Study on

Low-GWP alternative technologies in the

Transport Refrigeration Sector

OZONE CELL

Ministry of Environment, Forest and Climate Change (MoEF&CC)

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MESSAGE

India's transport refrigeration market is growing rapidly, driven by the expanding food and pharmaceutical industries. With the technological advancements, improving cold chain logistics, the transport refrigeration sector is projected to see significant growth in the coming years.

While the growth in transport refrigeration will be associated with significant environment and socio-economic implications, it is imperative that policy measures are adopted to reduce cooling requirement, refrigerant consumption as well as energy demand in this sector. Towards this, the India Cooling Action Plan (ICAP) recommends adoption of low GWP alternative technologies in different sectors including transport refrigeration.

Low global warming potential (GWP) technologies in transport refrigeration offer environmental benefits in addition to operational advantages of improved energy efficiency and the potential for technological innovation in system design, components, and safety.

This study assesses the feasibility of adoption of low GWP technologies in the transport refrigeration and proposes measures for promoting their adoption. I congratulate all those involved in the preparation and consultation of this report.

(Bhupender Yadav)

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एक कदम स्वच्छता की ओर

सत्यमेव जयते

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भारत सरकार
MINISTER OF STATE
ENVIRONMENT, FOREST AND CLIMATE CHANGE
EXTERNAL AFFAIRS
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MESSAGE

The transport refrigeration sector is experiencing significant growth driven by rising demand for temperature-controlled goods like pharmaceuticals and food, the expansion of e-commerce and the increasing need for sophisticated cold chain logistics. Technological advancements in refrigeration units and the expansion of the food and pharmaceutical industries are also key factors for this this upward trend. Towards this it is imperative that policy measures are adopted to reduce cooling requirement, refrigerant consumption as well as energy demand in this sector.

The India Cooling Action Plan (ICAP) has specific recommendations for reducing cooling and refrigerant demand and promoting sustainable cooling in various sectors, including transport refrigeration sector. Adoption of low global warming potential (GWP) technologies in the transport refrigeration sector will not only enable to meet the targets under the Montreal Protocol including its Kigali Amendment but also ensure a sustainable supply chain by maintaining quality of food and critical items like vaccines, extended product shelf life and broader market access.

The publication of the study report on “low GWP technologies in the transport refrigeration sector” would serve as an important resource material and should be disseminated widely amongst all concerned stakeholders.

(Kirti Vardhan Singh)

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AND CLIMATE CHANGE

MESSAGE

Transport refrigeration sector in the country is expanding with increased use of refrigerated trucks for transporting perishable goods and commodities and advancements in technology like temperature-monitoring devices. With the current fragmented cold chain, transport refrigeration sector has substantial opportunities for growth.

Transport refrigeration is a significant part of the cold chain. Transitioning to low Global Warming Potential (GWP) technologies is a vital step in the larger effort to combat climate change by reducing greenhouse gas emissions from refrigerated transport units as well as preserving the quality of perishable goods like food and medicine. The expanding global trade, and advancements in cold chain technology necessitates sustainable refrigeration systems with greater fuel efficiency, stringent environmental regulations and safety standards.

The study assesses the low-GWP technology options in the transport refrigeration sector and will be a useful reference document for all the concerned stakeholders. I compliment the team associated with the preparation of this report.

(Tanmay Kumar)

Place: New Delhi
Dated: September 12, 2025

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1. Background

India's cold chain infrastructure, encompassing an integrated network of temperature-controlled storage, transportation, and distribution facilities, plays a pivotal role in ensuring food security, reducing post-harvest losses, and supporting the pharmaceutical and healthcare sectors. With a diverse agro-climatic landscape and growing demand for perishable goods, the cold chain has emerged as a critical enabler of economic growth, rural development, and public health. The sector has witnessed robust growth in recent years, driven by rising demand from organized retail, food processing, e-commerce, exports, and rising need for healthcare. Valued at approximately INR 2,287.5 billion in 2024, the Indian cold chain market is projected to reach INR 6,061.7 billion by 2033, exhibiting a growth rate (CAGR) of 10.86% during 2025-2033 (IMARC, 2025).

Transport refrigeration, particularly through refrigerated vehicles or "reefers," forms the backbone of the cold chain logistics network. The figure below illustrates a typical reefer vehicle. These mobile units ensure temperature-controlled movement of perishables such as fruits, vegetables, dairy, meat, seafood, and vaccines across vast distances. As India expands its cold chain capacity, the number of reefers is projected to grow significantly, driven by rising consumer demand, export ambitions, and government initiatives to strengthen agricultural value chains. This acceleration brings a dual challenge: increased energy consumption and a corresponding rise in greenhouse gas (GHG) emissions. Transport refrigeration systems typically rely on high-GWP (Global Warming Potential) refrigerants such as hydrofluorocarbons (HFCs), which significantly contribute to climate change through leakage and end-of-life losses. Additionally, the dominance of diesel-powered refrigeration units contributes significantly to CO_2 emissions from fuel consumption, exacerbating climate change.

This study focuses on the road-based refrigerated transport sector, since it is the most relevant and widely used mode in India's cold chain. Road-based reefers handle the majority of refrigerated trips and tonnage- including first/last-mile and most intercity distribution (NITI Aayog, RMI and RMI India, 2021). The below Figure 1 shows a typical road-based refrigerated vehicle.

Adopting low-GWP refrigerants and technologies in transport refrigeration systems is essential to reduce climate impacts and to meet India's Montreal Protocol obligations through HPMP Stage III, and HFC phasedown.

Figure 1: Road-based refrigerated vehicle

Source: Microsoft. (2025). Microsoft Copilot (Image generation) [Artificial intelligence system]. https://copilot.microsoft.com/

2. About the Study

To proactively address the challenges posed by the refrigerated transport vehicles in the cold chain sector, the Ozone Cell, Ministry of Environment, Forest and Climate Change (MoEF&CC), with the United Nations Environment Programme (UNEP) as the implementing agency, has initiated this study under the non-investment component of India's HPMP Stage-III, which focuses on sector-based policy development and awareness.

The primary objective is to develop a comprehensive knowledge base and a set of actionable recommendations to accelerate the adoption of low-GWP and climate-friendly technologies in India's transport refrigeration sector. It aims to build awareness across the cold chain ecosystem by providing a clear understanding of the current landscape, viable low-GWP alternatives, and best global practices. Ultimately, the study seeks to create a strategic roadmap for India that reduces both direct (refrigerant) and indirect (energy) emissions while enhancing cold-chain reliability and safety.

2.1 Methodology and **Scope of the Study**

To achieve the study's objectives, a multi-pronged methodology was adopted, combining desk research, extensive stakeholder consultations, and on-ground field visits. This approach ensured that the findings are based on a robust evidence base, validated by real-world insights, and directly aligned with the agreed-upon Scope of Work (SoW) (Figure 2).

a. Desk Research

A comprehensive literature review was conducted to build a foundational understanding of the sector. This involved analyzing industry reports, academic papers, government publications, and international standards. This research was instrumental in addressing the following SoW requirements:

SoW 1 & 2

Mapping the available non-ODS and low-GWP refrigerant technologies and identifying global practices and trends.

SoW 3

Compiling information on existing safety guidelines and standards from the Bureau of Indian Standards (BIS) and Bureau of Energy Efficiency (BEE).

SoW 6

Documenting international case studies of successful low-GWP technology implementation to draw lessons for India.

b. Stakeholder Engagement

Direct engagement with key players across the cold chain ecosystem was crucial for gathering primary data and validating research findings. One-on-one interviews and group consultations were held with transport operators, refrigeration system manufacturers, vehicle OEMs, government agencies, and academic experts. This engagement directly informed:

SoW 4

Identifying the practical gaps, challenges, and risks associated with adopting low-GWP technologies in the Indian context.

SoW 5

Assessing the perceived and experienced benefits (economic, environmental, and operational) of transitioning to new technologies.

SoW 6

Exploring the infrastructure requirements, supply chain issues, and servicing challenges that could impede widespread adoption.

c. Site Visits

Site visits were conducted to observe reefer vehicles in operation, providing ground-level insights into day-to-day practices and implementation realities. The team examined deployed technologies, insulation quality, and maintenance protocols. These visits were vital for:

SoW 1 & 4

Gaining a practical understanding of established technologies in use and the operational challenges faced by fleet owners and drivers.

SoW 5

Observing factors influencing energy efficiency and emissions, such as door-opening frequency, loading patterns, and maintenance quality

d. Analysis and synthesis

The insights gathered from all three activities were triangulated, analyzed, and synthesized to formulate a holistic view of the sector. This final step was essential for developing a set of prioritized and practical solutions, directly fulfilling.

SoW 8

Providing evidence-based recommendations to accelerate the adoption of non-ODS and low-GWP refrigerants in India's transport refrigeration sector.

Desk Research

- Reviewed industry reports, academic papers, govt publications, international and national standards
- SoW: 1& 2 (map non-ODS/low-GWP tech, global trends); 3 (BIS/BEE safety standards); 6 (international case studies)

Stakeholder Engagement

- Interviews/consultations with operators, system manufacturers, vehicle OEMs, govt agencies, academia.
- SoW: 4 (gaps, challenges, risks); 5 (benefits: economic, environmental, operational); 6 (infrastructure, supply chain, servicing)

Site Visits

- Observed reefer operations: deployed tech, insulation quality, maintenance protocols
- SoW: 1 & 4 (tech in use, operational challenges); 5 (drivers of energy/ emissions: door openings, loading, maintenance)

Analysis and synthesis

- Triangulated insights to prioritize practical solutions
- SoW: 8 (evidence-based recommendations to accelerate non-ODS/low-GWP adoption)

Figure 2: Methodology and Scope of Work

3. Landscape of the Refrigerated Transport in Cold Chain in India

This chapter examines the role of refrigerated vehicles across agriculture, dairy, and pharmaceutical supply chains. It segments reefers by vehicle class and payload, and summarizes the prevailing refrigeration technologies, commonly used refrigerants, insulation materials, and digitization practices in current fleets. It also evaluates low-GWP alternatives for each element—technology, refrigerants, insulation, and digital controls—highlighting feasibility, readiness, and implications for performance and safety.

