

# Release of the Addendum to the 2022 TRU Technology Assessment

*May 2024*

California Air Resources Board (CARB) staff developed the 2022 Technology Assessment: Non-Truck Transport Refrigeration Units (2022 TRU Technology Assessment) to help CARB assess the technological feasibility of various zero-emission transport refrigeration unit (TRU) technologies for the purposes of meeting the directive of the Governor's Executive Order N-79-20. The goal of the 2022 TRU Technology Assessment is to understand the current and projected development of zero-emission technologies for non-truck TRUs (trailer TRUs, domestic shipping container TRUs, railcar TRUs, and TRU generator sets).

Staff published the 2022 TRU Technology Assessment in October 2022 and have continued to research zero-emission technologies for non-truck TRUs. The Addendum to the 2022 TRU Technology Assessment (Addendum) is an update to Appendix A of the 2022 TRU Technology Assessment and is intended to help share the new products and technology demonstrations that staff have learned about since publishing the 2022 TRU Technology Assessment. The Addendum covers updates on TRU technologies from November 2022 through March 2024.

If you have additional information to share on non-truck TRU technologies, please contact [freight@arb.ca.gov](mailto:freight@arb.ca.gov).

## I. Appendix A. TRU Demonstration Projects for Non-Truck Transportation Refrigeration Units (Trailer TRUs, Domestic Shipping Container TRUs, Railcar TRUs, and TRU Generator Sets) (2015 - 2024)

*CARB staff seeking the following information on demonstration projects:*

- *Additional information on the demonstration projects presented in this appendix, as indicated in Table A - 1.*
- *Additional non-truck TRU demonstration projects not listed in this appendix.*

Table A - 1 includes a list of demonstration projects of zero-emission technologies for non-truck TRUs. The information provided contains projects covered in the 2022 TRU Technology Assessment, including updates and new projects. Projects are listed in the same order as they appear in the 2022 TRU Technology Assessment and any updated or new projects are marked with \* in the ID column. Specific changes are underlined. CARB staff are seeking results for each demonstration project listed.

Table A-1: Zero-Emission Non-Truck TRU Demonstration Projects (2015 - 2024)

ID	Technology or Technology Configuration <sup>1</sup>	Company or Organization/Product or Project Name	1. Deployment Location 2. Deployment Phase <sup>2</sup> 3. Customer	Start Date to End Date (if available)	Units Deployed	Project Description	Results (if available)
<b>Zero-Emission Trailer TRU Demonstrations</b>							
1	<b>Battery-electric TRU</b> (Advanced Energy Machines brand TRU with range-extending technologies)	<i>Advanced Energy Machines/</i> "SolarTech 48k-16"	1. Riverside, CA, United States (U.S.) 2. Commercialized 3. United Natural Foods Incorporated	May 2021	23 of 53, as of Nov 2021	Deploying 53 48-foot multi-zone temperature-controlled trailers with battery-electric TRUs with range-extending technologies at -10°F for the frozen zone and 34°F for the refrigerated zone. The project uses the <i>Clean Off-Road Equipment voucher incentive program (CORE)</i> . <sup>3</sup>	All units operated successfully. A 32-hour battery life was confirmed (with no door openings). 90 pounds (lb.) of fine particulate matter (PM2.5) was eliminated in 2021 as compared to operating diesel-powered TRUs. 125 megawatt-hours (MWh) of grid power was used for charging in 2021.

<sup>1</sup> Demonstrations are categorized into zero-emission trailer TRUs, zero-emission TRU generator sets, or infrastructure for zero-emission TRUs, then alphabetically by technology, then alphabetically by company name.

<sup>2</sup> Deployment phases include prototype, demonstration, pilot, and commercialized. Prototype means that one or two units are built in a lab environment for proof of concept. Demonstration means the development of one or two working units to prove out the technology or application. Demonstration units are not used for revenue service but are installed on the trailer and tested with actual temperature-controlled products and delivery routes. Pilot means that small numbers (usually one or two) of non-production units are being tested in real-world, commercial applications. These are often the demonstration units. Commercialized means that units are production level and are used by end customers for revenue service.

