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The Current State and Future Trends in Temperature-controlled Transportation

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Abstract
The green shift is making outdated technology as well as environmentally destructive and wasteful practices more apparent across industries. This is particularly true for cold transportation, as enormous quantities of perishable goods like food and medicine are wasted every year in a system reliant on outdated solutions. As the 2020s has seen major developments in environmental action by law- and policymakers, it has become more viable as well as more important to success for companies to shift to newer, cleaner alternatives. In this article we aim to give a holistic overview of the current state of the field of cold transportation, examining the prevalent technologies and their weaknesses, the ongoing changes in EU legislation and regulations affecting the field, and the topical research with applications in cold transportation. Finally, we present two innovations with significant environmental and economic benefits over the most prevalent systems currently in use.

Keywords: Temperature-controlled Transportation, Cold Chain, Sustainability, Environmental Legislation, Emissions Reduction, Cold Storage Innovations

Introduction

As demands for sustainability across our whole economy are growing, many industries are forced to take on a path of rapid change in the coming years if not now. Cold transportation is no exception, as it is largely relying on old, polluting technology and infrastructure. Anticipating the direction of change and upcoming research requires knowledge of the legislative actions taken to propel the green transition, the current problems within the field of cold transportation, the current state of cold transportation research as well as fresh innovations in the field. This paper aims to provide a holistic view of the state of cold transportation, focusing heavily on road based cold transportation, as in the coming years road transportation is facing a rapid shift to clean technologies within the EU. The second chapter gives an overview of the legislative and regulatory overhauls affecting road transportation and cold transportation companies, while also broadly pointing out the problems of and necessary developments for the cold chain. The third and fourth chapters delve into solutions provided by existing research, with the fourth chapter highlighting AI-based solutions. The fifth chapter presents two fresh innovations whose wider adoption could significantly reduce the energy intensity of cold transportation, as well as make the cold chain more reliable and flexible. The article is based on presentations in ECCOMAS 2024 (European Congress on Computational Methods in Applied Sciences).

The Role of Innovation in Adapting to Legal and Regulatory Changes as Europe Goes Green

The cold chain – the vital network responsible for the delivery of perishable goods such as food and medicine across the globe – is facing an era of rapid change. As climate change prevention and mitigation is taking increasing priority in politics, the European Union is passing new environmental legislation and regulations to curb emissions as a part of the European Green Deal. For many companies this means direct obligations to more sustainable practices or to report their emissions according to a common standard. Though transportation is facing possibly the most infrastructurally significant changes as combustion engines are being phased out, the impacts are designed to be felt by the manufacturer rather than the consumer. Though the European cold chain is not directly affected by many of these legislative changes, this era of rapid change presents a multitude of opportunities for companies in the field of cold transportation. Understanding the problems of the current cold chain as well as the legal and regulatory changes in the EU allows for forming a picture of the future directions of cold transport research and the cold chain. As our research surrounding cold transportation has been largely focused on the urban environment, the focus of this review is on road transportation.

Problems in the Urban Cold Chain

As it is, the cold chain has some significant sustainability issues, with lots of room for economic and environmental optimization. Firstly, road-based cold transportation often relies on special vans and trucks outfitted with cooling equipment to get perishable goods from point A to point B. In addition to their high price, these vehicles need to power their cold compartment with either an external power source or with the vehicle's engine itself. As even the external power source is often diesel powered, this leads to greater fuel consumption for the vehicle. This means that the time spent idling in traffic or in the loading/offloading phase is even more wasteful than it is for another road traffic. The single big cold compartment is also wasteful in that heat is let in every time something is loaded to or offloaded from the vehicle. In addition to the problems already mentioned, nowadays many urban areas have partial or full bans on diesel powered generators due to the noise pollution they cause, which means a transition to alternative power sources for cooling is in some areas already a must.

