



DOE

**HEAVY TRUCK VEHICLE-INTEGRATED
PHOTOVOLTAICS (VIPV)**

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1.0 Introduction

Vehicle-Integrated Photovoltaics (VIPV) has been a subject of interest and analysis for a number of years. Market segments most frequently cited as promising include: (1) buses, (2) local delivery trucks (3) transport refrigeration units and (4) medium/heavy duty trucks. This report focuses on heavy duty tractor-trailers which may have integrated PV that is seamlessly integrated into the truck's exterior or aftermarket vehicle-added PV. Based strictly on a secondary literature review, this report seeks to address the current state of the art and VIPV's prevalence in the domestic and international trucking industries.

2.0 VIPV Panels for the Trucking Industry

It has been noted that the value proposition for VIPV with heavy duty trucks is difficult to compute. In part, this is caused by the fact that in the U.S. the tractor and the trailers are manufactured by different entities, whereas in Europe heavy duty trucks are built and designed as an integrated structure. However, in the U.S. trailers are swapped out constantly in order to carry different loads for fleet owners. The question thus becomes who gleans the benefit from VIPV - the truck manufacturer who makes the tractor, the trailer manufacturer who make the trailers or the fleet-owner? This section suggests answers to some of these questions.

Case studies have tended to suggest the value of VIPV in the trucking industry includes driver comfort, charging during idling and lowered GHG emissions. In general, U.S. studies documenting the true cost savings, pay back, and benefits of truck VIPV are hard to come by. There appears to be little verified data in the public domain calculating the payback from the investment in PIVP for trucks.¹ What one most commonly finds in the literature are claims touting the benefits of VIPV to fleet owners.

According to Robby Peibst, Professor and Research Coordinator at the Institute for Solar Energy Research in Hamelin, it is "difficult to make a purely economic argument for VIPV, given that the depreciation periods for vehicles will be much shorter than those of stationary PV systems." These "difficulties do not preclude VIPV from becoming a bigger market possibility over the medium term." However, "a number of potential factors could

help to facilitate future growth such as manufacturers of refrigerated trucks could reduce their CO₂ emissions footprints if they integrate PV, for example.”²

Cost Savings

PV is viewed as one way to help “lower operational costs by reducing diesel auxiliary power unit (APU) run time by 20 to 30%, extending battery life to five or more years, and helping match APU and tractor preventive maintenance.”³ Fuels savings appears to be a motivation on the part of fleet owners when adding PV to trucks. In addition, the extra power available from the PV can augment power from the engine alternator maintaining the batteries at a higher average state of charge, extending battery life, hence avoiding emergency roadside assistance for dead batteries.⁴

Energy Saving

A 2017 press release, Bob Doane Vice President and Chief Technology Officer of eNow, a PV manufacturer and a developer of trailer integrated PV commented on why it is difficult calculate VIPV ROI:

“It’s difficult to calculate how much sun exposure a truck will need to see an improvement in energy usage. Factors include total wattage of the solar energy system (higher is better), type of charge controller (MPPT or PWM), battery state of health, type of batteries (flooded lead-acid or AGM), number of batteries (four for electric auxiliary power units, up to three for liftgates), other charging sources (alternator or trailer charger) and the application’s power demands.”⁵

Emissions Reduction and Truck Idling

Some fleet owners and PV manufacturers report that PV is useful especially during with rising temperatures, which can affect batteries,

“Battery-powered units have allowed fleets to significantly reduce their idle time. However, as the effects of climate change have caused higher temperatures, the battery HVAC systems are not powerful enough for long amounts of time. These systems have enough power to make it through a driver’s mandated 30-minute rest break after up to 11 hours of driving. However, they often cannot make it through the 10 consecutive hours of off-duty time mandated after 11 hours of driving.”⁶

With respect to GHG, a value proposition for VIPV for heavy duty truck is lowered emissions from reducing truck idling.⁷ For instance, in a press interview, one fleet owner suggests that,

“For a single week of resting in the sleeper during the summertime, a heavy-duty truck idling 50 percent of the time would burn about 19 gallons of diesel, producing 420 pounds of carbon dioxide. Compare this to burning around two gallons of diesel using a battery HVAC system augmented with solar panels. About 1 million such tractor-trailers are in North America and given that only 10 percent of current sleepers use these systems today, the industry could save 1.7 million gallons of diesel fuel and reduce CO₂ emissions by 19,000 tons each summer week.”⁸

Further expanding on benefits of solar during truck idling times, a 2020 article by Mike Roeth, Executive Director North American Council for Freight Efficiency suggested that:

“Historically, drivers’ power needs were supplied by idling their vehicles’ 400 plus horsepower engine. It was common for trucks to have 50 percent idle time during the summer, meaning if they drove for 11 hours, the truck would idle for 11 hours while the driver was not driving. That amounts to over 2,000 hours per year of non-driving idling, which is costly and loud and generates emissions, and which can nearly completely be removed.”⁹

Driver Comfort

Driver comfort is also mentioned frequently as a benefit of VIPV. “The battery HVAC system gets charged while the vehicle is moving down the road. In some cases, fleet terminals or truck stops have shorepower plugs that allow the truck’s HVAC system to run off electricity. But not enough of these options are available, so drivers can’t always rely on their battery HVAC systems to keep them cool. Solar panels on trucks with battery HVAC systems keep drivers cool and help them manage their hotel loads with less fuel use and reduced greenhouse gas emissions. Infrastructure development could increase adoption of solar powered truck HVACs, if there were more plugs at places where drivers stop.”¹⁰

Several advantages are also mentioned by fleet owners in a 2017 article, “How Fleets are Using Solar Power,”¹¹ which includes idling, longer battery and alternator life, and increased driver comfort and satisfaction. Various individuals interviewed in the article noted that,

“It is hard to figure the **ROI, because it’s not an exact science**. But if you save two

jump-starts a year, that's \$600. If your driver comfort is better, how do you put a price on that? And we used to replace all eight batteries every year, but the trucks with the solar panels have had them for four years."¹²

In a press interview, one fleet owner based in South Dakota that has fleets with diesel-powered APUs, the installed ThermoLite solar panels from Thermo King were addressing the need for driver comfort. This company was testing solar panels on the cab to charge the refrigerator in the sleeper when the driver is off the truck for extended periods. The normal policy a driver that is going to be away from the truck for more than 24 hours is to empty the refrigerator and turn it off. With the solar panels, the refrigerator can stay on. In another example, one of Canada's largest trucking companies that has VP installed on its more than 150 units has seen advantages of VIPV including:

- "Keep drivers comfortable without idling
- Keep batteries charged in cold weather
- Keep batteries charged on methane detectors on trucks powered by liquefied natural gas. It now has those.
- Expects a return on investment, based on fuel savings to be about 3.5 years."¹³

PV Extends Battery Lifetime

It appears that the "aerodynamic penalty" was a problem in earlier model PV panels. The same 2017 article references the President and CEO of Mesilla Valley Transportation who observed that, with solar power, installing panels on the truck cab extended the amount of time electric auxiliary power units could operate, however, the "aerodynamic penalty was too great," so he abandoned that particular effort but "discovered that the batteries on those trucks were lasting far longer." However, since then, newer, thinner, flexible solar panels have solved the aerodynamic problem.¹⁴

3.0 Fleet Owners and VIPV

Some fleet owners have experimented with and adopted VIPV. It should be noted that refrigerated truck, also referred to as "reefers" appear to be using VIPV. This may be because some have an integrated tractor-trailer. Other potential reasons why refrigerated trucks might consider utilizing solar panels is to further mitigate the spoilage of goods.

Note also that in the examples that follow, weight for the VIPV does not appear to be an issue, at least weight is not identified as a restraint in the secondary literature.

PV panels on the market lend themselves to various configurations, for instance, they are flexible, thin, lightweight, weigh less than 20 pounds, and can be affixed to straight surfaces such as trailer or curved surfaces such as the tractor (or cab). In addition, none of the trucking companies that have after-market VIPV on their trucks mention payload reduction or if in fact they reduced the payload to compensate for the additional weight. The extent to which the addition of PV requires payload reduction is unclear from a secondary literature review, however, it likely depends on several factors, such as fleet operations and vehicle type:

- “Some trucks, such as delivery vehicles, are packed based on volume, therefore capacity not weight, is their main payload limitation.
- For larger trucks that move heavy freight or trucks that run at high cargo capacity, payload capacity reduction will be a larger concern, since it can directly affect the revenues from shipments.”¹⁵

The following trucking fleets have solar panels installed on truck roofs or trailer tops. It appears that these panels were installed aftermarket. It may be that solar PV will follow the same method used for battery HVAC or electric auxiliary power unit (APU). Heavy trucks battery HVAC and APU **are installed either at the factory when the truck is produced or added later once the fleet takes ownership of the vehicle.**¹⁶

3.1.1 DHL Express

In 2022, DHL Express announced plans to install solar panels on 67 of its trucks to reduce fuel consumption and limit emissions. According to DHL, PV recharges the vehicle’s battery, power the tail lifts and other auxiliary services whilst reducing the load on the system’s alternator and thus lower fuel consumption. According to a company press release, “the solar array will be used to charge the truck’s battery, power lift gates and other ancillary services. This reduces load on the system’s alternator, reducing the fuel use of heavy-duty trucks.”¹⁷ Figure 1 on the following page shows a DHL truck with solar roof.



Figure 1: DHL Solar Powered Truck
Source: DHL (February 2022)¹⁸

3.1.2 Performance Food Group

Founded and headquartered in Richmond, Virginia, Performance Food Group Company (PFG), markets more than 250,000 food and food-related products from 142 distribution centers to over 300,000 customer locations across North America including independent and chain restaurants; businesses, schools and healthcare facilities; vending and office coffee service distributors; and big box retailers, theaters and convenience stores.¹⁹

PFG is committed to mitigating its carbon footprint and being responsible stewards of the environment, for instance, by “partnering with industry-leading companies, PFG has implemented the use of direct-emissions-free transportation and refrigeration technologies, and incorporated solar power generation capabilities, into its Gilroy facility. Each of these initiatives play a significant role towards ensuring PFG’s success in achieving key sustainability goals and metrics.”²⁰

In 2024, PFG, Advanced Energy Machines (AEM), FreeWire Technologies, GridMarket and Volvo Trucks North America, partnered to hold a special open house event at PFG’s Gilroy, CA facility to showcase PFG’s zero-emission fleet, that has solar panels. PFG partnered with AEM to replace its diesel-powered TRUs with 30+ of AEM’s zero-emission SolarTechTRUs. According to PFG, “each of the electric TRU installations completed within PFG’s fleet of refrigerated trailers has helped PFG eliminate approximately 20 tons of CO₂ per transport refrigeration units, per year. PFG has paired the Volvo VNR Electric trucks with electric transport refrigeration units.”²¹

3.1.3 Marten Transport

Founded in 1946, Marten became a public company in 1986, and trades under the NASDAQ Global Select Market symbol: MRTN. Marten is a temperature-sensitive

truckload carrier in specializing in transporting and distributing food and other consumer packaged goods that require a temperature-controlled or insulated environment. In 2023, Marten generated \$1.131 billion in operating revenue. Its carrier services are mainly in the Southeast, West Coast, Midwest, South Central and Northeast region. Most of the trailers are manufactured by Kenworth and Freightliner. The company owns 5,653 trailers, consisting of 3,347 refrigerated trailers and 2,306 dry vans. Most of our refrigerated trailers are equipped with Thermo-King refrigeration units.²²

On its website, Marten Transport (Mondovi, Wisconsin) states it has installed solar panels on its fleet of 3,500 trucks at 15 terminals across the country to help maintain battery charge, resulting in saved [auxiliary power unit] run times and fuel savings. According to the company, solar panels power batteries during driver's down time versus running the engines.²³



Figure 2: Marten - Solar Panels on Trucks

Source: Marten (2019)²⁴

3.1.4 Keller Trucking

Keller Trucking began in 1978, The company has a fleet of over 300 tractors and 1000 trailers. Keller Trucking was recognized as SmartWay High Performer Status. Just over 2% of SmartWay carriers operate so clean and efficiently that they make the High Performers list for all metrics. A company blog states Keller acquired “a couple” of Volvo tractors equipped with solar panels for beta testing. It appears that the solar panels were installed after market and not at OEM factory. Figure 3 shows the Volvo trucks with an array of solar panels built into the roof of the trailer.²⁵



Figure 3: Keller Trucking - Solar Panels on Volvo Trucks

Source: Keller Trucking (2023)²⁶

According to the blog, the stored solar energy helps to power the vehicle’s batteries and other auxiliary electrical components, offering an eco-friendly alternative to idling traditional diesel-powered tractors. The following benefits were observed by Keller during testing:

“Reduced Environmental Impact

For instance, parked idle. Volvo tractors equipped with solar panels dramatically decrease carbon emissions by converting stored solar energy to electricity. This allows the driver to utilize the tractor’s auxiliary accessories without having to idle it. Does it eliminate idling altogether? No. However, the reduction in idle time through renewable solar energy reduces emissions and overall dependence on fossil fuels.

