White Paper

September 2009

Defining and Determining Emissions from Refrigerated Shipping Containers and the Total Refrigeration Process in the Vicinity of Shipping Ports

Some Background on Refrigerated Transport

As global agriculture grows, there is a worldwide demand to expand the cold storage industry, since perishable items are the largest, most profitable, and fastest growing sector of international trade. Additionally, the frozen and refrigerated items for the retail, pharmaceutical, and food service industries are on the rise. Given these dynamic increases, the cold chain industry is quickly becoming central to all kinds of global trade in just about all commodities.

Globalization has made the relative distance between areas of the world much smaller, however the physical separation of these same regions is still a very important reality. The greater the physical separation, the more likely freight becomes damaged moving in the import and export processes. To ensure that shipments are not compromised during transport, many businesses are turning to, and relying on cold chain technology.

The cold chain industry is expanding and moving beyond a traditional cooler or freezer unit. The current market consists of ships, refrigerated shipping containers, intermodal transportation, and quality warehouse facilities. However, the companies that offer individualized and added value services as part of a complete package succeed far beyond competitors. In the current market, customers are demanding services such as inventory tracking, recall efforts, exporting and transportation services throughout the cold supply chain. They are looking for an integrated company structure to perform all functions.

The primary components of a successful cold supply chain involves the following major players: (1) Ports; (2) Ships; (3) Refrigerated Shipping Containers; (4) Intermodal land transport; (5) Product Preparation Specialist; and (6) Refrigerated Warehousing Companies. The success of the individual companies depends on factors such as high service levels, lower cost, faster inventory turnovers, quicker reporting, and the ability to provide customers with faster and more efficient service. Instead of simply offering one service operating companies are consolidating services, making it more convenient and cost effective for their clients. For example, the cold supply chain must provide many services such as blast freezing, obtain certificates of export and USDA stamps of approval, consolidate the load for distribution, and make all arrangements until the shipment leaves port.

Some Background on Refrigerated Transport in the Vicinity of Ports

In this section of the paper we will use the ports of Los Angeles and Long Beach as examples to describe the structure and workings of the cold chain industries and the shipping, storage, and distribution of refrigerated products. At the present time refrigerated shipping containers dominate the industry, and their electrical refrigeration systems can be powered by ship power, shore power, or diesel engine Auxiliary Power Units, APU. These systems are very flexible, and in some situations it is possible for the refrigerated shipping container to go from producer to the consumer directly. However, that situation occurs rarely, and there is a need for many intermediate steps between the producer and consumer. Shown in Figures 1 and 2 is a sketch of typical processes that are encountered for export, Figure 1, and import, Figure 2, of refrigerated shipping containers. Of particular importance in Figures 1 and 2 are the many possibilities for the refrigerated shipping container to be repaired, refurbished, or recycled during the import or export paths. These type of actions are quite possible since refrigerated shipping containers are sophisticated and expensive devices.

