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Reducing Emissions in Transport Refrigeration Without Compromising Load Integrity

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Introduction

Transport refrigeration units (TRUs) are important to the cold chain, but they also present a unique emissions challenge. As regulatory scrutiny increases, particularly around diesel particulate matter (PM) and black carbon, fleet operators must balance emissions compliance with operational reliability and cargo protection.

This paper examines how diesel particulate filters (DPFs), optimized TRU practices, and system-level planning can reduce environmental impact without compromising load integrity or system uptime. Whether managing a regional distribution fleet or a national logistics operation, decision-makers need technically sound strategies to maintain compliance, reduce costs and ensure product quality.

Focus Areas for Fleet Operators

- Operational Efficiency: How improvements in TRU control and maintenance can reduce fuel consumption and extend asset life.
- Risk Mitigation: The impact of refrigeration mismanagement on spoilage rates, unplanned downtime, and regulatory penalties.
- Compliance Pathways: Understanding how new equipment and verified DPF technology can meet current and emerging emissions regulations.
- Cargo Integrity: Preventing temperature excursions and product losses through tighter control of TRU cycling and maintenance.
- Strategic Planning: Using retrofit technologies and emission-reduction strategies to bridge toward long-term decarbonization goals.
- Fleet Sustainability: Meeting corporate Environmental, Social, and Governance (ESG) goals through equipment selection, driver programs, and fuel efficiency measures.

Variables in Transport Refrigeration and Their Impact

Numerous parameters influence the operation and emissions of TRUs, including:

- **Setpoint (Fresh, Frozen, Keep from Freezing)**: Determined by the nature of the cargo.
- **Initial Product Temperature (Precooled, Field Heat)**: Affects the required cooling capacity and energy use.
- **Respiratory Rate (High, Low, Non-respiring)**: Affects the required cooling capacity and energy use.
- **Ambient Temperature (Location, Time of Year, Time of Day)**: Directly impacts the cooling load.
- **Engine RPM (High Speed, Low Speed)**: Influences fuel consumption and emissions.
- **Operating Mode (Stop/Start, Continuous)**: Affects fuel consumption, emissions, and product integrity.

While these parameters may be adjusted, shippers and carriers typically follow recommendations from original equipment manufacturers (OEMs) to minimize risk to the load and their reputation. Deviating from these recommendations can result in significant product loss and reputational damage. Thermo King offers onboard recommendations based on commodity to optimize product shelf life and reduce the potential for operator error. This system, called OptiSet, provides product setting guidelines based on years of scientific research from highly regarded sources.

The Carbon Footprint of Refrigerated Cargo

It is important to recognize that the carbon footprint of a single refrigerated trailer load can be substantial, depending on the cargo. For example:

Freight	CO_2e (kg)
Apples	8,000
Tomatoes	40,000
Chicken	200,000
Cheese	477,600
Beef	1,420,000

Figure 1 GHG emissions per kg of food product, Source: Our World in Data [1]

A single load loss can negate any emissions savings achieved through changes in temperature setpoint or other operational variables, highlighting the importance of maintaining product integrity. Cargo loss not only results in financial and reputational damage but also has a significant climate impact. The embedded carbon in lost goods, especially high-value, high-carbon products like beef, far outweighs the emissions savings that could be achieved by adjusting operational parameters. Therefore, shippers and carriers prioritize load integrity over emissions reductions from operational changes.

Emissions from Transport Refrigeration Units

Nearly all TRUs in use today are powered by diesel engines, which emit PM, nitrogen oxides (NO_x), and carbon dioxide (CO_2). Diesel PM, including black carbon, is a known carcinogen and contributes significantly to climate change and public health issues. Black carbon is responsible for a large share of deaths from environmental causes and is linked to respiratory and cardiovascular diseases.

Regulatory Timeline: Emissions Standards for TRUs and Diesel Engines

State and federal regulators are tightening the rules on emissions from TRUs, and the deadlines are closer than many fleets realize. From California Air Resource Board's (CARB) aggressive zero-emission targets to the U.S. Environmental Protection Agency's (EPA) proposed Tier 5 standards, compliance is no longer optional, it's necessary.

Why It Matters Now

Although some TRUs are marketed as Tier 4 Final compliant, that standard permits particulate matter (PM) emissions up to 0.30 g/bhp-hr. This is significantly higher than CARB's ULETRU standard of 0.02 g/bhp-hr, and substantially above the 0.005 g/bhp-hr PM limit for EPA 2007-compliant on-road diesel engines.

This regulatory discrepancy has allowed higher-emitting TRUs to remain in service, despite growing scrutiny from state and federal agencies tasked with reducing air pollution for both public health and climate objectives. As PM exposure is directly linked to respiratory and cardiovascular disease, access to clean air is increasingly recognized as a critical social determinant of health. Companies operating high-emission equipment in densely populated or vulnerable areas may face escalating regulatory, legal, and reputational risks.

