foam (PUF), extruded polystyrene (XPS), phenolic foam, mineral wool, and glass wool. Depending on the facility design, insulation may be provided in the form of rigid boards, panel insulation, foam-in-place systems, or precast concrete insulation panels. The minimum insulation thickness is determined by both the chosen material and the type of cold facility.

Insulation is applied to floors, doors, roofs, and walls, with careful consideration of material conductivity, heat transfer or gain, and solar radiation effects. Key factors include:

- Thermal Conductivity – Cold storage insulation materials typically have a thermal conductivity between 0.02 and 0.07 W/m·°C. Lower conductivity values result in better insulation performance.
- Heat Transfer – The insulation thickness should be selected based on the maximum anticipated heat load under extreme environmental conditions.

- Solar Radiation – When the storage facility is exposed to direct sunlight, the impact of solar radiation must be accounted for in the design.
- Shading – Wherever possible, direct sunlight on cooling spaces should be avoided. Shading structures can be provided to reduce thermal load.
- Safety – Insulation materials must offer adequate fire resistance and withstand adverse dynamic conditions without degradation.

The R-value of an insulating material measures its resistance to heat flow. It is a key parameter for determining the required insulation thickness—higher R-values indicate greater resistance to heat transfer and, therefore, better insulating performance. Table 3.1 lists some commonly used insulation materials along with their respective thermal conductivity values and Table 3.2 shows the thickness of some insulating materials for different applications.

Table 3.1: Thermal conductivity of insulating materials used in cold facilities (Source: ASHRAE).

Rigid Materials	Thermal conductivity (W/m·K)
Extruded polystyrene (XPS)	0.03-0.04
Expanded polystyrene (EPS)	0.025-0.035
Expanded polyurethane foam (PUF)	0.023-0.027
Glass fibre	0.04-0.05
Polyisocyanurate	0.023
Wood or cane fibre board	0.045
Foamed-in-Place Insulation	
Sprayed expanded urethane	0.023-0.03
Urea-formaldehyde	0.4-0.5

Table 3.2: Minimum insulation thickness for various insulation materials based on recommended u values for -4 to +2°C cold storages (Source: ASHRAE).

Type of insulation Material	Density Kg/m3	K value (at 10C) W/mK	External Walls	Internal Walls	Ceiling/ roof U value = 0.24 W/m2K	Floor U value = 0.29W/m2K
			Thickness mm	Thickness mm	Thickness mm	Thickness mm
EPS	20	0.036	150	75	150	125
PUF	40	0.023	100	50	100	100
XPS	30-35	0.025	100	50	100	100
Phenolic foam	50	0.026	100	50	125	100
Mineral wool	48	0.033	125	50	125	100
Bonded fiber glass/ glass wool	32	0.033	125	50	125	100

3.4: Monitoring Systems in Cold Chain Infrastructure:

A cold storage monitoring system utilizes advanced technologies to continuously track and control environmental conditions within storage facilities, ensuring optimal product quality and safety. These systems typically incorporate sensors, data loggers, and automated alert mechanisms to monitor parameters such as temperature, humidity, and other critical factors. The collected data is often transmitted to a centralized platform for real-time analysis and remote accessibility. Figure 3.5 shows different sensors and a Programmable Logic Controller (PLC) system.

Figure 3.5: Sensors and Programmable Logic Controller (PLC) system

Such monitoring solutions are highly versatile, offering universal functionality to serve the needs of multiple industries simultaneously.

Industry	Applications
Food & Beverage	Ensuring freshness of fruits, vegetables, meat, dairy, and frozen foods.
Pharmaceuticals	Maintaining precise conditions for vaccines, medicines, and biological samples.
Chemicals	Storing chemicals that require specific temperature ranges to prevent degradation or reactions.
Logistics	Monitoring temperature-controlled shipments during transportation to avoid spoilage.
Retail	Managing walk-in freezers and chillers in supermarkets and grocery stores.
Research Labs	Preserving specimens and conducting experiments under controlled conditions.

3.5: Operation and Maintenance for reliable energy integration:

In the cold chain sector, effective operation and maintenance (O&M) practices are essential to ensure the reliable and efficient performance of refrigeration systems, storage facilities, and reefer transport units. However, in India, several challenges hinder their rigorous implementation. Limited awareness of best practices, inadequate personnel training, and a fragmented cold chain infrastructure are key factors contributing to the weak enforcement of O&M standards, particularly in the handling of perishable goods such as fruits and vegetables.

3.6: Gap, challenges, and risks associated with adopting low-GWP and ammonia technologies:

The use of ammonia as a refrigerant comes with certain challenges and risks, largely due to its toxicity and flammability, which demand strict handling procedures and robust safety measures. Although ammonia is environmentally friendly, with a very low global warming potential, its corrosive properties and the possibility of leaks present hazards to both human health and equipment longevity.