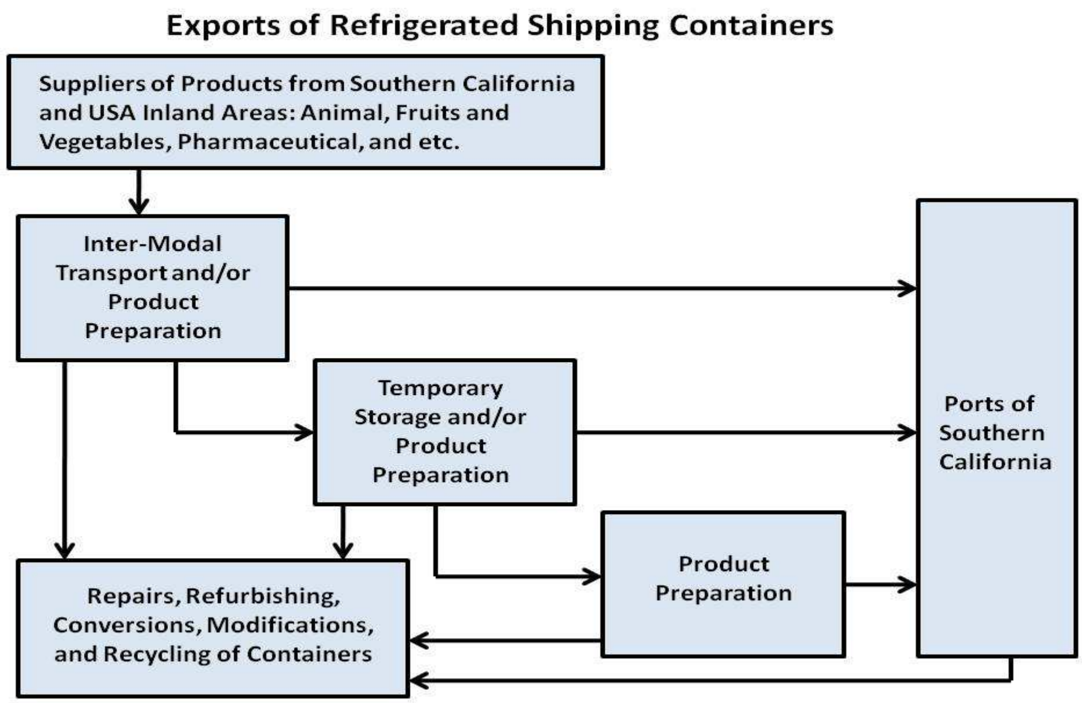


Figure 1 – Steps in the Export of Refrigerated Products from California Ports

We begin by considering the export of refrigerated products from Southern California Ports which are dominated by the Ports of Los Angeles and Long Beach. At the present time suppliers are local as well as inland states such as Arizona, and the products cover a wide range, such as animal, vegetable, fruit, and pharmaceutical. In general the product has to be taken by truck to a location and prepared and packaged for intermodal transport by a refrigerated shipping container. In some cases a controlled atmosphere is necessary to keep the product from damage during transportation to the consumer.

Many large inland product suppliers, such as meat packers, have the ability to prepare their product for a refrigerated shipping container, and ship it directly to the port. However, a large number of suppliers must use temporary storage warehouses to prepare, package, and store their product. Also, there is the possibility of an individual shipping container transporting different loads at different temperatures.

In order to support the cold supply chain there are many facilities surrounding the ports, and these facilities take up a space that is much larger than the port itself. For example, a partial list of the support facilities in the Los Angeles/Long Beach regions is the following:

- Near-Port Cold Storage Facilities
- Inland Empire – Home of 350 million square feet of warehousing
- Alameda Corridor – 20 miles of port facilities outside the ports
- Support facilities for trucking and refrigeration

In order to understand the problems and emissions from refrigerated shipping containers it is necessary to include the entire infrastructure of the cold chain shipping industry, not just the port areas.