Solar Energy Cost Savings

As mentioned above, the integration of solar panels brings notable cost savings to trucking companies in two primary areas: fuel consumption and maintenance. Traditionally, the electric APU (Auxiliary Power Unit) in the tractor was charged and recharged by idling the tractor, which burns fuel. The APU now draws from the solar energy reserve to ensure you have your heater, lights, and other auxiliary items without ever having to turn the key past accessory.”²⁷

3.1.5 Nussbaum Transportation

Nussbaum, located in Hudson, Illinois serves customers in the Midwest region and throughout the continental United States. These locations include Iowa, Wisconsin, Minnesota, Nebraska, Missouri, Indiana, Ohio, Pennsylvania, Texas, Georgia, and more.²⁸

In the company’s blog titled, “The Solar Advantage,” the company bills that “to help reduce idle time and maximize battery life, Nussbaum uses Road Warrior Pro solar panels from Merlin Solar Technologies. At less than 12 pounds, these flexible panels conform seamlessly to the roofline of Freightliner Cascadias.” By the end of 2022, the company planned to have 70% of its fleet trucks equipped with Merlin solar panels. According to

the company, the main advantage is extending battery life, which is useful in driver idling situations:

“In the past, our truck batteries lasted a maximum of 10 hours and even less for drivers who use a CPAP machine or other “extra” amenities (TV, gaming). After 10 hours max, the truck would need to idle for two hours or travel down the road for four hours to recharge the batteries fully. And if a driver is waiting at a shipper or held up for some other reason, their only option for more battery life would be to idle.

However, the solar panels can generate an additional 10 hours of battery life, outputting 500 watts and 40 amps. This means a driver can comfortably enjoy their 10-hour break without having to idle. And if needed, they could power their base amenities (air conditioner, lights, fridge) for up to 20 hours! During a 34-hour weekend, the solar panels can recharge the battery multiple times, enabling a driver to spend their entire reset with no idle time. Data from Merlin suggests that trucks using solar panels see an average idle time reduction of 4.2%. If a truck’s idle time is normally 10-15%, this represents a total reduction of 25-40%.”

Additional benefits the company claims it has seen since developing solar panels on its trucks include:

- “Fuel savings and increased productivity. Save one gallon of diesel fuel (\$5.57 – the current national average) for every hour of reduced idle time. During a 34-hr weekend, our drivers can save up to 12 hours of idle time (12 gallons = \$66.84).
- Increased battery life. Before deploying solar panels, our truck batteries lasted only 18 months. Today, our truck batteries last 3-4 years, cutting the replacement cost from \$5,333 to \$1,600 over the 5-year life of the truck.
- Increased longevity for starters and alternators.”²⁹

This section indicates that a number of fleet owners have found benefits in using VIPV as part of their commitment to reducing their carbon while increasing the comfort of their truck drivers. Trucking is important to domestic supply chains and improving the working conditions of the drivers enhances retention.

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3.2. U.S. Companies that make PV panels for Trucks

This section looks at another player in the supply chain – the companies that make VIPV. There are less than a handful of U.S. companies marketing PV panels for the transportation industry compared to traditional PV panels. This section provides examples of companies marketing solar panels to the trucking industry. By technology, flexible PV modules appear to be the most common, which are suitable for both new and aftersales market by adding PV modules to existing vehicle parts. Commercial offerings within this product category are limited. In the numerous product brochures and catalogs reviewed for this report, weight, maintenance, payload reduction to compensate for the extra weight are not addressed by manufacturers.

Table 1 lists solar PV manufacturers which manufacture solar panels and their associated materials for the transportation industry. Pricing information is unavailable.

Table 1: U.S. Trucking Industry PV Panel Manufacturers
(Not an Exhaustive List)

Company	Year Founded	HQ / Company origins	City	State	Product	Type	Weight	Address
Thermo King,	1938	USA	Bloomington	MN	Thermolite Panels	Flexible Polymer	The panels range from 2 lbs. to 6 lbs.	314 W 90th St, Bloomington, MN 55420
Advanced Energy Machines	2012	USA	Mesa	AZ	Solartechtru	NA	NA	4245 E Norcroft St, Mesa, AZ 85215
Carrier Transicold	1970	USA	Palm Beach	FL	Transicold Solar Panel	NA	With all components weighs ~3.6 kg	700 Olympic Drive Athens GA 30601
PowerFilm Solar, Inc.	1988	USA	Ames	IA	Soltronix 24W	Semi-Flexible Solar Panel	The panels range from 2 lbs. to 6 lbs Panels range from ~2 lbs. to a ~6 lbs.	1287 Xe Pl, Ames, IA 50014
Phillips Industries	1928	USA	Irvine	CA	Various Solar Kits	Monocrystalline Silicon		5231 California Ave. Suite 220. Irvine, CA 92617

Merlin Solar Technologies	2016	USA	San Jose	CA	Various Peel and Stick Panels	Flexible Panels	weighing less than 20 lbs.	5225 Hellyer Ave, San Jose, CA 95138
Sol-Go, Inc.	2019	USA	San Francisco	CA	Sol-Go panels	monocrystalline silicon	NA	555 Bryant St #716, Palo Alto, CA 94301
Xantrex LLC	1983	Canada	Burnaby	CA	Xantrex Solar Max Panel (115W, 115W SLIM, 220W, 330W)	Monocrystalline Cells with PERC Technology	~5.7 lbs.	110 – 8555 Baxter Place Burnaby, British Columbia

3.2.1 Advanced Energy Machines

Advanced Energy Machines (AEM) is a privately held company that specializes in clean power systems, zero emissions, and cold chain solutions. They are headquartered in Mesa, Arizona and were founded in 2012. AEA has 51–200 employees.³⁰ The company markets a 100% electric transport refrigeration unit (TRUs). A **“SolarTechTRU”** kit includes a rooftop solar panel array of 35 kilowatt-hours per day along with a lithium-ion battery pack.

According to the company, “the solar panels alone provide 100% of daily power for 34 degrees Fahrenheit and above, and about 35% for sub-zero temperatures.” In addition, SolarTechTRU is engineered to be removed and installed on another new trailer or installed as a retrofit on existing diesel-powered trailers. According to the company, “SolarTechTRU outlives the typical life span of cold chain trailers. The SolarTechTRU is designed to be installed onto new trailers, or to take the place of dirty diesel TRUs, and it can be moved from trailer to trailer.” Below are additional insights:

“The ultra-thin solar panels install on top of the trailer - **adding less than 1/2" to the height** and **adding less than 8 ounces of weight per square foot to the trailer**. The batteries are encased in a patent-protected, fireproof case, with additional safety design features inside the case - uniquely insulating each battery.”³¹

One of their customers is Performance Food Group (PFG), a food marketer. With more than 150 locations, PFG is one of North America’s largest food and foodservice distribution companies. It is reported that PFG has replaced more than 30 conventional TRUs with AEM’s new zero-emission SolarTechTRU models. PFG’s Gilroy, California, vehicles supply various edibles and food-related products from the warehouse to restaurants, schools, hotels and other customers. Their trucks were outfitted with a new battery-electric Class 8 trucks that mate to trailers fitted with zero-emission TRUs.³² The

Figure 4 shows a PFG’s Volvo electric truck integrated with a reefer trailer equipped with a zero-emission SolarTechTRU from Advanced Energy Machines.



Figure 4: Volvo Electric Truck Integrated with a Reefer Trailer Equipped with a Zero-Emission SolarTechTRU

Source: Advanced Energy Machines (2024)³³

Advanced Energy Machines sell products through select distributors. For instance, solar refrigerated trailers are available through PLM Trailer Leasing (Newark, New Jersey) a company with nationwide locations dedicated exclusively to the leasing, rental, maintenance, IoT solutions and fleet management of refrigerated trailers in the cold supply chain. PLM is the exclusive sales and marketing company for the Advanced Energy Machines electric TRU and a California Clean Air Off-Road Equipment program approved dealer offering on-site consulting for facility and refrigerated trailers. Figure 5 shows an example of their refrigerated trailers. The test and demonstration trailers are available in various lengths and designs.³⁴



Figure 5: PLM's Zero Emission Refrigerated Trailer

Source: PLM Trailer Leasing (January 2021)³⁵

3.2.2 Carrier Transicold

The Carrier Transicold brand was formed in 1970, when Carrier acquired Transicold Co., based in California, and combined it with its Special Products Division, which had experience in trucking applications extending back to 1940. The business is involved all types of transport refrigeration, including reefers for ocean-going containers.³⁶ Carrier Transicold provides trailer refrigeration systems for light commercial vehicles, trucks and trailers.

The company markets the Carrier Transicold Solar Panel, specifications are shown in the following table.

Table 2: Carrier Transicold Solar Panel specifications

50 W model	Electrical characteristic		External characteristic		Service model			
	Nominal Voltage (V)	Nominal Amperage (A)	Weight (kg), all components	Dimension (mm), solar panel only	Kit content	Installation (min)	Maintenance	Warranty
	17	2,85	3,6	535 x 645 x 4	Solar panel, cables, box, controller, miscellaneous, instruction	60 (installation + functional tests)	<ul style="list-style-type: none"> • Depending of applications • Clean-up solar panel minimum every 3 months 	2 years

Source: Carrier Transicold (2021)³⁷

Transicold markets solar PV kits to fleet owners so they can “power accessories and better leverage trailer units’ battery.” According to Carrier Transicold, solar panels to help

offset refrigeration system battery draws from ancillary devices, such as fuel-level sensors, interior trailer lighting and telematics systems during dwell periods. This helps to avoid depleting the battery.³⁸



Figure 6: Transicold Solar Panel benefits

Source: Carrier Transicold (2021)³⁹

In 2023, Carrier Transicold (Palm Beach Gardens, Florida) introduced an enhanced solar charging system for transport refrigeration unit batteries that has a “wider array of choices and greater power delivery for faster charging.” In a press statement, Jason Forman, Director, Aftermarket Parts Sales and Marketing, Carrier Transicold suggested that gains in solar panel technology have enabled the company to make significant improvements to solar charging systems. Carrier Transicold also offers various solar technologies including:

- [“TRU-Mount Solar Charging System](#) – a design that provides a custom fit on the narrow, curved top surface of Carrier Transicold trailer refrigeration units.

This system now delivers 2.25 amps of power, a 12.5% boost over the original model.

- 50-watt Trailer Rooftop-Mount System – This system now provides 4.2 amps of power delivery, which is about 2.5 times greater than Carrier Transicold’s original rooftop system, delivering significant amps per watt for TRU applications.
- 20 Series 50-watt Rooftop-Mount System – Part of Carrier Transicold’s 20 Series line of aftermarket products for trailer units, this system delivers greater efficiency and power than standard 30-watt panels provided by the original TRU equipment manufacturer.
- 50-watt Rail-Optimized Door-Mount System – This system is designed for intermodal containers that are double-stacked on flatbed railcars, which limits the application of rooftop mounted systems.”⁴⁰

Figure 7 below shows solar PV panel mounted on top of the cab’s edge.



Figure 7: Carrier Transicold TRU-Mount Solar Charging System

Source: Carrier Transicold⁴¹

One of Carrier Transcold’s customers is Gainesville, Georgia-based Tribe Transportation. Tribe Transportation has more than 400 tractors and nearly 900 trailers, serving the refrigerated and deep-frozen freight. In 2021, Tribe Transportation acquired 111 53-foot trailers equipped with Carrier Transicold X4 7500 refrigeration units” integrated with Carrier Transicold TRU-Mount solar panels to help meet demand in the fast-growing life sciences sector, which includes the transport of pharmaceutical products.”⁴²

3.2.3 Merlin Solar Technologies, Inc.

Merlin Solar Technologies (San Jose, California) develops and manufactures crystalline silicon-based solar panels. The company markets PV for deployments such as on metal roofs, auxiliary power for transportation, flush-mounted residential solar, and military applications, through its manufacturing partners.⁴³ Merlin markets the Merlin panels, which the company describes the panels as “peel and stick” (Figure 8 below).



Figure 8: Merlin Peel and Stick Solar Panel

Source: Merlin Solar Technologies⁴⁴

Described as “plug-and-play,” the kits are designed for “rapid installation and scalability.” They are designed specifically for the transportation industry and are customizable to “fit roof contours and designs for most major truck OEMs.”⁴⁵



Figure 9: Merlin peel and stick solar panel

Source: Merlin Solar Technologies⁴⁶

Merlin bills that its “flexible panels weighing less than 20 pounds and have an adhesive allowing them to be attached to the roof of a truck, where they capture the sun’s energy. The energy is stored in the battery bank of a cab’s electric power units, significantly reducing fuel costs by minimizing time spent idling. The panels can power everything inside a sleeper cab throughout the night or keep drivers cool while they endure long waits at delivery docks.”⁴⁷



Figure 10: Merlin solar panel integrated with trucks

Source: Merlin Solar Technologies⁴⁸

Merlin has deigned PV panels specifically for the transportation industry are customizable to fit roof contours and designs for most major truck OEMs, shown below.