<sup>3</sup> Business Wire. (2021, May 5). UNFI Adopts Emerging Transportation Technology to Reduce Emissions. <https://www.businesswire.com/news/home/20210505005564/en/UNFI-Adopts-Emerging-Transportation-Technology-to-Reduce-Emissions>

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2	<b>Battery-electric TRU</b> (Advanced Energy Machines brand TRU with range-extending technologies)	<i>Advanced Energy Machines/</i> <i>"SolarTech 48k-16"</i>	1. Irvine, CA, U.S. 2. Commercialized 3. Albertsons	Nov 2020	9	Deployed nine single-zone, 50-foot freezer trailers with battery-electric TRUs that operate daily at -20°F and charge wirelessly. The project uses <i>CORE</i> .	Over 15,000 total hours of operating time successfully maintaining the -20°F temperature requirement. Over 18,000 successful wireless charges. A total of 80 lbs. of PM2.5 was eliminated in 2021 as compared to operating diesel-powered TRUs. Additionally, Albertsons combined two of these trailers using this battery-electric TRU with Volvo battery-electric tractors to demonstrate a 100 percent zero-emission commercial grocery delivery. <sup>4</sup>

<sup>4</sup> Supermarket News. (2021, May 28). Albertsons marks milestone with 100% zero-emission truck delivery. <https://www.supermarketnews.com/issues-trends/albertsons-marks-milestone-100-zero-emission-truck-delivery>

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3	<b>Battery-electric TRU</b> (Advanced Energy Machines brand TRU with range-extending technologies)	<i>Advanced Energy Machines/</i> "SolarTech 48k-16"	1. Gilroy, CA, U.S. 2. Commercialized 3. Performance Food Group/ Freightliner	May 2021	10	Deployed 10 36-foot multi zone trailers with the frozen zone set to -10°F and the refrigerated zone set to 35°F. These battery-electric units operate six days per week with 14 stops per day. The project uses the <i>CORE</i> .	A 32-hour battery life was confirmed (with no door openings). Consistent temperature control and continuous operation with no downtime was confirmed with telematics system. 18 lbs. of PM2.5 was eliminated in 2021 as compared to operating diesel-powered TRUs. 34 MWh of grid power was used for charging in 2021.
4	<b>Battery-electric TRU</b> (Advanced Energy Machines brand TRU with range-extending technologies)	<i>Advanced Energy Machines/</i> "SolarTech 48k-16"	1. Rancho Cucamonga, CA, U.S. 2. Commercialized 3. Evolution Fresh/ Starbucks	Dec 2020	4	Four stationary 53-foot temperature-controlled trailers with battery-electric TRUs containing frozen goods operate continuously using both grid and solar power. The project uses the <i>CORE</i> .	22 lbs. of PM2.5 was eliminated in 2021 as compared to operating diesel-powered TRUs. 38 MWh of grid power was used for charging in 2021 using an average of 2.3 kilowatts (kW) per hour per battery-electric TRU when direct sunlight is not available for the solar system.

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5	<b>Battery-electric TRU</b> (Advanced Energy Machines brand TRU with range-extending technologies)	<i>Advanced Energy Machines/</i> "SolarTech 48k-16"	1. Multiple locations 2. Commercialized 3. Multiple companies	2021	3	These three temperature-controlled trailers with battery-electric TRUs and range-extending technologies are being evaluated by multiple companies before they move forward purchasing more units. The project uses the <i>CORE</i> . <sup>5</sup>	There have been 23 demonstrations with these three units as of December 2021 logging 6,320 hours of successful operation in 2021 resulting in the elimination of 22 lbs. of PM2.5 as compared to operating diesel-powered TRUs.

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<sup>5</sup> PLM. (2021, Jan 5). PLM Paves the Way with Zero Emissions for the Transport Refrigeration Unit. <https://www.plmfleet.com/about-us/news-and-articles/2021/01/05/plm-paves-the-way-with-zero-emissions-for-the-transport-refrigerated-unit>

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6	<b>Battery-electric TRU</b> (Advanced Energy Machines brand TRU with range-extending technologies)	<i>Advanced Energy Machines/</i> "SolarTech Generation 1"	1. Multiple locations 2. Commercialized 3. Multiple companies	2014	68	Various companies purchased these temperature-controlled trailers with battery-electric TRUs and range-extending technologies between 2014 and 2019 for commercial food service and grocery deliveries. The projects were self-funded demonstrations by the various companies.	These battery-electric TRUs logged 642,332 operational hours over 7 million road miles, predominantly in California, with the electric motor operating 48 percent of the time. A total of 1,800 lbs. of PM2.5 was eliminated by using these zero-emission battery-electric TRUs instead of diesel-powered TRUs. The total grid power consumption for all units was a combined three gigawatts.