This study focuses on the following key sectors:

1. Agriculture (perishables)

- **Supply chain:** Produce moves from farm/collection points to a packhouse for rapid pre-cooling and short-term holding. It then goes either to cold storage/ripening rooms or directly onto long-haul routes to distribution centres, followed by urban distribution to retail and consumers. Export consignments typically branch off after the packhouse or cold store and move to ports/inland container depots (ICDs), often in reefer containers. Reefer linkages in the agricultural supply chain are shown in Figure 3 below.
- **Temperature requirements:** Temperature handling for fresh fruits and vegetables is in the range of 0–13°C, and between -18°C to −20°C for frozen food (ARCON Blogs, 2025). The Engineering Guidelines and Minimum System Standards (EG&MSS) 2025 by National Centre for Cold-Chain Development (NCCD)) (NCCD, 2025) mentions the various temperature ranges for fruits and vegetables.
- **Reefer application:** Typically, reefers are used while transporting a high-temperature-sensitive/high-value produce, or when the route is long (if perishable commodity is to be transported intercity), for export, or when the export/buyer requires logs, transport of frozen products, or for perishables which must retain shelf life. In some cases, E-commerce companies requiring good-quality produce may use reefers for transporting agricultural products.

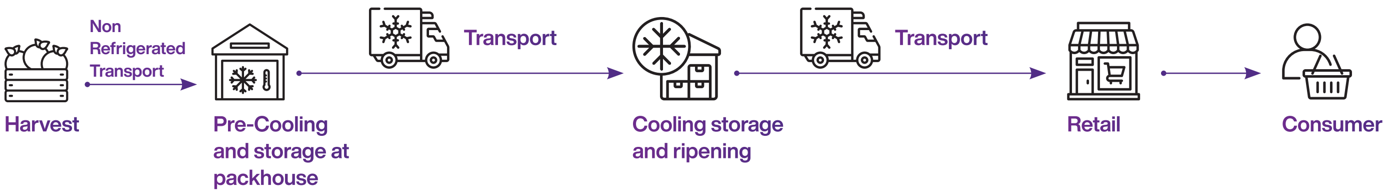


Figure 3: Application of reefers in the agriculture sector

2. Dairy

- **Supply chain:** Dairy farmers in remote areas produce milk. Milk is collected at village-level centres and then transported to chilling centres or bulk milk cooling units, where it is cooled to about 4°C to slow down spoilage. Processed milk and dairy products are then transported in reefer trucks to retail stores, food service, and directly to consumers (Figure 4).
- **Temperature requirements:** Milk is typically chilled to about 4°C and kept near this temperature in insulated/refrigerated road tankers; ice cream is stored and transported at −18°C or below (FSSAI, 2018).
- **Reefer application:** Bulk insulated tankers handle raw milk, and finished goods move on reefer vans up to 20–24 ft trucks, with phase change material (PCM) solutions supporting frequent urban drops.
  - » Operations prioritize quick turnarounds, strict cleaning of tankers, sanitized crates, and tight temperature and door discipline to protect product quality.

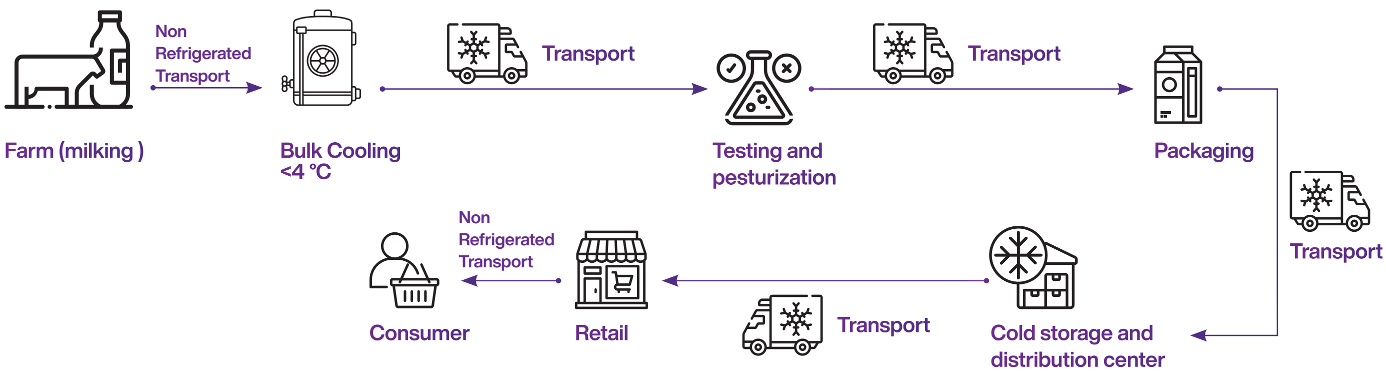


Figure 4: Application of reefers in the dairy sector (milk)

3. Pharmaceuticals:

- **Supply chain:** Vaccines are first produced at manufacturing units and then transported, often via refrigerated vehicles (reefers), to the National Vaccine Store. From there, they move through State and District Vaccine Stores, each equipped with cold chain infrastructure like walk-in coolers and ice-lined refrigerators. At the local level, vaccines are delivered to Primary Health Centres (PHCs) and sub-centres using cold boxes and carriers, where they are finally administered to beneficiaries. Reefer linkages in the pharmaceutical supply chain are shown in Figure 5 below.
- **Temperature requirements:** Vaccines are usually maintained 2–8°C (vaccines) from storage to transport in reefers. Only a limited share that needs sub-zero conditions is moved in reefers, often with dry ice (ARCON Blogs, 2025).
- **Reefer application:** Transport relies on small to mid-size reefer vans and 9–20 ft trucks equipped with calibrated sensors, continuous data loggers, and temperature-mapping, while many urban and last-mile drops use insulated boxes with PCM inside non-reefer vans or bikes.
  - » Operations follow strict loading and door discipline, segregated storage by temperature class, sealed consignments with GPS geofencing and tamper-evident locks, rigorous calibration and audit schedules, and multi-drop city routes are planned to minimize temperature excursions in India's high-traffic, high-heat conditions.

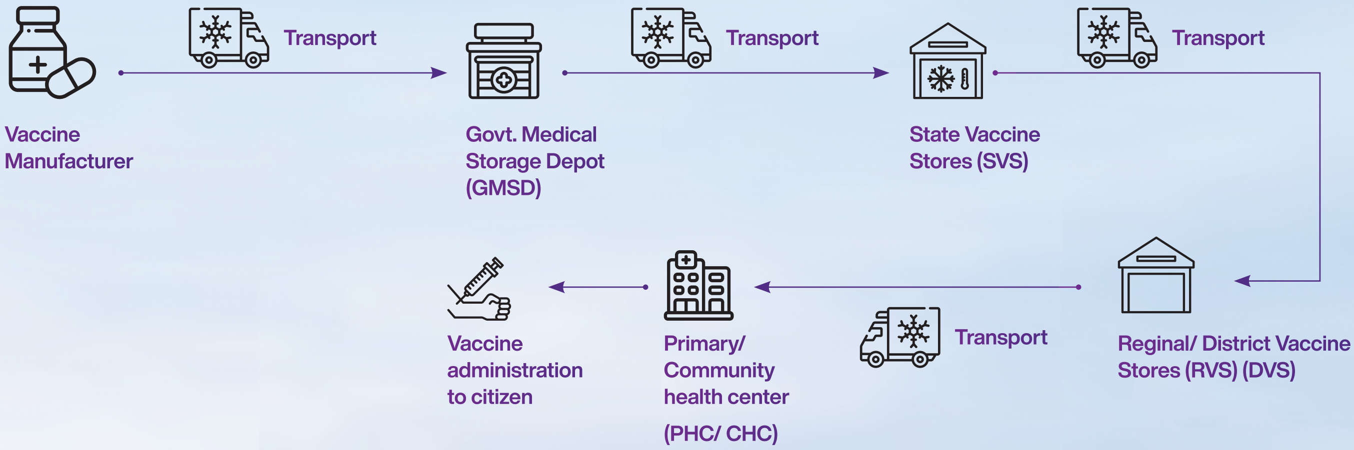


Figure 5: Application of reefers in the pharmaceutical sector (Vaccines)

Interoperability of reefer vehicles

Operators may deploy the same reefer trucks across dairy, agri/horticulture, meat, and pharma lanes with suitable temperature maintained within the reefer based on the produce being transported and the particular application. Pharma sector application is more stringent as compared to the other value chains, which may include lane validation and documentation before the reefer operation.

The notable exceptions are bulk milk, which typically moves in insulated (non-refrigerated) tankers, and ultra-cold pharma, which is handled using passive packaging rather than vehicle-based refrigeration.

3.1 Market Segmentation

Vehicle Type:

Small-format vehicles are primarily urban delivery vans, accommodating payloads generally from 0.5 to 3 tons for products like milk pouches, bakery items, frozen snacks, and pharmaceuticals. Medium-duty trucks (payloads of 3-18 tons) cater to processed food, pharmaceutical, and seafood logistics, while heavy-duty trucks (payloads of 18-31 tons) facilitate inter-city transport of meat, dairy products, and vaccines (Table 1).

Table 1: Market segment by vehicle type

Segment	Typical Use Cases	Description	Payload
Small format	Milk pouches, bakery, frozen snacks, pharma	Urban delivery vans	0.5–3 tons
Medium duty	Processed food, pharma, seafood	Intra/inter-city trucks	3–18 tons
Heavy duty	Intercity meat, dairy, and vaccines	Long-haul reefer trucks	18–31 tons

Note: Payloads and use cases have been derived based on consolidated evidence from structured consultations with stakeholders and secondary research; there is no official bifurcation of these segments.

Temperature Application

The sector utilizes diverse temperature ranges to meet specific requirements (Table 2):

- Chilled: Maintains temperatures >0°C (generally, in the range of 1°C to 13°C) for goods such as dairy, vaccines, fruits and vegetables.
- Frozen: Operates at temperatures from ≤ −18°C, for ice cream, seafood, meat, and other frozen foods.
- Multi-temp Trucks: Feature partitions for both chilled and frozen items for enabling efficient multifunctional transport.

Table 2: Market segment based on temperature application

Product Category	Temperature Range	Examples
Chilled	>0°C (generally, in the range of 1°C to 13°C)	Dairy, vaccines, and fruits
Frozen	≤ −18°C	Ice cream, seafood, and meat
Multi-temp Trucks	Chilled + Frozen partitions	Storing products with different temperature requirements

Note: Temperature ranges have been derived based on consolidated evidence from structured consultations with stakeholders and secondary research; there is no official temperature range for these segments.

Fuel Type:

Through our stakeholder consultations and site visits, it has been observed that diesel remains predominant in Indian heavy-duty trucking because it delivers the lowest total cost of ownership on long intercity routes, market availability, ease, performance, and a mature nationwide fueling and service network.

Battery-electric trucks are emerging in small to medium-duty, with return-to-base operations such as urban and short regional delivery. In such cases, the predictable routes and depot charging enable lower operating costs and zero tailpipe emissions under supportive national and state electric vehicle (EV) policies (NITI Aayog & WRI India, 2022).
Hybrid vehicles combine diesel and electric power to cut idling and recover energy during braking. This boosts efficiency and extends range, making them a good fit for intermediate payloads.

