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Transport

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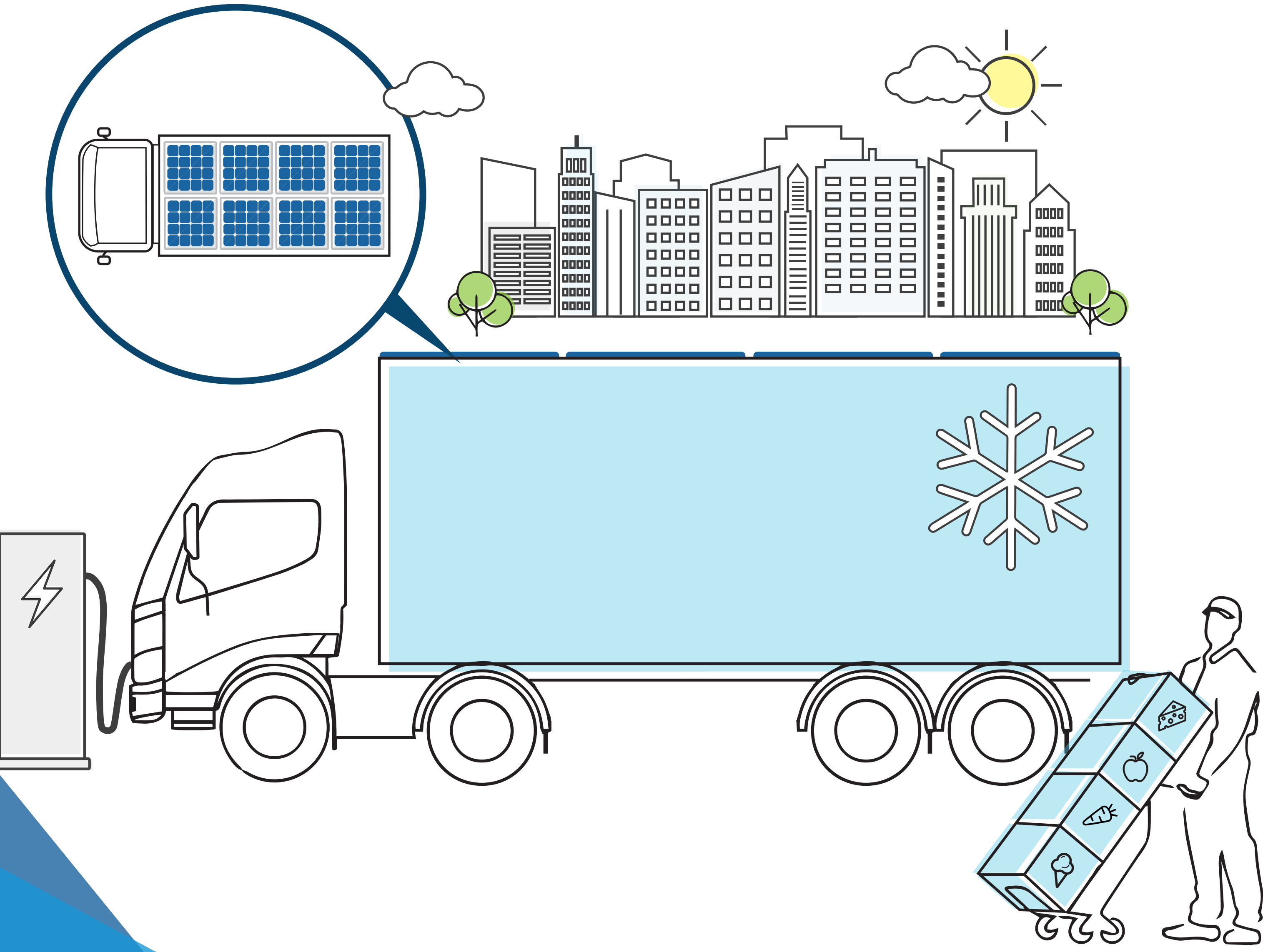
Refrigerated Transport Insights:

A ZERO White Paper



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Introduction

While our transport sector moves to lower emission vehicles, the diesel auxiliary engines, which provide power to the refrigeration units on vehicles, continue to emit far more emissions than the vehicles' main engine. This Cenex white paper provides an introduction to refrigerated transport, the current state of the art, and the requirement for more sustainable technologies.