Preparing for Regulatory Transitions

California's ULETRU (Ultra-Low Emission Transport Refrigeration Unit) regulation requires diesel TRUs to meet particulate emissions standards by specific compliance dates. Looking ahead, the proposed EPA Tier 5 regulations are expected to further tighten federal emissions limits. Retrofitting diesel TRUs with verified DPFs provides a pathway to align with current and future standards while maintaining operational reliability.

Technical and Strategic Considerations of Retrofitting

- Regulatory Alignment: Verified DPF systems support compliance with CARB ULETRU mandates and may reduce risk in jurisdictions with evolving emissions policies.
- Asset Utilization: Retrofitting extends the operational life of existing diesel TRUs, allowing fleets to maximize ROI while planning for long-term transitions to alternative technologies.
- Operational Continuity: DPFs are engineered to reduce PM without affecting TRU temperature control, supporting uninterrupted cold chain performance.
- Fleet Readiness: Implementing proven filtration technologies now can reduce the burden of future retrofits or replacements under more stringent federal standards.

The Most Effective Emission Reduction Strategies

Emissions from the direct consumption of diesel fuel accounts for the majority of greenhouse gas (GHG) emissions for refrigerated transportation, followed by diesel PM and fugitive emissions from hydrofluorocarbons (HFC) refrigerants (not covered in this paper). Direct consumption can be reduced with several strategies including aerodynamic skirting, driver behavior modifications, reduced speeds and reduced idling. Reduced diesel consumption will directly reduce transportation costs, providing a direct return on investment. Investing in newer equipment can also have significant fuel savings, be it at a longer payback time.

Given the fixed nature of TRU fuel consumption and the risks associated with altering operational parameters, the most effective way to reduce TRU emissions without compromising load integrity is to:

- **Use Low-Emission TRUs**: Select units that meet or exceed current regulatory standards. These units are readily available from all major TRU manufacturers and marketed as '50-state compliant' units.
- **Retrofit Existing TRUs with DPFs**: DPFs, such as those from Rypos, can reduce PM emissions by up to 95%. Retrofitting existing units with DPFs is a proven, interim solution that delivers immediate emissions reductions while maintaining operational reliability.

Impact of Equipment Selection and Best Practices

When looking at total environmental impact of refrigerated transportation, the direct fuel consumption of the tractor is typically the largest contributor of CO_2e, followed by the fuel consumption of the TRU, and then the PM emissions of the TRU. CO_2e is a unit of measure that expresses the impact of a climate pollutant on global warming by converting their effects into the equivalent amount of CO_2 based on their global warming potential.

The Opportunity Hiding in the Trailer

While TRUs are smaller than tractors, their emissions, particularly PM, carry a disproportionately high CO_2e penalty. Selecting a TRU that meets CARB's ULETRU standard (<0.02 g/bhp-hr PM) or retrofitting with a DPF can significantly reduce your emissions footprint.

Example Impact of Equipment Choices:

- A 500 hp tractor running 62,000 miles/year emits ~97,000 kg CO_2e, including 5,000 kg CO_2e from PM.
- A TRU operating 2,200 hours/year emits:
  - ~20,000 kg CO_2 from direct fuel consumption
  - ~15,300 kg CO_2e from PM
- Retrofitting with a verified DPF can reduce that PM-related climate impact by ~14,500 kg CO_2e per year.