Table 3: Market segment based on fuel type

Fuel Type	Description	Usage Scenario
Diesel	Predominantly used in heavy-duty trucks	High payload, long-distance transport, and cost-effective
Electric	Emerging in small to medium-duty vehicles	Short-distance delivery, environmentally friendly
Hybrid	Combines diesel/electric	Intermediate payloads, improved efficiency & range

3.2 Refrigeration Technologies Used in Reefers

Currently used technologies

This section reviews the two predominant refrigeration technologies used in India's refrigerated transport, which are vapor compression refrigeration (VCR) systems and phase change material (PCM)-based systems. Based on stakeholder consultations and desk research, VCR remains the standard for transport refrigeration, while PCM units are typically employed for short hauls or operations with frequent door openings.

Vapor Compression Refrigeration (VCR) Systems:

The vapor compression refrigeration system is the most widely utilized cooling technology in refrigeration applications. It operates on the principle of electricity-driven compressor machines. In this system, the refrigerant undergoes a cyclic process: commencing in the evaporator, where it absorbs heat and transitions to the compressor, undergoing adiabatic compression to high temperature and pressure.

The compressed refrigerant then moves to the condenser for cooling at constant pressure. Subsequently, it is expanded through an expansion valve, leading to a decrease in both temperature and pressure. The evaporator, operating at constant pressure, absorbs heat, facilitating the cooling of the surrounding space. This cycle perpetuates itself, forming the core mechanism of the vapor compression.

From our stakeholder interaction and site visits, the following observations were made:

- The refrigeration units usually let us set temperatures from about −25°C (or lower, depending on the model) up to +15°C, depending on the application.
- VCRs are provided in two main configurations: vehicle-powered direct drive units for vans and light trucks, where the compressor is driven by the vehicle engine. And self-powered transport refrigeration units for medium and heavy trucks and trailers with their own diesel engines.
- Many models are offered with an electric standby to operate from external power at depots.
- Multi-temperature operation is supported through partitioned cargo spaces with multiple evaporators and independent control.

Phase Change Material (PCM) systems:

A PCM-based reefer vehicle incorporates PCMs such as gels, paraffins, or salt hydrates that absorb or release large amounts of heat energy during a phase transition (e.g., from solid to liquid) without much temperature change. PCM-based reefers offer up to 80% savings in operation costs by eliminating the use of diesel to run the refrigeration system (Ozone Cell, MoEFCC, 2021).

Based on the insights from the stakeholder consultations, PCM systems are used mainly on short-haul and last-mile routes in small and medium vans for ice-cream, frozen foods, bakery, and dairy value-added products, and some pharma last-mile, and hence can handle a wide range of temperatures. Lower energy consumption and less frequent refrigeration maintenance reduce operating costs significantly, leading operators to prefer PCM-based reefer vehicles over conventional VCR systems for short-haul transits (Pluss Technologies, 2025).

However, advancements in PCM (Phase Change Material) technologies have made them suitable for long-distance transport, though their widespread adoption remains limited.

3.3 Refrigerants

The Indian cold chain sector plays a crucial role in preserving perishable goods through temperature-controlled transportation, heavily relying on refrigerated containers (reefers). Refrigerants used in these reefers are critical for their operational efficiency and environmental compliance.

In a refrigeration system, refrigerants act as a heat-carrying fluid that absorbs heat from an inside space, cools it, and then releases that heat into a warmer environment, thereby creating a cooling effect. The refrigerant goes through a cycle of changes in pressure and state (liquid to gas and back to liquid) to efficiently transfer heat from the area that needs to be cooled to an exterior location.

Currently used Refrigerants

Hydrofluorocarbon (HFC) refrigerants like R-404A and R-134a have dominated the Indian reefer market due to their excellent thermodynamic performance and system reliability. R-404A is commonly used in larger reefers, while R-134a finds application in smaller or niche units. However, both refrigerants carry high Global Warming Potentials (GWP 3922 for R-404A and 1430 for R-134a), which contribute significantly to greenhouse gas emissions.

Key properties of the prevalent refrigerants are mentioned in the Table 4 below.

Table 4: Prevalent refrigerants in the reefer vehicles in India- application

Refrigerant	GWP	Application	ASHRAE 34 safety class (flammability)	Key properties/notes
R-134a	1430	Chilled (Medium temperature)	A1 (non-flammable, Low toxicity)	Single-component HFC; moderate pressures; widely used.
R-404A	3922	Frozen (Low temperature)	A1 (non-flammable, Low toxicity)	HFC blend; very high GWP; good low-temp capacity.

3.4 Insulation

Existing Insulation Practices

India's ambient temperatures range from sub-zero in hilly regions to around 45°C or higher in the plains during heat waves, so reefer bodies require adequate insulation thickness, effective vapor/moisture barriers, and smooth, non-absorbent, cleanable GRP/fiberglass interior skins for durability and hygiene. Based on the insights drawn through the stakeholder consultations,

- **Polyurethane foam (PUF)** sandwich panels are widely used in the reefer vehicles. PUF can reliably maintain frozen products down to −25°C and chilled products at +2 to +8°C. It is the preferred material for long-haul agriculture, dairy, seafood, and pharmaceutical applications (NCCD, 2025) particularly in a humid climate. However, to ensure the best insulation performance, it is important to check if the joints are properly sealed to avoid absorption of moisture.

- **Expanded polystyrene (EPS)** is also a commonly used insulating material in reefers for short-haul, small-format reefer vehicles serving e-grocery and urban deliveries. PUF is more commonly used than EPS in reefer vehicles. EPS has a lower upfront cost than PUF and is mostly used in legacy vehicles, but its higher heat leak and moisture susceptibility can increase compressor run-time and energy use, often reducing overall service life and eroding lifetime cost savings.
- **Vacuum Insulated Panels (VIP)** and **aerogel insulations** are the emerging alternatives for insulation practices in India. However, they are in the early stages of adoption. Therefore, the details of the materials are covered under section 5.2.

3.5 Digitization

Digitization plays a supportive, enabling role in India's refrigerated road transport by improving visibility, control, and documentation. Digitization in reefers refers to the adoption of digital technologies to monitor, control, and manage refrigerated transport operations efficiently and transparently. Telematics is a core enabler of this digitization. Telematics systems installed in reefers collect and transmit real-time data (Figure 6) such as:

- GPS location tracking
- Internal temperature and humidity levels
- Compressor and refrigeration system status
- Door open/close events
- Battery status and power usage

When this telematics data is linked to a Transport Management System (TMS), it provides an integrated platform to broadly monitor real-time location and condition, optimize logistics and routing, ensure compliance and quality control, generate automated alerts and reports, and improve documentation and audit trails.

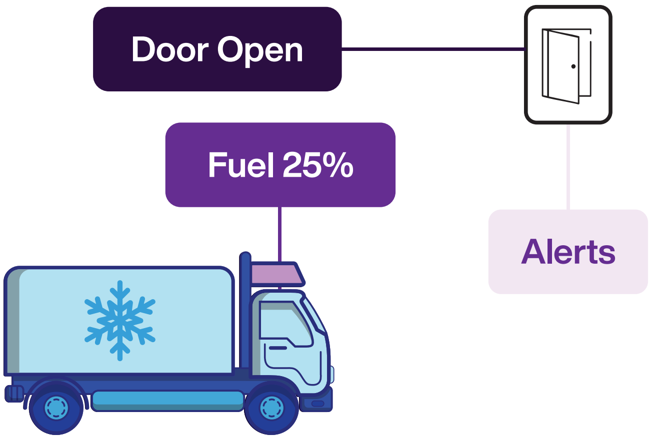


Figure 6: An example of integration of telematics in reefers

Source: Microsoft. (2025). Microsoft Copilot (Image generation) [Artificial intelligence system]. https://copilot.microsoft.com/

The following sections outline current practice and emerging trends as digital monitoring and traceability scale across corridors and last-mile routes:

Current Status

The maturity of digitization in refrigerated transport across India varies significantly across different sectors. Large, organized fleets in industries such as pharmaceuticals, e-commerce, and dairy are among the earliest and most advanced adopters of digital technologies in reefers. In contrast, many MSME (Micro, Small and Medium Enterprises) operators, particularly in the horticulture sector, remain at nascent stages of adoption.

Pharmaceutical companies have comparatively implemented continuous temperature monitoring and data logging systems to ensure compliance with relevant regulatory frameworks. For instance, Indian pharma supply chains leverage IoT-enabled sensors within reefers to maintain real-time temperature control and generate compliance reports during transit, mitigating the risk of product spoilage and maintaining drug efficacy mainly guided by the Good Distribution Practices (GDP). In case of dairy, large and established dairy companies have embraced GPS-based vehicle tracking (Figure 7) and sensors, allowing real-time visibility of fleet location and load conditions. These fleets often supplement telematics with door sensors and fuel monitors, effectively reducing loss and optimizing routes.

Further, pharma cold chains in India have digitalized record-keeping to meet audit requirements, reducing manual errors and enabling faster issue resolution.

Many MSME operators in the horticulture or other sectors struggle to adopt digitization due to high upfront costs for monitoring devices and ongoing subscription fees. Many work in rural areas with patchy mobile coverage, making real-time GPS and IoT use difficult. Limited technical know-how and low awareness of long-term benefits further slow adoption.