Advantages of Ammonia as refrigerant:

- Environmentally Friendly: ODP = 0, GWP = 0
- Excellent thermodynamic performance
- High latent heat & vapor density
- High COP
- Low price and widely available

Disadvantages of Ammonia as refrigerant:

- Irritation begins at 25 ppm: dangerous >500 ppm
- Flammable between 16%–25% concentration in air
- Incompatible with Copper, requires stainless steel or compatible materials
- High Discharge Temperature: Increases compressor stress

R290 (propane) refrigerant provides notable environmental advantages but also carries significant challenges and risks due to its high flammability. Primary concerns include the possibility of leaks leading to flammable concentrations in enclosed areas, the necessity for strict safety protocols during handling and installation, and the need for specialized equipment along with adequately trained personnel.

3.7: Key supply chain issues, and challenges that hinder the adoption of these sustainable technologies in the cold chain sector:

Cold chain logistics is the management and transportation of temperature-sensitive products within a controlled environment to ensure their quality, integrity, and safety throughout the supply chain. It encompasses a series of activities and specialized infrastructure aimed at maintaining the required temperature conditions for perishable goods, pharmaceuticals, biologics, and other sensitive items from the point of production to final consumption.

The cold chain shipments encounter several critical challenges that can compromise the quality and safety of these products. Some of the key challenges are outlined below:

Parameters	Challenges
Temperature Excursions	Temperature excursions occur when the products are exposed to temperatures outside the acceptable range during storage or transportation. Maintaining the desired temperature range is crucial in cold chain shipments.
Infrastructure Limitations	Inadequate infrastructure and equipment can pose challenges in maintaining temperature control. Insufficient or malfunctioning refrigeration systems, inadequate insulation, or limited availability of temperature-controlled storage facilities and vehicles can compromise the effectiveness of the cold chain.
Temperature Monitoring and Data Management	Accurate and real-time temperature monitoring is vital for identifying and addressing temperature excursions. However, challenges may arise in ensuring proper monitoring systems, data collection, and management. Lack of reliable monitoring devices, improper placement of sensors, or inefficient data management practices can hinder timely detection of temperature deviations.
Compliance with Regulations	Cold chain shipments must comply with various regulatory requirements and industry standards to ensure product safety and quality. Meeting these standards, such as Good Distribution Practices (GDP) or Good Manufacturing Practices (GMP), can be challenging due to complex and evolving regulations, documentation requirements, and the need for rigorous quality control processes.
Supply Chain Complexity	Cold chain shipments often involve multiple stakeholders and complex supply chain networks. Coordinating activities among manufacturers, distributors, carriers, and retailers requires effective communication, collaboration, and seamless information flow. Any breakdown in coordination or delays in transit can lead to disruptions and temperature fluctuations.

3.8: Quantification of the energy efficiency gains through the alternative refrigerants in cold chain applications, including their impact on system design, cooling efficiency, and operational load:

Alternative refrigerants in cold chain applications can enhance energy efficiency by influencing system design, cooling performance, and operational load. These improvements can result in reduced energy consumption and lower operating costs. The thermodynamic and performance properties of various alternative refrigerants, outlined below, provide valuable guidance for selecting the most suitable refrigerant for different types of cold chain infrastructure.

Table 3.3: COP and power consumption for different refrigerants (Source: Ref. [1])

Refrigerant	NBP (°C)	Pressure Ratio	Discharge Temp. (°C)	Power Consumption (kW/TR)	COP
R600a	-11.67	4.58	30	0.756	4.62
Ammonia	-33.33	4.76	39	0.739	4.76
R290	-42.09	4.5	36	0.767	4.5
R407C	-43.63	4.5	48	0.781	4.5
R404A	-46.22	4.21	36	0.833	4.21
R410A	-51.44	4.41	51	0.781	4.41

Various refrigerants are used for both industrial and domestic refrigeration applications. Refrigerants such as R410A, R404A, and Ammonia are predominantly employed in industrial systems, while other refrigerants are more common in domestic refrigeration. From Figures 3.6 and 3.7, it is evident that Ammonia exhibits a higher Coefficient of Performance (COP) and lower power consumption (kW per ton) compared to other refrigerants, making it a highly efficient choice for large-scale operations.

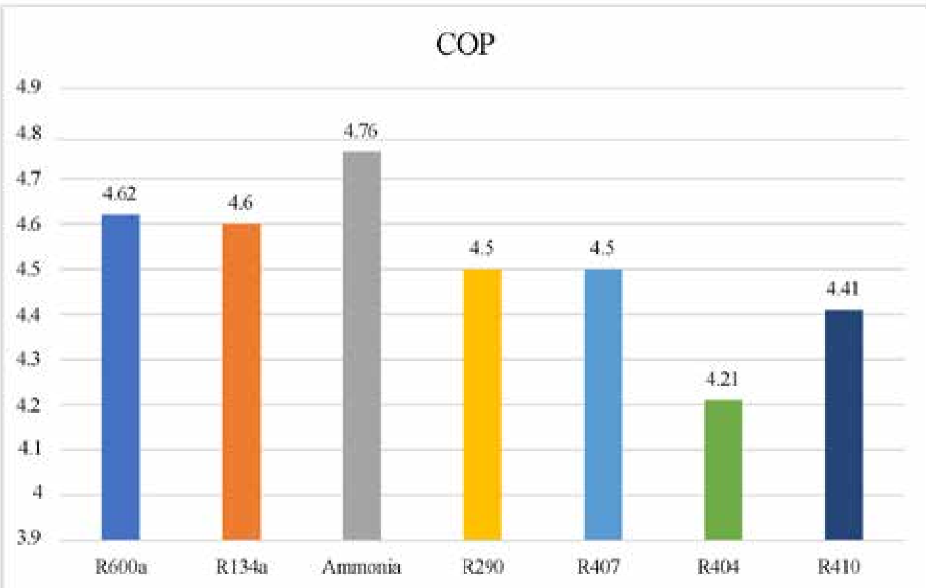


Figure 3.6: Coefficient of performance for various refrigerants (Source: Ref. [1])