The second point of weakness in the urban cold chain is that it must rely on the road infrastructure of the local urbanity and compete for space with passenger traffic. Road transportation in cities is often highly inefficient with congestion slowing down travel times for goods and for people. As keeping the perishable goods cold takes extra energy, and the longer the trip the bigger the risk of spoilage, an ecological cold transport delivery should not get stuck in traffic. In addition, as the temperature of the truck places a constraint on the goods it can deliver, trucks are often loaded with low product variety, sometimes leaving the truck half empty. This both creates a need for a bigger fleet of vehicles and leads to inefficient routes with lots of overlap.

Lastly, keeping products cold reliably is still a challenge, and there is a significant amount of spoilage in the cold chain, though much of the spoilage occurs in rural areas with minimal infrastructure. Reliable cooling is also facing a challenge in the form of many plastics with good insulation properties being phased out due to them having adverse effects on the environment.

The European Green Deal

The Green Deal is propelling a rapid transition to a more sustainable energy and transportation infrastructure within the EU. In this chapter we outline the new legislation and regulations pertinent to urban cold transportation, which include the Corporate Sustainability Reporting Directive (CSRD), the Emissions Trading System 2 (ETS2), and revised CO_2 targets for new passenger and light commercial vehicles as well as proposed ones for new heavy-duty vehicles. This list isn't comprehensive, and the environmental law and regulations will inevitably keep getting stricter as time goes on. Nevertheless, understanding the overhauls examined here gives some insight into the future directions of logistics and cold transportation.

Out of this set of legislation and regulations, the Corporate Sustainability Reporting Directive (CSRD) is the one with the clearest direct impact on some logistics and cold transport companies. CSRD establishes a new standard for reporting environmental as well as social impacts, making the sustainability practices of a company transparent and comparable to consumers and investors [1]. This comparability allows for sustainability competition on a new level, as companies ahead of the curve can leverage their sustainability in standing out to consumers and investors. The directive will apply to companies with at least 250 employees, €40 million turnover and €20 million assets. Although this leaves many small businesses unaffected, this still accounts for three quarters of all EU companies [2]. The compliance schedule for CSRD has already begun, with company's subject to the Non-Financial Reporting Directive (NFRD) required to comply from the start of 2024. The directive falls over other large companies from the start of 2025, small. And medium-sized enterprises from the start of 2026, and third country companies from the start of 2028.

The Emissions Trading Systen 2 (EST2) is an extension to the pre-existing system, set to cover combustion emissions from road transportation, buildings, and some smaller industries [3]. It is intended to serve as a disincentive for fuel producers rather than consumers, and producers are required to monitor and report cost rollover affecting consumers. The law states that the European Parliament will take additional measures to prevent rollover if consumers are affected, though these measures are yet to be defined. EST2 will take effect from 2027, with the caveat that if fuel prices are high in 2026, adoption could be postponed to 2028. For the first three years the allowance price will be kept under €45 by releasing more allowances when necessary. Allowances may also be released to slow the rate of price increase. Though the intent is minimal impact on consumers, the real effect on fuel prices is hard to predict.

As for the future price development of ETS2 allowances, it seems likely the price will rise far beyond the initial cap of €45. The price of the first Emission Trading System allowances was at its peak in February 2023 at €100,34, and the average over the same year was €83,66 [4, 5]. The Intergovernmental Panel on Climate Change (IPCC) has stated, however, that the abatement cost of one metric ton CO_2 to limit atmospheric warming to 1,5°C is \$170–\$290 [6]. A successful disincentive, whether a tax or allowance, should incur more costs to the emitter than carbon abatement. This means that even the pre-existing ETS is far from the course set in the Paris Agreement. It is likely that the allowances of both systems will reach new highs as time goes on, but precise predictions are difficult to make.