This paper was developed in collaboration with Sunswap as part of the Innovate UK funded ZERO project – Zero Emission Refrigerated Operations. This paper focuses mainly on refrigerated trailers operated by supermarkets.

What is Refrigerated Transport?

Refrigerated transport is a method for shipping temperature sensitive products in a temperature-controlled environment. The vehicle transporting the products has a built-in refrigeration system, otherwise known as a Transport Refrigeration Unit (TRU), and an insulated body that keeps the produce at a set temperature. Set temperatures can range from fresh vegetables at up to +8°C to ice cream at -25°C. Refrigerated vehicles range in size from panel vans to 44-tonne trailers. There are around 100,000 refrigerated vehicles operating within the UK[1].

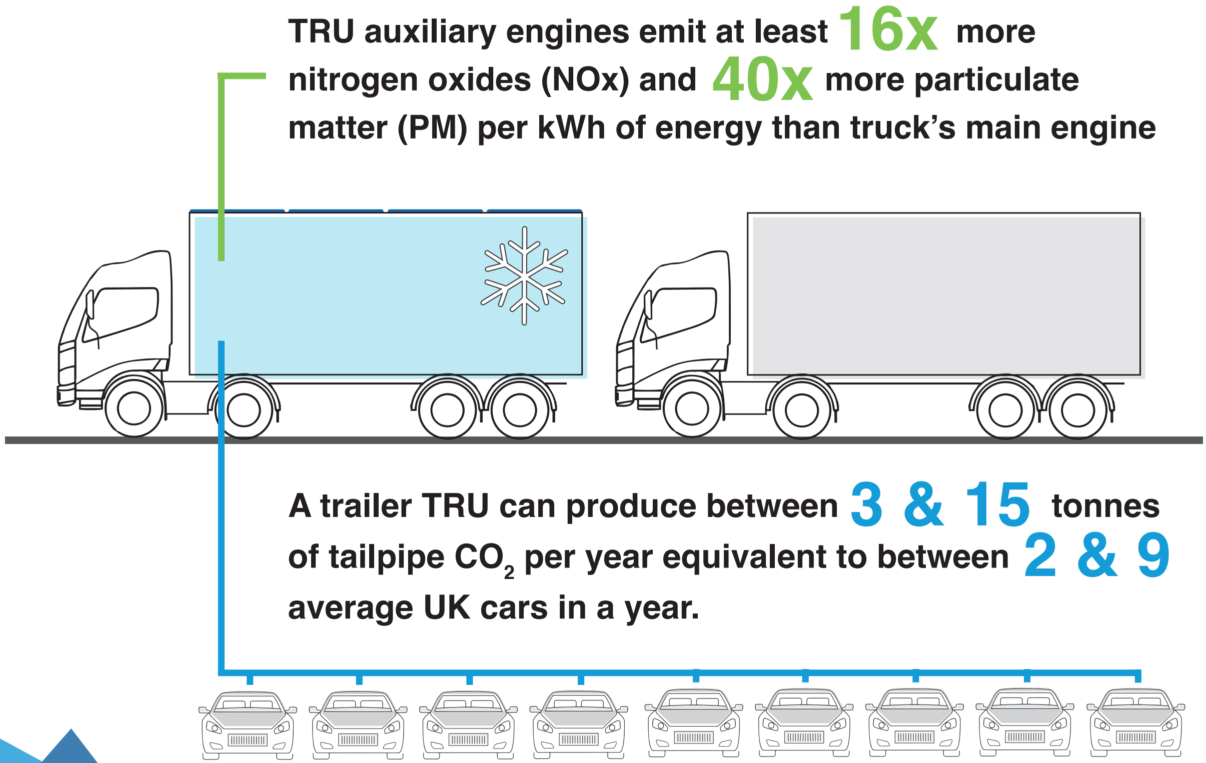
Today, these refrigerated vehicles are most predominantly powered by diesel. The smaller vehicles (vans and smaller rigid trucks) utilise power from the vehicle engine to run the refrigeration system. However, the larger vehicles (larger rigid trucks and articulated trucks pulling a trailer) use an auxiliary engine, typically diesel, with much less strict emissions standards than diesel engines used for vehicle propulsion. Depending on the daily operating hours and the types of goods transported, a trailer TRU operating in the UK can have an annual energy consumption (referred to as thermal load – which we will explain later) of between 13,000 and 32,000 kWh[2], equivalent to between 17 and 40 UK average domestic fridge-freezers in a year[3]. To meet this demand, the trailer TRU would require between 1,300 and 6,000 litres of diesel per year[4].