Figure 11: Merlin solar panel roof on contour integrated

Source: Fontain Modification⁴⁹

An example of MerlinSolar's customer is dry van carrier, GP Transco. GP Transco had plans to install PV on its entire fleet of ~600 trucks after testing the technology on 10 trucks during a six-month period. Merlin also markets a custom-fit panel design for Freightliner's Cascadia that GP Transco was installing on more than 200. GP Transco installs the panels and wiring on its trucks in-house. It takes about two hours to complete the process. The carrier replaces its tractors every 3 ½ to four years and expects the panels to still be functional "well beyond" that time frame. That means the units will modestly increase the value of its equipment when sold in the secondary market. Also, the company will avoid replacing any of the eight batteries in an APU system (approximately \$300 each) during its ownership.⁵⁰

Further research indicates there are aftermarket commercial heavy duty trucks installers for Merlin solar. For instance, once company called [Fontaine Modification](#) installs Merlin Solar panels at its modification centers in Charlotte and Statesville, North Carolina; Chillicothe and Springfield, Ohio; Garland and Laredo, Texas; Dublin, Virginia; and Mineral Wells, West Virginia.⁵¹

3.2.4 Phillips Industries

Phillips Industries (Irvine, California) was founded in 1928, as a Los Angeles auto and truck parts distributor, to a global business, manufacturing and distributing over 8,000 products in more than 40 countries. Phillips Industries is a manufacturer of electrical and air brake system components, as well as electronic solutions for communicating vehicle data to fleets and their drivers for the commercial truck and trailer industry. Phillips Industries operates three manufacturing facilities, in California, Mexico and China staffed with more than 1,000 employees.⁵²

Phillips is marketing solar panels for the commercial vehicle market. Solar panels are available in seven distinct kits ideal for Class 8 tractors, reefer units and liftgates, each including the necessary panels and components for complete installation and deployment. The kits feature easy peel-and-stick installation, heavy-duty solar chargers, and advanced jump-start avoidance technology.⁵³

According to the company, its monocrystalline silicon design is 80% lighter than traditional glass systems, while producing 20% more energy with a 50% higher power density using thin film technology. Further, the company bills that, the "solar technology has patented flexibility and lightweight Mono cSi panels. These panels are described by the company as 50 times more durable than standard alternatives, redefine reliability in renewable energy. Phillips is offering the panels in kits ideal for Class 8 tractors, reefer

units and liftgates, shown below. Each kit includes the necessary panels and components for complete installation and deployment, including the panels, solar chargers and advanced jump-start avoidance technology.⁵⁴



Figure 12: Phillips Industries solar kits

Source: Phillips Industries⁵⁵

According to the company,

“The aerodynamic panels are peel-and-stick and can withstand extreme vibrations, winds up to 155 mph, and impacts from debris. ... A recent study showed that fleets with these panels achieved an average of 0.23 mpg higher fuel efficiency than similar models, saving more than 400 gallons of fuel and reducing CO₂ emissions by 9.3 tons per truck, per year.”⁵⁶

Phillips touts the following benefits for its solar panels for the trucking industry:⁵⁷

- **“Extended battery life:** Frequent engine starts and the high electrical demand from auxiliary equipment can lead to increased battery wear and failures. Phillips’ solar helps maintain battery charge levels, reducing strain on the battery and extending its lifespan, which in turn decreases maintenance costs and downtime due to battery replacement.
- **Compliance and decreased fuel costs:** Many regions have strict anti-idling laws to reduce emissions, forcing drivers to turn off engines during stops, which can affect the operation of critical systems like HVAC. Phillips’ solar helps power these systems without the engine running, reducing fuel consumption and ensuring compliance with regulations.

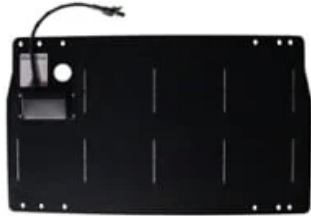
- **Driver comfort and retention:** Maintaining a comfortable environment in the cab is crucial for driver satisfaction and retention, especially given the current driver shortage in the industry. Phillips' solar panel capture energy to help run heating and cooling systems, and power devices such as refrigerators and entertainment systems, enhancing driver comfort during long hauls without the need for additional batteries.
- **Environmental impact and sustainability goals:** With increasing pressure to reduce carbon footprints, companies in the commercial vehicle industry are looking for ways to decrease diesel consumption and emissions. Phillips' solar provides a clean energy source that can supplement or replace diesel usage for various functions, aiding companies in achieving sustainability targets.
- **Operational efficiency in remote areas:** Vehicles operating in remote or rural areas may not have easy access to power sources for recharging batteries or running equipment. Phillips' solar ensures that essential systems can function independently of external power sources, improving operational reliability and efficiency in off-grid scenarios."

3.2.5 PowerFilm Solar, Inc.

PowerFilm (Ames, Iowa) was founded in 1988. PowerFilm is a manufacturer of flexible thin film solar PV modules and is a provider of solar products for industrial, consumer and military remote power applications. PowerFilm's amorphous silicon (a-Si) thin-film solar modules are both built into solar charger products as well as sold to OEM integrators.⁵⁸ PowerFilm specializes in designing, engineering, manufacturing, and assembly of custom solar solutions. PowerFilm's proprietary manufacturing provides custom amorphous silicon panels. The company's expertise in solar panels manufacturing includes:

- "Manufacturing flexible amorphous silicon (a-Si) material. PowerFilm provides solutions from uW to kW, from panels an inch square to yards square.
- Custom design and assembly of semi-flexible crystalline silicon (c-Si) solutions, from 18W to 300W+, leveraging the advantages of full-cell assemblies with integrated charge controllers."⁵⁹

Products for the trucking industry are shown in the Figure 13. PowerFilm designed the Soltronix 24W Semi-Flexible Solar Panel specifically for the Thermo King Precedent Trailer Refrigeration Unit.



24W Semi-Flexible Solar Panel with Integrated Charge Controller for Thermo King Precedent Trailer Refrigeration Unit (R3-7F13.7VTK)

Current: 1.5 - 2.0A

Voltage: 13.8V float, 14.5V max

Weight: 1.93lb / 0.87kg

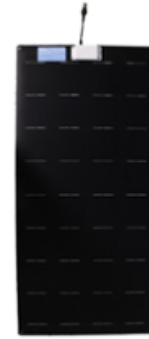


50W Semi-Flexible Solar Panel with Integrated Charge Controller and Butyl Adhesive (R3-15F13.7VB)

Current: 2.8 - 3.8A

Voltage: 13.8V float, 14.5V max

Weight: 3.8lb / 1.7kg



110W Semi-Flexible Solar Panel with Integrated Charge Controller and Butyl Adhesive (R3-32F13.7VB)

Current: 6.0-8.5A

Voltage: 13.8V float, 14.5V max

Weight: 6.2lb / 2.8kg

Figure 13: PowerFilm's solar panels for trucking industry

Source: PowerFilm⁶⁰

3.2.6 Sol-Go, Inc.

Based in San Francisco, California, Sol-Go, Inc. was founded in 2019 by former SunPower employees with the goal to deliver lightweight solar panels for the off-grid solar market. According to LinkedIn, the company has between 11-50 employees.⁶¹ "The driving force is that of effectively fulfilling a market need for high-quality, reasonably priced, customizable solar panels. With what amounts to many decades of advanced expertise in flexible panel design and manufacturing represented among the Sol-Go assembling team, the effort is further to refine current knowledge, expertise and experience to deliver durable, cost-effective solar solutions for off-grid applications, including [trucking](#), [boating](#), and [RVs](#)."⁶²

The company markets the Sol-Go panels use the SunPower Maxeon monocrystalline silicon solar cells.

SG FLEX SERIES MODELS



SG-FLEX-160 SX

SG-FLEX-115 SX

SG-FLEX-100 CX

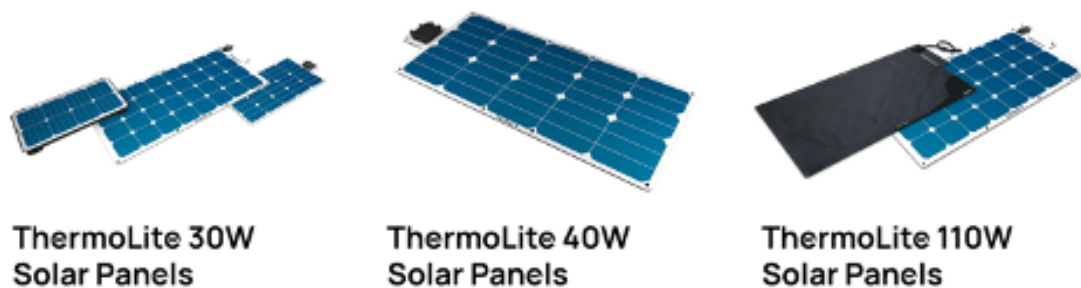
SG-FLEX-50 CX

Figure 14: Sol-Go Flexible Solar Panels

Source: Sol-Go⁶³

3.2.7 Thermo King LLC

Thermo King, a brand of Trane Technologies, a manufacturer of truck refrigeration equipment and supplies established in 1938 and based in Bloomington, Minnesota. Thermo King manufactures a wide range of trailers, such as single-temperature, multi-temperature, and heating trailer units. It also manufactures rail cargo, refrigeration units for trucks and vans, coldtainers, containers, and generator sets. Thermo King also offers three types of solar PV kits (brand name Thermolite) for tractor trailers.



**ThermoLite 30W
Solar Panels**

**ThermoLite 40W
Solar Panels**

**ThermoLite 110W
Solar Panels**

Figure 15: Thermo King – ThermoLite Solar Panels for Trucks and Other Applications

Source: Thermo King⁶⁴

The 330W panels can be integrated on school buses, trucks, among others are shown in Figure 16.



Figure 16: Thermo King solar PV kits for tractor trailers

Source: Thermo King⁶⁵

Table 3 below provides specifications for the panels. ThermoLite panels were originally designed to work with the refrigeration units. The panels range from 2lbs to 6lbs.⁶⁶

Table 3: Thermo King Solar Panel Comparison Guide



	ThermoLite			Competitor's Panel	Generic Panel
	30W	40W	110W		
Size	13" x 22"	13" x 29"	22" x 45"	40.5" x 26.5"	14" x 30"
Weight	6 lbs	2 lbs	5 lbs	4 lbs	10 lbs
Output	30W peak output	40W peak output	110W peak output	28W peak output	30W peak output
Install time	30 minutes	60 minutes	90 minutes	90 minutes	At least 60 minutes
Panel Construction	Flexible polymer	Flexible polymer	Flexible polymer	Amorphous silicon	Polycrystalline (Glass)
Warranty	5 years - Full warranty	5 years - Full warranty	5 years - Full warranty	5 years - Limited warranty	1 year - Limited warranty
Install Conditions	Any	40°F-100°F	40°F-100°F	Must be in shade, dry, and between 40°F-80°F	Any

Source: Thermo King⁶⁷

Although ThermoLite panels were originally designed for refrigeration units, they are also installed on a trailer's chassis and connected to the generator set's battery. In a press statement, Thermo King noted the PV provides several benefits including,

“Even in low light, Thermo King’s solar panels collect energy to keep the battery fully charged. This eliminates the risk of battery discharge and the need to use the genset engine to charge the battery, contributing to reduced fuel consumption and CO₂ emissions.”⁶⁸

Other benefits include:

“ThermoLite solar panels, by Thermo King, help lower operational costs by reducing diesel APU run time by 20 to 30%, extending battery life to five or more years, and helping match APU and tractor preventive maintenance. With APUs, solar offsets daytime heat loads, helps maintain peak performance, and provides a full battery bank even in low light conditions. Plus, the weatherproof construction is durable, and quick and easy to install.”⁶⁹

One customer that has been publicly identified by Thermo King is B&H Logistik, a German company that transports refrigerated containers for the pharmaceutical, chemical and food industry. Transportkühlung Thermo King GmbH installed Thermo King SGCM300 gensets in combination with ThermoLite solar on trucks for B&H Logistik.⁷⁰

Through partnerships, Thermo King is developing electric refrigerated trucks. For instance, in May 2024, Range Energy and Thermo King announced a partnership between the two companies to “advance” electric refrigerated trailers in the Americas. The companies will “align on an electric trailer technology system, including integrating Range’s electric trailer platform with Thermo King’s hybrid trailer refrigeration units and electric TRUs. The integration process will also include extensive testing, customer pilots and the public demonstration of an electric refrigerated trailer.” Decarbonization is mentioned as one of the benefits because of this partnership. In accompany press release, Chris Tanaka, Thermo King’s Vice President Product Management commented the partnership with Range, stating “has the potential to contribute significantly to the acceleration of the industry’s decarbonization efforts.”⁷¹



Figure 16: Integration of Range’s Electric Powered Trailer Platform with Thermo King’s Trailer Refrigeration Units

Source: Thermo King (May 2024)⁷²

3.3. Xantrex LLC

Xantrex (British Columbia, Canada) manufactures thin, flexible solar panels to fit the truck’s curved surfaces. Products include:

- “[Xantrex Solar Max Panel](#) (115W, 115W SLIM, 220W, 330W) - designed with a highly protective top-layer called ETFE (Ethylene-Tetra-Fluoro-Ethylene), this allows for better light transmittance, corrosion resistance, stain-resistance, weather resistance, and overall superior durability over a wide temperature range.”⁷³
- “[Xantrex Solar Flex Panel](#) (110W) - 100W and 160W panels are rugged with the frame and mounting brackets designed specifically for vehicle-use, the panels are extreme vibration-tested to ensure it can withstand rocky and mountainous vehicle road travel with no power loss. The panels feature monocrystalline cells with PERC technology that are up to 12% more efficient than conventional solar cells.”⁷⁴

According to the company, [Max Flex panel](#) can also harvest up to 20% more of the sun’s energy during the day and in low-light conditions compared to a rigid solar panel. The Max Flex panel cells are Monocrystalline PERC. It weighs about 5.7lbs (2.6kg).