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7	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<i>Carrier/</i> "Vector® eCool™"	1. United Kingdom (UK) 2. Demonstration 3. Not applicable	Oct 2020	1	A temperature-controlled 47-foot trailer with a battery-electric TRU and range-extending technologies was constructed in the UK to be used for demonstration purposes. This unit is not being pulled by zero-emission tractors but can be to produce a full zero-emission solution. <sup>6</sup>	[CARB staff seeking input]
8*	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<i>ConMet/</i> "Preset Plus eHub™"	1. U.S. 2. Demonstration 3. Not applicable	2021	2	Two temperature-controlled trailers with battery-electric TRUs are being tested. ConMet was seeking partners for full commercialization, <u>which includes Great Dane and Meritor.</u> <sup>7,8</sup>	[CARB staff seeking input]

<sup>6</sup> Cooling Post. (2020, October 7). Vector eCool is first autonomous electric refrigeration trailer. <https://www.coolingpost.com/products/vector-ecool-is-first-autonomous-electric-refrigerated-trailer/>

<sup>7</sup> Conmet (2022, March 22). ConMet eMobility Commercial eHub Partnerships. <https://conmet.com/conmet-emobility-announces-commercial-partnerships-amid-first-deliveries-of-ehub/>

<sup>8</sup> Work Truck. (2021 September 12). ConMet Aims to Address TRU Emissions Regs with Zero-Emission Trailer. [https://www.worktruckonline.com/10151231/conmets-aims-to-address-tru-emissions-regs-with-zero-emission-trailer?utm\\_source=website&utm\\_medium=contentoffers&utm\\_campaign=111021](https://www.worktruckonline.com/10151231/conmets-aims-to-address-tru-emissions-regs-with-zero-emission-trailer?utm_source=website&utm_medium=contentoffers&utm_campaign=111021)



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9	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<i>eNow, XL Fleet/ "Rayfrigeration™"</i>	1. CA, U.S. 2. Demonstration 3. Not applicable	Mar 2020	1	A 53-foot temperature-controlled trailer with a battery-electric TRU and range extending technologies was unveiled at the Work Truck Show in Indianapolis, IN. <sup>9</sup>	[CARB staff seeking input]
10	<b>Battery-electric TRU</b> (Brand-agnostic TRU with range-extending technologies)	<i>Emerald Technologies/ "KECS"</i>	1. Tampa Bay, FL, U.S. 2. Demonstration 3. Caspers Company	2013 to 2015	1	A single temperature-controlled trailer with a battery-electric TRU and range extending technologies was deployed to deliver food to McDonald's. <sup>10</sup>	The demonstration showed that the kinetic energy generation system generated enough power to run the TRU and simultaneously charge a battery to be used when the temperature-controlled trailer was not in motion. The demonstration was a success in that no diesel fuel was used for the duration of the demonstration.

<sup>9</sup> Work Truck. (2020, March 5). Enow Demonstrates Solar-Electric Reefer. <https://www.worktruckonline.com/351917/enow-demonstrates-solar-electric-reefer>

<sup>10</sup>Toby Sullivan. (2016, June 28). Game Changer – Caspers Cold Storage & Distribution Kinetic Energy. <https://www.youtube.com/watch?v=CWnOge7ra6g>

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11*	<b>Battery-electric TRU</b> (Thermo King brand TRU with range-extending technologies)	<i>Maxwell and Spark/</i> "Advantage.li"	1. Netherlands 2. Pilot 3. TIP Trailer Services, Unilever, and Daily Logistics Group	Sep 2021 to May 2022	4	Demonstration involves a nine-month pilot in which diesel refrigeration TRUs in temperature-controlled trailers will be replaced by zero-emission battery-electric TRUs. <sup>11</sup>	<u>The demonstration exceeded its target of 80% diesel fuel reductions and achieved 99% reductions.</u> <sup>12</sup>  [CARB staff seeking input on the situations in which the diesel backup was used and whether it could be removed]
12*	<b>Semi-Direct-Drive Battery-Electric Hybrid TRU</b> (Carrier brand TRU with range-extending technologies)	<i>ConMet/</i> "Preset Plus eHub™"	1. Riverside, CA, U.S. 2. Pilot 3. Sysco	Early 2022	[CARB staff seeking input]	<u>The Preset Plus eHub was used on trailers owned by Sysco Corp. as part of their commercial evaluation program.</u> <sup>13</sup>	[CARB staff seeking input]
13	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<i>Sunswap/</i> "Endurance"	1. Chesterfield, UK 2. Demonstration 3. Gist	April 2022	1	Sunswap's proprietary battery-electric trailer TRU, equipped with their rooftop solar-assist technology, is being tested.	[CARB staff seeking input]

<sup>11</sup> Maxwell and Spark. (2021, September 29). Ice cold - but without the CO2: 100% electric reefer trailers released for a pilot with Unilever. <https://maxwellandspark.com/ice-cold-but-without-the-co2-100-electric-reefer-trailers-released-for-a-pilot-with-unilever/>

<sup>12</sup> Maxwell and Spark (2022, July 20). Electric reefer trial successful in keeping ice-cream cold the green way. <https://maxwellandspark.com/electric-reefer-trial-successful-in-keeping-ice-cream-cold-the-green-way/>