Emissions from Refrigerated Transport

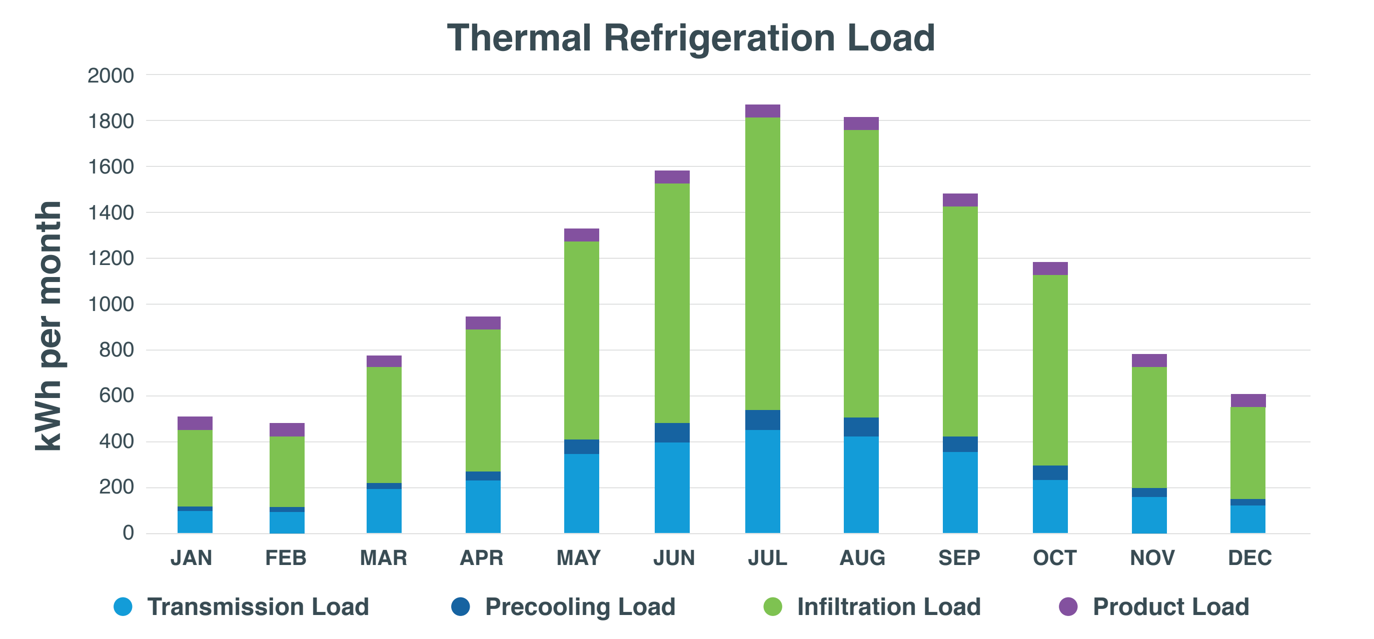
In terms of carbon emissions, auxiliary engines for transport refrigeration have a significant impact, as a trailer TRU can produce between 3 and 15 tonnes of tailpipe CO_2 per year (based on the previous diesel use), equivalent to between 2 and 9 average UK cars in a year[5]. In a study commissioned by Transport for London, Cenex estimated that diesel TRUs account for around 9% (83,500 tonnes per year) of all well-to-wheel (WTW) CO_2 emissions from temperature-controlled transport that enters London[6].