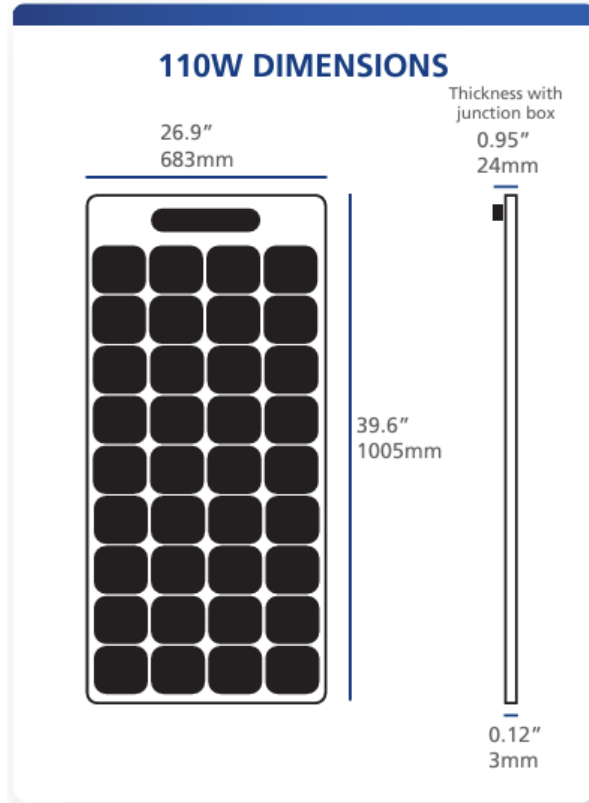


Figure 17: Xantrex Solar 110W flex pane
Source: Xantrex (2021)⁷⁵

What is noted in looking at the U.S. VIPV manufacturers is that many of these are after-market add-ons which can be readily installed. The exception of course, is refrigerated trucks.

U.S. VIPV manufacturers often provide their products as after-market add-ons.

3.4. International VIPV Panel Manufacturers

On the international scene, several companies supply solar PV trucking industry. The table below provides a summary of five companies in Europe marketing truck PV (note this is not an exhaustive list).

Table 4: International Trucking Industry PV Panel Manufacturers

Company	Year Founded	Country	City	Product	Type	Weight	Address
a2 - solar Advanced and Automotive Solar Systems GmbH	2013	Erfurt	Germany	Spherical curvature PV	NA	NA	Am Urbicher Kreuz 18, 99099 Erfurt, Germany
IM Efficiency	2014	Helmond	Netherlands	SolarTop	flexible solar	6 kg	Automotive Campus 30, 5708

					panels with thin-film cells		HZ Helmond, Netherlands
SOLBIAN Energie Alternative	2007	Avigliana	Italy	Various	flexible solar panels	NA	Viale Gandhi 21b, 10051 Avigliana (TO) ITALY
Opes Solutions	2012	Schönefeld	Germany	SolFlex	crystalline solar cells	Varies, between 1.8 kg and 8 kg	Zeppelinstraße 1, 12529 Schönefeld, Germany
Valoe Ojy	1978	Mikkeli	Finland	Various Truck modules	NA	NA	Insinöörinkatu 8. 50150 Mikkeli. Finland

3.4.1 A2-solar – Advanced and Automotive Solar System GmbH

Germany-based a2-solar manufactures solar PV for the transportation industry. “a2-solar draws back on more than 30 years of proven knowhow and technological expertise for innovative solar solutions in the field of building-integrated (BiPV) and “automotive” solar systems.” According to the company, the team “incubates trend-setting module technologies for all kinds of solar applications. Flat, bent and spherically curved solar modules for any vehicle such as cars, boats, trucks and trains belong to our core markets.” The company’s experience “ranges from the Audi A8 (SOP 1993) equipped with a 30 W solar sliding roof, the Fisker KARMA PHEV (SOP 2011) with a 120 W solar module roof up to the new KARMA Revero (SOP in 2016) with a 200 W solar car roof module. As a high-performance innovator in the industry our automotive solar systems have been integrated into the Volvo SuperTruck cab (270W in 2016) and the Audi e-tron quattro concept car (400W in 2015) as well as into numerous solar passenger trailers which are running already throughout Europe’s touristic attraction parks.”⁷⁶

a2-solar developed a novel solar system for the Volvo SuperTruck cab. The spherically curved solar truck roof modules described below:

“With a spherical curvature of more than 40cm on a surface of 2.5m x 1.3m (so not only a 2 dimensional bend), but it is also the biggest and with 270Watts most powerful rigid solar module ever developed for a truck. Within the solar module, a battery charging system was connected in parallel with a parking ventilation system. Both electrical systems are “directly interconnected” without requiring additional components – another worldwide unique innovation.”⁷⁷

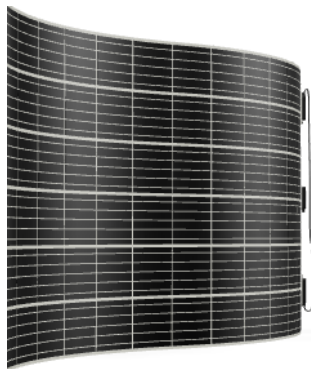


Figure 18: Spherically Curved Solar Truck Roof Modules

Source: a2Solar (2016)⁷⁸

3.4.2 IM Efficiency

IM Efficiency describes itself as an “innovative Dutch technology company with R&D-activities in both hardware and software, focusing on decreasing emissions in trucks and semi-trailers. With the introduction of our first commercial technology, the SolarOnTop, transportation companies are offered a low-cost solution to immediately decrease fuel consumption among their vehicles.”⁷⁹



Wattage

430 Watt-peak per solar module.

Robustness

Resistant to washing and scratches.

Thickness

3 mm.

Dimensions

2m x 1m.

Weight

6 Kg.

Figure 19: SolarTop

Source: IM Efficiency⁸⁰

SolarTop is described as “lightweight and flexible solar panels, installed on the trailer roof, clean and renewable electricity. This energy is stored in a SolarOnTop's lithium battery to power the Truck cabin electronics, trailer electric appliances, and support the alternator while driving. “The SolarOnTop technology is compatible with both new and existing trucks and trailers. It can be easily retrofitted to current fleet or seamlessly installed on brand new vehicles.”⁸¹

In 2020, IM Efficiency completed an undisclosed funding round, raising a total oversubscribed Seed Round from BOM, Rockstart, and other investors. According to a company press release, the “investment will be used to accelerate the growth of SolarOnTop,” its “onboard solar technology designed specifically for trucks and trailers to reduce fuel consumption and their carbon footprint. With over **50 SolarOnTop installations already on the road, this investment will help to scale up the production of the SolarOnTop and meet the growing market demand.** Additionally, the funds will be used to complete the development of new onboard solar products for various applications.”⁸²

An interview with Norbert Reijnders, the fleet manager of Vos Logistics Benelux Distribution provides insights into the impact of SolarOnTop on their operations :

“A total of 5 trailer/truck combinations are equipped with SolarOnTop. Each trailer has 10 panels. These panels primarily ensure the battery for the cabin and tailgate remains fully charged.

SolarOnTop installation on the trailer requires minimal modification to the truck. Solar energy is automatically transferred from the trailer to the truck without any action needed from the driver. No additional maintenance is required.”⁸³

3.4.3 OPES Solutions and Fraunhofer Center for Silicon Photovoltaics CSP

OPES Solar Mobility was founded in 2012 with more than 1,000 employees. The company has R&D facilities in China and Germany.⁸⁴ In 2023, the company announced plans to establish manufacturing capacities for vehicle-integrated photovoltaics in an undisclosed location in Germany for the manufacturing of an advanced version of the “Solflex” module. OPES currently has a facility with 300 employees in Changzhou, China.⁸⁵

The company’s PV for trucks is the SolFlex PV. That is based on crystalline solar cells and achieves around 30% more power per square meter than current flexible modules that use thin-film technology. Its bending radius of up to 15 degrees makes it applicable for any vehicle surface. At 2.9mm, it is 70% lighter than conventional solar modules and has a cell efficiency of over 22%.⁸⁶

Table 5: OPES Solutions – SolFlex Solar Panel for Transportation

	SFX 95 F	SFX 95 R	SFX 150 F	SFX 150 R	SFX 420 F	SFX 420 R
						
	J-Box (Front)	J-Box (Rear)	J-Box (Front)	J-Box (Rear)	J-Box (Front)	J-Box (Rear)
ELECTRICAL SPECIFICATION						
Power Output (Pmp)	95W	95W	150W		420W	
Short-Circuit Current (Isc)	5.05A	10.10A	6.57A		9.79A	
Open-Circuit Voltage (Voc)	24.31V	12.16V	27.88V		56.50V	
Current at Pmax (Imp)	4.58A	9.16A	6.27A		8.87A	
Voltage at Pmax (Vmp)	20.74V	10.37V	24.24V		47.34V	
Cell Type	Mono crystalline					
Cell Efficiency	≥23%					
Electrical Tolerance	-5%~+10%					
MECHANICAL PARAMETERS						
Module Weight	1.8kg	1.6kg	2.5kg		8kg	
Module Dimension	1030 x 545 x 3mm	1030 x 545 x 3mm	1120 x 775 x 3mm		2000 x 1230 x 3mm	
Bending Radius	25°					
Operating Temperature	-40 - 95°C					

Source: OPES Solutions (2021)⁸⁷

In a 2022 press interview with PV Magazine’s Jonathan Gifford, Robert Händel, the CEO and founder of Opes Solutions, provided insights into some of the market restraints including,

“We started [on VIPV] four to five years ago with Fraunhofer CSP with research projects. From a principle’s perspective, we think this is huge. [In EVs] there is a battery and solar, which means Opes is in a good place. There is also a lot of surface area [for solar] if you combine all the vehicles together. Our approach from a technical perspective is that we are solar cell independent – we can use n-type, TOPCon, PERC mono. And we try to make these cells feasible for the harsh conditions in the vehicular environment – vibrations, impacts, bended 3D surfaces, interconnections. Compared to the standard module industry our whole business is very different – solar is a component. In the vehicle sector it is a bit more sophisticated because the conditions are new, **there is a lot of regulation, and it has a longer process in development.** There are usually institutes to work with, the vehicle industry, and several partners like sub-suppliers. It is a complex process.”⁸⁸

The company believes integration of solar modules holds enormous potential for the transport sector, including electric buses.⁸⁹