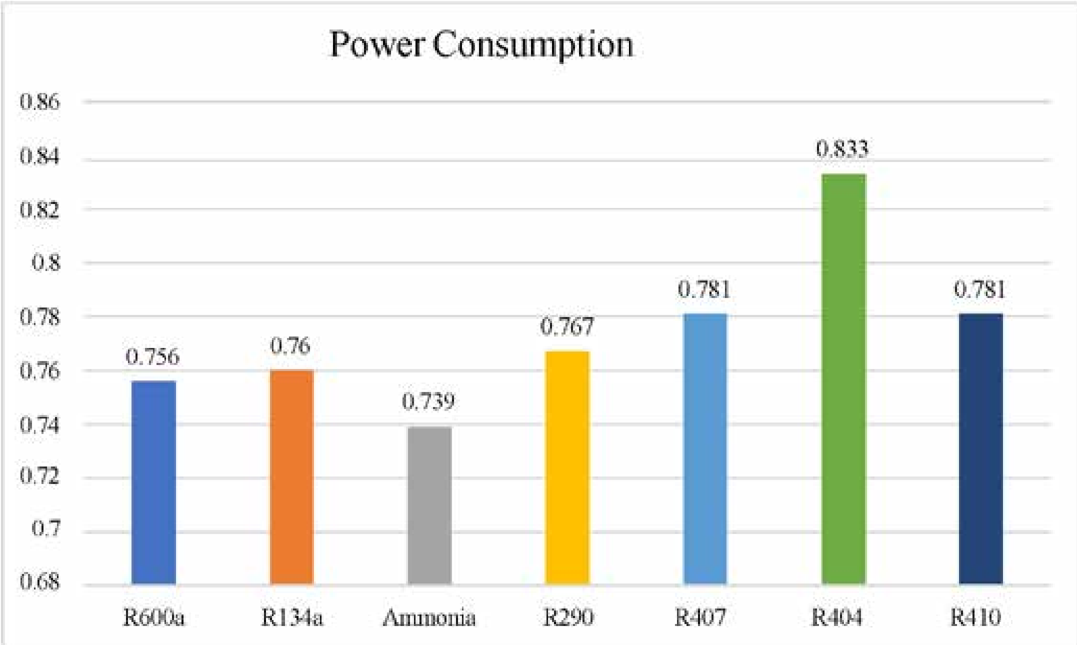


Figure 3.7: Power consumption for various refrigerants (Source: Ref. [1])

For a cold storage facility operating at 100 kW load for 4000 hours annually with an electricity tariff of ₹7 per kWh, the annual operating cost was calculated for different refrigerants. The analysis clearly shows that ammonia (R-717) offers the lowest operating cost compared to other commonly used refrigerants in the industry. This significant cost advantage is attributed to its higher COP and superior thermodynamic efficiency. The comparison highlights ammonia's economic viability for large-scale refrigeration systems. The trend is clearly illustrated in Figure 3.8.

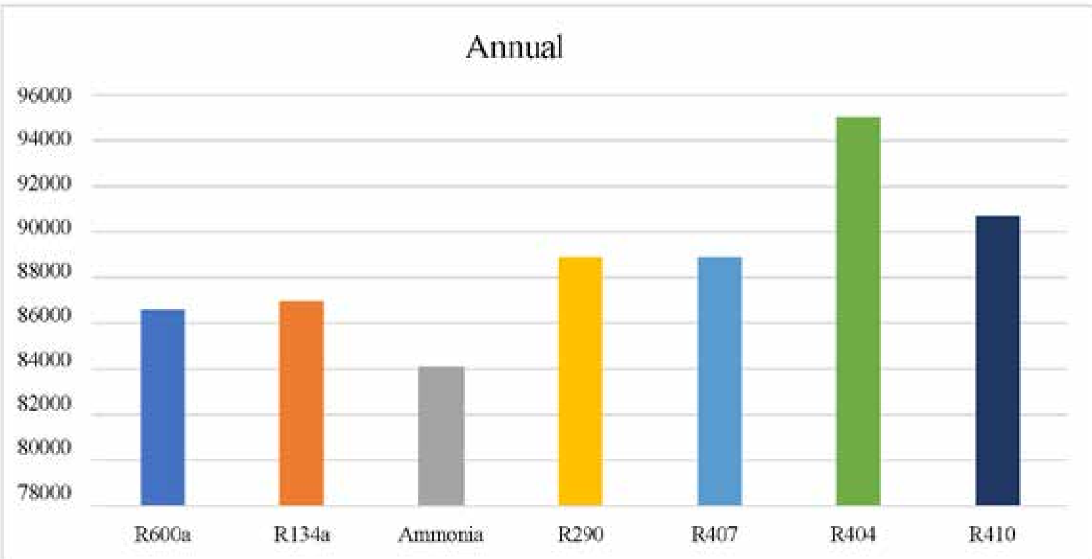


Figure 3.8: Annual Operating cost in rupees for various refrigerants (Source: Ref. [1]).