Moreover, diesel trailer TRUs are very polluting. If we compare the latest stage V non-road mobile machinery (NRMM) emissions standards for auxiliary TRU engines against the latest Euro VI standards from truck main engines, auxiliary engines emit 16 times more nitrogen oxides (NOx) and 40 times more particulate matter (PM) per kWh of energy[7,8].

This is an optimistic estimate, as stage V NRMM standards were introduced in 2019 as opposed to 2013 for Euro VI truck engine standards, meaning that most auxiliary TRU engines on the road do not comply with the stage V standard. In fact, prior to 2019, new diesel auxiliary TRU engines under 19 kW were not obliged to comply with any emission standard at all if they operated within UK borders. In a study of TRU emission in Leeds, Cenex estimated that, with the implementation of a Class B clean air zone (CAZ) where most vehicles are Euro VI compliant, auxiliary TRU engine emissions would then account for around 54% of all NOx emissions from temperature-controlled transport vehicles as traction engines emissions reduce.



Understanding Thermal Load



To explain the energy requirements of TRUs and how they can be reduced, it is useful to understand what makes up thermal load requirements.

Thermal loads can be separated into transmission, precooling, infiltration, and product load. The combination of these loads represents the thermal energy load the refrigeration system is required to provide in order to keep products cold. An example of the thermal demand is shown, as calculated by a Cenex refrigeration model for a trailer TRU operating for 13 hours/day with 4 deliveries transporting vegetables at 0°C[10].

1 **Transmission load** represents the heat loss through the walls, floor, ceiling and doors of the trailer. This is solely the thermal transmittance through the fridge construction.

2 **Precooling load** represents the energy required to cool the trailer down to the desired set temperature before loading it with products. This process needs to cool the thermal mass of the walls, ceiling, floor and doors of the trailer, plus the thermal mass of the air within the trailer.

3 **Infiltration load** is the thermal energy lost when the TRU doors are opened. This thermal energy is lost via three mediums:

- **a.** the air: volume of chilled air that is replaced by outside ambient air
- **b.** the product: thermal energy lost from the product to the now ambient internal air temperature
- **c.** the fridge constructions: additional thermal energy lost from the inside surface of the fridge walls, floor, ceiling and doors to the now ambient internal air

4 **Product load** refers to the heat of respiration, which occurs in “living” produce including fruits and vegetables. These products generate heat when stored above freezing temperatures. Who thought cucumbers could breathe?

Best Practice for Fleets: How to Reduce Refrigeration Demand

Ensuring good management of temperature-controlled logistics can help to reduce energy requirements, which in turn reduces the environmental footprint and fuel costs. There are several ways in which refrigeration energy can be optimised.