The regulations revising the standards for new road vehicles are set to completely phase out new internal combustion engine (ICE) cars and vans, reducing emissions by 100 % from 2021 levels, and, if passed, reducing emissions from new heavy-duty vehicles (HDV) to 10 % of their 2019 levels [7, 8]. As it is, because emissions are measured from exhausts, there is no exemption for vehicles running on e-fuels or biofuels. A future exemption for e-fuels – demanded by Germany – has been agreed upon. No such plans exist for biofuels. It is important to note that special purpose vehicles (SPV) are exempt from this regulation, meaning it is possible, though not necessarily economical, for car manufacturers to keep selling new cooled ICE vans and trucks.

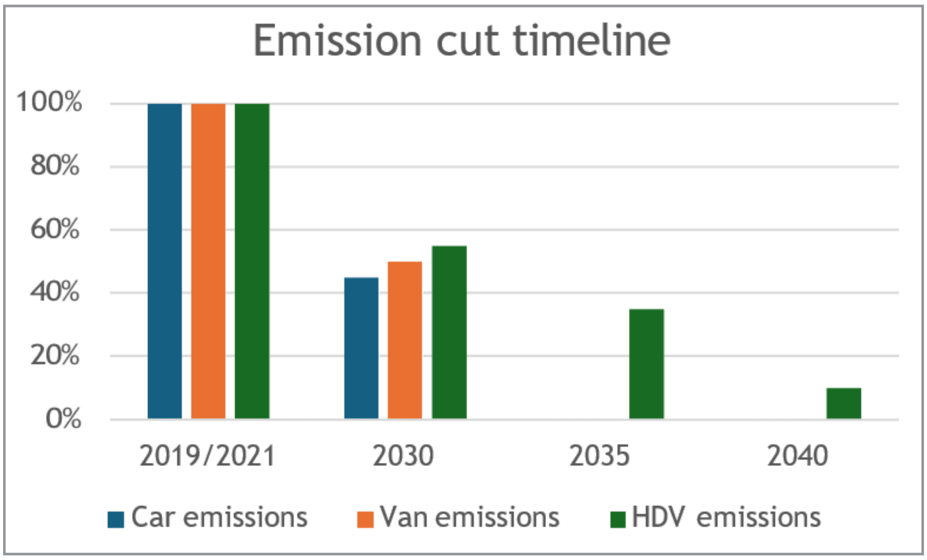

Figure 1: Emission reduction timeline for new cars and vans (as compared to 2021 levels) [7] and for new heavy-duty vehicles (as compared to 2019 levels) [8].

The EU expects these regulations to shift the car fleet majorly towards Electric Vehicles (EV). Although battery metals experienced a price shock in 2021–2022, it has subsided as rising interest has led to new lithium deposits being discovered. Though battery metals will remain crucial for energy security, it is important to acknowledge the adverse environmental, social, and economic impacts of battery metal mining on local communities and surrounding areas, as there is a significant tradeoff between sustainability and energy security [9]. As for the battery supply chain itself, the nickel magnesium cobalt (NMC) battery supply chain is largely in control of China, as Chinese companies control most of the world's cobalt deposits [10]. Lithium iron-phosphate (LFP) batteries on the other hand have less supply chain vulnerabilities [10]. LFP batteries, though less energy dense than NMC batteries, are more stable, durable, and non-toxic, which both makes them safer and more sustainable. The lower energy density does mean lower maximum charge, however, which again results in a lower maximum distance a vehicle with an LFP battery can travel before having to recharge. This presents a problem to cold transport vehicles, which often need extra power to cool the cold compartment and do need to drive inter-city and sometimes longer routes, for which current EV battery power is insufficient, especially as charging infrastructure is sparse. Charging times are also significantly greater than the time it takes to fill an ICE tank with fuel. As cold transport vehicles are in very frequent use, battery degradation also becomes an issue. Though EVs do exist as cold transport vehicles, they are not common, and do still come with many restrictions as compared to ICEV cold transport vehicles.