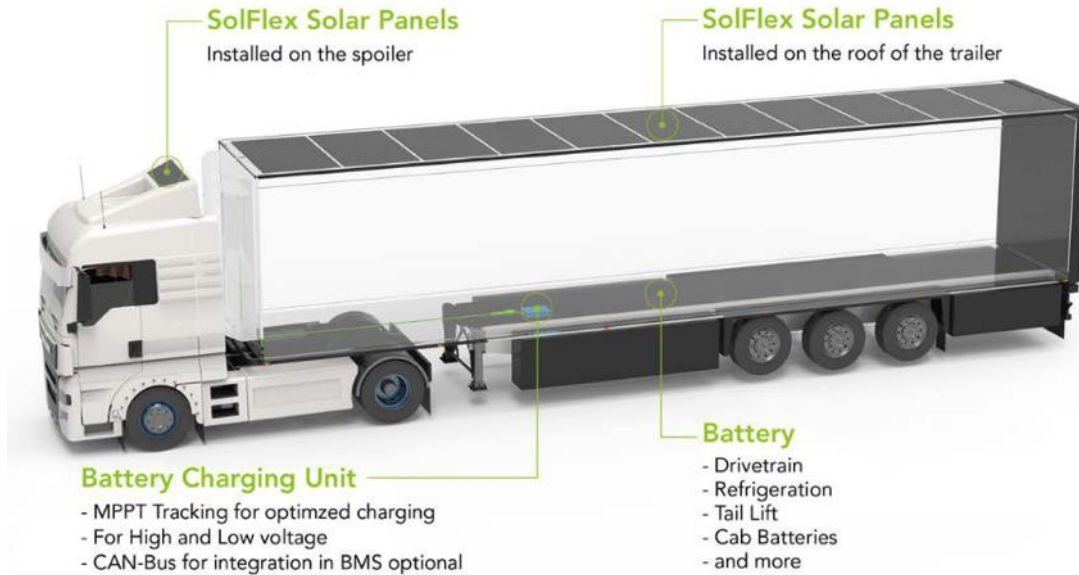


Figure 20: Solar PV Made for Trucks
Source: OPES Solutions (2021)⁹⁰

3.4.4 Solbian Energie Alternative Srl

Solbian Energie Alternative was founded in 2007 in Italy. Their journey began with boats, where they aimed to develop flexible solar panels capable of withstanding the dynamic movements of the boats.⁹¹ “The company's goal is to produce innovative photovoltaic panels in order to expand the scope of their applicability to sectors where lightweight, flexibility and efficiency are fundamental requirements. The characteristics of these flexible photovoltaic panels allow the production of energy from the sun, wherever there is a need, even in extreme conditions: marine, electric mobility, caravans, trekking and in special building-integrated architectural situations.” According to LinkedIn, the company has between 10 -50 employees.⁹²

Solbian’s panels “use Solbianflex technology, with a patented formula-between layers, polymers, and surface treatments of the envelope and cells-elaborated over several years, starting in 2007. This technology makes it possible to have solar cells capable of converting more than 24 percent of sunlight into electricity and thus offer high powers even with small panels (and installation space).⁹³

SP Series

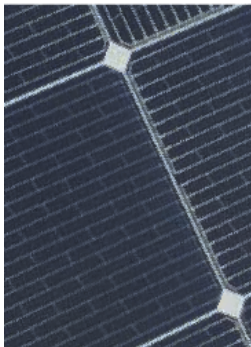


SP series is at the top of the range, thanks to the use of selected SunPower™ monocrystalline silicon cells, reaching a record 23% conversion of sunlight into electricity and with a pleasant appearance thanks to back-contact technology which hides the electrical contacts. SunPower™ cells represent the most advanced available technology on the market, and make the SP Solbian panels the highest-efficiency flexible panels.

	SP 125	SP 112 L	SP 112 Q	SP 100	SP 75	SP 50 L	SP 50 Q
Power	125 W	112 W	112 W	102 W	76 W	51 W	51 W
Length	1363 mm	1236 mm	855 mm	1109 mm	855 mm	1109 mm	601 mm
Width	546 mm	546 mm	800 mm	546 mm	546 mm	292 mm	546 mm
Thickness	2 mm	2 mm	2 mm	2 mm	2 mm	2 mm	2 mm
Weight	1.7 kg	1.6 kg	1.6 kg	1.4 kg	1.1 kg	0.8 kg	0.8 kg
N. of cells	40	36	36	32	24	16	16

Super Rugged Series.

SR Series



The monocrystalline high efficiency SR cells are sandwiched by two patented metallic grids. The grid on the front is carefully tailored to optimize the current harvesting, while the one behind the cell offers strong mechanical support. The grids essentially form a double shield that acts as a conducting reinforcement to the solar cell. Extreme crack and bend tolerance are built in, enabling novel crystalline silicon architectures. A guaranty of high efficiency and unmatched durability in flexible solar panels.



	SR 156 L	SR 156 Q	SR 104	SR 70 L	SR 70 Q	SR 60
Power	156 W	156 W	104 W	70 W	70 W	61 W
Length	1523 mm	1046 mm	1046 mm	1364 mm	728 mm	1205 mm
Width	683 mm	996 mm	683 mm	365 mm	683 mm	365 mm
Thickness	2 mm	2 mm	2 mm	2 mm	2 mm	2 mm
Weight	2.4 kg	2.4 kg	1.6 kg	1.2 kg	1.2 kg	1 kg
N. of cells	36	36	24	16	16	14

Figure 21: Solbian PV

Source: Solbian⁹⁴

Solbian 's photovoltaic modules are very light, in fact weighing just 2.5 kilograms per square meter, also allowing the customer to choose the number of cells, the color and shape of the panel to be installed, and the electrical characteristics best suited to their energy needs."⁹⁵



Figure 22: Solbian Flexible solar panels on a milk transporter

Source: Solbian⁹⁶

[Valoe Oyj](#) is a Finland-based company engaged in the design, development, manufacture and marketing of automation solutions for the electronics industry. Valoe Oyj offers Valoe-PV modules and Valoe-PV systems. The firm specializes in utilization of solar energy also develops and sells Finnish solar energy technology to global markets. The company was founded in 1978 and is headquartered in Mikkeli, Finland.⁹⁷

Valoe specializes in IBC (Interdigitated Back Contact) solar cells and PV modules for vehicles and other new Odd Form module solutions. Valoe is a vertically integrated solar electricity company with PV cell and module manufacturing. The company's headquarters is in Mikkeli and the company has a solar module factory in Finland in Juva and an IBC cell factory in Vilnius, Lithuania. The solar modules include:

“In a Valoe solar module, the solar electricity is derived from a module-sized conductive backsheet, not through electrical wires. Therefore, the conductive backsheet is vibration-resistant and functions even if cells are mechanically damaged by an impact or other means.

Valoe’s photovoltaic system allows to switch automatically from electricity to diesel. The automatic optimization system of the photovoltaic system first uses electricity from the battery and automatically starts the diesel engine when electricity runs out.

Valoe’s truck module is protected by a very strong and lightweight chemically tempered glass or polymer. The module is mounted on an aluminum fastening and cooling element. The floating structure cools the panel and prevents heat from transferring to the goods. The fastening mechanism allows for easy replacement of damaged modules.”⁹⁸



Figure 23: Valoe's Truck Module

Source: Valoe⁹⁹

Valoe's truck module is protected by a very strong and lightweight chemically tempered glass or polymer. The module is mounted on an aluminum fastening and cooling element. The floating structure cools the panel and prevents heat from transferring to the goods. In 2023, TIP Group, a company that owns more than 16,000 reefers globally and Valoe signed a contract for integrating Valoe solar systems onto TIP's refrigerated trailers. The intention of the contract is to "equip hundreds of trailers by the end of 2025." TIP's strategy is "to reduce CO₂ emissions by 12 million kilograms per year. Under ideal conditions, a photovoltaic system can save 3,500 liters of diesel and consequently reduce 9,000 kilograms of CO₂ emissions annually for every single trailer. Electrifying 1,000 refrigerated trailers would meet 75% of TIP's annual target."¹⁰⁰

4.0 Heavy Duty Trucks Manufacturers

Heavy-duty long-haul trucks are critical to the movement of goods in the U.S. These vehicles are characterized by high fuel consumption, fast market turnover, and rapid

uptake of new technologies.¹⁰¹ The heavy-duty segment of the U.S. truck market falls into the Class 8 trucks category, the target of this report. Class 8 trucks are categorized by the U.S. Federal Highway Administration (FHA) as vehicles with a gross vehicle weight rating in excess of 33,000 pounds and are often configured as combination trucks comprised of a truck-tractor and a trailer containing the cargo. Many truck manufacturers also build trucks in smaller segments such as Classes 4-7.¹⁰² In 2019, there were more than 11.6 million medium and heavy-duty truck registrations in the U.S.¹⁰³ The U.S. trucking industry continues to grow, with an estimated 65 percent of freight tonnage expected to be shipped by truck in 2050.¹⁰⁴

4.1. Heavy Truck Manufactures and VIPV Initiatives

There are four principal manufacturers in the U.S. and Canada commercial truck market. Class 8 truck manufacturers include **Navistar** (its heavy-duty truck brand include International),¹⁰⁵ **Daimler Truck North America (brands include Freightliner and Western Star)**,¹⁰⁶ **Volvo Group (brands include Mack Trucks, and Volvo Trucks North America)**,¹⁰⁷ **PACCAR (brands include Kenworth, Peterbilt and DAF)**.¹⁰⁸ Their market share is shown in the Figure 24. Freightliner and Western Star, brands of Daimler Truck North America, claims the largest market share with accounting for 32.7% of the market.

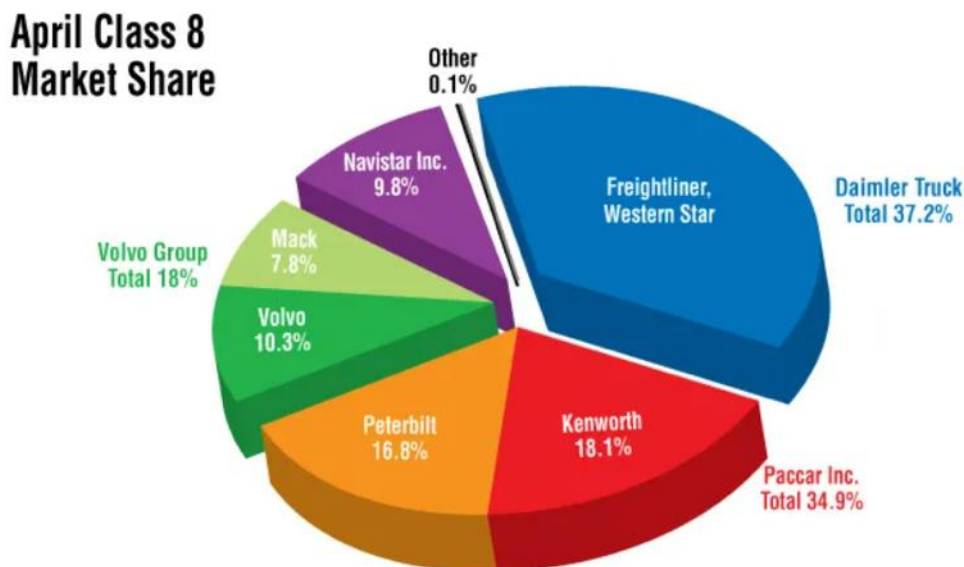


Figure 24: U.S. - Market Share of Key Manufactures in April 2024

Source: Connor D. Wolf, *Transportation Topics* (May 2024)¹⁰⁹

With respect to the installed base, Freightliner has the largest market share (Figure 25). Through 2020, Daimler’s Freightliner division had more than 30% Class 8 truck market share, Freightliner is also the market leader in the United States.

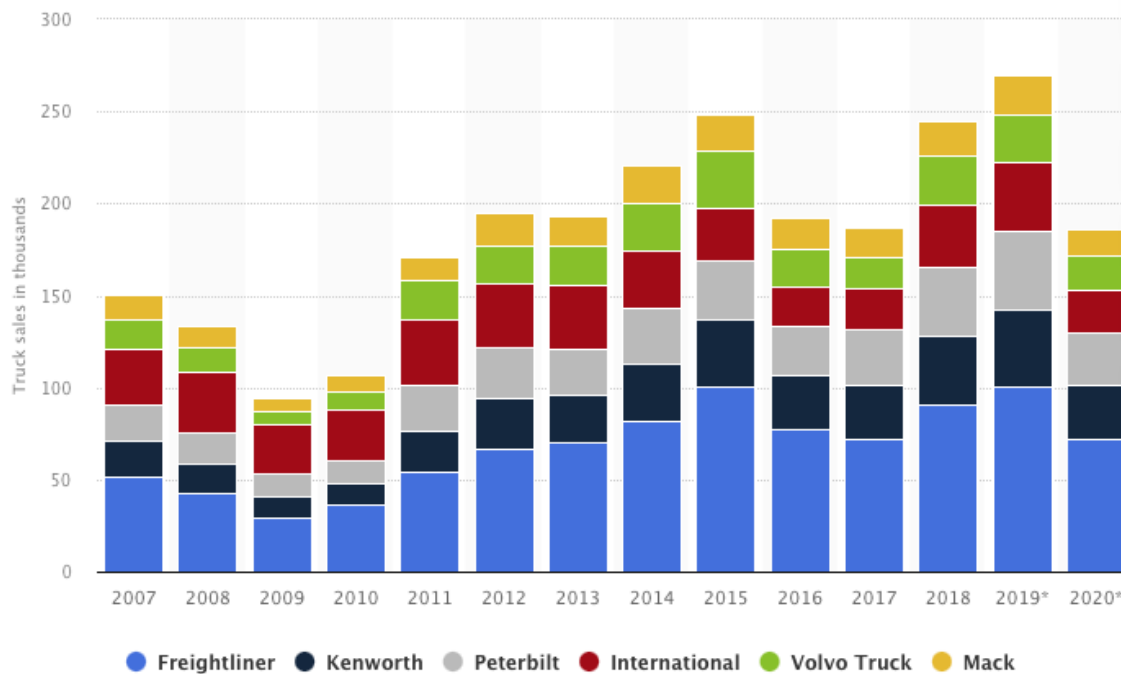


Figure 25: U.S. - Market Share of Key Manufactures Through 2020 (in ‘000)
Source: Statista (July 2023)¹¹⁰

The balance of this section provides information on each of the OEMs and their investments or interest in VIPV. We note that aside from Volvo Trucks and its subsidiary Renault Volvo Trucks, and Daimler, the PACCAR and Navistar (International Trucks) do not show up in public literature as having invested in VIPV.