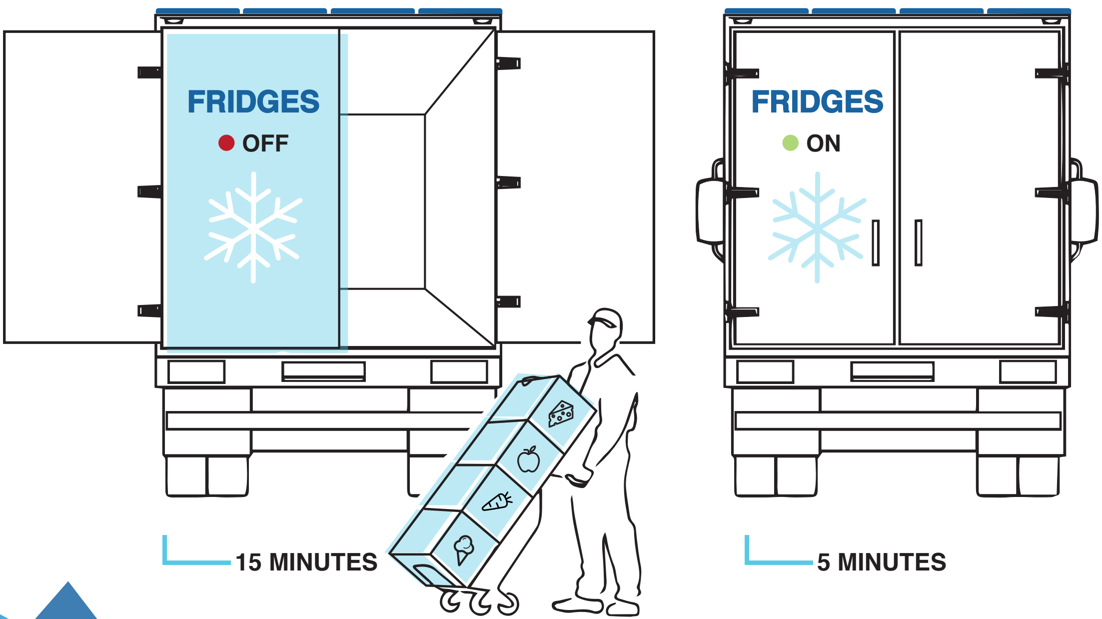
1. Trailer (un)loading procedures: The correct procedure whilst unloading a trailer is to turn off the refrigeration system, then open the doors and proceed to unload. To avoid produce spoiling during the longer unloading processes (which can exceed 1 hour), the doors are closed to allow the produce and cargo space to re-cool. Through stakeholder engagement with several major UK supermarket fleets, Cenex was informed that the most common procedure for trailer TRUs is to unload for 15 minutes (doors open and fridge off), followed by 5 minutes of allowing the trailer to re-cool (doors closed and fridge on). This cycle is repeated until all the produce is unloaded. Moreover, if unloading procedures can be accelerated and door opening times reduced by 25%, this would involve between 9 and 13% fuel savings.

2. Vehicle body colour: A dark body vehicle has a 27% higher transmission load compared to a white body vehicle on the same duty cycle. The total tailpipe CO_2 per year from the whole London refrigerated fleet can be reduced by approximately 2,000 tonnes if all refrigerated vehicle bodies are coloured white or silver. This is a potential 1.3% reduction in total annual CO_2 from the refrigerated transport fleet[6].

3. Parking location: Cooling requirements of stationary vehicles can increase by 20% when exposed to sunlight for several hours.

4. Refrigerant use: Many refrigerants used in TRUs have a significant global warming potential (GWP), and therefore any leakages would be harmful to the environment. For example, the organic refrigerant R404a, used in over 90% of refrigerated vehicles in the UK, has a GWP nearly 4,000 times higher than CO_2.

5. Trailer insulation maintenance: Insulation can decay at a rate of 5% per annum[9], i.e. a TRU with an insulation rating of 0.4 W/(m²K) that is 5 years old, may now have an insulation rating of 0.5 W/(m²K), resulting in a 25% increase in transmission load. To put these figures into context, an empty switched off TRU trailer at 0°C (internal temperature) in an ambient temperature of 20°C will warm up to ambient temperature after 5.5 hours using a 0.4 W/(m²K) insulation. If the insulation decays to 0.5 W/m²K, that time would reduce to 4 hours.



The most common unloading procedure, from stakeholder engagement

TRU Duty Cycles and Temperature Requirements

TRUs are used in a multitude of ways, so it is not possible to claim a specific use case that they will always operate, and hence design a technology suited to meet every scenario. Cenex, via feedback from supermarket fleet operators, understand that a refrigerated trailer operating from a distribution centre to a shop/supermarket would be used between 12 and 18 hours per day, completing 2 to 5 deliveries.