Alternatives to EVs do exist, but don't have significant market or environmental advantages over EVs. As mentioned before, there is a plan to exempt e-fuels from the restrictions, but for biofuels there seemingly is no such plan. E-fuel production is very expensive compared to other fuel types, and though biofuel can be produced from agricultural and domestic waste, to be a significant energy source for traffic biofuel would need to be produced from crops or farmed algae, which would take critical resources away from our already strained food systems [11]. Hydrogen Fuel Cell Vehicles (HFCV) are perhaps the most prominent future alternative for EVs, but they are also lacking in infrastructure, and still have significantly higher lifetime costs than EVs [12]. As all of the alternatives mentioned here use air to maintain the combustion reaction, pollutants like nitrous oxides and soot are produced simply because of the high heat of the reaction, even in HFCVs [13, 14].

Directions for Cold Transportation

Though these legislative and regulatory changes have few direct impacts on the field of cold transportation, they are driving a larger infrastructural shift that presents many opportunities for cold transportation companies and research. Companies falling under CSRD will be capable of competing in sustainability in a standardized and transparent way, which means early adopters of new technologies and more sustainable practices may benefit. Being ahead of the curve, though requiring upfront investment and possibly leading to increased costs in the short term, also holds promise of savings and efficiency improvements in the medium and long term. Though much can be achieved with just an infrastructural shift to newer technology, research and innovation are needed to solve some of the pressing issues in cold transportation.

Many avenues exist for improved and more sustainable cold transportation. Currently cooling is still largely done with fossil fuels and insulation uses unecological plastics. Green alternatives for refrigeration and cold storage, done with green energy and ecological, reuseable, and recyclable insulation materials, are needed. Making cold containers smaller and autonomous from the delivery vehicle could also significantly lower the energy wasted as the cold compartment doesn't need to be opened when loading or offloading a vehicle, as well as increase the modularity of shipments, allowing for a greater variety of goods transported in a variety of temperatures and removing the need for half empty deliveries. Though EVs are already in many cases a viable option for last mile delivery, better EV infrastructure such as rapid charging stations along delivery lines and better EV batteries would allow for wider adoption of electric vehicles in cold transportation, making longer delivery journeys possible. More reliable temperature control, which can in many places be achieved with better infrastructure, also needs to be achieved to diminish wasted goods. As new technologies are adopted, cityscapes are changing, and electronic sensing is improving, algorithmic optimization of delivery routes and traffic can also reach new heights.

Though the urbanity of the 20s is still quite universally defined by cars, future cities will likely shift away from automobility in many places, opening further opportunities for cold transportation and logistics. Drone based last-mile delivery, though currently mostly viable in suburban areas, is a hot research topic, as airborne drones can deliver small packages at unparallelled speeds, unaffected by the wider traffic system. Though urban areas have so far posed a great challenge to drone deliveries because of the verticality of the environment, even urban applications may become available in the future as sensing and autonomous piloting improves. As China is building new cities, a lot of focus is placed on research around underground logistics systems (ULS) and metro based ULS (M-ULS). When a city is built ground up with our modern technological knowledge, it is possible to design logistics from scratch, creating efficient underground lanes for the movement of goods in and out of the city. M-ULS on the other hand proposes a synergistic system responsible for both the transport of passengers and goods. These kinds of public transport logistics hybrid systems have been researched in other areas and with other modes of transport as well and present a whole new paradigm of logistics and cold transport for future cities.

Cold Transportation Systems and their Impact on the Environment

Currently most refrigerated transportation uses Vapor Compression Refrigeration (VCR), Phase Change Materials (PCM), or a combination of these methods to keep the transportable goods cool [15]. VCR systems work like domestic fridges or air conditioning and can be powered through different means, like by drawing power from the engine or a separate generator. In both cases the power source needs to provide constant electricity, meaning the engine or the generator can't be turned off during any phase of transport between loading and unloading, even when the vehicle is stationary in a parking lot or in traffic, resulting in wasted energy and greater emissions.