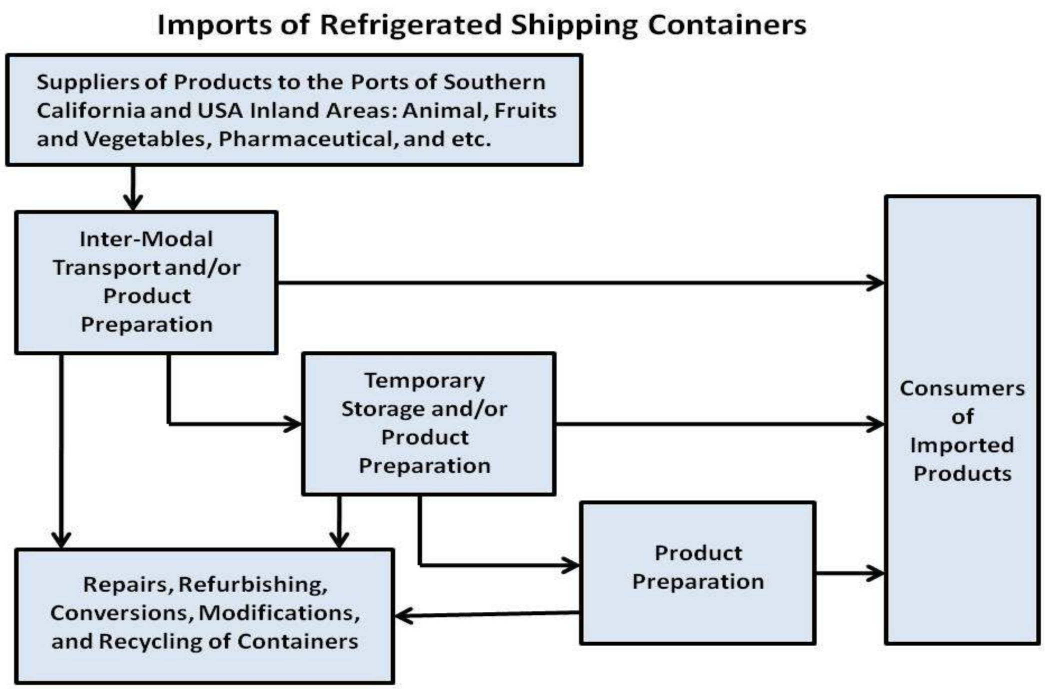


Figure 2 – Steps in the Import of Refrigerated Products to California Ports

Shipping Containers and Their Emissions

The primary purpose of this paper is to determine the sources of emissions from refrigerated shipping containers, and it has been necessary to consider the entire port area rather than just the port itself. Both refrigerant and regulated emissions from shipping containers are recognized as a significant source of greenhouse gas (GHG), and at the present time we lack basic information about the total refrigeration operation. As can be seen from the discussion given in the introduction, the refrigeration process involves a complex interaction from the product supplier, to intermodal transport, to temporary storage, to ocean shipper, to port, to temporary storage again, to intermodal transport again, to wholesaler, and to seller.

Refrigerated shipping containers that are involved in ocean transport face a harsh environment on the ship due to waves and storms, as well as intermodal transport on trucks and trains. For these reasons they typically leak 25% of their refrigerant per year, which is much larger than mobile road travel. However, both the refrigerated load and the refrigerated container are much more valuable than other container loads. The refrigerated shipping container are very sophisticated, see Appendix, and an individual container can have compartments at multiple temperatures. For these reasons, they are frequently supplied with refrigerant and spare parts, and they must continually be connected to a power source. While on a ship or at a storage location electrical power can be supplier directly, but during ground transport they need a diesel APU.

With this operating environment there are four sources of emissions from the refrigerated shipping containers:

- Direct leakage of refrigerant, and the most used refrigerant at the present time is HFC-134a which has a high global warming potential. Most of the other refrigerants, such as HFC-404a are even higher than HFC-134a in global warming potential.
- Emissions from the diesel APU engines used during road transport or when shore power is not available.
- Emission of refrigerant from decommissioned shipping containers when placed out of service.
- Emissions from controlled atmospheres in the shipping containers, such as ethylene for fruit storage.

At the present time we do not know the details of the cold chain process in the port area, and in order to estimate the emissions we have to know the amount of time spent in the various parts of Figures 1 and 2. Given below is a partial list of the questions that have to be answered to determine where and at what level are the emissions from refrigerated shipping containers.

- Are the statistics for refrigerated shipping containers the same as non-refrigerated containers?
- What is the typical time for a refrigerated shipping container on the ship, in the port, at the port, at cold storage, and external storage waiting for transport to the consumer?

- What is the time for empty containers to be stored for shipping to a new destination? This is a serious problem in Southern California due to the imbalance of imports over exports.
- What are the criteria for decommissioning a refrigerated shipping container?
- When a shipping container fails during intermodal transport, how is it handled?
- Where are shipping containers decommissioned? Does it go to a recycling or refurbishing company?
- What are the characteristics of a typical diesel APU used on refrigerated shipping containers?