The TRU would be running for about 70% of that time, and the vehicles would drive between 30 min and 3 hours to deliver 100% of their load in the supermarket, then returning empty to the distribution centre to complete another delivery.

Most UK vehicles require multiple compartments, with only 30% of refrigerated vehicles operating with a single refrigerated compartment[6]. The remaining 70% of refrigerated vehicles operate with multiple compartments, each with a different set temperature. A generic example for supermarket trailers would be a frozen compartment at -25°C, a chilled compartment at +1°C, and an ambient temperature compartment. The table below shows the typical temperature set points depending on the produce being transported.

Products	Temperature (°C)
Chilled high temperature vegetables: potatoes, tomatoes, cucumbers, bananas etc.	8
Chilled meat and cooked meats pre-packaged for consumer use, offal & other prepared foods, untreated, unpasteurised milk, fresh cream, cottage cheese etc.	3
Chilled fresh fish (in ice).	2
Chilled low temperature vegetables: apples, cabbage, carrots, lettuce, onions etc.	1
Frozen meat	-10
Frozen ice and ice cream	-25

Removal of Red Diesel Subsidy

Red diesel is chemically identical to regular diesel (other than its red dye) and is taxed at a lower rate.

It can be legally used in “excepted vehicles”: agricultural vehicles, gritters, mowers, construction vehicles and mobile generators, such as the TRU auxiliary engine. The red dye is added to facilitate its detection when used illegally in normal road vehicles.

The UK government announced in its 2020 budget the removal of the red diesel entitlement from April 2022 onwards, except for agricultural vehicles[11]. Red diesel has been historically taxed at 11.14 pence per litre, compared to 57.95 pence per litre for regular diesel. When they reach tax parity in 2022, the fuel cost of TRU units will therefore increase by 60-70%. For a trailer TRU using 3,000 litres per year in fuel, this will cost an additional £1,400 per year in increased taxes. This highlights an interesting opportunity to move TRUs to zero emission and lower emitting fuel sources.

Cleaner Options

The move towards lower and zero emission fuels, and the forthcoming discontinuation of low-cost red diesel use in TRUs, are driving fleets and product developers to explore cleaner alternatives. The options to reduce the pollution of TRUs are often seen to be alternative fuels, cryogenics or electrification, with various options for supplying the electrical energy[12].

1. **Alternative fuels**: TRUs can be operated on biodiesel or renewable diesels, such as hydrotreated vegetable oil (HVO). HVO is produced from virgin and waste vegetable oils and can be used directly in diesel TRUs with no impact on operational requirements, as it is classified as a ‘drop-in’ fuel, with greenhouse gas emission savings of 91% compared to red diesel. Bespoke TRU auxiliary engines in America are also fuelled with compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), and their renewable versions (biomethane and bio-LPG). Cenex has researched these technologies in the past[13], and the use of biomethane (bio-CNG and bio-LNG) can result in CO_2 savings of 80% when compared to diesel.

2. **Cryogenics:** An insulated tank is filled with a precooled cryogenic fuel. As cooling is needed, a valve is opened to facilitate cooling of the cargo space via a heat exchanger, or directly releasing the cooling gas into the cargo space. Cryogenic systems have low maintenance requirements and are generally refuelled daily with liquid nitrogen, liquid air, or liquid CO_2.

3. **Electrification:** For zero emission operation, the auxiliary diesel engine can be replaced with electricity stored or generated on the vehicle to run the refrigeration compressor[14]. This electricity can be sourced from a battery, fuel cell, or even a solar photovoltaic (PV) array.

Project ZERO: A Collaboration Between Sunswap and Cenex

An example of electrification technology is being developed by Sunswap and Cenex in the Innovate UK funded project ZERO: Zero Emission Refrigerated Operations.

The large environmental impact of current TRUs, the financial consequences of the removal of red diesel subsidies, plus tightening legislations and corporate social responsibility, all mean that customers require a clean and economical alternative. The solution proposed by the project is to replace the diesel TRU with a solar and battery powered system.