In addition to its superior performance, Ammonia offers considerable environmental advantages, as highlighted in the table above, with zero Global Warming Potential (GWP) and zero Ozone Depletion Potential (ODP). A comparative analysis of alternative refrigerants shows that, although some options also provide zero GWP, their flammability and associated safety risks limit their adoption in large-scale industrial applications.

Refrigerant	Favourable Factors	Unfavourable Factors
R-290	Zero GWP; Compatible with mineral oil; Positive pressure in evaporator; Low discharge/winding temps; Low power consumption; Low starting torque motor; Small refrigerant charge; Easily available	Flammable; Poor performance at 43°C ambient; Needs small piston displacement compressors
R-134a	Non-flammable; Positive evaporator pressure; Lower discharge/winding temps than R-12	Higher GWP than R-152a; Hygroscopic synthetic oil (moisture sensitivity); Demands high-quality workmanship; 50% higher energy consumption vs R-12; High starting torque needed; Reactivity with Cu and winding enamel uncertain
R-152a	Zero GWP; Compatible with mineral oil; Lower starting torque requirement (vs R-134a)	Slightly flammable; Slight vacuum at -25°C; Higher discharge/winding temps; Higher torque needed vs R-12
R-600a	Zero GWP; Compatible with mineral oil; Lowest system pressures & light design; Cool-running compressor; Low energy use; Low starting torque motor; Very small refrigerant quantity; Easily available	Flammable (but charge is very small)
R-290 + R-600a (50/50 Mix)	Zero GWP; Compatible with mineral oil; R-12 compatible system pressure; Drop-in substitute potential; Low discharge temps; Small refrigerant charge; Easily available	Flammable; Temperature glide during phase change; Leak/composition imbalance risk

To establish a cold infrastructure facility, it is essential to obtain approvals and permissions from multiple authorities, as illustrated in Figure 3.9.

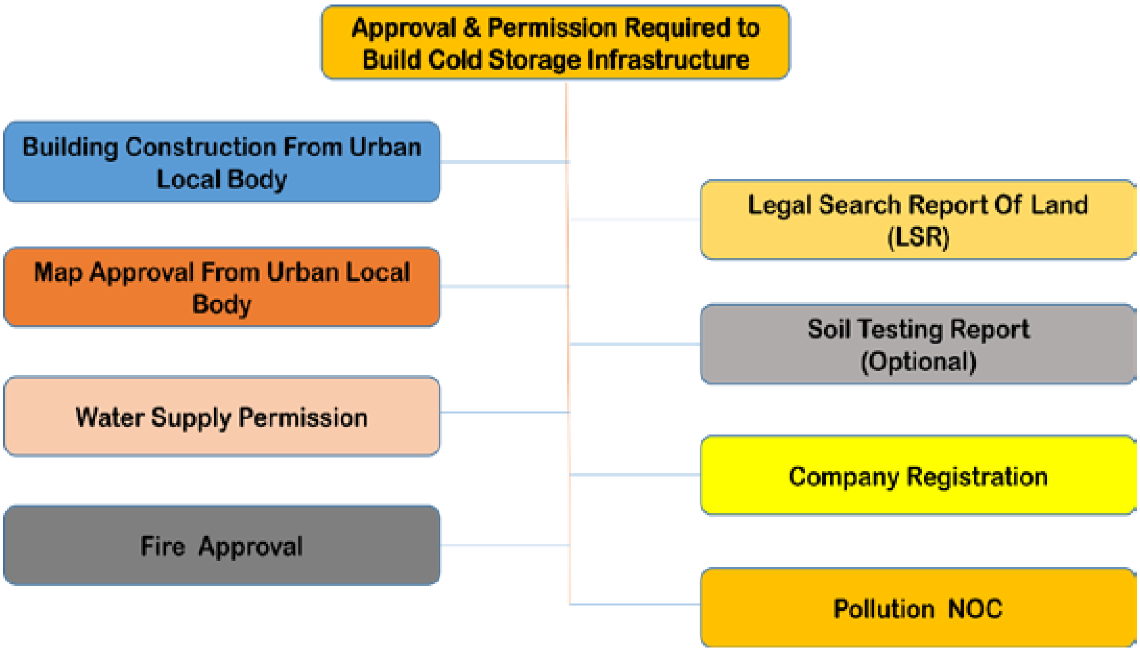


Figure 3.9: Regulatory requirements for setting up cold storage infrastructure

4. CASE STUDIES ON THE ADOPTION OF AMMONIA AND LOW-GWP REFRIGERANTS

4.1 Case studies:

India is steadily transitioning toward the use of low-GWP refrigerants, in line with the Kigali Amendment to the Montreal Protocol, which mandates the gradual phase-down of hydrofluorocarbons (HFCs). Among the preferred alternatives, ammonia (NH_3) stands out as a natural refrigerant with zero Ozone Depletion Potential (ODP) and very low Global Warming Potential (GWP). It is already being widely adopted across the country, particularly in large-scale industrial refrigeration setups such as cold storages. In India many cold storage facilities have implemented ammonia-based refrigeration systems due to their high thermal efficiency and low environmental impact. These installations are representative of a growing national trend toward environmentally responsible cooling technologies.