PCMs on the other hand are materials that provide cooling by absorbing heat and via endothermic phase change. Examples include ice used to transport fish or dry ice to transport medical products. The main problem for PCMs is that some of them are toxic or otherwise hazardous and thus can cause severe problems if the container is broken and the material leaks into the products or into the environment [16]. Many PCMs are also unsuitable for air transport, because they undergo phase transition as air pressure changes, releasing gases and reducing their functionality [17].

The equipment in a cold transport vehicle can also experience malfunctions or breakdown during a delivery, which often results in the goods being transported spoiling, especially in areas lacking in supporting infrastructure. Of the globally produced food, around 13 %, or about 720 million tons, is wasted during transportation [18]. Most medicines requiring a specific storage temperature are even more sensitive to temperature fluctuations than most food products and their waste has a bigger societal cost, as their manufacturing is often expensive, and losses have direct impacts on the capacity of healthcare units to provide certain treatments. One fourth of vaccines are degraded due to flawed shipping, nearly one third of pharmaceuticals are scrapped due to logistical issues and one fifth of temperature-sensitive medical products are damaged due to failures in the cold chain [19]. Improving the reliability of the cold chain would not only reduce economic losses but also have a real impact on the availability of medicines, especially in rural and undeveloped areas.

Environmental Impact

The cold chain often has poor environmental performance due to the technology and infrastructure currently in use. The current logistics and infrastructure are built so that even though other methods are being studied the last mile delivery of refrigerated transportation is done by road on nearly every occasion. Since the last mile is often the most inefficient part of the whole transportation journey due to smaller loads that are not filled to their capacity travelling inefficiently and in varying speeds, we will focus on that. Around 7% of the world's CO_2 emissions are released by freight transportation on road and around 18% is released by the whole road transportation sector. For comparison, the whole transportation sector accounts for 24% of the world's CO_2 emissions, which means that road transportation accounts for nearly three fourths of it [20].

Transportation on the road has a significant impact on air pollution, noise pollution and release of microplastics. According to WHO 99% people breathe air with particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide or carbon monoxide levels that exceed the recommendations for long-time exposure [21]. It is estimated that air pollution causes 4,2 million premature deaths worldwide per year, disproportionately affecting people with lower income. These deaths are due to cardiovascular and respiratory diseases, and cancer, which are caused by exposure to fine particulate matter [22]. The impact of noise pollution on human health is not well known yet, but it is suggested that it has a correlation to cardiovascular disease and sleep disturbance [23]. The impact might be even worse on children and cause impairment of early childhood development [24]. Tires are one of the biggest sources of microplastic in the environment [25]. Even though there has not been wide research on the impact of microplastics, they seem to have some connection to inflammatory lesions, neurodegenerative diseases, immune disorders and cancers [26].

Even though many of these problems apply to road transportation in general, the impact is increased in refrigerated transportation due to its higher energy needs. Thus, the optimization of refrigerated transportation would be impactful. In an ideal world we would reduce modal share of road freight and replace it with more environmentally friendly methods like rail transportation.

Points of Optimization in the Cold Chain

When considering optimizing cold transportation we need to decide, we need to look at how we can make it more efficient and identify the points that could be optimized. Based on the last chapter, our aim is to minimize the emissions and pollution emitted by refrigerated transportation. We will also focus on the last mile, the trip from a warehouse or a storage building to the destination like a store or a pharmacy. The points for optimization on this last mile delivery are route optimization, utility maximization, and maintenance of the required temperature inside the refrigerated compartment.

The route has significant importance, because it affects the distance driven and time taken, which affects how energy-efficient the trip was and how much emissions were released. The route optimization is a multifaceted and dynamic problem, because the traffic conditions can vary throughout the day, the stops on the route might have different requirements on the delivery times and there might be some unseen events like a car accident on the route. Traffic conditions are an especially important factor in environmentally friendly route planning due to traffic congestion decreasing the efficiency significantly. Thus, traffic prediction in the route-planning phase is essential. When looking at road transportation, prevention and monitoring or traffic congestion are points for optimization that would benefit all the vehicles as well as the refrigerated transportation.