At the core of the product is the patent-pending battery technology enabling the TRU to meet a wide range of customer requirements. Additionally, the trailer roof is covered with solar panels, providing extra on-board energy.

Sunswap is a start-up developing electric transport refrigeration technology utilising energy prediction, adaptive battery capacity and solar power to decarbonise the cold chain. Cenex, established as the UK's first Centre of Excellence for Low Carbon and Fuel Cell technologies in 2005, lowers emission in transport and associated energy infrastructure and operates as an independent, not-for-profit research & technology organisation (RTO) and consultancy.

Sunswap's main role within the project is the development of a next generation electrical architecture and control strategy for the zero emission TRU. Moreover, Sunswap is in charge of the overall project management and commercial exploitation of the technological solution. In partnership with a Customer Requirements Group, facilitated by Cenex, the project delivers a TRU bespoke electrical system that meets the needs of the industry. The project will allow Sunswap to demonstrate a viable alternative to existing diesel TRUs.

SUNSWAP cenex

Cenex's role is investigating the customer needs and independently validating operational design requirements, as well as the economic and environmental performance of the system. As part of this role, Cenex has formed a Customers Requirements Group to understand the needs and operational patterns of refrigerated transport operators and vehicle builders. The Group comprises supermarkets and logistics operators such as Aldi, Howard Tenens, Ocado, Sainsbury's, Tesco, Waitrose and Wincanton, as well as refrigerated vehicle leasing provider Petit Forestier, the Cold Chain Federation industry body, and vehicle builders Gray & Adams, Paneltex and Solomon Commercials. Moreover, Cenex is also developing a refrigerated fleet techno-economic model, as well as a life-cycle assessment (LCA) model to calculate the emissions associated with the product manufacturing, use and end-of-life phases. The results from this modelling are informing Sunswap's development to refine the design of the TRU electrical system.

To keep in touch with Project ZERO developments and receive an invite to the project dissemination webinar, join the Cenex mailing list here.

References

[1] Refrigerated vehicles contribute to thousands of deaths and costs across EU. The ACR Journal, Oct 2015

[2] Based on operation of 13 h/day with 4 deliveries at 0°C trailer temperature, and 18 h/day with 4 deliveries at -18°C trailer temperature, respectively. Deliveries from full to empty, full meaning 50% payload and 100% volume load.

[3] Based on 300 kWh average domestic fridge-freezer annual electricity consumption (link) and 2.7 average fridge-freezer COP..

[4] Assuming 30% diesel engine efficiency, 85% alternator efficiency, and a year-average COP between 2.1 and 4.5 (depending on difference between trailer and ambient temperatures).

[5] Based on average UK car tailpipe emissions of 145 gCO2/km (BEIS, weighted average of all fuel types) and average annual car mileage of 7,400 miles (National Travel Survey 2019).

[6] Auxiliary Temperature Reduction Units in the Greater London Area. Prepared for Transport for London (TfL) by Cenex, LowCVP, Brunel University, Dec 2017 (link)

[7] Emission Standards, EU: Nonroad Engines (link)

[8] Emission Standards, EU: Heavy-Duty Truck and Bus Engines (link)

[9] Transport of perishable foodstuffs (ATP). Objectives-key provisions-benefits. UNECE Transport Division (link)

[10] Standard trailer of 13.7 x 2.7 x 2.7 metres. Deliveries from full to empty, full meaning 50% payload and 100% volume load.

[11] Reforms to the tax treatments of red diesel and other rebated fuels: consultation. HM Treasury, July 2020 (link)

[12] Technology Assessment: Transport Refrigerators. California Environmental Protection Agency, August 2015 (link)

[13] Dedicated to Gas, An Innovate UK Research Project to Assess the Viability of Gas Vehicles. Cenex, October 2019 (link)

[14] Refrigeration compressors pump the refrigerant through the fridge system. The refrigerant flows in a closed circuit through pipes and coils, absorbing heat inside the fridge and releasing it to the ambient outside the fridge.

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