Countries around the world, particularly in Europe, Japan, and North America, are leading in the adoption of natural and low-GWP refrigerants. Ammonia has long been used in industrial refrigeration in these regions, often integrated with CO_2 systems for added safety and efficiency. Europe, through its F-Gas Regulation, has set strict limits on the use of high-GWP refrigerants, promoting alternatives like ammonia, CO_2, and hydrocarbons.

4.2: Implementation of non-ODS and low GWP refrigerant technologies in the cold chain sector

Several cold storage facilities across India are increasingly adopting low-GWP and non-ODS refrigerant technologies as part of the shift toward sustainable and energy-efficient operations. These efforts not only help in reducing greenhouse gas emissions but also improve system performance and offer long-term cost benefits.

For instance, a feasibility study in Andhra Pradesh demonstrated the successful transition from R-404A to an NH_2–CO_2 brine refrigeration system in seafood and cold storage plants. This change led to 24–30% energy savings across varying load conditions, a reduction in CO_2 emissions by approximately 119–241 tonnes per year, and annual cost savings of ₹90–180 lakh (₹9–18 million). The system also proved financially viable, achieving a payback period of less than four years.

Similarly, a case study of Saw Anand Cold Storage in Nashik, carried out under the guidance of the Association of Ammonia Refrigeration (AAR), showcased the benefits of switching from an R-22 based direct expansion (DX) system to an ammonia-based refrigeration system. This upgrade resulted in a 50% reduction in power consumption—from around 153 kW to 81 kW along with a doubling of pre-cooling capacity. As a result, the facility observed improved product quality, a reduced carbon footprint, and an attractive payback period of approximately 5 years.

These real-world examples highlight the growing momentum behind the adoption of eco-friendly refrigerant technologies in India's cold chain sector and underscore the potential for widespread replication of such models.

Best Practices Observed:

Safety First: Strict safety protocols are essential while using the ammonia as refrigerant. Systems must be equipped with sensors calibrated to detect refrigerant concentrations near their Lower Flammability Limits (LFL). Emergency alarms, ventilation controls, and well-documented evacuation procedures are mandatory to mitigate risk. These safeguards ensure that any leak is quickly identified and addressed to protect personnel and property.

Targeted Technician Training: Operating refrigeration systems using ammonia or hydrocarbons requires specialized, hands-on training. Technicians must undergo expert-led programs that emphasize both theoretical understanding and practical exposure. Learning by shadowing experienced professionals helps build confidence and accelerates mastery. Continuous skill development is also crucial to keep pace with evolving technologies and safety protocols.

Regulatory & Standards Alignment: Compliance with national and international standards supports the safe adoption of low-GWP refrigerants. In India, the BIS safety standards for ammonia systems provide structured safety guidance. Globally, the F-Gas Regulations and Kigali Amendment promote phasing down high-GWP substances. Aligning with such standards ensures consistency, environmental compliance, and industry-wide best practices.

4.3: Operation and Management (O&M) of Cold Chain:

It involves overseeing the storage, transportation, and distribution of temperature-sensitive products to maintain their quality and integrity by ensuring they stay within required temperature ranges throughout the supply chain.

4.3.1: Existing practices being followed:

i. Temperature-controlled storage is a key component of cold chain operations in India. Cold rooms, refrigerated warehouses, and insulated containers are widely used to store perishable goods such as fruits, vegetables, dairy products, meat, and pharmaceuticals. These facilities help maintain the required temperature range to preserve product quality and safety throughout storage.

ii. Refrigerated transportation plays a vital role in moving temperature-sensitive goods across various regions. Reefer trucks, vans, and containers are commonly used to ensure that products remain within the desired temperature limits during transit across states and cities. However, the availability and accessibility of such vehicles vary, especially in rural areas.

iii. Pre-cooling and sorting units are employed near farms to remove field heat from freshly harvested produce before storage or transport. This step is crucial in extending the shelf life of agricultural products and maintaining their freshness by reducing the risk of spoilage during subsequent handling and distribution.

iv. Cold storage facilities follow safety standards as per BIS 4544:2025, ensuring a basic level of compliance across the sector. Common safety practices include the use of ammonia masks, safety valves, and firefighting systems to protect personnel and infrastructure in case of emergencies. Additionally, the consistent display of safety instructions within the premises helps reinforce awareness and adherence to safety protocols among workers and operators.

4.3.2: Capacity building requirement for operators and associated manpower:

Capacity building for operators and associated manpower is essential to ensure the efficient and safe operation of cold chain systems. This includes comprehensive training in the handling of temperature-sensitive products, operation and maintenance of refrigeration equipment, understanding various cooling technologies—including ammonia-based systems—and strict adherence to safety protocols.