There are situations where the temperature inside the refrigerated truck is at risk of going outside the limits, which leads to products perishing or degrading. The biggest threats come during loading and unloading when the doors need to stay open, as well as on the occasion that the truck breaks down. If the refrigerated truck uses a VCR system the engine needs to stay on during loading and unloading to maintain the required temperature, which causes additional emissions and pollution.

The products should be distributed between the refrigerated trucks optimally and so that multiple trucks do not need to visit the same stops. This saves energy because the truck still uses around the same amount of energy as when driving full, so the energy is wasted if the truck is not filled to its full capacity. It also minimizes the number of trucks on the road driving to the same or close-by destination.

Optimization Solutions for Refrigerated Transportation

There isn't much research related to the problem of temperature changes during loading and unloading. The problem is very practical, and it doesn't have an easy solution in the form of computational methods or algorithms. In section 4.2 one practical solution for this problem is presented in the form of a modern, autonomous, hand movable cold container. As a significant portion of cooling happens within the boxes, and box temperature can be monitored with intelligent sensing, the products being transported never come in contact with warmer air. This solution would also aid in filling transport vehicles to their full capacity, because products that require different temperatures could be transported in the same cargo space.

Predictive maintenance could ease the food degradation and waste caused by vehicle breakdowns. PM could be used to predict the optimal time for the maintenance of a RU, so that it does not break down, but so that it is not subjected to unnecessary maintenance. In many application areas of PM, prediction is carried out by using sensors to detect vibration and sound anomalies in electronic equipment, which are then used as indicators of deteriorating device condition.

The problem of getting a refrigerated vehicle from the warehouse to the customer (so called last mile delivery) is a typical vehicle routing problem. There are multiple variations of VRPs, but the most interesting variations and combinations for the purposes of this article are Green, Multi-Depot and Split Delivery VRPs as well as VRPs with multiple time windows. Solutions that are presented for optimization of these VRP problems is applicable to our problem as well.

As for traffic congestion, the driver cannot really affect road conditions, so here we have two options: find a route around the traffic or get rid of the traffic congestion altogether. The former solution is temporary and benefits only those that are using the route-optimization tools to do so, while the latter would benefit the whole road transportation sector. The route around the traffic could use some traffic prediction and route planning to avoid the rush hours [27-29]. One effective way to ease or outright prevent traffic congestion is to install smart traffic lights that use an adaptive algorithm that, based on smart sensing, calculates the optimal times to switch traffic lights to green or red to keep both car and foot traffic fluid [30]. The same system, if fed real time data about traffic conditions in the area, can prepare for incoming traffic by clearing cues pre-emptively so that congestion is avoided later.

For optimizing cold deliveries from warehouses to sellers, we propose a three-part AI system, consisting of Prediction, minimization, and route optimization. First, we need to predict the needs of the customer, so we have the required products available. Next, we need to organize the available resources so that we use them optimally. This means, for example, organizing the vans so that no van is driving half-empty or to the same destination and thus reducing the number of vans on the road. Lastly, we need to find the best route for the individual vans with certain limits, like time restrictions. The route optimization also includes avoiding traffic.

To conclude, the last mile transportation, which is often the most inefficient part of the transportation has room for optimization in how the products are distributed among the vehicles, which routes they take and when, how to avoid getting stick in a traffic congestion, and how the temperature is maintained within the vehicle. All these points have a variety of solutions that could be utilized to optimize transportation and reduce the environmental impact of refrigerated transportation systems. We need to look at the whole picture from the warehouse to the consumer like we do in the proposed AI-system to fully optimize the last mile refrigerated transportation system.