Figure 7: GPS vehicle tracking on Indian corridors

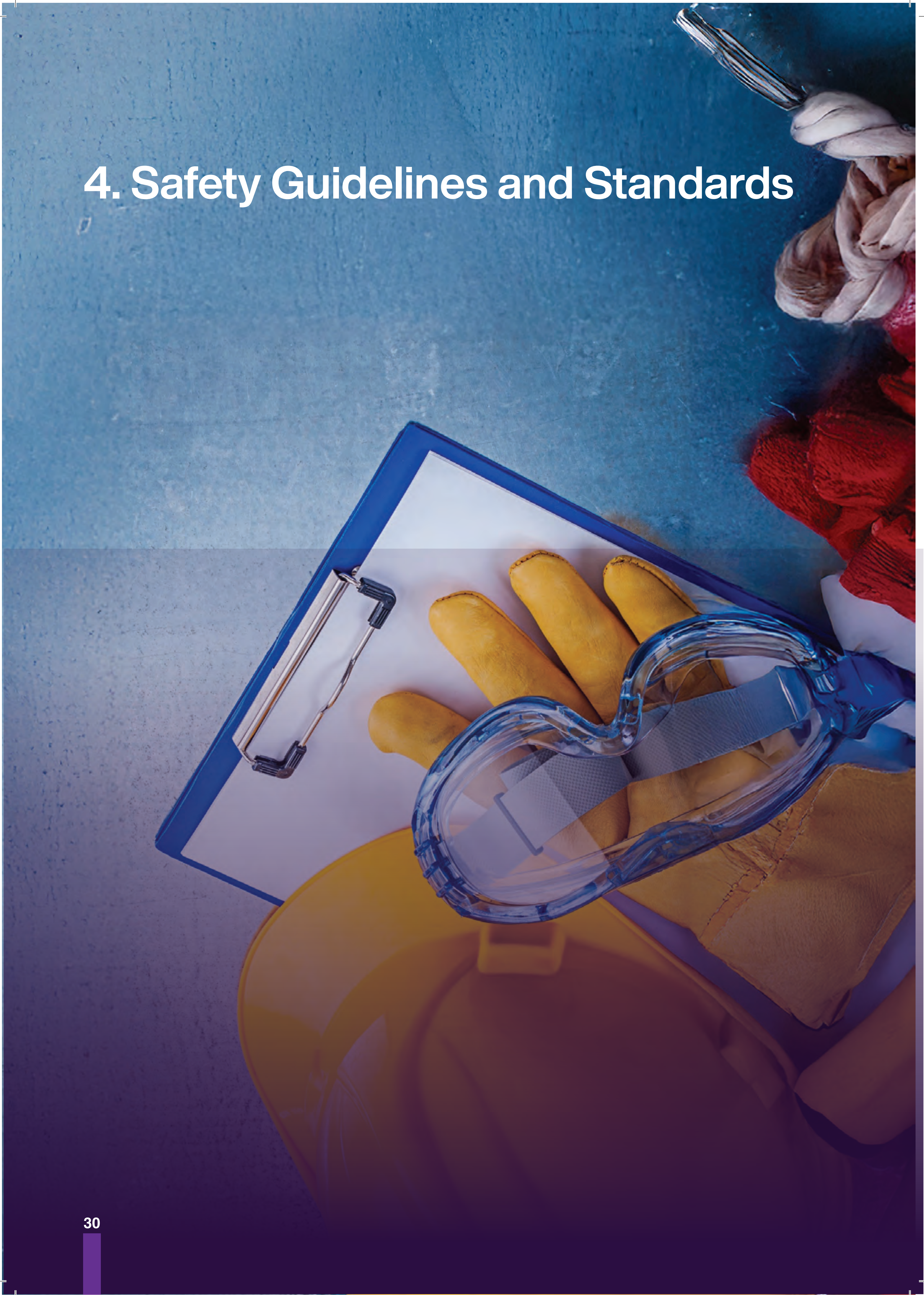
Source: Microsoft. (2025). Microsoft Copilot (Image generation) [Artificial intelligence system]. https://copilot.microsoft.com/

Emerging Trends

The digitization of the refrigerated transport sector in India is moving toward wider use of telematics and data logging in transport operations. The National Centre for Cold-chain Development recommends GPS-based vehicle tracking, continuous temperature monitoring, and calibrated data loggers for cold-chain transport, with documentation for audits (NCCD, 2025).

The National Logistics Policy introduces platforms such as the Unified Logistics Interface Platform to integrate logistics data and services across modes and operators (Ministry of Commerce & Industry (Logistics Division), 2022). In pharmaceuticals, export-oriented track-and-trace requirements mandate serialization and digital reporting. In the vaccine cold chain, operational guidelines specify the use of temperature data loggers during storage and transport to maintain required temperature ranges (Ministry of Health and Family Welfare, 2020). FSSAI guidance similarly emphasizes continuous temperature control and consistent record-keeping during the transport of perishable foods (FSSAI, 2018). These are shaping the adoption of IoT-enabled monitoring in reefer operations in India through explicit requirements and recommended practices.

4. Safety Guidelines and Standards



Understanding and adhering to regulatory standards is crucial for advancing the effectiveness and safety of refrigerated transport within India's cold chain. Safety standards and guidelines define how vehicles are built, how temperatures are controlled, how hygiene is maintained, and how records are kept. This is essential in India's conditions of high heat, long hauls, and dense urban deliveries.

There are sector-specific requirements, e.g.,

- Agriculture sector: guidelines call for commodity-appropriate temperature bands, ventilated crates, gentle handling, and care to avoid chilling injury or wastage.
- Dairy sector: requirements highlight strict cold holding for raw and packaged products, fast door discipline for frequent urban drops, sanitized crates, and routine cleaning and verification at each stage.
- Pharmaceutical: checks are more stringent with validated lanes, sealed consignments, continuous data logging with calibrated sensors, defined alarm response, secure handling, and audit-ready documentation at every handover to protect product potency.

However, the core refrigeration technology and the technical requirements to maintain operational efficiency in reefer vehicles are largely the same across for all the sectors considered in this study.

The standards and guidelines outlined below (Table 5) help to ensure operational safety, promote energy efficiency, and address environmental and technological aspects of refrigerated transport in India:

Table 5: Relevant Safety Guidelines and Standards

Application area	Code/Reference	Key use in reefer operations	Issuing body
Operating best practice	Engineering Guidelines & Minimum System Standards for Implementation in Cold Chain Components	Recommended specifications for insulation, doors/floors, airflow, temperature monitoring/ data logging, hygiene, and safety during transport	National Centre for Cold-chain Development (NCCD)
Food safety (agriculture & dairy)	FSSAI Schedule 4	Hygiene, temperature control, cleaning/ sanitation, and record-keeping for perishable food transport	Food Safety and Standards Authority of India (FSSAI)
Food safety (agriculture)	IS/ISO 1496-2	Specifications and test requirements for insulated/refrigerated freight containers used in multimodal cold-chain transport	Bureau of Indian Standards (BIS)
Pharma distribution	Guidelines On Good Distribution Practices for Pharmaceutical Products	Validated temperature-controlled transport, continuous monitoring/data logging, calibration, SOPs, security	Central Drugs Standard Control Organization (MoHFW)
Vaccines	UIP (Universal Immunization Programme) Operational	Use of temperature data loggers; storage and road-transport practices to maintain required ranges (e.g., 2–8°C)	Ministry of Health & Family Welfare (MoHFW)
Refrigeration safety	IS 660:1963	Safety and good practices for TRUs and service/maintenance of mobile refrigeration	BIS
Refrigeration safety/ environment	IS/ISO 5149	System-level safety for design, installation, maintenance, and refrigerant handling (transport applicable)	BIS/ISO
Refrigerant classification	ISO 817	Safety classes and naming for refrigerant selection, labelling, and service	ISO (referenced by BIS)

Implementing the outlined guidelines and standards requires substantial capital investment across the refrigerated transport sector. Procuring AIS 113–compliant insulated bodies and transport refrigeration units (TRUs), installing calibrated data loggers and telematics, upgrading sanitation and power systems, and training operational crews all contribute to high upfront and ongoing costs. These challenges are especially pronounced for MSMEs, farmer-producer organizations (FPOs), transporters, and last-mile delivery fleets. Given India's demanding conditions- extreme heat, long hauls, and dense urban routes—such investments are critical for ensuring safety, product quality, and operational reliability, yet often difficult to finance. The following section outlines key support schemes that help reduce the financial burden and operational risks of owning and running reefers, enabling companies to meet compliance standards and strengthen cold chain performance.

Financial incentives to support the adoption of refrigerated transport in India

The refrigerated transport sector in India, critical for transporting perishable goods like fruits, vegetables, dairy, and pharmaceuticals, is undergoing a significant transformation driven by government initiatives to strengthen the cold chain infrastructure in the form of schemes and subsidies. These schemes provide financial incentives such as subsidies and loans to support the adoption of refrigerated transport (reefers) in the value chains under discussion.

The following table (Table 6) outlines key government schemes/ policies, their types, nodal entities, applicability, and core aspects:

Table 6: Govt. initiatives supporting reefer vehicles in India

Scheme	Scheme Type	Nodal Entity	Applicability	Key aspects
Scheme for Integrated cold chain and Value Addition Infrastructure Scheme (Ministry of Food Processing Industries, 2024)	Subsidy	MoFPI (Ministry of Food Processing Industries)	reefer vehicle/mobile pre-cooling van	Credit-linked back-ended subsidies covering 50% of the cost of a new reefer vehicle or mobile pre-cooling van, with a maximum limit of INR 50 lakh.
Mission for Development of Horticulture (MIDH) (Ministry of Agriculture & Farmers Welfare, 2025)	Subsidy	MoAFW and state horticulture departments	For vehicle capacity 15 MT and above. Note: Component has to be implemented in accordance with NCCD guidelines only.	Up to 35% of the eligible project cost (max up to 80 lakhs in general areas) and up to 50% in difficult areas (eligible project cost up to 100 lakhs).
Agriculture Infrastructure Fund (AIF) (Ministry of Agriculture & Farmers Welfare, 2025)	Loan	Ministry of Agriculture and Farmers Welfare (MoAFW)	New setup of agriculture-related infrastructure, which also covers the cold chain sector.	Collateral-free term loan up to INR 2 crores and interest subvention of 3% on the term loan availed for creation of post-harvest infrastructure.
Agricultural Marketing Infrastructure (AMI) – A sub-scheme of the Integrated Scheme for Agricultural Marketing (ISAM) (MyScheme, Government of India, 2025)	Subsidy	MoAFW	Mobile infrastructure for post-harvest operations. Available to Individuals, Farmers, Groups of farmers/growers, Registered Farmer Produce Organizations (FPOs) / FPCs, firms, companies, corporations, NGOs, SHGs, Cooperatives, Cooperative Marketing Federations, Autonomous Bodies of the Government, Local Bodies, Panchayats, State Agencies, etc	Subsidy @25% or plain areas and 33.33% for hilly areas, Women/SC/ST promoters & FPOs
Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PMFME) (MyScheme, Government of India, 2025)	Credit-linked subsidy and loan	MoFPI	The program has four broad components addressing the needs of the sector: ▪ Support to individuals and groups of micro enterprises. ▪ Branding and Marketing support. ▪ Support for strengthening of institutions. ▪ Setting up a robust project management framework.	35% credit-linked grant for common infrastructure created by FPOs/SHG federations/ cooperatives/SPVs/State agencies—this can include cold rooms, pack houses, and reefer vans/trucks for a cluster.