4.1.1 Volvo AG

[Volvo AG](#) was founded in 1927 and is headquartered in Gothenburg, Sweden. Volvo is a leading manufacturer of trucks, buses, construction equipment, and marine and industrial engines. Volvo Trucks is the second largest heavy-duty truck brand in the world. The company’s business segments include trucks, buses, construction equipment, financial services, Volvo Penta, and others. Volvo offers various models of high-performance heavy-duty trucks such as Volvo FH series, Volvo FMX series, and Volvo FM series. The company has a wide regional presence, with 52 manufacturing plants and subsidiaries spread across 18 countries.

Volvo has been involved in partnership to advance solar on trucks. For instance, in 2021, **Volvo Trucks North America, Dependable Highway Express (DHE), SunPower Corp. and Kuehne+Nagel** partnered on a sustainable freight initiative to transport solar PV products using **solar-powered Volvo VNR Electric trucks**. In the fall of 2020, DHE became one of the first fleet operators in North America to deploy Volvo VNR Electric trucks.¹¹¹

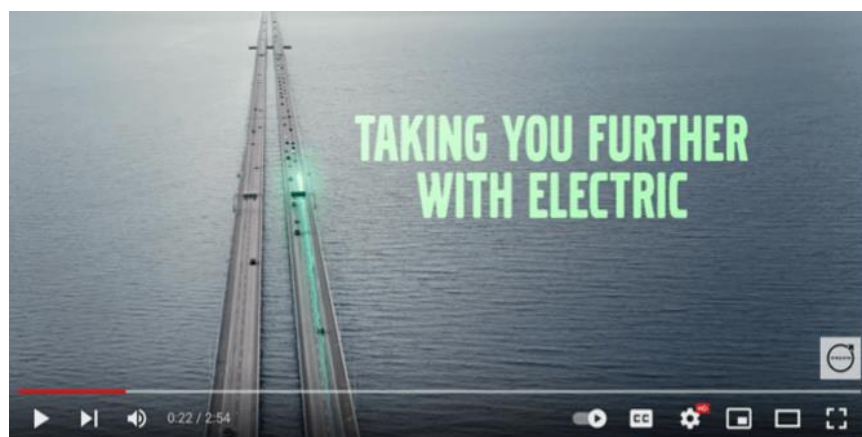


Figure 26: Volvo Trucks: Our Next-gen Volvo VNR Electric Takes You Further

Click [here](#) to see video

With respect to VIPV, in 2016, Volvo announced the company was leveraging Volvo's battery 8 trucks to deliver high-efficiency solar panels. For instance, a2-solar Advanced and Automotiv, a German company developed a solar system for the Volvo SuperTruck demonstrator. Volvo began the SuperTruck project in 2009 after the DOE set a challenge to build a truck that improves freight efficiency by 50 percent. According to a 2016 Volvo Trucks North America press release, the redesigned chassis is made almost entirely of aluminum, which halved the chassis weight and contributed to an overall tractor-trailer weight reduction of 3,200 pounds.¹¹²



Figure 27: SuperTruck demonstrator - with solar panels on top of cab

Source: Volvo Trucks North America (2016)¹¹³

Mr. Reinhard Wecker, CEO of a2-solar, reported the “Volvo’s SuperTruck concept vehicle achieved a freight efficiency improvement of 88 percent, boosted fuel efficiency by 70 percent - exceeding 12 miles per gallon with some test runs showing more than 13 miles per gallon – in road tests, and powertrain brake thermal efficiency reached 50 percent.”¹¹⁴



Figure 28: Volvo SuperTruck 2

Click [here](#) to see video

In another VIPV project, California-based MiaSolé, and Solar Cloth, a company based in Mandelieu-la-Napoule, France, developed solar fabrics with films made of copper, indium, gallium and selenide and amorphous silicon and germanium encapsulated into flexible,

structured textiles for Renault Volvo Truck.¹¹⁵ The 300-watt solar panel is made of MiaSolé’s lightweight solar cells, which are based on a “high efficiency thin-film technology” and was blended into a custom solar panel by Solar Cloth.¹¹⁶ Renault Trucks presented its latest innovations at the 16th Solutrans trade fair, which took place in November 2021 in France.



Figure 29: Renault truck with Solar Cloth PVs

Source: Renault Volvo Truck (2021)¹¹⁷

Solar Cloth is an OEM supplier to Volvo-Renault Trucks,¹¹⁸ implying that perhaps Volvo-Renault Trucks is selling OEM installed track PV. A further search indicates Volvo-Renault Trucks is marketing a fully electric Renault Trucks 26-ton D Wide Z.E. One of its customers is Rhyner Logistik, a company that supplies Denner supermarkets. Rhyner Logistik also fitted solar panels onto the body of its electric truck to power the refrigeration unit. “Rhyner Logistik decided to have solar panels fitted onto the vehicle body to provide green energy for the refrigeration unit. This system is particularly suited to temperature-controlled transport, because it is when outside temperatures are high - and the sun is therefore strong - that the cooling is most needed.”¹¹⁹ Figure 30 shows the Rhyner Logistik truck outfitted with solar panels on the roof.



Figure 30: Rhyner Logistik truck outfitted solar panels on rooftop

Source: Volvo-Renault Trucks (2021)¹²⁰

4.1.2 Daimler Truck Holding AG

Daimler Truck AG (operates as Daimler Truck North America) is headquartered in Leinfelden-Echterdingen, Germany is a global commercial truck manufacturer. The Daimler Truck and Daimler Buses divisions include the eight vehicle brands: BharatBenz, Freightliner, FUSO, Mercedes-Benz Trucks, RIZON, Setra, Thomas Built Buses and Western Star. Daimler Truck is the global market leader in the medium and heavy-duty truck segment with a gross vehicle weight of over 6 tons.¹²¹

With respect to solar panels on trucks, in 2017, Freightliner announced an optional solar panel system would be available on model Freightliner Cascadia, class 8, raised roof sleeper trucks. New truck can be ordered with the eNow **eCharge solar system as a Pre-Delivery Installation at the Custom Truck Service centers as an option**. A company press release noted that,

“The eNow solar system is a good fit for the Freightliner's aerodynamic design as the solar panel is just 0.125" thick and its flexible design follows the roof contours. The eNow system will supply ongoing power to the batteries, ensuring that the driver's power needs (HVAC, TV, microwave, etc.) are always met while reducing idle time and fuel costs, while creating the ultimate fuel efficient truck.

Several existing Freightliner fleets have already added the eNow system and have returned the following conclusive results:

- Increased daily run time for auxiliary equipment, such as in-cab HVAC
- Increased overall battery life from 6 months to 3 years
- Reduced fuel consumption by 3 gallons per day from reduced engine idling
- Decreased maintenance cost due to reduction in engine idling.”¹²²



Figure 31: Solar Panels on Freightliner Cascadia ‘2022

Source: Henry Albert (2022)¹²³

Note that the eNow is installed predelivery, not at OEM factory. The eNow system can be ordered through the Freightliner dealerships and installed at the Custom Truck Service centers located at each of the manufacturing plants.¹²⁴ This research was unable to identify eNow solar system for trucks to get an idea of specifications.

With respect to electric truck development, in May 2024, Penske Truck Leasing, Daimler Truck North America and Carrier Transicold introduced an all-electric refrigerated medium-duty truck, Class 7 Freightliner eM2 Class-7 Freightliner eM2 battery-electric box truck with Carrier Transicold’s Supra e11 eCool electric refrigeration unit on a 26-foot refrigerated body.¹²⁵ Note that the Daimler electric truck had collaborations and partnerships. For instance, in 2018, Penske, along with 29 other Daimler customers, formed a council to help co-create and launch Daimler’s Freightliner electric trucks. In the same year, Daimler delivered the first truck in Penske’s electric fleet – a Freightliner eM2. “Since then, the companies have been collaborating on testing and introducing electric vehicles – including the Freightliner eM2 and eCascadia models – to a customer base that increasingly demands them.”¹²⁶



Figure 32: Class-7 Freightliner eM2 Battery-electric Truck with Carrier Transicold's Supra e11 eCool Electric Refrigeration

Source: *Heavy Duty Trucking* (May 2024)¹²⁷

4.1.3 PACCAR, Inc.

PACCAR was founded in 1905 and is headquartered in Bellevue, Washington. The company's business segments include truck, parts, and financial services. PACCAR markets its medium, and heavy-duty trucks under the Kenworth, Peterbilt in North America.¹²⁸ In Europe, trucks are sold under the DAF brand whereas in Australia and South America, these are sold under the Kenworth and DAF brands. PACCAR competes in the North American Class 8 market, primarily with Kenworth and Peterbilt conventional models.¹²⁹ In 2023, PACCAR delivered 204,00 trucks across the globe.¹³⁰

PACCAR sells its trucks to dealerships. In their latest annual report, the company stated that, all trucks are sold to independent dealers. The Kenworth and Peterbilt nameplates are marketed and distributed by separate divisions in the U.S. and a foreign subsidiary in Canada. The Kenworth nameplate is also marketed and distributed by foreign subsidiaries in Mexico and Australia.¹³¹ This may imply that customer request for custom equipment and optional equipment starts at the dealerships. Indeed, PACCAR states,

“Most trucks are ordered by dealers according to customer specifications. Some units are ordered by dealers for stocking to meet the needs of certain customers who require immediate delivery or for customers that require the chassis to be fitted with specialized bodies.”¹³²

PACCAR is working on its SuperTruck 3 program to continue the development of its Class 8 Kenworth and Peterbilt battery-electric and fuel cell vehicles, along with its vehicle charging stations. Kenworth and Peterbilt developed state-of-the-art vehicles in the prior SuperTruck and SuperTruck 2 programs.¹³³ According to the company, many of the technologies developed in the earlier SuperTruck programs were deployed in production vehicles, benefiting the environment and PACCAR's customers. However, none of these technologies include VIPV.

It does not appear as if PACCAR has invested in VIPV for trucks. However, the company's research and development efforts include demonstration and development projects for Kenworth, Peterbilt and DAF vehicles, including battery-electric, hydrogen fuel cell, hydrogen combustion and hybrid technologies. PACCAR is currently producing battery-electric Kenworth, Peterbilt and DAF trucks.¹³⁴

4.1.4 Navistar, Inc. (Traton Group)

[Navistar, Inc.](#) is a leading manufacturer of commercial trucks, school and commercial buses, defense vehicles, and engines. Earlier, this company was known as International Harvester. In 2021, it became a wholly owned subsidiary of Traton (Germany). In July 2021, Traton Group (Germany), a part of Volkswagen Group, acquired Navistar International Corporation.¹³⁵ Its brands Scania, MAN, Navistar, and Volkswagen Truck & Bus. Navistar, Inc. operates through a network of more than 1,000 dealer outlets in Canada, Brazil, Mexico, and U.S.¹³⁶ The company also provides Navistar manufactures truck through its International Trucks business.¹³⁷

4.2. Heavy Truck IPV – International Initiatives

In Europe photovoltaic panels on the roofs of trailers and trucks are being tested and demonstrated. Examples are provided in this section.