<sup>13</sup> Cannon, J. Commercial Carrier Journal (2022, March 6). ConMet seeing high battery performance, range from its PreSet Plus eHub. <https://www.ccdigital.com/alternative-power/article/15289298/conmet-seeing-range-from-its-preset-plus-ehub>

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14	<b>Battery-electric TRU</b> (Thermo King brand TRU)	<i>Thermo King/</i> <i>"evolve™"</i>	1. Shafter, CA 2. Pilot 3. Walmart	Late 2021	1	A hybrid battery-electric trailer TRU was used in a two-month trial to run 18 routes transporting groceries from a Walmart distribution center in Shafter, CA to surrounding stores. Diesel was used as a backup power source.	When the batteries depleted mid-haul, the trailer TRU switched to diesel power to complete routes. The TRU operated on battery electricity 83% of the operation time.
15	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<i>Westhill Innovation/</i> <i>"SunShifter™"</i>	1. Hamilton, Ontario, Canada 2. Pilot 3. Loblaw	[CARB staff seeking input]	1	A solar-assist technology was retrofitted to the rooftop of a battery-electric trailer and tested by Canadian grocer Loblaw. <sup>14</sup>	[CARB staff seeking input]

<sup>14</sup> Trucknews. (2019, December 16). Loblaw, Westhill testing solar-powered reefer. <https://www.trucknews.com/transportation/loblaw-westhill-testing-solar-powered-reefer/1003123586/>

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16	<b>Cryogenic TRU system</b>	<i>Clean Cold Power/</i> "Dearman Engine™"	1. Waltham Abbey, UK 2. Pilot 3. Sainsbury's	Jun 2016 to Oct 2016	1	A liquid nitrogen-powered engine is being used for a three-month trial. <sup>15</sup>	The trial demonstrated the operational benefits of the TRU including cool-down rates 50 percent faster to frozen state over diesel systems and noise levels at 60 decibels as compared to diesel-powered TRUs which operate between 75 and 85 decibels. <sup>16</sup> The trial also demonstrated that it was cost-comparable to existing diesel systems.

<sup>15</sup> UK.gov. (2016, June 22). Sainsbury's trials Dearman's world-leading cooling technology. <https://www.gov.uk/government/news/sainsburys-trials-dearmans-world-leading-cooling-technology>

<sup>16</sup> WJV Acoustics, Inc. (2017, January 25). Acoustical Analysis, Producers Dairy Parking Lot 450 East Belmont Avenue, Fresno, California. <https://www.fresno.gov/dam/wp-content/uploads/sites/10/2017/03/Appendix-G-Acoustic-Study.pdf>

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17	<b>Cryogenic TRU system</b>	<i>Clean Cold Power/</i> "Dearman Engine™"	1. Netherlands 2. Pilot 3. Unilever	Jun 2017 to Dec 2017	1	A cryogenic TRU system was used in a six-month deployment of frozen produce deliveries across the Netherlands. <sup>17,18</sup>	<u>During the trial, the TRU operated for 661 hours across 26 weeks, traveling 18,000 km (11,200 miles). The TRU successfully delivered ice cream during this time.</u> The trial demonstrated the operational benefits of the TRU including cool down rates 50 percent faster to frozen state over diesel systems. The trial demonstrated that it was cost-comparable to existing diesel systems.

<sup>17</sup> Unilever. (2018, March 29). Could we switch to a carbon-free clean-cold fleet? <https://www.unilever.com/news/news-search/2018/could-we-switch-to-a-carbon-free-clean-cold-fleet/>

<sup>18</sup> Fleet Owner, (2018, April 26). Dearman partners with Unilever to deploy zero-emission TRU in Europe. <https://www.fleetowner.com/refrigerated-transporter/refrigerated-vehicles-equipment/article/21231382/dearman-partners-with-unilever-to-deploy-zero-emission-tru-in-europe>

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18	<b>Cryogenic TRU system</b>	<i>Clean Cold Power/</i> "Dearman Engine™"	<ol style="list-style-type: none"> <li>1. Italy</li> <li>2. Pilot</li> <li>3. Unilever</li> </ol>	Sep 2019	1	A cryogenic TRU system was used in a one-month deployment of frozen produce deliveries from south to north Italy.	Four tests were conducted, each involved 90 hours of frozen produce storage including operation of the TRU system over a weekend followed by a 410-mile trip for final delivery of the cargo. The trial demonstrated cool down rates 50 percent faster to frozen state over diesel systems and four successful duty cycles of 90 hours. After the demonstrations, the customer requested a vertical, front-mounted system instead of the existing under-mounted system.