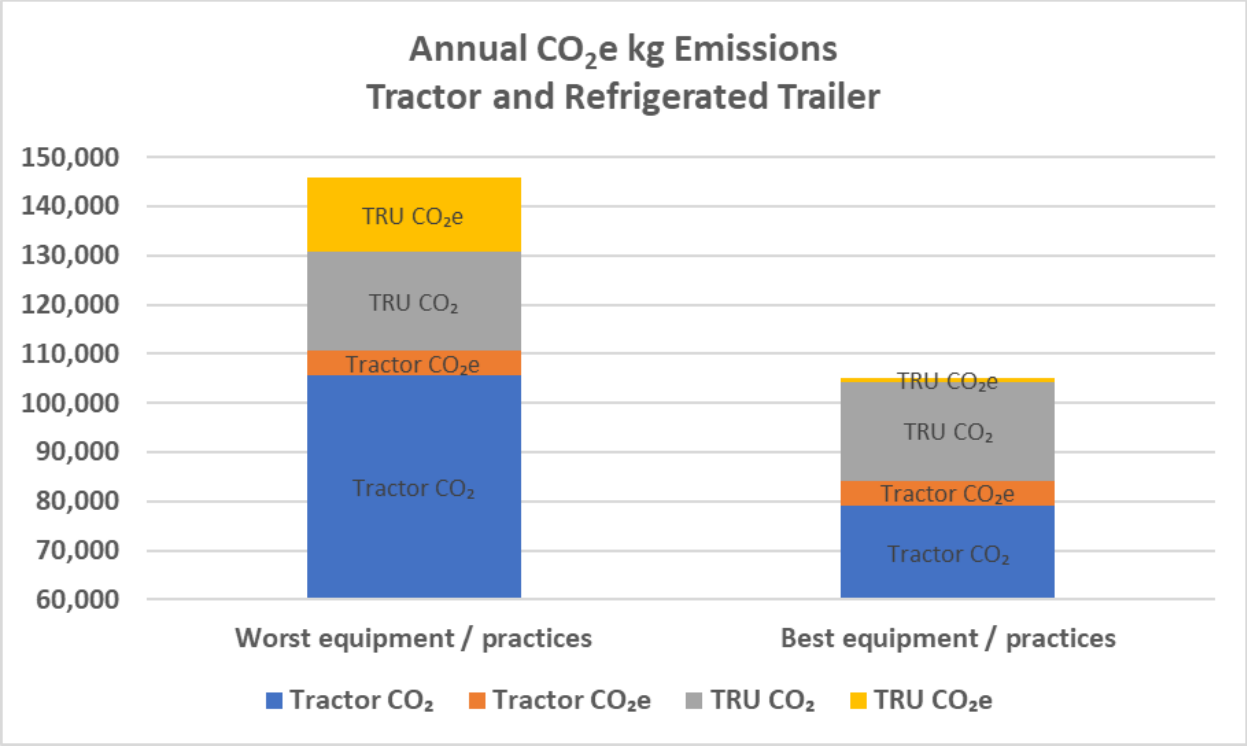

Figure 2 Tractor and TRU CO_2e kg emissions comparison

Assuming the variables involved in refrigerated transportation cannot be significantly changed due to the potential for product loss or degradation, tractor equipment, reefer unit selection and driver behavior are the primary areas for emissions improvements. Since there are already incentives in place to reduce these emissions on the tractor, focus should be on reducing Short Lived Climate Pollutants (SLCPs) like black carbon in diesel PM emissions on the reefer unit.

The Role of DPFs

DPFs are emission control devices designed to capture and oxidize PM produced by diesel engines, including those used in TRUs. DPFs use a combination of physical filtration and thermal regeneration to remove soot from exhaust gases, significantly reducing black carbon output.

Black carbon is a component of PM with a Global Warming Potential (GWP) of 1,588, indicating a high short-term climate impact. Reducing these emissions not only improves local air quality but also contributes to climate mitigation efforts, particularly in dense freight corridors and high-traffic urban zones. Verified DPF systems are engineered to meet CARB and EPA standards without interfering with TRU cooling performance.

Minimizing Downtime: What to Expect with a DPF Retrofit

Retrofitting diesel TRUs with a DPF is a practical, low-disruption solution that can typically be completed in just a few hours. It's one of the fastest, most effective ways to reduce emissions without compromising cargo integrity or system reliability.

Key considerations for fleet managers:

- Most TRU DPF installations are completed within one business day
- No changes are required to existing refrigeration controls or load protocols
- TRUs remain fully functional and ready for immediate use after retrofit
- Installation is performed without risk to cargo or refrigeration reliability

Unlike full electrification or major engine upgrades, DPF retrofits deliver measurable climate impact with minimal interruption to daily operations.

Reducing SLCPs like black carbon not only improves air quality, it also buys time for the development and adoption of long-term, sustainable fleet solutions.

Conclusion

While there are many variables that can be adjusted in the operation of transport refrigeration units, most shippers and carriers follow established best practices to protect product integrity. The most effective way to reduce emissions without compromising load integrity is to use low-emission TRUs or retrofit existing units with DPFs. The carbon footprint of refrigerated cargo is substantial, and any cargo loss can negate the climate benefits of operational changes. Therefore, equipment-based solutions—such as DPFs—offer the greatest potential for emissions reductions while safeguarding the integrity of the supply chain.

Appendix

Chart of existing low emission and high emission Transport Refrigeration Units

High emission TRUs	Low emission TRUs
Carrier X4 7300 / 7500	Carrier X4 7700
Carrier Vector 8500	Carrier Vector 8700
Carrier Vector 8600MT / 8611MT	Carrier Vector 8800MT
Thermo King Precedent C-series	Thermo King Precedent S-series
Thermo King SB and Spectrum	Any TRU with a DPF like Rypos

Additional Sources:

Representing the Reduction of Diesel Particulate Matter Emissions as a Reduction in CO2 Equivalent Emissions

[1] “Greenhouse gas emissions per kilogram of food product” graphic, courtesy of Our World in Data, from https://ourworldindata.org/grapher/ghg-per-kg-poore?country=Beef+%28beef+herd%29~Poultry+Meat~Tomatoes~Tofu+%28soybeans%29~Apples~Cheese~Beef+%28dairy+herd%29

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