A Preliminary Estimate of Emissions in the Southern California Region

I. Refrigerant recovery from decommissioned shipping containers

There is insufficient data on the emissions of refrigerant during refrigerant recovery from decommissioned shipping containers. As a result, RD staff initiated a new study entitled "*Evaluation of Potential for Refrigerant Recovery from Decommissioned Shipping Containers at California Ports*", which will begin during the 2009/2010 fiscal year. The primary objective of the study is to investigate the total refrigeration process in the port vicinity and to specifically investigate how decommissioned shipping containers are handled, disposed of, or stored in California port regions. It is estimated that a maximum of 300,000 shipping containers are currently decommissioned or refurbished at the Los Angeles-Long Beach ports each year. This estimated is based on the following data:

- Approximately 20 million shipping container TEUs, Twenty-Foot Equivalent Units, enter California ports per year and 30% of these units, 6 million, are refrigerated shipping containers.
- The average lifetime of a refrigerated shipping container is 20 years, therefore a maximum of 300,000 containers are decommissioned per year.

The majority of the present shipping containers utilize the refrigerant HFC -134a with a charge ranging from 13 to 16 pounds, and it is reasonable to assume that 9 pounds of charge remains in the system at decommissioning. Therefore, the minimum bank per year of decommissioned refrigerant is approximately 1200 MT of HFC-134a, or 1.56 $MMTCO_2E$ per year, and this source is likely to grow in the coming years due to the expansion of refrigerated cargo. Also, as much as 40% of the shipping containers use refrigerants other than HFC-134a, such as HFC-404a and older CFC-based systems, and these refrigerants have a much higher GWP than HFC-134a. Assuming that the average GWP of decommissioned refrigerants is 2500, a better estimated of possible emission reductions would increase to 3.12 $MMTCO_2E$ at California ports per year.

In order to improve our estimations of refrigerant emissions we need to understand the total refrigeration process at the ports and determine the ultimate location of decommissioned refrigerated shipping containers. For example, as they approach end-of-life how many of these containers are used for other applications, and how many containers are refurbished or decommissioned after being transported to inland locations. Further study will refine the current estimate of 300,000 containers being decommissioned per year.

II. Leakage of refrigerant from shipping containers in California ports

RD staff has recognized that continuous leakage from refrigerated shipping containers is a source of refrigerant emissions at California ports. The leakage problem is due to the harsh environment of ocean ship transport, and refrigerated shipping containers leak approximately 25% of their refrigerant per year. Assuming that this leakage is uniform during the year, the amount of leakage that occurs while the containers are in port locations can be estimated from the following data:

- If the 6 million refrigerated TEUs that visit the California ports per year spend an average of 15 days in the port regions, then we have a total of 90 million days of shipping containers in the California port regions.
- A refrigerant leakage rate of 25% per year yields approximately million kg of refrigerant leakage per year per TEU.

Thus, the total amount of refrigerant released per year is 500 MT, and if we assume the GWP of the refrigerant is 2500, the annual emission rate in the California port regions would be 1.25 $MMTCO_2E$.

It should be emphasized that the amount of time that refrigerated shipping containers remain in the California port areas is not clearly defined. The above estimate is based on a fifteen day residence time, and further study is needed. For example, how long do containers remain on the ship, how long are they in temporary storage, how much time is required for the transfer to intermodal vehicles, and how long do they remain on the intermodal vehicles in the port areas?

Replacing current refrigerants with a low GWP refrigerant is the only feasible mitigation option to reduce GHG emissions at this time. HFO-1234yf may be a good replacement option for HFC-134a, since it is currently under consideration to replace HFC-134a in the automotive market. This refrigerant has a GWP almost three orders of magnitude less than HFC-134a, and its use would dramatically reduce the global impact associated with leakage from shipping containers while in California ports. Unfortunately, if a new low GWP refrigerant is introduced as the old fleet is retired, it will take up to 20 years to fully replace the current refrigerants being used.

III. Diesel engine emissions from refrigerated shipping containers during processing in California ports

During the last decade there has been considerable progress in reducing diesel engine use with electrification solutions at California ports. However, due to the large volume of refrigerated cargo handled at the ports, only a portion of refrigerated containers are presently using electrified shore power. In fact the emissions from the shipping container diesel engines may be larger than the emissions due to heavy duty (HD) truck idling. We can estimate the emissions from the following data:

- Assuming that the diesel engines on the 90 million days of refrigerated containers in the near port areas are used 5% of the time, there would be 108 million hours of refrigerated shipping container diesel engine use per year. [Note again: There is a very big need to know much more about the total refrigeration process at ports.]
- A reasonable estimate of fuel consumption for the diesel engines of the refrigerated shipping containers is 2.2 kg per hour, then the estimated total diesel fuel use is 237 million kg per year.
- Recent data from the California ports estimate that HD diesel trucks have an idling time of approximately 6 million hours per year inside the port region itself, and diesel fuel consumption can be estimated as 0.5 gallons per hour or approximately 2 kg per hour, and an estimated total diesel fuel use of 12 million kg per year.