A New Era in Temperature-controlled Transportation

Though there are a plethora of environmental and economic problems within the field of cold transport, there haven't been significant innovations to solve these issues within the recent years, with the biggest developments being the release of new refrigeration unit (RU) models. The standard mode of operation in the road based cold chain has remained the same across the 21st century, with the RU of the cold transport vehicle running all the way from loading to unloading and smaller goods transported in boxes made of thermal insulators like EPS or EPP, which can maintain a stable inner temperature for hours. In this chapter we present two new innovations to improve both the energy and cost efficiency of temperature-controlled transportation.

The Coldest Chain Oy Solution

With the patented invention of Mr. Jukka Proskin, Coldest Chain Oy provides new possibilities in temperature-controlled transportation [17]. The core of the Coldest Chain Oy solution is a modern cold container which can be scaled to fit customer needs, available in almost any custom shape or size up to 1 m3. The boxes can be manufactured from both EPP and EPS plastic, but EPP is preferrable as its thermal insulation properties are significantly better than those of EPS. EPP can also be reused and can withstand washing in high temperatures. The Coldest Chain cold containers are equipped with a capacitive gel cooling module, the temperature of which can be adjusted according to product requirements all the way from frozen to warm. The Coldest Chain boxes are also equipped with a cloud-based temperature monitoring unit with the capacity to also utilize GPS data. This solution extends the functional lifespan of the container and allows for high energy efficiency, thus reducing emissions from cold transport operations as well as equipment lice cycle emissions. With the Coldest Chain solution, expensive refrigerated trucks aren't needed for every delivery, as the cold containers can autonomously maintain the required temperature in many delivery scenarios. The Coldest Chain solution also eliminates the need to use dry ice to cool products – an additional cost especially when considering airborne cold transportation, where dry ice is considered a dangerous good incurring a surcharge.

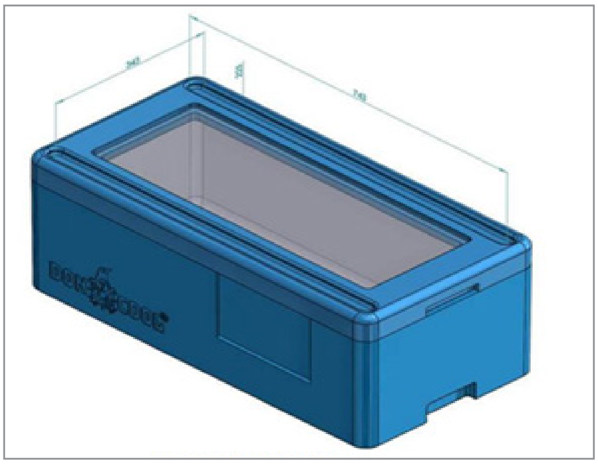

Figure 2: The Coldest Chain cold container

The New Patented Solution of Jaspi Holding L. L. C – FZ

Jaspi Holding L. L. C – FZ is holding the patent of a new innovation by Mr. Jukka Proskin, which uses capacitive gel cooling units (CGCU) installed onto the ceiling of either a transportation vehicle cargo space or a warehouse for refrigeration. As traditional cooling equipment needs to be running for the entire duration of the goods' presence – sometimes for days – this alternative solution achieves significant energy savings and emissions reductions. The cooling provided by the CGCU allows for RUs to run only a few hours in the period of multiple days as opposed to around the clock; a pre-cooled CGCU steadily cools the air around it to 1°C for up to 24–48 hours with only air circulation required, and occasional air conditioning by the RU prolonging the functional timespan of the CGCU. The solution also provides more reliable temperature control, as the pre-cooled gel mat's cooling effect is a passive process, which is a direct result of entropy, as opposed to a continuously running electronic device working against entropy in an active process. In the event of RU malfunction or breakdown, where the refrigerated goods would normally spoil if the problem wasn't fixed within an hour, the CGCU provides significant buffer time, keeping the products cool for hours to days. Further energy efficiency and cooling stability improvements are achieved by using cognitive AI to calculate the optimal timings for running the RU. The AI can also use GPS data to turn off the RU when driving in city centers to avoid unnecessary noise and air pollution, which is especially meaningful during nighttime when noise pollution has the potential to harm sleep quality.