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19	<b>Cryogenic TRU system</b>	<i>Clean Cold Power/</i> "Dearman Engine™"	1. Hemel Hempstead, UK 2. Pilot 3. Marks & Spencer	May 2018	1	A dual-compartment cryogenic TRU system was used on a temperature-controlled trailer. <sup>19</sup>	The trial involved approximately 1,500 hours of operation and demonstrated benefits of the cryogenic TRU system including cool down rates 50 percent faster to frozen state over diesel systems, noise levels at 60 decibels as compared to diesel-powered TRUs which operate between 75 and 85 decibels, overall ease of use, and that the cryogenic TRU system is cost-comparable to existing diesel systems. <sup>20</sup>

<sup>19</sup> Green Car Congress. (2018, May 31). Marks & Spencer to lease Dearman zero-emission TRU. <https://www.greencarcongress.com/2018/05/20180531-ms.html>

<sup>20</sup> WJV Acoustics, Inc. (2017, January 25). Acoustical Analysis, Producers Dairy Parking Lot 450 East Belmont Avenue, Fresno, California. <https://www.fresno.gov/darm/wp-content/uploads/sites/10/2017/03/Appendix-G-Acoustic-Study.pdf>

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20	<b>Cryogenic TRU system</b>	<i>Hyundai Translead/</i> "HT Nitro Thermo-Tech®"	1. CA, U.S. 2. Demonstration 3. Not applicable	Nov 2019	1	A full-size temperature-controlled trailer with a cryogenic nitrogen refrigeration technology system was developed to demonstrate the cryogenic TRU system concept. <sup>21</sup>	[CARB staff seeking input]
21	<b>Cryogenic TRU system</b>	<i>Boreas/</i> "Nitrogen Cooling System"	1. Austin, TX, U.S. 2. Pilot 3. Ruan	Sep 2017	1	A temperature-controlled trailer with a nitrogen-based cryogenic TRU system traveled on repeated routes from Austin to the Dallas metropolitan area for three days, transporting grocery cargo set at 35°F with up to four stops per route with outdoor temperatures reaching 96°F. <sup>22</sup>	The demonstration illustrated consistent temperature control within the trailer along with fuel cost savings.

<sup>21</sup> FleetOwner. (2019, November 6). Hyundai Translead nitrogen reefer tech reduces carbon footprint by 90%. <https://www.fleetowner.com/equipment/trucks-trailers/article/21704452/hyundai-translead-nitrogen-reefer-tech-reduces-carbon-footprint-by-90>

<sup>22</sup> Fleet Owner. (2019, September 29). Ruan experiences cool benefits in Boreas nitrogen system demo. <https://www.fleetowner.com/refrigerated-transporter/refrigerated-vehicles-equipment/article/21231226/ruan-experiences-cool-benefits-in-boreas-nitrogen-system-demo>



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22	<b>Cryogenic TRU system</b>	<i>Boreas/ "Nitrogen Cooling System"</i>	1. Tracy, CA, U.S. 2. Commercialized 3. Customer not disclosed	2011	42	The largest fleet deployment of cryogenic TRU systems in the U.S. (42 units) has been operating for 10 years.	Shows successful commercialization for at least 10 years of operations.
23*	<b>Hydrogen fuel cell powering an TRU</b> (Carrier brand TRU)	<i>Bosch, Carrier Transicold, Lamberet, and STEF/ "FresH2"</i>	1. France 2. Demonstration 3. STEF Chambéry	Sep 2021	1	A hydrogen fuel cell is powering an TRU installed on a temperature-controlled trailer. Development of this zero-emission solution is taking place at the Bosch site in Rodez, France. <sup>23</sup>	<u>On June 21, 2023, Bosch announced that it would discontinue operations of the Rodez site<sup>24</sup> and suspend plans to produce more hydrogen fuel cells due to the lack of immediate customers.<sup>25</sup></u>

<sup>23</sup> Cooling Post. (2021, September 15). Hydrogen fuel cell refrigerated trailer begins road testing. <https://www.coolingpost.com/world-news/hydrogen-fuel-cell-refrigerated-trailer-begins-road-testing/>

<sup>24</sup> Biogradlija, A. EnergyNews.biz (2023, June 23). Bosch Halts Hydrogen: The Future of Rodez Plant in Limbo. <https://energynews.biz/bosch-halts-hydrogen-the-future-of-rodez-plant-in-limbo/>

<sup>25</sup> Martin, P. Hydrogen Insight. Bosch factory may be closed after hydrogen fuel cell plan is suspended due to lack of customers. <https://www.hydrogeninsight.com/transport/bosch-factory-may-be-closed-after-hydrogen-fuel-cell-plan-is-suspended-due-to-lack-of-customers/2-1-1473841>