Scheme	Scheme Type	Nodal Entity	Applicability	Key aspects
Agriculture and Processed Foods Export Promotion Scheme of APEDA (2021-2026) (Operational Guidelines, 2021)	Financial assistance	APEDA (Agricultural and Processed Food Products Export Development Authority)	Purchase of insulated, reefer transport /mobile pre-cooling units	The assistance will be up to 40% of the total cost, subject to a ceiling of Rs. 200 lakhs
NCCD Engineering Guidelines 2025 (Engineering Guidelines & Minimum System Standards for Implementation in Cold Chain Components, 2025)	Guidelines	NCCD	Cold Chain Sector, including Reefers	Outlined standards for reefer containers and trucks to ensure quality of perishable goods during transit. They cover load capacity calculations, component specifications (insulation, refrigeration units), temperature ranges (-30°C to +30°C, up to -70°C), and cargo-specific requirements. The guidelines emphasize pre-cooling, proper packing, real-time monitoring, and telematics for compliance with ATP, EN 13445, HACCP, and ISO 15800 standards. Subsidy details under NHM (4-14 MT) and NHB (15-30 MT) schemes are included, promoting technologies like Liquid N_2 and GPS integration.

While these schemes encourage reefer adoption, there is a critical need for greater focus on low-GWP alternatives in the reefer segment. Current refrigeration systems in reefer often rely on high-GWP refrigerants, contributing to environmental concerns. Government and industry efforts, such as exploring electric or hybrid reefers and renewable energy integration (solar-powered units), are emerging but are limited. Enhanced subsidies, incentives for green technologies, and regulatory support for low-GWP refrigerants and digitization are essential to align the growth of the sector with sustainability goals, ensuring both economic and environmental benefits.

5. Global Trends and Practices

The global refrigerated transport sector continues to shift toward low-GWP, non-ODS technologies from high-GWP HFCs like R-404A to low-GWP alternatives such as R-452A, R-407F, and increasingly CO_2 (R-744), which is gaining traction due to its environmental benefits and regulatory support. Some OEMs are trailing HFO-1234yf as a transitional option (Maersk Container Industry, 2023).

Key regulations that led to the uptake of low-GWP refrigerant technologies are explained below.

European (EU) F Gas Regulation

- EU rules to cut fluorinated gas emissions by phasing down hydrofluorocarbons (HFCs), restricting high GWP refrigerants in new equipment, and requiring leak checks, recovery, technician certification, and reporting.
- Accelerated shift from high GWP HFCs (e.g., R -404A) to lower GWP and natural refrigerants (CO_2/R-744, hydrocarbons, A2L blends), including in transport refrigeration; stronger leak management and servicing practices; tighter supply and higher prices for legacy gases, prompting efficiency and design improvements.

American Innovation and Manufacturing Act (AIM) Act

- US law directing a national phase-down of HFC production and consumption and enabling Environmental Protection Agency (EPA) rules on sector transitions, allowances, leak minimisation, recovery, and reclamation.
- Faster move away from high GWP refrigerants toward CO_2 and A2L alternatives across refrigeration and transport refrigeration; improved recovery/reclaim and technician practices; reduced availability and higher costs for high GWP gases, encouraging updated equipment and lower GWP options.

United States

The low-GWP refrigerants market is accelerating due to EPA HFC phasedown under the AIM Act, green building standards, energy-efficient investments, and corporate net-zero goals. Adoption is rising in HVAC, automotive A/C, and commercial refrigeration, with momentum for R-1234yf, CO_2 (R-744), and ammonia. Advances in leak detection, safer blends, and R&D partnerships are improving cost and safety profiles.

Germany

Strict EU policies and an efficiency-focused culture in Germany promotes adoption of natural refrigerants. Supermarkets, transport, and industrial cold chains, plus policy-backed heat pump rollouts, drive demand. CO_2, hydrocarbons (R-290, R-600a), and ammonia dominate, while heat pumps and emerging magnetic refrigeration gain ground, supported by strong engineering and government backing.

China

Guided by the Kigali Amendment and “dual carbon” goals (peak by 2030, neutrality by 2060), China is rapidly shifting from HFCs. Growth Centers on automotive, industrial, and commercial A/C, with major OEMs investing in R-32, R-290, and CO_2. Cold chain expansion, green buildings, and robust policy in low GWP transition.

Takeaways for the Indian context

It becomes important to understand the key global regulations that have helped catalyse the shift to lower GWP alternatives within the global cold chain refrigerated transport sector. However, considering the properties of the alternatives, a baseline assessment can be conducted to map operating conditions (urban and long-haul), current HFC use/imports, and the supply chain barriers, infrastructure requirements, and trained technicians to evaluate the feasibility of adoption of the regulations in the Indian context. These initiatives can be gradually implemented, tested, and tailored to suit India's climate, transportation routes, and vehicle diversity. They can be supported with training programs and focused financing to ensure safety and performance are upheld while transitioning to refrigerants with lower Global Warming Potential (GWP).

5.1 Emerging Alternate Low GWP Refrigerants

Globally, for instance in the EU, refrigerants such as HFOs (e.g., R-1234yf) are being introduced, offering significantly lower GWPs (typically under 150) and better environmental profiles. Additionally, natural refrigerants like CO_2 (R-744) are increasingly gaining traction due to their sustainability and are suited for long-haul transport of perishable commodities (Subzero Blog, 2025). Similarly, direct-injection liquid nitrogen systems for trucks have been demonstrated as a zero direct-GHG alternative at the point of use, offering fast cool-down and low noise, with safety managed through oxygen monitoring and interlocks (United Nations Environment Programme, 2022). OEMs have adopted R-452A across truck and trailer transport refrigeration units as a lower-GWP replacement for R-404A, with comparable cooling performance and significantly reduced GWP. For smaller, vehicle-powered direct-drive units historically using R-134a, industry literature notes ongoing evaluation of lower-GWP alternatives (including HFO blends) subject to safety classifications and standards evolution for mobile applications (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2022). Table 7 lists down few emerging low-GWP alternative refrigerants.

Table 7: Low GWP Alternatives

Refrigerant	GWP	Application	ASHRAE 34 safety class (flammability)	Key properties/notes
CO_2	1	Chilled and Frozen	A1 (non-flammable, low toxicity)	Natural refrigerant; very high operating pressures.
Liquid Nitrogen	0	Chilled and Frozen; Cryogenic freezing; Spot cooling	A1 (non-flammable, low toxicity)	Natural refrigerant; inert; extreme cold burn hazard; requires good ventilation and insulated transfer lines
HFO blends-R1234yf	<1	Chilled (medium temperature)	A2L (low flammability, low toxicity)	With low flammability, it requires safety measures to be deployed widely.
R-452A	2141	Chilled and frozen	A1 (non-flammable, low toxicity)	HFO/HFC blend; similar capacity to R 404A with lower discharge temps; much lower GWP than R 404A; low glide.

5.2 Emerging Insulation Materials

Vacuum-insulated panels (VIPs) are among the most advanced insulation options available. They use a sealed vacuum core to greatly reduce heat transfer, delivering very high insulation in a thin, lightweight panel. Because they take up little space, VIPs can be added to containers with minimal loss of storage volume. This makes them well-suited for temperature-sensitive goods that must hold steady temperatures over long distances. However, VIPs are costly and raise concerns about damage and repair, so polyurethane foam (PUF) sandwich panels remain the practical standard for most vehicles (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2022). VIP integration is viewed as the next step in India as costs reduce and service capability matures.

Aerogel Insulation is a next-generation insulation material that is extremely light and provides excellent thermal performance in a very thin layer. It has very low heat conductivity and can deliver strong insulation without adding much weight or taking up space. These properties make aerogel a good fit for long-haul refrigerated containers in India's hot and variable climates. However, its use in the reefer vehicles is still in the early stage, but interest and trials are growing. As the technology matures, aerogel could become a valuable option for moving high-value, temperature-sensitive goods over long distances (Subzero Blog, 2024).

5.3 Alternative Fuels and Power Sources

Solar-Assisted Refrigeration: Solar-assisted refrigeration systems (Figure 8), affixed with solar panels to power refrigeration units, are gaining support in the EU. In India, while the concept is recognized, significant adoption and implementation remain to be seen. Stakeholders acknowledge the potential benefits, even if concrete actions await initiation. As observed through our stakeholder consultation, the key challenges include limited roof area yielding only partial load coverage, added weight that reduces payload and affects structure and efficiency losses from heat and soiling that require maintenance. Integration with transport refrigeration unit (TRU) power, electrical safety, and warranties, and higher upfront costs also need to be addressed.

Figure 8: Solar-Assisted Reefer

Source: Google (2025). Google Gemini (Image generation) [Artificial intelligence system]. https://gemini.google.com/

Electric Reefer: Electric reefers (Figure 9), powered by electricity instead of diesel, are in an early adoption phase globally, led by markets in Asia and Europe. In India, companies such as Subzero Reefers and Thermo king are venturing into this domain. Though initial developments are promising, widespread adoption is still evolving.

Figure 9: Electric Reefer

Source: Google (2025). Google Gemini (Image generation) [Artificial intelligence system]. https://gemini.google.com/

5.4 Global Safety Standards

Multiple international standards are developed and periodically revised requirements for refrigeration and refrigerants, including those that are flammable, for all the major sectors covered in the study, i.e., the agriculture sector, dairy sector, and pharmaceuticals. Leading organizations include the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), the American National Standards Institute (ANSI), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and Underwriters Laboratories (UL).

Table 8 summarizes global safety standards relevant to refrigerated transport. These provide a common technical and procedural basis to ensure temperature integrity, product quality, worker and public safety, and environmental compliance from equipment design through in-service verification.

Table 8: Global Safety Standards

Standard	Context
ATP Agreement	Ensures temperature control for perishable goods during transit.
EN 13485	Accuracy and calibration requirements for thermometers used in food logistics.
EN 12830	Performance criteria for temperature recorders used in transport and storage.
EN 13486	Routine testing, inspection, and calibration of temperature recorders.
EN 378 (Parts 1–4)	Safe design, installation, operation, and maintenance of refrigeration systems.
CARB TRU Regulation	Limits emissions and encourages low GWP refrigerants in transport refrigeration units.
EN 16440 (Parts 1–2)	Requirements and test methods for temperature-controlled road transport; in service verification.
Codex CXC 44-1995 (Fresh Produce)	Code of practice for packaging and transport of fresh fruits and vegetables (airflow, stacking, handling).
Codex CXC 57-2004 (Milk & Milk Products)	Hygienic practice for milk and milk products, including transport hygiene.

Standard	Context
ISO 21973:2020 (Pharma)	Transport of temperature sensitive pharmaceutical products (qualification, mapping, monitoring).
EU GDP 2013/C 343/01 (Pharma)	Good Distribution Practice for medicinal products (traceability, monitoring, documentation).
IATA Temperature Control Regulations (TCR)	Packaging, handling, and monitoring for air and multimodal pharma shipments.
3 A Sanitary Standards (Dairy transport tanks)	Hygienic design and cleanability for dairy transport equipment.