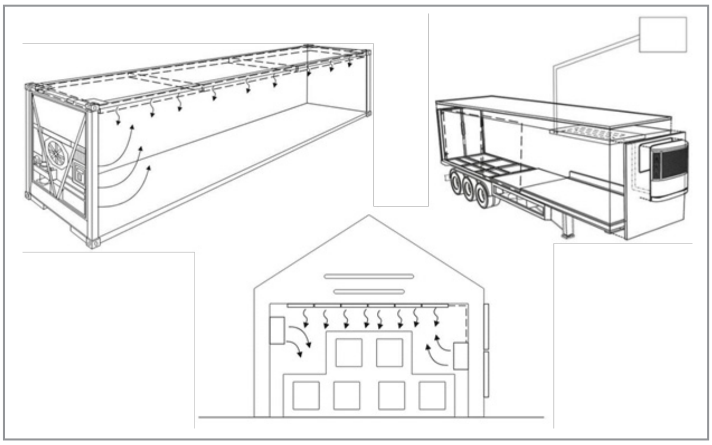

Figure 3: The CGCU installation in container-, trailer-, and warehouse-environments.

The CGCU provides the best energy efficiency improvements when pre-cooled, because the pre- cooling process is highly efficient and can provide up to 48 hours of steady cooling. Pre-cooling the CGCU can be done by linking the air or refrigerant flow of a RU to the unit, the latter being the faster cooling option, though applying nano gas as a condenser has been observed to be the fastest of the experimented with cooling methods.

Future Outlook for the Presented Innovations

The solutions presented have many applications for temperature-controlled transportation as well as the medical field and could significantly improve both the future environmental and economic performance of these fields. These solutions can be applied to both storage and transportation of food, medicine, medical samples, as well as organ transplants. The innovations provide a new level of reliability, accuracy, and monitoring in temperature control: a staggering advantage over previous methods of refrigeration for all cold transports and especially for the medical field, where these features are vital for the safe delivery of valuable goods. Both companies are in the startup phase and looking for larger partners for investment as well as partners operating on other continents.

Conclusions

This article is an expanded version of the ECCOMAS 2024 technical session on cold transport. The collection of smaller articles aims to provide a holistic view of the current state of road based cold transportation – the environmental problems of, and waste in, the cold chain, as well as the topical research addressing environmental and efficiency optimization of cold transportation – and future trends in the field – the changing EU legislation and regulations affecting road transportation as well as a couple brand new innovations.

Although cold transportation still has many issues in both its environmental performance and efficiency, the topical literature provides ample methods for addressing them. Many algorithmic and AI solutions are still quite theoretical and their implementation into managing cold chains needs more research. This does indicate that environmental optimization research within cold transportation is still finding its footing, and there is a lot of untapped potential in research topics. As the field is facing massive changes in the form of EU legislation in the form of, for example, an all- out ICEV ban, it is likely that research funding and material realization of new research and innovations within cold chains will significantly accelerate and increase. The two innovations presented in this collection, the scalable autonomous cold container and the CGCU, act as perfect examples of current advancements that have significant potential for energy efficiency savings and more reliable cold transportation operations, leading to less emissions, less wasted goods, and more economical operations of the cold chain. We are witnessing a huge infrastructural shift, where the roles of research and innovation are paramount. The key finding for companies is that though adopting new technologies always requires greater investment than continuing the use of older technologies, new solutions not only hold the promise of cheaper and more reliable operation but can also make the company compelling for investors and consumers, as CSRD will standardize environmental reporting and make the competitiveness of a company's sustainability practices more transparent. Sustainability competition, both environmental and social, will be a new norm in just a few years' time, and the companies well prepared for it stand a chance to stand out and get ahead.

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