4.2.1 Kuehn+Nagel AG – Solar Powered Truck

In 2022, Kuehne+Nagel, a company based in the Netherlands announced plans to reduce CO₂ emissions by integrating solar installed on the top of trucks. According to a company press release, "the solar panels reduce fuel consumption by up to 1.200 liters per year, per vehicle. This reduces a truck's overall fuel consumption by up to 6%, lowering CO₂ emission per truck by 3.8 tons on an annual basis."¹³⁸



Figure 33: Kuehne+Nagel Solar Installed on the Top of Trucks

Source: Kuehne+Nagel¹³⁹

The company touts the following benefits for truck solar:¹⁴⁰

“Traditionally, trucks consume a large amount of electricity which is generated by the alternator. The photovoltaics now supply the trucks with solar electricity. When driving, there is a decreased load on the engine which lowers fuel consumption. An integrated solar management system also allows the charging of electric appliances such as phones and computers and to power the air-conditioning (AC) within the truck cabin and the tail lift, which is needed for loading and unloading. Additionally, the driver can measure how much solar electricity has been delivered to the vehicle by the solar panels and how much per activity is consumed. During the summer months with more sun, the fuel consumption is even lower.”

According to the company, the solar technology used on Kuehne+Nagel’s trucks was developed by [IM Efficiency](#) (Helmond, Netherlands), a solar innovation company for vehicles, based in the Netherlands. In a press statement, Martijn Ildiz, IM Efficiency CEO suggest one benefit of their technology is “providing a sustainable solution to reduce fuel consumption of trucks with [SolarOnTop](#).”¹⁴¹

4.2.2 Scania Tests Solar Powered Truck

Scania, one of the trucking companies in Sweden is working on a haulage trailer covered in solar panels. Scania in collaboration with Uppsala University developed a solar power top for the trailer portion of a truck. The trailer can be paired with a hybrid powertrain to make the truck much more fuel efficient. In 2023, Scania tested solar power trucks on

public roads as part of a two-year research collaboration with research (Uppsala University), vehicle manufacturers (Scania), trailer manufacturers (MT Eksjö), solar cell manufacturers (Midsummer), energy companies (Dalakraft) and users (Ernsts Express). “The unique 560 hp plug-in hybrid truck was paired with an 18 m trailer covered in new lightweight tandem solar panels, with the truck set to be tested on public roads by haulage company Ernsts Express AB.” Solar panels on the trailer are described as,¹⁴²

“More than 100 sq m of space on the trailer has been covered by unique thin, lightweight and flexible solar panels. These include Midsummer’s new perovskite solar cells, which allow for double the solar energy generation compared to traditional solar cells. They produce a maximum efficiency of 13.2 kWp (kilowatt peak), which will replenish 300kWh of batteries on the vehicle – 100kWh on the truck and 200kWh in the trailer. ... The solar energy produced gives the hybrid truck a prolonged driving range of up to 5,000km annually in Sweden. In countries like Spain, with more sun hours, the vehicle could feasibly double its driving range.”

The Figure 34 on the following page shows a Scania Truck integrated with vertical side solar panels.



Figure 34: Scania hybrid solar powered truck

Source: Scania AB (2023)¹⁴³

More information on the solar cells and battery pack arrangement:

“There are nine batteries placed in the truck along with the trailer with capacity of 48Ah battery. The capacity of batteries is around 220 kWh. The charger used in the truck is Kempower dc movable charger of 20 kW/40 kW rating. The solar cells are expected to produce 14000 kWh annually in Sweden thus saving around 5-10% fuel theoretically.”¹⁴⁴

In August 2023, Scania reported the company planned to develop a solar-powered truck, whose electrical propulsion is generated by the vehicle’s own solar cells. Scania haulage

customer and partner Ernst Express, who will test the prototype in actual operational conditions on Swedish roads. The prototype took a team to put it together:

“An initial six-month pre-study in late 2019 and early 2020 made the team realize that it did make sense to explore this technology now. Once they received funding from the Swedish state innovation agency, Vinnova, a full-scale project began in January 2021, with solar cell development by Uppsala University.

The Scania team consists of software developers, hardware developers and project management, with no more than a dozen people involved over the 19-month development process.”¹⁴⁵

In a press statement, Eric Falkgrim, Project Manager of Scania’s Solar-powered Truck development stated the company believes a commercial application for the truck is some years away.¹⁴⁶

4.2.3 TIP Group

TIP Group, headquartered in Amsterdam, the Netherlands, TIP is one of Europe and Canada’s leading equipment service providers is developing sustainable solutions for reefer units. In January 2023, TIP launched a pilot to test the “Endurance,” a battery and solar-powered Transport Refrigeration Unit (TRU). The system is described as being “fully electric and depending on conditions, the solar panels can typically provide 65% to 100% of the charge needed to operate the refrigeration unit.” Frigoscandia, TIP and Valoe are collaborating to develop refrigerated trailers (trucks) equipped with PV systems. In June 2024, TIP received the first refrigerated trailer pilot, equipped with Valoe’s solar system. The trailer will be operated by Frigoscandia. TIP and Valoe signed a contract in January 2023 for equipping hundreds of trailers by the end of 2025.¹⁴⁷ Once the pilot project is completed, “the technology could be deployed more widely by TIP.”¹⁴⁸



Figure 35: Solar PV refrigerated trailer

Source: TIP Group (2023)¹⁴⁹

TIP Group has also partnered with Sunswap. In January 2024, TIP Group expanded an existing partnership with Sunswap by placing another minimum order of 20 Endurance transport refrigeration units and commencing customer trials to deliver sustainable temperature-controlled transport solutions at scale across Europe. TIP began offering reefer trailers equipped with Sunswap’s battery- and solar-powered TRUs in 2023 through a 12-month pilot program.¹⁵⁰ The Endurance TRUs are purpose-built, battery and solar powered. The fully electric system is a zero-emission, viable alternative to diesel power and by matching the battery size precisely to a delivery cycle, it provides the right amount of power without excess weight or unnecessary cost.¹⁵¹

5.0 Refrigerated Trucks – United States

Another type of specialty truck is refrigerated trucks often referred to as reefers. They have a transport refrigeration unit. These are used on insulated trailers, straight trucks, intermodal shipping containers and rail cars to keep temperature-sensitive goods at the right temperature.¹⁵² “The types of cargo carried is diverse, involving more than just refrigerated temperatures. Both cold temperatures and heat are required for some products. Others require significant control of the humidity of the cargo. Even with the cold temperatures, multiple temperatures are required from intense cold for pharmaceuticals to near room temperature for products that could melt in high temperatures, such as candles and chocolate.”¹⁵³

Almost all perishable foods and medicines are delivered in trucks or tractor trailers equipped with TRUs, which are most often powered by small diesel engines.¹⁵⁴ Electric TRU is an alternative to diesel-powered TRUs. The batteries in an electric TRU can be charged with onboard solar panels. TRU manufacturers are developing electric units for fleets. It is reported that,

“The integration of electric reefer units now involves software coordination and diagnostic compatibility between the TRU and truck manufacturers. For example, medium-duty applications, electric reefer units will rely on the electric power takeoff (ePTO) system that connect directly to the chassis batteries of battery electric vehicles. However, given the diverse regulatory landscape and applications demands, Thermo King, for example, is also developing independent battery packs to provide flexibility. As an application example, battery packs are being tested for eTRU trailer applications.”¹⁵⁵

Trailers are integral to the U.S. refrigerated trucking market, serving industries requiring large-scale transportation of perishable goods over long distances. The demand for refrigerated trailers remains robust, driven by sectors such as agriculture, food processing, and pharmaceuticals. A commonly cited estimate is about 500,000 reefers – refrigerated trailers – on the roads in the US. Refrigerated trailer production of 521,800 during the last 14 years (2008-2021) represents 15.2 percent of the total trailer production of 3,426,028. Annual production of refrigerated trailer production for the five manufacturers shows consistent growth in this segment from under 30,000 units per year to 45,000 units typically since 2015.¹⁵⁶

5.1. Refrigerated Truck Manufacturers

The truck refrigeration unit market is dominated by a few globally established players such as Daikin (Japan), Carrier, Thermo King, Denso (Japan), and Webasto (Germany). These companies have expanded in various geographical locations and also enter joint ventures/collaborations with other industry players to sustain their position in the market.¹⁵⁷

Both Thermo King and Carrier have invested in PV for its reefers. These companies are covered in Section 2 of this report. For instance, in 2020, Carrier Transicold introduced a solar charging system for transport refrigeration unit batteries that fits on top of the unit. The TRU-Mount Solar Charging System delivers 2.0-amp power delivery by combining ultrapure silicon cells with a high-performance charge controller. The panel design provides a custom fit on the narrow, curved top surface of Carrier Transicold X4 and X2 series trailer refrigeration units and Vector [8000](#) and 6000 series units.



Figure 36: Vector™ 8500 Trailer Refrigeration Unit
Source: Carrier¹⁵⁸

5.1.1 Refrigerated Carriers as Adopters of VIPV

In June 2022, TMC published an information report – entitled “North American Refrigerated Trailer Survey Report: Next Generation Trailer Expectations,” – which polled North American trailer rental/lease companies to determine their views of the next generation trailer and the adoption of advanced technologies. The study identified **refrigerated carriers as early adopters** of technology driven by the need to track temperatures and the high cost of failures.¹⁵⁹ With respect to solar, the study found that,¹⁶⁰

“A significant factor is the high level of adoption of solar charging panels for the telematics units. But where can you place a solar panel to be effective and avoid damage? The roof is good for efficiency of the solar cells. Mounting it on the front of the trailer, high or low, seems to be the preferred location, but may interfere with rivet heads. For flatbeds and trailer chassis applications, mounting to the underside was mentioned. Surprisingly, the fleets indicated these locations were still acquiring enough solar energy to keep the units running.”¹⁶¹

Further, it is observed that, “this industry is devoted to the principle of “Customer First.” If a customer wants something, has sufficient quantities to make it worthwhile, and is willing to pay for the option, a solution will be found.”¹⁶²

Manufacturers have come up with various iteration. For instance, in 2017, eNow and Volta Power Systems partnered to develop a solar electric refrigerated trailer. Solar panels and lithium ion battery packs power the trailer cooling system significantly reducing emissions, sound and operation expenses. According to a Volta press release, “the 53-foot refrigerated trailer includes three of the largest Volta modules totaling 75 kWh of power, enough energy to run the trailer for a full day of deliveries. The lithium ion system is recharged by eNow’s proprietary 5.4KW solar panels permanently adhered to the top of the trailer, and its patented charge controller. The advanced photovoltaic panels are lightweight and flexible, yet sturdy enough to withstand the natural elements. The battery bank can also charge on-site, using shore power during loading.”¹⁶³



Figure 37: ENow Solar-Electric Reefer
 Source: Lauren Fletcher (2020)¹⁶⁴

6.0 Truck Trailer Manufacturers

Truck trailer manufacturers primarily manufacture and sell dry vans, reefers, flatbeds and other specialty truck trailers. Five manufacturers account for the vast majority of refrigerated trailer production—Utility, Great Dane, Hyundai, Vanguard, and Wabash. Hyundai Translead from South Korea have the large share of market in North America. According to IBISWorld, market share concentration for the truck trailer manufacturing industry in the U.S. is low, which means the top four companies generate less than 40% of industry revenue. The industry's most prominent manufacturers, like Wabash and Utility Trailer Manufacturing Corporation, have developed strong positions across key markets to secure market shares. These companies often have strong links with numerous manufacturers, retailers, wholesalers and shipping companies to ensure stable demand.¹⁶⁵

According to the “2023 Trailer Output Report” by the top 26 North American truck-trailer OEMs built 358, 634 truck trailers in 2023. The largest builder of truck-trailers in North America was Hyundai Translead, headquartered in San Diego, California, built 82,485 trailers in 2023. Hyundai owns manufacturing plants in Tijuana and Rosarito, Mexico.

Table 6: 2022/2023 Top 26 North American Truck-Trailer OEM

Rank	Manufacturer	2023	2022
1	Hyundai Translead	82,485	82,125
2	Utility	48,799	50,023
3	Wabash	43,928	51,090
4	Great Dane	41,000	40,000
5	Stoughton	34,000	24,750
6	Vanguard National	21,557	20,563
7	Fontaine	10,212	9,182
8	EnTrans	8,617	8,107
9	MANAC	7,950	7,450
10	MAC	7,909	7,628
11	Fruehauf North America	7,045	5,821
12	XPO Logistics	6,620	4,705
13	Strick Trailers	6,300	5,800
14	Timpte	5,035	4,473
15	Reitnouer	4,306	3,401
16	Kentucky Trailer	3,372	2,601
17	Dorsey Trailer	3,356	3,217
18	Di-Mond	2,798	1,432
19	Pitts Trailers-Dorsey Intermodal	2,785	11,104
20	East Mfg.	2,719	2,425
21	Trail King NA	1,800	NA
22	Felling	1,362	1,401
23	Tremcar	1,307	1,184
24	Extreme	1,291	889
25	Premier	1,044	2,318
26	Western Trailer	1,037	NA

Source: Trailer Body Builders (2024)¹⁶⁶

Although market players adopt various strategies including collaborations, joint ventures and partnerships to introduce new product offering and increase their market share in the refrigeration unit market,¹⁶⁷ there is no indication that the trailer manufacturers are installing PV on trailers at the factory.