The global safety standards show that the refrigerated transport sector can be significantly improved in terms of energy efficiency and emissions (via low-GWP refrigerants), temperature integrity and product quality, safety and hygiene, reliability and maintenance, and traceability through calibrated monitoring and data logging. They also strengthen regulatory compliance and audit readiness.

5.5 Operations and Maintenance Practices

Effective Operations and Maintenance (O&M) of refrigerated containers (reefers) is critical to ensuring optimal performance, energy efficiency, and product safety in the cold chain. Regular maintenance helps prevent breakdowns, maintain consistent temperature control, and reduce energy consumption by ensuring refrigeration systems operate at peak efficiency, leading to reduced emissions. Well-executed O&M practices lead to lower operational costs, extended equipment lifespan, minimized spoilage, and product loss. The integration of digital tools, modern equipment, and consistent training is an essential step to bridge the existing gaps.

Proposed O&M practices for reefer vehicles will remain consistent across various sectors (agriculture, pharmaceutical, and dairy, and the suggested practices are mentioned below (Table 9).

Table 9: Reefers O&M practices In India and proposed suggestions for improvement

Activities	Indian Practices	Suggestions
Pre-loading Inspection	Mandated by FSSAI/CDSCO, compliance varies with infrastructure and training differences.	Digital checklists and IoT verification, periodic audits, and targeted incentives can support a wider uptake.
Loading and Unloading Procedures	Manual loading is common; attention to airflow and door-open time varies, especially in rural or small scale / unorganized sector operations.	Palletization, quick-door protocols, and GPS/temperature alerts are feasible; semi-automation is emerging.
Temperature Monitoring and Logging	Manual logs remain widespread; digital tools are growing with cost and power considerations.	Affordable IoT loggers and cloud dashboards are available; WHO-aligned vaccine validation supports consistency.
Cleaning and Sanitation	Required by FSSAI/CDSCO; practices vary by region, operators and the perishable handled.	Standard SOPs with training and water-efficient, eco-friendly cleaning can improve consistency.
Fuel Management	Fuel supply and costs vary by route; route monitoring practices differ across operators and with the value chains (pharma / dairy / agriculture).	Fuel-tracking apps, efficient reefers, and urban pilots for electric/hybrid units can improve visibility and costs.
Insulation Checks	Checks can be irregular, particularly for older vehicles.	Routine insulation checks with thermal cameras can highlight retrofit opportunities.
Driver Training	Training depth and coverage differ; a mix of formal and on-the-job learning is common.	Standard curricula and periodic refreshers can complement current practices.
Emergency Preparedness	Backup systems and response procedures vary by operator and fleet size.	Backup power packs, automated alerts, and response checklists can aid faster recovery.
Documentation and Compliance	Paper and digital records coexist; digital adoption is increasing with regulatory expectations.	Integrated digital documentation with monitoring and phased audits can improve traceability.

6. Gaps and Challenges in the Indian Scenario for the adoption of low GWP technologies

This section outlines the key gaps and challenges in the Indian landscape for adopting low-GWP technology in refrigerated transport. The gaps and challenges related to adoption for four major components covered in the study, i.e., refrigeration system and technologies (design, safety, equipment components), refrigerants (CO_2/R744, R290, A2L/HFO blends and their supply), insulation (thermal performance and durability), and digitization (continuous monitoring, alerts, and traceability).

Interest in low GWP alternatives like CO_2, hydrocarbons, and HFOs is growing, but uptake is constrained by limited local availability of compliant refrigeration components and controls, uneven technician skills for these newer technologies, variability in insulation standards and thermal performance across bodies, higher upfront costs and uncertain lifecycle economics tied to refrigerant and parts supply, supply chain constraints for gases and spares, and limited testing and validation under India's high ambient, multi stop conditions. These factors, including uneven digital monitoring and documentation, affect uptime, safety, and consistent temperature control across long-haul and urban routes, and influence decisions by fleets, OEMs, shippers, financiers, and insurers.

Availability of suitable components

Local supply of A2L-compliant compressors, expansion valves, controls, gas detection, and rated electrical components is still building and thus India still depends on imports for this compatible equipment. Patents and licensing on some HFOs and low domestic volumes slow localisation of these HFO alternatives. This results in higher costs, more downtime, slower fleet upgrades, and fewer choices for operators and OEMs. Charge-size limits, multi-evaporator configurations, and the need for intrinsically safe or spark-proof components narrow the set of workable designs.

Supply chain and distribution challenges

Outside major cities, A2L gases (and refrigeration-grade purity), compatible cylinders or valves, leak detectors, and rated controls are not consistently available. Hydrocarbon supply exists, but refrigeration-grade purity, compliant cylinders, charge management, and logistics require tighter control. Many critical A2L/A3 components are imported, causing longer lead times and price variability; patents and limited cross-brand compatibility can further restrict sourcing. Recovery, reclaim, and certified disposal networks are expanding but not yet widespread, and service hubs with the right spares and tools are concentrated in metros. These factors lead to service delays, higher spare inventories, and slower roll-out on long-haul routes.

Testing and validation for Indian conditions

India-specific evidence for A2L blends and hydrocarbon options in refrigerated transport remains limited, especially under high-ambient, multi-stop duty cycles with frequent door openings and urban congestion. Few accredited testbeds and India-specific protocols exist for transport refrigeration, and OEM–fleet pilots across climate zones/load profiles are still sparse. Evidence from Indian routes and weather is still limited for the low-GWP alternatives discussed and suggested in the study.

Training and expertise shortages

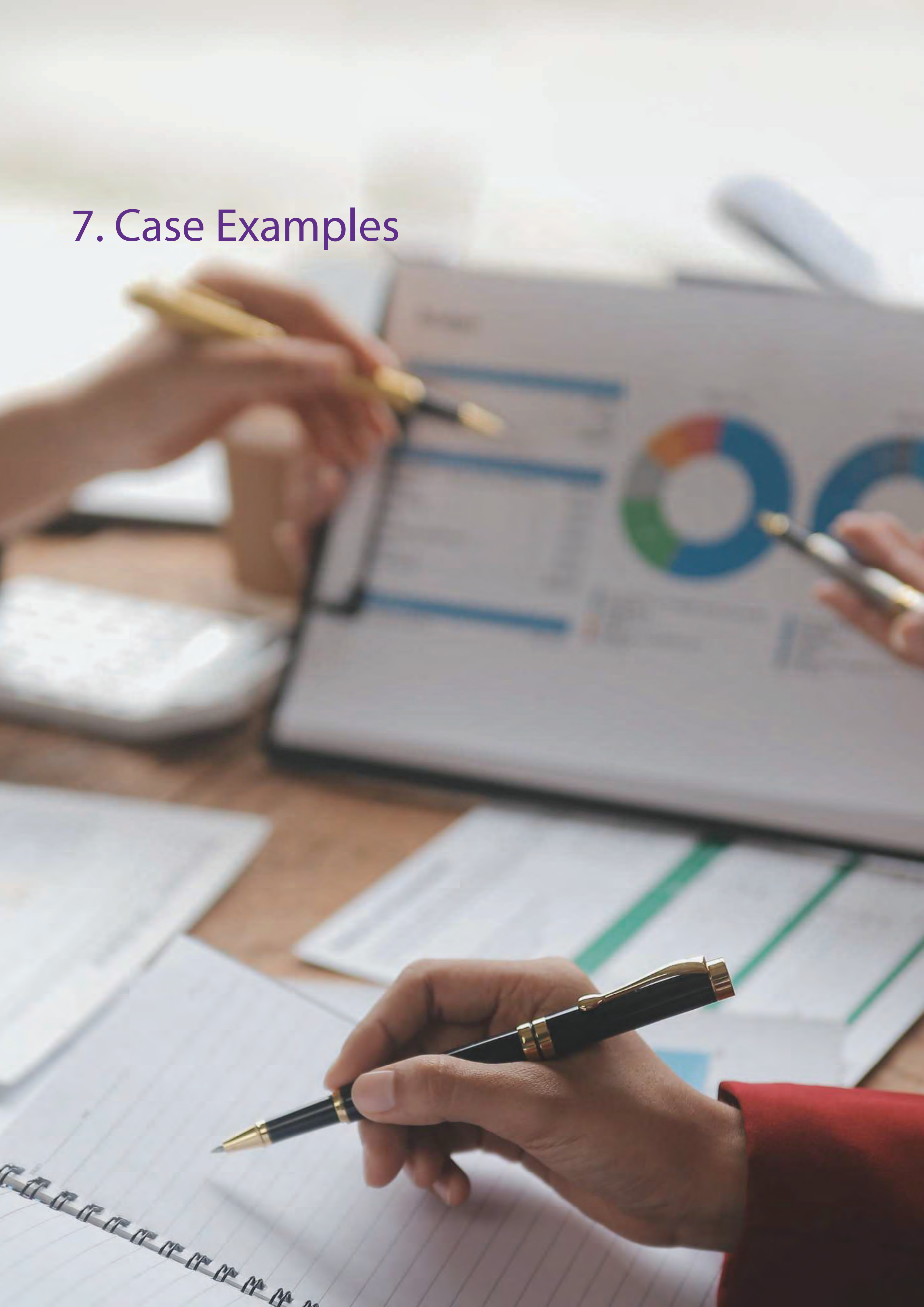
The servicing workforce needs new skills to handle mildly flammable A2L refrigerants, highly flammable A3, and hydrocarbons, and modern telematics used in road reefers. Many technicians are trained on legacy A1 HFC systems; practical training for A2L/A3 and mobile applications is limited, and service networks outside big cities are fragmented. Gaps include safe handling and ventilation practices, LFL awareness, leak testing and calibration of detectors, correct assembly for tightness, documentation, and controller diagnostics. These gaps lead to incorrect installation/servicing, higher leak and mishandling risk, missed safety steps, more breakdowns and temperature excursions, shorter equipment life, and higher operating costs- reducing confidence among operators and buyers.

Cost of transition and lifecycle considerations

Upfront costs are higher for low GWP technologies due to safety features (gas detection, ventilation, intrinsically safe components), specialised parts, tooling, and training. Costs reflect early-stage market volumes and import dependence. Service capability varies by region, affecting downtime risk and insurance/financing terms.

Consequently, many fleets phase upgrades: transitional A1 blends remain in some builds; new A2L systems are prioritised where service coverage exists; hydrocarbons appear mainly in small, plug-in units. Misalignment between design, duty profile, and service capability can yield mixed retrofit results and a higher total lifecycle cost.