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24	<b>Hydrogen fuel cell powering an TRU</b> (Carrier brand TRU)	<i>Chereau/</i> <i>"ROAD"</i>	1. France 2. Demonstration 3. Not applicable	Jul 2019	1	A hydrogen fuel cell is powering an TRU on a temperature-controlled trailer. The trailer range was increased, payload capacity was increased by 430 kilograms, aerodynamics was improved, and safety features were enhanced. <sup>26</sup>	Successfully operated with zero-emissions during a one-day localized distribution test and a 2.5-day long-distance refrigerated freight transport test. Both tests used 14 kilograms of hydrogen. Due to the use of vacuum insulated panel technology, energy consumption was reduced by 25 percent. Aerodynamic improvements resulted in 6 percent reduction of fuel used by the tractor during demonstrations.

<sup>26</sup> Fuel Cells Works. (2020, February 11). Chereau Trials Hydrogen-Powered Refrigeration as Part of its Inogam Evo Project. <https://fuelcellsworks.com/news/chereau-trials-hydrogen-powered-refrigeration-as-part-of-its-inogam-evo-project/>

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25	<b>Hydrogen fuel cell powering an TRU<sup>27</sup></b>	<i>Pacific Northwest National Laboratory, Carrier, Thermo King, Nuvera, Ballard/</i> "Fuel Cell Auxiliary Power Unit (APU) to Power Truck Refrigeration Units (TRU) in Refrigerated Trucks" <sup>28</sup>	1. U.S. 2. Prototype 3. Business case analysis done by Walmart	Apr 2013 to Jun 2018	1 lab prototype	A 24-month multi-phase project was funded by Pacific Northwest National Laboratory that was to involve a business case analysis, prototype development, and ultimately a demonstration of two hydrogen fuel cell TRU systems for temperature-controlled trailers. <sup>29</sup>	A business case analysis was conducted, and a lab prototype was developed but the project terminated before the demonstration phase. The project showed that hydrogen fuel cell technology is feasible for TRUs. The project addressed barriers including inadequate user experience and infrastructure.

<sup>27</sup> Lutkauskas, T. & Block, G. (2013, August 30). *Demonstration of Fuel Cell-Based Auxiliary Power Unit for Refrigerated Trucks: Phase I Business Case Report* (pp. 16-17).

<sup>28</sup> Pacific Northwest National Laboratory uses the acronym TRU for truck refrigeration unit. CARB uses the acronym TRU for transport refrigeration unit. TRUs are used for temperature-controlled trucks, trailers, domestic shipping containers, and railcars. TRU generator sets are used for temperature-controlled ocean containers. This project involved the development of hydrogen fuel cells for use with trailer TRUs.

<sup>29</sup> PNNL et al. (2018, June 13). *Demonstration of Fuel Cell Auxiliary Power Unit (APU) to Power Truck Refrigeration Units (TRUs) in Refrigerated Trucks*. [https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review18/mt014\\_brooks\\_2018\\_p.pdf?Status=Master](https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review18/mt014_brooks_2018_p.pdf?Status=Master)

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<b>Zero-Emission TRU Generator Set Demonstrations</b>							
26	<b>Hydrogen fuel cell powering a containerized TRU powerpack generator set for temperature-controlled ocean containers</b>	United States Department of Energy (U.S DOE), <i>Sandia National Labs, Young Brothers/</i> "Maritime Fuel Cell Generator Project"	1. HI, U.S. 2. Prototype 3. Not applicable	Aug 2015 to Jun 2016	1	A 20-foot containerized hydrogen fuel cell generator powered temperature-controlled ocean containers at the Port of Honolulu. <sup>30</sup>	The commissioning process identified several technical issues with the hydrogen fuel cell generator that were corrected. The hydrogen fuel cell generator was used by Young Brothers on 52 different days for a total of 278 hours. It averaged 29.4 kW (gross) during this period for a total energy generation output of 7,285 kW-hours. <sup>31</sup>

<sup>30</sup> Sandia National Laboratories. Maritime Hydrogen Fuel Cell Generator Project. <https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/fuel-cells/maritime-applications/maritime-hydrogen-fuel-cell-generator-project/>

<sup>31</sup> Sandia National Laboratories. (2017, May). Maritime Fuel Cell Generator Project. <https://energy.sandia.gov/wp-content/uploads/MarFC%20Final%20Report%20R2.pdf>