7.0 State Regulations

There are no specific regulations regarding VIPV that could propel market growth or adoption, although the state of California appears to have some guidance, but no regulations. Below are some regulations related to solar panels and trucks in California.

Advanced Clean Cars II

Advanced Clean Cars II regulation requires that all new trucks, passenger cars, and SUVs sold in California be zero-emission vehicles by 2035. Zero-emission Vehicle Regulation to require an increasing number of zero-emission vehicles, and relies on currently available advanced vehicle technologies, including battery-electric, hydrogen fuel cell electric and plug-in hybrid electric-vehicles, to meet air quality and climate change emissions standards.¹⁶⁸

Zero-Emission Truck TRU Technologies

California Air Resources Board's regulations suggest zero-emission trucks can use on-board batteries to power fans, compressors, and controls. The batteries can be recharged by plugging into the grid while stationary or by using on-board solar panels. Specifically,

"Electric power for compressors, fans, and controls may come from on-board batteries, provided they are not re-charged by an alternator or generator that is driven by the vehicle engine or powertrain, trailer wheels, trailer axle/differential, or any other contrivance that adds to the vehicle engine load. Examples of zero-emission truck TRUs include, but are not limited to, truck TRUs with refrigeration systems and/or fans that are powered by batteries when on-road and use battery chargers that are plugged into the grid while stationary or connected to on-board solar panels."¹⁶⁹

8.0 Summary and Conclusions

Vehicle-Integrated Photovoltaics (VIPV) has been a subject of interest and analysis for a number of years. Market segments most frequently cited as promising include: (1) buses, (2) local delivery trucks (3) transport refrigeration units and (4) medium/heavy duty trucks. This report focused on heavy duty tractor-trailers. Based strictly on a secondary literature review, this report sought to address the current state of the art and VIPV's prevalence in the domestic and international trucking industries. In the U.S., fleet owners appear to be the most actively engaged with VIPV. This after-market addition appears to be relatively inexpensive and is used to increase the comfort of truck drivers and reduces idling times. In addition, refrigerated trucks carrying food, pharmaceuticals and other

temperature sensitive products appear to be a more likely candidate for integrated VIPV, as the load carried tends to be higher value and more critical.

Appendix 1

U.S. Heavy Duty Trucks Decarbonization

Before looking specifically at VIPV for heavy trucks, it is useful to frame the problem in terms of the ultimate goal, which is reducing greenhouse gas (“GHG”) emissions. The transportation sector is also the largest source of GHG emissions in the United States, with heavy-duty vehicles accounting for 28 percent of GHGs in that sector in 2022.

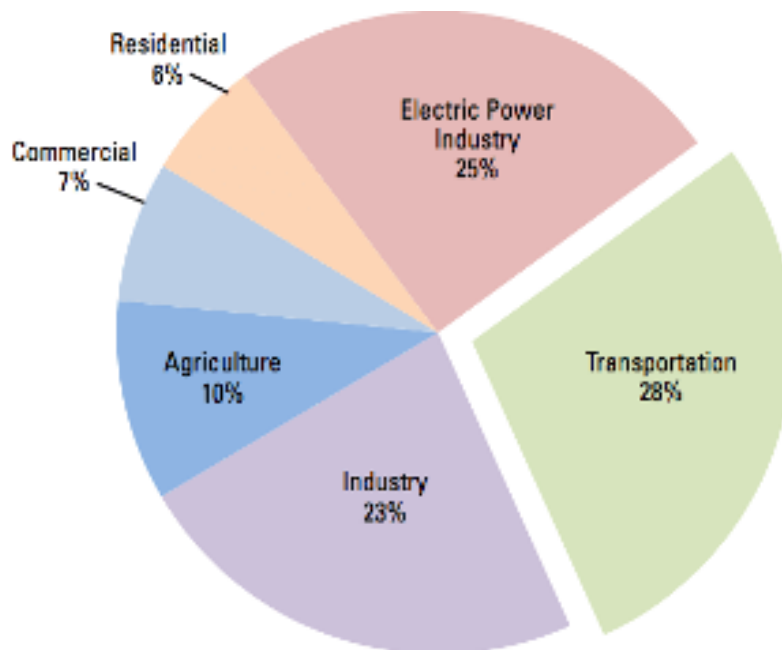


Figure 36: U.S. GHG emissions by economic sector in 2022

Source: U.S. Environmental Protection Agency (May 2024)¹⁷⁰

Medium- and heavy-duty vehicles are an important part of the economy. They provide long-haul and local delivery, transport people and products, collect garbage, support construction, and much more. In 2022, they accounted for roughly 23 percent of the sector's total emissions, with only light-duty trucks having a larger share. Though they represent only a small fraction of total vehicles on the road (approximately 5 percent in the United States), in 2020 they contributed approximately 26 percent of greenhouse gas emissions coming from the transportation sector.¹⁷¹

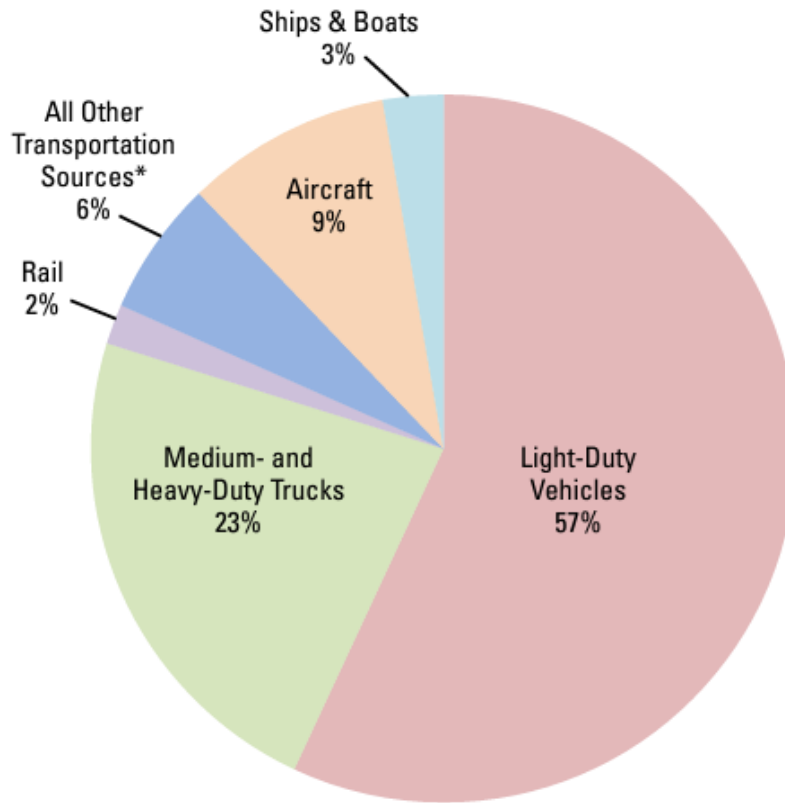


Figure 37: Share of U.S. Transportation Sector GHG Emissions by Source, 2022

Source: U.S. Environmental Protection Agency (May 2024)¹⁷²

The quest for decarbonization in the trucking industry means an additional of meeting the ever-growing stringent regulations. Decarbonizing trucks – to reduce both greenhouse gases and air pollution is an important goal mitigating climate change. In March 2024, EPA finalized GHG standards for the manufacture, sale, or importation of heavy-duty trucks. The standards are expected to drive the production of trucks fueled by electricity and hydrogen and aim to reduce GHG emissions up to 60 percent by 2032 for some vehicle classes.¹⁷³ For tractors such as day cabs and sleeper cabs on tractor-trailer trucks, the Phase 3 standards vary according to vehicle type and range up to 40% (Table 7). Phase 3 GHG regulations set strict emissions standards for heavy-duty trucks covering model years 2027 through 2032. It requires, among other things, a 25% reduction in CO₂ emissions from all sleeper tractors (trucks) sold in 2032.

Table 7: U.S. Greenhouse Gas Emissions – Phase 3 Standards

Percent Reduction from the Phase 2 CO ₂ Emission Standards						
Model Year:	2027	2028	2029	2030	2031	2032
Light-Heavy Vocational	17%	22%	27%	32%	46%	60%
Medium-Heavy Vocational	13%	16%	19%	22%	31%	40%
Heavy-Heavy Vocational	--	--	13%	15%	23%	30%
Day Cab Tractors	--	8%	12%	16%	28%	40%
Sleeper Cab Tractor	--	--	--	6%	12%	25%

Source: U.S. Environmental Protection Agency (2024)¹⁷⁴

States are also setting stricter standards for various types of heavy-duty vehicles such as garbage trucks, delivery vans and tractor-trailers.¹⁷⁵ The state of California is a prime example of where both state and federal standards drive fleet decisions.¹⁷⁶ California requires all new trucks to be zero-emission by 2042. It applies to fleets performing drayage operations, those owned by state, local, and federal government agencies and "high priority fleets." High priority fleets are defined as entities that own, operate or direct at least one vehicle in California, and that has either \$50 million or more in gross annual revenues, or that own, operate, or have common ownership or control of a total of 50 or more vehicles.¹⁷⁷

Electric trucks are expected help meet regulatory requirements. For instance, Penske has invested heavily in EV development and even has a test fleet that evaluates a variety of vehicles for various markets and real-world use. Electric test fleet includes the Volvo VNR tractor (Class 8), the International eMV (Class 6 and 7), the Ford E-Transit (Class 2), the FUSO eCanter (Class 4), the Kalmar Ottawa Electric Terminal Tractor T2E (Class 8-yard tractor) and the Orange EV electric terminal truck (Class 8-yard tractor). "The company's electric fleet numbers change regularly as Penske works with manufacturers to rotate their prototypes in and out of the fleet while they are tested in real-world use cases."¹⁷⁸

GHG Reduction in U.S. Trucking Industry

Many of the fleet owners have publicly announced their plans or have already invested in fleets that have GHG reduction technologies, including adoption of battery-electric technologies, battery-electric, hydrogen fuel cells technologies and converting to zero-emission vehicles, etc. As their plans or previous investments may affect their potential interest in VIPV, examples are provided in this section, noting that the push is for electric trucks, and truck IPV is hardly ever mentioned.

Electric Fleets

While the electrification of the transportation industry is occurring in the heavy truck transportation industry. Below are examples. In all the examples below, VIPV is not mentioned or referenced.

Another example is Carrier's Vector eCool system, which is an all-electric refrigerated trailer system that fully regenerates while the unit is in motion. The in-wheel electric motor within the hub assembly captures energy that would otherwise go wasted as heat from friction brakes. The electricity is stored in a high-capacity battery. "An electric power takeoff (ePTO) allows the Supra e11 unit to use energy directly from the truck's high-voltage battery, eliminating fuel consumption, emissions and noise associated with engine-driven systems while providing comparable refrigeration performance."¹⁷⁹



Figure 38: Carrier's Vector eCool system

Source: Carrier (2022)¹⁸⁰

Thermo King and Range Energy

In Range Energy's trailer electrification platform, the e-axle, battery pack, and smart kingpin package provide power to auxiliary devices and enables zero-emission precooling for transportation refrigeration units. In May 2024, Range Energy and Thermo King announced a strategic collaboration to accelerate the commercialization of electric refrigerated trailers. This collaboration will see Range's electric trailer platform integrated with Thermo King's hybrid trailer refrigeration units and electric transport refrigeration unit.¹⁸¹

Performance Food Group Company, Navistar, Great Dane and Carrier Transicold, part of Carrier Global Corporation

In 2023, Performance Food Group Company, Navistar, Great Dane and Carrier Transicold, part of Carrier Global Corporation collaborated to develop and launch a commercial evaluation program using all-electric refrigeration technology on a battery-electric truck for sustainable, direct-emissions-free distribution of refrigerated and frozen food. The truck has Carrier Transicold's Supra eCool electric truck refrigeration unit, an International eMV Series battery-electric truck with a factory-installed ePower electrical system and a 22-foot Alpine S-Series insulated body by Great Dane. The truck will serve Performance Food Group Company operations in California.¹⁸²



Figure 39: Performance Food Group Company, Carrier Transicold, Navistar and Great Dane truck

Source: Carrier (May 2023)¹⁸³

Isuzu Commercial Truck of America and Thermo King

In May 2024, Isuzu Commercial Truck of America in collaboration with Thermo King unveiled an all-electric Isuzu NRR EV truck integrated with the Thermo King e300 all-electric transport refrigeration unit. The Thermo King e300 is part of the evolve portfolio of electrified refrigeration solutions. This Class 5 refrigerated truck solution developed by Thermo King is fully integrated into the OEM's electric vehicle chassis. Customers can order an EV chassis with an all-electric transport refrigeration unit to meet their delivery needs.¹⁸⁴

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