Currently, the Association of Ammonia Refrigeration (AAR), based in Pune, is the only specialized center providing training to operators specifically in the handling of ammonia-based refrigeration systems. AAR plays a key role in promoting the safe use of ammonia as a refrigerant by offering education, technical information, standard operating procedures, and training materials.

4.4 Field visits to various cold storage facilities:

Field visits were conducted to 21 cold storage facilities across the country. Data was collected on several aspects, including the types of refrigerants in use, refrigeration capacities, commodities stored, refrigeration systems installed, compliance with safety norms, and the adoption of energy-efficient technologies. Data collected on these aspects was collated and summary is presented below in Table 4.1.

Table 4.1: Details of cold storages data collected during field visits

Name of the cold storage	Type of Commodity to be stored and storage capacity	Total Refrigeration Load	Types of Refrigerants Used	Whether safety norms are followed or not (As per BIS 4544:2025)	Details of Energy recovery system used on not	Details of Sensors installed
M/s. S K Cold Storage Village Lalouri Kalan Tehsil Samral District Ludhiyana (P.B.)	Potato 7500 MT (05 Chambers)	535 kW (03 Mycom compressor installed Total Refrigeration Capacity 1104Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	05 No of Energy recovery system provided Make A one logic solutions VFD for compressor is provided	Temperature, RH, CO_2 and Ammonia sensors are provided in each chamber
M/s Fashion Suitings Private Limited, Plot No. P-1, Araji No. 684,685,686,687,688, Kesariya Industrial Park, Near RSEB Grid, Growth Centre, Revenue Village-Swaroopganj, Tehsil-Hamirgarh, District Bhilwara, Rajasthan	Spices 5764 MT (05 Chambers)	535 kW (03 Mycom compressor installed Total Refrigeration Capacity 705Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided Make A one logic solutions VFD for compressor is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber

Name of the cold storage	Type of Commodity to be stored and storage capacity	Total Refrigeration Load	Types of Refrigerants Used	Whether safety norms are followed or not (As per BIS 4544:2025)	Details of Energy recovery system used on not	Details of Sensors installed
M/s MAA Bhagwati Cold Storage Village.- Thawlay, Tal.- Dr. Ambedkar Nagar, Distt.- Indore (M.P.)	Potato 5600 MT (05 Chambers)	388 kW (03 Mycom compressor installed Total Refrigeration Capacity 821Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s Shiv Shakti Cold Storage Village Guradiyakala, Tehsil-Bagli, Distt.- Dewas (M.P.)	Potato 6500 MT (05 Chambers)	398 kW (03 Mycom compressor installed Total Refrigeration Capacity 821Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s Mangal Murti Kishan Sewa Kendra Village Manpura Tehsil Kumbhraj District Guna (M.P.)	Spices 7500 MT (04 Chambers)	260 kW (03 Kirloskar compressor installed Total Refrigeration Capacity 1020Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	Not required in case of dry product	Temperature, RH and Ammonia sensors are provided in each chamber
M/S Mithulal Kacholiya Cold Storage Llp On C-7/2 At Limbada Midc Hingoli Tq District Hingoli (M.H.)	Tamarind, Dry Red Chili, spices 03 Chambers Total capacity 6500MT	372 kW (03 kirloskar compressor installed Total Refrigeration Capacity =709kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	Not required in case of dry product	Temperature, RH and Ammonia sensors are provided in each chamber
M/s. Sunanda Enterprises Gummanahalli Road Byadgi, Taluka Haveri District Karnataka	Tamarind, Dry Red Chili, spices 03 Chambers Total capacity 6500MT	205 kW (10 compressor installed Total Refrigeration Capacity =235 kW)	R404A Freon based Refrigeration system installed	All safety arrangements are followed as per the standards: (safety valves, firefighting system)	Not required in case of dry product	Temperature and RH sensors are provided in each chamber
M/s. Kamal Chand Kailash Chand cool chain Pvt Ltd Village Rajidpur Saboli Tehsil Rai District Sonipat (HR)	Fruits, vegetables Tamarind, Dry Red Chili, spices 16 Chambers Total capacity 8956MT	598 kW (03 Mycom compressor installed Total Refrigeration Capacity 821Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber

Name of the cold storage	Type of Commodity to be stored and storage capacity	Total Refrigeration Load	Types of Refrigerants Used	Whether safety norms are followed or not (As per BIS 4544:2025)	Details of Energy recovery system used on not	Details of Sensors installed
M/s / GURUKRIPA COLD STORAGE KH # 3/1/3, Village SUHAGPURA Tahsil: Pithampur, Distt: Dhar MP	Potato 6100 MT (05Chambers)	491 kW (03 kirloskar compressor installed Total Refrigeration Capacity =709kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s / MAA PARVATI COLD STORAGE Ambedkar Nagar District Indore (M.P.)	Potato 6230 MT (05Chambers)	462 kW (03 kirloskar compressor installed Total Refrigeration Capacity =709kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s CHOUDHARY COLD STORAGE Kh. No. 428, 429 & 430 Village Agra, Tehsil Hatod, District Indore (M.P.)	Potato 6230 MT (05Chambers)	462 kW (03 kirloskar compressor installed Total Refrigeration Capacity =709kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s. B G Sheetgrah Pvt Ltd. Village Agvar Khas, Etmadpur Khandauli Road Tehsil Etmadpur, District Agra (U.P.)	Potato 3514 MT (02Chambers)	311 kW (01kirloskar compressor installed Total Refrigeration Capacity =368kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	01 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s. Priyanka Cold Storage, Chintakunta Village, Markapur Mandal, Prakasam Dist., (A.P.)	Tamarind, Dry Red Chili, spices 04 Chambers Total capacity 12450MT	398 kW (03 Mycom compressor installed Total Refrigeration Capacity 821Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (safety valves, firefighting system)	Not required in case of dry product	Temperature and RH sensors are provided in each chamber
M/s. Renuka Cold Storage Ponnekallu Village, Tadikonda Mandal, Guntur Dist., (A.P.)	Tamarind, Dry Red Chili, spices 04 Chambers Total capacity 10480MT	370 kW (03 Mycom compressor installed Total Refrigeration Capacity 821Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (safety valves, firefighting system)	Not required in case of dry product	Temperature and RH sensors are provided in each chamber

Name of the cold storage	Type of Commodity to be stored and storage capacity	Total Refrigeration Load	Types of Refrigerants Used	Whether safety norms are followed or not (As per BIS 4544:2025)	Details of Energy recovery system used on not	Details of Sensors installed
M/s. Venkatesh Cold Storage Pvt Ltd at Katha No. 187 Sy. No. 70/5 Kalkere Village Nargund Taluka Gadag District Karnataka	Tamarind, Dry Red Chili, spices 03 Chambers Total capacity 10300MT	320 kW (20 compressor installed Total Refrigeration Capacity =325 kW)	R404A Freon based Refrigeration system installed	All safety arrangements are followed as per the standards: (safety valves, firefighting system)	Not required in case of dry product	Temperature and RH sensors are provided in each chamber
M/s Sanjot Cold Storage At- Survey No: 224/2/1/1, Village Morod haat, Tehsil: Khudel, Dist: Indore (MP)	Potato 6320 MT (05Chambers)	462 kW (03 kirloskar compressor installed Total Refrigeration Capacity =709kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s. Pyasa Cold Storage Village Dhinsa Tehsil Ferozpur District Ferozpur (P.B.)	Potato 5520 MT (04Chambers)	400 kW (02 Frick India compressor installed Total Refrigeration Capacity =739kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	04 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s J P Agro food Village Garhi Tarkhana Samrala Road Machhiwara Samrala District Ludhiana (P.B.)	Potato 6086 MT (06Chambers)	462 kW (03 Mycom compressor installed Total Refrigeration Capacity =1293kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	06 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber
M/s Salasar Agro Preservation Pvt Ltd. MIDC Industrial Area District Latur (M.H.)	Tamarind, Dry Red Chili, spices 02 Chambers Total capacity 7125MT	370 kW (03 Mycom compressor installed Total Refrigeration Capacity 884Kw)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (safety valves, firefighting system)	Not required in case of dry product	Temperature and RH sensors are provided in each chamber
M/s SHIVGORI Cold Storage Pvt. Ltd Khasra No. 28/1/1, Vill.- Amba Chandan, Taluka-Mhow, Distt.- Indore (M.P.)	Potato 6150 MT (10 Chambers)	450 kW (03 Metalex compressor installed Total Refrigeration Capacity =963kW)	Ammonia (Over feed refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	02 No of Energy recovery system provided VFD for ACU is provided	Temperature, RH, CO_2, and Ammonia sensors are provided in each chamber

Name of the cold storage	Type of Commodity to be stored and storage capacity	Total Refrigeration Load	Types of Refrigerants Used	Whether safety norms are followed or not (As per BIS 4544:2025)	Details of Energy recovery system used on not	Details of Sensors installed
M/s. Indraprastha Ice and Cold Storage Pvt Ltd Village Boyal Mauza Nirmand Talika Nirmand and District Kullu (H.P.)	Apple 7800 MT (31 Chambers	530 kW (03 Frick India compressor installed Total Refrigeration Capacity =1383kW)	Ammonia (Binary refrigeration system)	All safety arrangements are followed as per the standards: (Ammonia mask, safety valves, firefighting system)	CA components (Nitrogen generator, CO_2 scrubber, gas analyzer etc. are provided VFD for ACU is provided	Temperature, R H, CO_2, and Ammonia sensors are provided in each chamber

Table 4.1 depicts present status of cold storages during the site visit. The field study covered a wide range of commodities stored in cold chain facilities, including potato, spices, tamarind, dry red chili, fruits such as apple, and vegetables. Storage capacities varied between 3,500 MT and 12,500 MT, with most units operating 4–6 chambers, while advanced facilities, such as the controlled atmosphere (CA) apple storages in Himachal Pradesh, had up to 31 chambers.

Ammonia-based overfeed systems emerged as the predominant refrigeration technology due to their efficiency and cost-effectiveness, with only a few exceptions using R404A Freon-based systems in Karnataka and Andhra Pradesh. Installed refrigeration loads typically ranged between 200–600 kW, with total refrigeration capacities of 350–1,300 kW, highlighting the sector's high energy demand.