7. Case Examples



Case Example 1: ASKO, Norway - liquid CO_2 cryogenic refrigeration

ASKO deployed Thermo King's CryoTech liquid CO_2 (R-744) cryogenic refrigeration on urban delivery trucks to eliminate HFC refrigerants and diesel-driven refrigeration and to reduce noise. The system stores liquid CO_2 in an onboard tank and expands it through an evaporator coil to remove heat; cargo air is circulated by vehicle-powered fans. CO_2 is refuelled from depot tanks, and the system supports multi-compartment operation for fresh, chilled, and frozen goods.

ASKO selected liquid CO_2 over liquid nitrogen due to higher refrigeration capacity per litre, safer storage temperature (approximately −57°C versus −196°C for LN_2), and a lower carbon footprint for the application (UNEP & CCAC, 2016)

System outcomes reported in the case (per UNEP) include lower cumulative global warming impact compared with diesel or LN_2 systems from the refrigeration unit, no particulate or other diesel emissions from refrigeration, reduced spoilage (example: reduction on the order of 0.25% of retailer turnover), faster pull-down than conventional units, and near-silent operation enabling night deliveries that can save time and fleet costs (UNEP & CCAC, 2016).

Benefits

- **Environmental:** Uses CO_2 recovered from waste streams, avoids HFC refrigerants, and eliminates diesel emissions from the refrigeration unit; UNEP reported a lower cumulative climate impact for the refrigeration unit compared with diesel or liquid nitrogen systems in the documented case (UNEP & CCAC, 2016).
- **Performance:** Delivers fast temperature pull-down and rapid recovery after door openings, supporting maintenance of required product temperatures during multi-stop deliveries (UNEP & CCAC, 2016).
- **Operational:** Operates at low noise levels suitable for night-time deliveries and supports multi-compartment configurations for mixed fresh, chilled, and frozen loads on a single route (UNEP &CCAC, 2016).

Case Example 2: Carrier Corporation, USA (NaturaLINE CO_2 Container Refrigeration System)

Carrier Transicold's NaturaLINE container refrigeration unit uses carbon dioxide (R 744) with a global warming potential of 1 and zero ozone depletion potential; R 744 is classified as A1 (non-flammable, low toxicity) (UNEP &CCAC, 2016) . The NaturaLINE system was operated across approximately 120 shipments over more than 28,000 operating hours in ambient conditions from about −40°C to +50°C, transporting frozen and perishable goods (UNEP & CCAC, 2016).The system employs a CO_2 transcritical cycle with features such as a multi-stage reciprocating compressor, variable speed drive, a wrap-around gas cooler coil, a flash tank for refrigerant management, two-speed fans, and advanced control software; operation involves higher pressures than HFC systems, with reinforced components and safety design as described in the case (UNEP & CCAC, 2016).

Benefits

- **Environmental:** The use of R 744 eliminates high GWP HFCs and zero ozone depletion potential, thereby avoiding risks associated with HFC phasedown and related policy instruments (UNEP & CCAC, 2016).
- **Performance:** Benefits characteristics include specific cooling capacities at multiple setpoints (for example, on the order of 9,400 W at 2°C, 6,000 W at −18°C, and 4,400 W at −29°C) and part load efficiency favourable for perishable cargo, with average energy use comparable to HFC 134a units under the reported test conditions (UNEP & CCAC, 2016).
- **Operational:** UNEP reports that the unit is intended for serviceability similar to established container systems, using proven component families and global training and support arrangements (UNEP & CCAC, 2016).

Case Example 3: EcoFridge Production Company Ltd, Ukraine (Nature Fridge Liquid Nitrogen System)

EcoFridge Production Company Ltd.'s nature Fridge system is a liquid nitrogen (LN_2) direct cryogenic refrigeration technology for rigid trucks and trailers that replaces diesel-driven mechanical systems using high-GWP HFCs such as R404A (UNEP &CCAC) The system comprises an onboard LN_2 storage tank, an evaporator with a sprayer that injects nitrogen gas directly into the cargo space, and thermostatic controls; subsystem elements include supply (one or two tanks refillable from delivery trucks or filling stations), control, power, cooling, and safety (oxygen sensors, emergency stops, audio/visual alarms, and gates interlocked to prevent entry below 18% oxygen) (UNEP & CCAC, 2016). It was observed that diesel systems are associated with 3.53 kg CO_2 equivalent per liter (including refrigerant leakage), whereas LN_2, has zero direct greenhouse gas emissions with only indirect CO_2 from production; operating data in the case indicates LN_2 consumption lower than indirect (secondary loop) cryogenic systems (UNEP & CCAC, 2016).

Benefits

- **Environmental:** Zero direct greenhouse gas emissions from the refrigeration unit, with indirect emissions from LN_2 production quantified at approximately 0.064–0.32 kg CO_2 equivalent per litre—corresponding to an estimated 24–88% reduction compared with diesel systems under the case study assumptions (UNEP & CCAC, 2016).
- **Performance:** Rapid cool down (to −20°C in under 30 minutes versus 90–180 minutes for mechanical systems), stable temperatures without defrost cycles, and effectively unlimited cooling capacity constrained by fuel supply (UNEP & CCAC, 2016).
- **Operational:** Very low noise (less than 20 dB), self-testing electronics, minimal downtime due to the absence of mechanical compressor components, and multi-temperature capability within a single vehicle (UNEP & CCAC, 2016).

Case Example 4: Solar-Powered Refrigerated Trailers by eNow and XL Fleet

XL Fleet announced a partnership with eNow to electrify refrigerated trailers using roof-mounted solar photovoltaic panels that charge underfloor lithium-ion batteries to power electric transport refrigeration units, replacing diesel-powered refrigeration on Class 8 commercial trailers. The announcement stated that XL Fleet would invest USD 3 million in eNow and supply battery and power electronics for the first 1,000 units, with an option to acquire eNow ((Businesswire, 2021)). Reporting on the project describes battery electric refrigeration supported by trailer-mounted solar with plugin depot charging, and states operation of more than 12 hours between charges for refrigerated trailers.

Benefits

- **Environmental:** Replacing diesel TRUs with battery electric refrigeration eliminates tailpipe emissions from the refrigeration unit and addresses emissions associated with diesel TRU idling.
- **Performance:** Reported operation of more than 12 hours between charges provides extended runtime for refrigerated service without diesel engine operation
- **Operational:** Trailer-mounted solar maintains battery charge and plugin depot charging supports operations, allowing fleets to replace diesel TRU operation on Class 8 trailers

Case Example 5: PCM-Enhanced Refrigerated Vans in Europe (Spanish and European Case Studies, 2017)

European research has documented the integration of phase change materials (PCMs) into refrigerated vans and trucks to provide latent-heat storage that buffers temperature fluctuations and reduces reliance on continuous mechanical refrigeration during distribution (Oró, 2012). Studies from Spain and broader Europe report implementations in which PCM panels are embedded within vehicle walls or used as modular batteries, enabling passive or hybrid operation alongside conventional vapor-compression units (Arce et al., 2011). Experimental and pilot systems have included multi-layer PCM walls with different melting points to adapt to varying ambient conditions, as well as PCM-incorporated refrigeration concepts tested in laboratory and field settings for mobile cold-chain applications (Lit et al., 2012). Reviews conclude that PCM integration can enhance temperature stability and reduce energy use in cold storage and refrigerated transport contexts when appropriately matched to target setpoints and operating profiles (Pielichowska, 2014).

Benefits

- **Environmental:** Reviews report that PCM-based cold thermal energy storage can reduce energy consumption associated with cooling services, which in turn lowers indirect CO_2 emissions when compared with equivalent service delivered solely by continuous mechanical refrigeration (Oró, 2012); (Pielichowska, 2014).
- **Performance:** PCM integration enhances temperature stability by absorbing and releasing latent heat near the target setpoint, mitigating temperature spikes during loading/unloading and short idle periods (Arce, 2011); (Oró, 2012)
- **Operational:** PCM provides holdover capacity that allows partial or temporary operation without the compressor, reducing runtime, noise, and wear, and supporting hybrid strategies in distribution routes (Oró, 2012); (Pielichowska, 2014).

8. Recommendations

To address the identified challenges and gaps in the adoption of low-GWP alternatives within the refrigerated transport sector, the following recommendations are put forward (Figure 10):

Figure 10: Key recommendations

Awareness and Capacity Building:

- Launch targeted educational campaigns to raise awareness among stakeholders about the environmental and economic benefits of adopting low-GWP refrigerants.
- Develop comprehensive training programs to equip technicians with the necessary skills for managing low-GWP refrigerant technologies such as HFOs, CO_2, others. Certification programs can enhance competence and confidence within the industry.

Infrastructure Development:

- Promote awareness to develop the necessary infrastructure for low-GWP refrigerant distribution and maintenance.
- Facilitate local manufacturing of low-GWP technologies to reduce reliance on expensive imports and lower overall costs for industry participants.
- Promote retrofitting existing refrigeration systems to accommodate low-GWP refrigerants, aiding in the gradual transition and cost reduction.

Comprehensive Policy Frameworks:

- Strengthen policy and regulatory frameworks to support the transition to low-GWP technologies. Align with international standards to ensure consistency and compatibility, making it easier for stakeholders to adopt new practices.

Technological Innovation and Research:

- Encourage research and development activities to explore and refine low-GWP technologies suitable for Indian climatic and market conditions. Partnerships with academic and research institutions can drive innovations that are contextually relevant.

- Promote the development and adoption of advanced insulation materials and techniques, such as vacuum-insulated panels, which can enhance energy efficiency and performance.

Standards and Safety Regulations:

- Formulate detailed standards for the production and operation of refrigerated vehicles, including efficiency and insulation requirements as stipulated in AIS 16164.
- Bridge existing certification gaps between stationary systems and transport refrigeration by harmonizing safety standards, ensuring a smooth and safe transition to new technologies.

Additional measures:

- Expand Internet of Things (IoT)-based temperature/energy monitoring and telematics across fleets to enable real-time compliance, reduce spoilage, and support MRV of energy and emissions; pair with rural connectivity and cybersecurity frameworks to address known gaps.
- Best practices from global and national cases should be adopted where ever feasible.
- Harmonize with destination-market requirements for low-GWP and digital traceability in pharma and perishables to boost export readiness, leveraging existing national standards and procurement mandates.