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<b>Infrastructure Demonstrations for Zero-Emission TRUs</b>							
27	<b>Electric grid plug-in infrastructure</b>	<i>Foster Farms/</i> "Foster Farms Livingston Electrification Project"	1. CA, U.S. 2. Commercialized 3. Foster Farms	2019	62 plugs	A project to install transformers, gantry system, and electric power plugs to supply power to the temperature-controlled trailers. Project enables a switch from diesel-powered TRUs to electrically-powered TRUs. <i>Proposition 1B: Goods Movement Emissions Reduction Program funding</i> was granted for two projects. Phase 1 project is complete; 62 plugs were installed at the facility. Phase 2 is on hold.	Phase 1 completed.
<b>New Demonstrations for the Addendum</b>							

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28*	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<a href="#">Sunswap/</a> "Endurance"	1. <a href="#">Amsterdam, Netherlands</a> 2. <a href="#">Pilot</a> 3. <a href="#">TIP Trailer Services</a>	<a href="#">Aug 2023 - ongoing</a>	40	<a href="#">Sunswap's battery-electric trailer TRU with solar assist technology is being tested in a twelve-month trial.</a> <sup>32</sup>	[CARB staff seeking input]
29*	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<a href="#">Sunswap/</a> "Endurance"	1. <a href="#">Boston, Linkenshire, UK</a> 2. <a href="#">Pilot</a> 3. <a href="#">Staples Vegetables</a>	<a href="#">Jul 2022</a>	[CARB staff seeking input]	<a href="#">Sunswap's battery-electric trailer TRU, equipped with their rooftop solar-assist technology, was tested.</a>	<a href="#">After a twelve-day trial, the results of the trial showed that 225.6 kg of tailpipe CO2 and 2.1 kg of NOx emissions were effectively removed.</a> <sup>33,34</sup>

<sup>32</sup> Cold Chain News. (2023, February 2). TIP adds Sunswap solar-power to reefers. <https://www.coldchainnews.com/tip-adds-sunswap-solar-power-to-reefers/>

<sup>33</sup> Sunswap (2023, September 18). Staples Vegetables invest in Sunswap TRUs to fulfil their 2024 fleet upgrade. <https://www.sunswap.co.uk/staples-vegetables-invest-in-sunswap-trus-to-fulfil-their-2024-fleet-upgrade/>

<sup>34</sup> Refindustry (2023, September 25). Staples Vegetables invest in Sunswap TRUs to fulfill their 2024 fleet upgrade. <https://refindustry.com/news/cold-chain/staples-vegetables-invest-in-sunswap-trus-to-fulfil-their-2024-fleet-upgrade/>

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30*	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<a href="#">Sunswap/</a> "Endurance"	1. <a href="#">Dover, UK</a> 2. <a href="#">Pilot</a> 3. <a href="#">DFDS</a>	[CARB staff seeking input]	[CARB staff seeking input]	Sunswap's battery-electric trailer TRU was used to transport DFDS' frozen produce.	<u>On one of their longest routes, Endurance provided 22 hours of cooling on a single charge over two days. It was determined that the solar panels could provide about 65% to all the charge needed to operate the fridge depending on conditions. The average time to fully charge the battery was 80 minutes.</u> <sup>35</sup>
31*	<b>Battery-electric TRU</b> (Carrier brand TRU with range-extending technologies)	<a href="#">Sunswap/</a> "Endurance"	1. <a href="#">Evesham, UK</a> 2. <a href="#">Pilot</a> 3. <a href="#">Bannister Transport</a>	Sep 2023	[CARB staff seeking input]	Sunswap's battery-electric trailer TRU, equipped with their rooftop solar-assist technology, was tested.	<u>Following a two-week trial, the fleet was able to run 80-85% of the time from solar energy.</u> <sup>36</sup> The trial also effectively removed 87 kg of direct CO2 and 0.9 kg of NOx emissions. <sup>37</sup>

<sup>35</sup> Coldchain News (2022, October 1). DFDS expands solar power for refrigerated fleet. <https://www.coldchainnews.com/dfds-expands-solar-power-for-refrigerated-fleet/>

<sup>36</sup> Coldchain News (2023, November 8). Bannister takes Sunswap solar power. <https://www.coldchainnews.com/bannister-takes-sunswap-solar-power/>

<sup>37</sup> Sunswap Ltd (2023 December 12). British Frozen Food Federation. Bannister Transport Adopts Sunswap's Innovative Zero Emission Innovation on an Unprecedented Scale. <https://bfff.co.uk/bannister-transport-adopts-sunswaps-innovative-zero-emission-innovation-on-an-unprecedented-scale/>