Most facilities reported compliance with BIS 4544:2025 safety standards, maintaining ammonia masks, safety valves, and firefighting systems, though dry commodity stores placed less emphasis on ammonia-specific protective gear. Energy efficiency measures such as energy recovery systems (1–6 units depending on scale) and Variable Frequency Drives (VFDs) for compressors and air handling units were commonly observed, while facilities handling dry commodities often did not employ recovery systems due to lower cooling requirements.

Monitoring systems were generally equipped with temperature and relative humidity sensors, with potato and other perishable stores also integrating CO_2 and ammonia detection, whereas dry commodity stores relied on partial automation. The CA storages demonstrated higher technological sophistication, incorporating gas analyzers, CO_2scrubbers, and nitrogen generators.

5. KEY FINDINGS AND CONCLUSIONS

The growth of ammonia-based cold storage in India is driven by the increasing demand for effective post-harvest infrastructure to reduce food losses and support the country's growing cold chain infrastructure. Ammonia based cold storage system are widely used in India across various sectors including agriculture perishable storage, dairy, food processing etc., due to its efficiency and environmental benefits as it has zero ODP and GWP. The key findings from the study are presented below:

- **Mounting of Sensors for Temperature and Relative Humidity (RH):** In most cold storages, sensors are mounted only at a single mezzanine floor, which makes it difficult to detect temperature and humidity inhomogeneity within the storage area. Such uneven distribution can adversely affect the quality and shelf life of stored food products. To overcome this issue, it is recommended to install multiple sensors at different levels and locations, ensuring accurate monitoring and uniform environmental conditions throughout the storage facility.
- **Use of Calibrated Monitoring Systems:** In many cold storage facilities, the monitoring systems are not properly calibrated, which negatively impacts overall performance and temperature control. Therefore, it is recommended to use regularly calibrated monitoring instruments to ensure accurate readings, efficient operation, and proper preservation of stored commodities.
- **Improvement in Safety Devices:** It was noted that in few cases water sprinkling systems were not installed in the storage chambers or machine rooms, posing a potential safety risk. Therefore, it is recommended to enhance safety measures.
- **CO_2 Sensor Mounting:** CO_2 sensors should be installed at the bottom of the last mezzanine floor to accurately measure the concentration of CO_2 within the storage chamber. However, it has been observed that some users are mounting these sensors in the middle levels and therefore, it is recommended to install CO_2 sensors at the appropriate location i.e. bottom of the last mezzanine floor to ensure reliable monitoring.
- **Synchronization of operating energy recovery devices with CO_2 generation:** In several cold storage facilities, energy recovery systems are not automatically integrated with CO_2 sensor readings. Consequently, the system does not adjust in response to fluctuations in CO_2 levels, posing potential risks to the quality and safety of stored products. To address this, it is recommended that energy recovery devices be operated in automatic mode, allowing real-time synchronization with CO_2 levels for improved storage conditions.
- **Installation of Programmable Logic Control (PLC) Systems:** It has been observed that many cold storage facilities do not use Programmable Logic Control (PLC) systems, resulting in refrigeration systems being operated manually. This manual operation often leads to difficulty in maintaining consistent storage conditions, which can compromise the quality of stored food items. Therefore, it is strongly recommended that PLC systems be installed across all cold chain infrastructure to enable automated, precise, and reliable operation of refrigeration systems.
- **Code of practices and standards:** There is need for cold storages to follow the code of practices guideline and updated standards for installation, operation and maintenance of cold systems.

- **Promote awareness about selection of refrigeration system:** In several cold storages across India, refrigeration systems are frequently installed with undersized condensers. This significantly affects the overall performance and efficiency of the storage facilities. To address this issue, it is essential to provide initial training to cold storage owners on the proper selection and sizing of refrigeration system components. Such awareness will ensure optimal system performance, improved energy efficiency, and longer equipment life. There is a need to promote adoption of low GWP and energy-efficient refrigeration systems.
- **Training for Operator:** The cold storage systems are often managed by operators relying primarily on personal experience rather than formal training. This lack of structured training can result in inefficiencies and potential safety concerns. It is therefore recommended that mandatory training programs be introduced for all operators. Such programs will support efficient handling of cold storage systems, encourage better energy consumption practices, enhance operational reliability, and reduce maintenance issues.
- **Certification System:** A mandatory certification system should be implemented for all personnel working with ammonia-based refrigeration systems. This will ensure that only trained and qualified individuals handle refrigeration systems, minimizing safety risks. Certified training will also enhance operational efficiency and compliance with safety standards.
- **Knowledge Sharing Facilitation:** Workshops, study tours, and interactive platforms should be organized to promote knowledge exchange among stakeholders in the cold chain sector. These initiatives will enable sharing of best practices, new technologies, and operational experiences.
- **Showcase Success Stories:** Implement pilot projects to demonstrate the efficiency and cost savings of advanced cold storage technologies. These success stories can serve as real-world examples to encourage wider adoption of energy-efficient and environmentally friendly systems.

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