During the stakeholder consultations following suggestions were received from the stakeholder for future studies and related initiatives:

i. Life-cycle management of discarded refrigerants
   - Opportunities exist to map the in-use refrigerant bank, typical leakage, and end-of-life flows, and to explore recovery, reclamation, and destruction pathways.

ii. Assess India-specific viability of carbon dioxide systems (mechanical R 744 and cryogenic CO_2):
   - Evaluation of carbon dioxide (CO_2) refrigeration, both mechanical R 744 and cryogenic CO_2, can be performed to assess performance in high ambient duty cycles, alongside safety, infrastructure readiness, local circumstances, costs, and inputs to future standards and training.

iii. Set Goals to achieve low GWP Transition in the refrigerated transport sector:
   - Transition to low GWP alternative technologies should be aligned to the Montreal Protocol and Kigali Amendment targets.

iv. Guidelines for Original Equipment Manufacturer (OEMs) to enable low-GWP technologies
   - Guidelines for OEM's need to be developed comprising of broad outline system design requirements, performance requirements, safety & compliance, digitization, service procedures for low GWP refrigerant / technology options, among others helping ensure reliable performance, compliance, and technical readiness for transition.

Abbreviation

Abbreviation	Full Form
3-A	3-A Sanitary Standards
A1	ASHRAE 34 safety class: non-flammable, low toxicity
A2L	ASHRAE 34 safety class: lower flammability, low toxicity
A3	ASHRAE 34 safety class: higher flammability, low toxicity
AIF	Agriculture Infrastructure Fund
AIM Act	American Innovation and Manufacturing Act
AIS	Automotive Industry Standard (India)
AISC	Automotive Industry Standards Committee (India)
AMI	Agricultural Marketing Infrastructure
ANSI	American National Standards Institute
APEDA	Agricultural and Processed Food Products Export Development Authority
ARAI	Automotive Research Association of India
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATP	Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for such Carriage
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
CAGR	Compound Annual Growth Rate
CARB	California Air Resources Board
CDSCO	Central Drugs Standard Control Organization
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CMVR	Central Motor Vehicles Rules
CO_2	Carbon dioxide
dBA	A-weighted decibels
EPA	Environmental Protection Agency
EPS	Expanded Polystyrene
EU	European Union
EV	Electric Vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FPC	Farmer Producer Company

Abbreviation	Full Form
FPO	Farmer Producer Organization
FSSAI	Food Safety and Standards Authority of India
GDP (pharma)	Good Distribution Practice
GRP	Glass-Reinforced Plastic
GPS	Global Positioning System
GWP	Global Warming Potential
HACCP	Hazard Analysis and Critical Control Points
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HPMP	HCFC Phase-out Management Plan
IATA	International Air Transport Association
ICAT	International Centre for Automotive Technology
ICD	Inland Container Depot
IEC	International Electrotechnical Commission
IMARC	IMARC Group
INR	Indian Rupee
IoT	Internet of Things
IS	Indian Standard
ISAM	Integrated Scheme for Agricultural Marketing
ISO	International Organization for Standardization
LFL	Lower Flammability Limit
LN_2	Liquid Nitrogen
MIDH	Mission for Integrated Development of Horticulture
MoAFW	Ministry of Agriculture and Farmers Welfare
MoEF&CC	Ministry of Environment, Forest and Climate Change
MoFPI	Ministry of Food Processing Industries
MoHFW	Ministry of Health and Family Welfare
MoRTH	Ministry of Road Transport and Highways
MRV	Measurement, Reporting and Verification
MSME	Micro, Small and Medium Enterprises
MT	Metric tonne
NCCD	National Centre for Cold-chain Development

Abbreviation	Full Form
NDDB	National Dairy Development Board
NHB	National Horticulture Board
NHM	National Horticulture Mission
NITI Aayog	National Institution for Transforming India
OEM	Original Equipment Manufacturer
O&M	Operations and Maintenance
ODP	Ozone Depletion Potential
ODS	Ozone-Depleting Substances
PCM	Phase Change Material
PHC	Primary Health Centre
PIB	Press Information Bureau
PMFME	Pradhan Mantri Formalisation of Micro Food Processing Enterprises
PMKSY	Pradhan Mantri Kisan SAMPADA Yojana
PUF	Polyurethane Foam
R-1234yf	2,3,3,3-Tetrafluoropropene (HFO-1234yf)
R-134a	1,1,1,2-Tetrafluoroethane (HFC-134a)
R-404A	HFC blend refrigerant
R-407F	HFC blend refrigerant
R-452A	HFC/HFO blend refrigerant (lower GWP)
R-744	Carbon dioxide (CO_2) refrigerant
R&D	Research and Development

Abbreviation	Full Form
RMI	Rocky Mountain Institute
SHG	Self-Help Group
SoW	Scope of Work
SOP	Standard Operating Procedure
SPV	Special Purpose Vehicle
TCR	Temperature Control Regulations (IATA)
TERI	The Energy and Resources Institute
TMS	Transport Management System
TRU	Transport Refrigeration Unit
UIP	Universal Immunization Programme
UL	Underwriters Laboratories
ULIP	Unified Logistics Interface Platform
UNEP	United Nations Environment Programme
USD	United States Dollar
VIP	Vacuum Insulated Panel
VCR	Vapor Compression Refrigeration (system/ technology)
VCS	Vapor Compression System
WHO	World Health Organization
WRI	World Resources Institute

References

- Agricultural and Processed Food Products Export Development Authority (APEDA). (2021). Operational guidelines for financial assistance schemes (2021–2026). Government of India. https://apeda.gov.in/sites/default/files/Financial%20Assistance%20Schemes/FAS_Guidelines_05102021.pdf
- American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2022). 2022 ASHRAE handbook—Refrigeration. ASHRAE.
- Arce, P. M., Medrano, M., Gil, A., Oro, E., & Cabeza, L. F. (2011). Overview of thermal energy storage (TES) potential energy savings and climate change mitigation in Spain and Europe. Renewable and Sustainable Energy Reviews, 15(9), 4797–4808. https://doi.org/10.1016/j.apenergy.2011.01.067
- ARCON. (2025, May 2). Understanding refrigerated shipping container temperature & optimal ranges for perishable products. ARCON Blogs. https://www.arconcontainer.com/blog/reefer-container-temperature-guide/
- Business Wire. (2021, July 21). XL Fleet and eNow announce partnership to electrify refrigerated trailers. https://www.businesswire.com/news/home/20210721005903/en/XL-Fleet-and-eNow-Announce-Partnership-to-Electrify-Refrigerated-Trailers
- Food Safety and Standards Authority of India (FSSAI). (2018, February). Food industry guide to implement GMP/GHP requirements: Milk and milk products. https://fssai.gov.in/upload/uploadfiles/files/Guidance_Document_Milk_14_03_2019.pdf
- IMARC Group. (2025). Indian cold chain market report by segment (cold chain storage, cold chain transportation), product (fruits and vegetables, meat and fish, dairy products, healthcare products), sector (private, cooperative, public), organised and unorganised. https://www.imarcgroup.com/indian-cold-chain-market
- Liu, M., Saman, W., & Bruno, F. (2012). Development of a novel refrigeration system for refrigerated trucks incorporating phase change material. Applied Energy, 92, 336–342. https://doi.org/10.1016/j.apenergy.2011.10.015
- Maersk Container Industry. (2023, March 3). R1234yf and its relevance for the reefer industry. https://www.mcicontainers.com/stories/r1234yf-and-its-relevance-for-the-reefer-industry/
- Ministry of Agriculture & Farmers Welfare. (2025). MIDH Operational Guidelines. https://shm.tg.nic.in/Download/MIDH%20Guidelines%202025-%20Final.pdf
- Ministry of Agriculture & Farmers Welfare. (2025). MIDH operational guidelines: Mission for Integrated Development of Horticulture. Department of Agriculture & Cooperation, Government of India. https://shm.tg.nic.in/Download/MIDH%20Guidelines%202025-%20Final.pdf
- Ministry of Commerce & Industry. (2022, September 28). National Logistics Policy. Government of India. https://dpiit.gov.in/logistics/national-logistics-policy
- Ministry of Food Processing Industries. (2024, February 6). Integrated cold chain and value addition infrastructure scheme. Press Information Bureau, Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2003085
- MyScheme, Government of India. (2025). Agricultural marketing infrastructure (AMI). https://www.myscheme.gov.in/schemes/ami

- National Centre for Cold-chain Development. (2025). Engineering guidelines & minimum system standards for implementation in cold chain components. Ministry of Agriculture and Farmers Welfare, Government of India. https://nhb.gov.in/writereaddata/284825054851ENGINEERING%20GUIDELINES-2025.pdf
- NITI Aayog, RMI & RMI India. (2021). Fast tracking freight in India: A roadmap for clean and cost-effective goods transport. https://www.niti.gov.in/sites/default/files/2021-06/FreightReportNationalLevel.pdf
- NITI Aayog & WRI India. (2021). Handbook of electric vehicle charging infrastructure implementation (Version 1). https://www.niti.gov.in/sites/default/files/2021-08/HandbookforEVChargingInfrastructureImplementation081221.pdf
- Oró, E., de Gracia, A., Castell, A., Farid, M. M., & Cabeza, L. F. (2012). Review on phase change materials (PCMs) for cold thermal energy storage applications. Applied Energy, 99, 513–533. https://doi.org/10.1016/j.apenergy.2012.03.058
- Ozone Cell, MoEFCC. (2021). Study on the cold-chain sector in India for promoting non-ODS and low-GWP refrigerants. Ministry of Environment, Forest and Climate Change, Government of India. https://ozonecell.nic.in/wp-content/uploads/2021/09/Cold-Chain-Sector-Report.pdf
- PIB. (2025, February 10). Boosting food processing & storage infrastructure in India. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2146934
- Pielichowska, K., & Pielichowski, K. (2014). Phase change materials for thermal energy storage. Progress in Materials Science, 65, 67–123. https://doi.org/10.1016/j.pmatsci.2014.03.005
- Subzero Blog. (2024, November 16). Top innovations in refrigerated container insulation. https://subzeroreefers.com/top-innovations-in-refrigerated-container-insulation/
- Subzero Blog. (2024, September 9). Understanding refrigerant gases used in reefer truck cooling systems. https://subzeroreefers.com/understanding-refrigerant-gases-used-in-reefer-truck-cooling-systems/
- United Nations Environment Programme (UNEP), & Climate and Clean Air Coalition (CCAC). (2016). Lower-GWP alternatives in commercial and transport refrigeration: A compilation of case studies on propane, CO_2, ammonia, and HFO. https://www.ccacoalition.org/sites/default/files/resources/Lower%20GWP%20Alternatives%20in%20Commercial%20and%20Transport%20Refrigeration.pdf
- United Nations Environment Programme (UNEP). (2022). Technology and Economic Assessment Panel: 2022 assessment report. https://ozone.unep.org/system/files/documents/TEAP-Assessment-Report-2022-April23.pdf

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