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32*	<b>Battery-electric TRU</b>	Surry-Yadkin Electric Membership Corporation and Hollar & Greene/ <i>Unknown Project Name</i>	1. <a href="#">North Carolina, United States (US)</a> 2. <a href="#">Demonstration</a> 3. <a href="#">Hollar &amp; Greene</a>	2023	[CARB staff seeking input]	[CARB staff seeking input]	[CARB staff seeking input]
33*	<b>Battery-electric TRU</b>	<a href="#">Thermo King/ "evolve™"</a>	1. <a href="#">Minneapolis, US</a> 2. <a href="#">Pilot</a> 3. <a href="#">Meijer</a>	2023	[CARB staff seeking input]	A three-month trial was conducted with an electric TRU for trailers. <sup>38</sup>	[CARB staff seeking input]
34*	<b>Semi-Direct-Drive Battery-Electric Hybrid TRU</b>	Surry-Yadkin Electric Membership Corporation and Hollar & Greene/ <i>Unknown Project Name</i>	1. <a href="#">North Carolina, United States (US)</a> 2. <a href="#">Demonstration</a> 3. <a href="#">Hollar &amp; Greene</a>	2023	[CARB staff seeking input]	[CARB staff seeking input]	[CARB staff seeking input]

<sup>38</sup> Thermo King. (2023, May 9). Electric TRU for Trailers Completes Trial with Meijer. <https://www.thermoking.com/na/en/newsroom/2023/05-may/electric-tru-for-trailer-trial-with-meijer-completed.html>



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35*	<b><u>Semi-Direct-Drive Battery-Electric Hybrid TRU</u></b>	<u>Carrier/Vector eCOOL</u>	1. <u>United Kingdom (UK)</u> 2. <u>Demonstration</u> 3. <u>Not applicable</u>	<u>Oct 2020</u>	1	<u>A temperature-controlled 47-foot trailer with a battery-electric TRU and range-extending technologies was constructed in the UK to be used for demonstration purposes.<sup>39</sup></u>	<u>[CARB staff seeking input]</u>
36*	<b><u>Semi-Direct-Drive Battery-Electric Hybrid TRU</u></b>	<u>ConMet/Preset Plus eHub</u>	1. <u>U.S.</u> 2. <u>Demonstration</u> 3. <u>Not applicable</u>	<u>2021</u>	<u>2</u>	<u>Two temperature-controlled trailers with battery-electric TRUs were tested. ConMet was seeking partners for full commercialization, which includes Great Dane and Meritor.<sup>40,41</sup></u>	<u>[CARB staff seeking input]</u>

<sup>39</sup> Cooling Post. (2020, October 7). Vector eCool is first autonomous electric refrigerated trailer. <https://www.coolingpost.com/products/vector-ecool-is-first-autonomous-electric-refrigerated-trailer/>

<sup>40</sup> ConMet (2022, March 6). ConMet eMobility Commercial eHub Partnerships. <https://conmet.com/conmet-emobility-announces-commercial-partnerships-amid-first-deliveries-of-ehub/>

<sup>41</sup>Work Truck. (2021, September 12). ConMet Aims to Address TRU Emissions Regs with Zero-Emission Trailer. [https://www.worktruckonline.com/10151231/conmets-aims-to-address-tru-emissions-regs-with-zero-emission-trailer?utm\\_source=website&utm\\_medium=contentoffers&utm\\_campaign=111021](https://www.worktruckonline.com/10151231/conmets-aims-to-address-tru-emissions-regs-with-zero-emission-trailer?utm_source=website&utm_medium=contentoffers&utm_campaign=111021)

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37*	<b>Battery-electric TRU</b>	<a href="#">Advanced Energy Machines/ "SolarTech 48k-16"</a>	1. <a href="#">Gilroy, CA, U.S.</a> 2. <a href="#">Commercialized</a> 3. <a href="#">Performance Food Service</a>	2024	30	30 Advanced Energy Machines SolarTech trailer TRUs are currently in use at the Performance Food Service distribution center in Gilroy, CA. <sup>42</sup>	<a href="#">Advanced Energy Machines TRUs are assigned to certain routes where they have the energy necessary to complete all deliveries. Charging is performed at the distribution center overnight. Grid upgrades were not necessary due to battery storage at facility.</a>
38*	<b>Battery-electric TRU Generator Set</b>	<a href="#">Modjoule Limited/ZE TRU Generator Set</a>	1. <a href="#">Unknown</a> 2. <a href="#">Prototype</a> 3. <a href="#">Not Applicable</a>	2024	0	<a href="#">Battery-electric TRU generator set currently in development.</a> <sup>43</sup>	<a href="#">[CARB staff seeking input]</a>

<sup>42</sup> Performance Food Service. (2024, April 22). Earth Day event attended by CARB staff.

<sup>43</sup> Modjoule Limited. (2024, May 1). CARB discussion with Modjoule Limited.