Therefore, it appears that the CO_2 and exhaust emissions from diesel-powered refrigerated containers are approximately twenty times greater than those from HD truck idling. The total CO2 emissions from the consumption of the fuel by the shipping container diesel engines are approximately 0.75 MMTCO2.

Many uncertainties are associated with the above analysis of diesel-powered refrigerated containers. For example, data is lacking on the emissions of criteria pollutants from the diesel engines that power the refrigerated shipping containers, since the harsh environment of the ocean vessels is another consideration that could strongly influence the operation of these engines. Therefore, further information must be obtained before proposing options to reduce emissions from these diesel engines.

The possible emissions can be summarized in the following **Table I**:

Table I Summary of total emissions at port regions

Emission Category (MMTCO2E)	**Ports**
Decommissioning of Shipping Containers	3.12
Leakage of Refrigerant	1.25
Shipping Container Diesel Engines	0.75
Total Sum of Emissions	**5.12**

Interaction with the Shipping Container Industries

In order to define both the cold chain and emissions from refrigerated shipping containers it will be necessary to work together with the major companies that make up the industry. A partial list is the following:

- **User of Refrigerated Shipping Containers: Wal Mart**
- **Constructor: Carrier-Transicold**
- **Port: Los Angeles and Long Beach**
- **Shipping Company: ?????**
- **Cold Storage and Product Preparer: Versacold Los Angeles**
- **Repairs, Refurbish, and Recycler: ConGlobal Industries, Los Angeles**

If we are able to obtain the cooperation of the listed companies or their equivalents, then we will be in a position to define a program to lower emissions. Without the cooperation of the companies there is a high probability of working on the wrong problem or only part of the problem.

Summary

As can be seen from the discussions presented in the above text, the treatment of refrigerated shipping containers is much different than non-refrigerated shipping containers. Since refrigerated shipping containers are a source of emissions, it must be determined what these differences in treatment are. To assume that their handling and statistics are the same as all shipping containers would be a serious mistake. Therefore, the first step in this process should be to understand the cold chain or total refrigeration process associated with the transport of refrigerated loads.

Appendix A. Anatomy of a Modern Shipping Container System

The purpose of this appendix is a give a brief description of a modern shipping container system. At the present time the two major industrial players in the world are Carrier-Transicold and Thermo-King, and Carrier-Transicold share of the market is larger than all of its major competitors combined. The major characteristics of a modern refrigerated shipping container are the following:

- The systems use R134a as the refrigerant.
- The systems are electrically driven, and they are semihermetic. These types of systems are more efficient and leak less refrigerant than mechanically driven systems. Some of the newer systems use scroll compressors that are more efficient mechanically than piston driven compressors.
- The electrical power supply can come from a ship central electrical generator or from an add-on generator-set that is driven by a diesel engine. The industry trend is to use add-on generator-sets since the shipping containers are located in the atmosphere to allow for easy loading and unloading.
- The diesel engines used for the generator-sets are essentially the same as the diesel engines currently used on large TRU refrigerated trucks in California.

A brief description of a system will be presented with the use of pictures and data from typical industry and Carrier-Transicold systems. Shown in Figure 1 is a typical container ship with a load of externally mounted shipping containers. The average load of refrigerated containers on a container ship is 30%.

Externally mounted shipping containers

Figure 1. An example of a container ship with a load of shipping containers

Shown in Figure 2a is a shipping container being transported from a container ship, and the electrically driven refrigeration system is shown on the end of the shipping container. The refrigeration system is quite narrow, and it can be easily replaced.

Figure 2a. A shipping container being unloaded from a container ship with a view of the thin electrically driven refrigeration system

Shown in Figure 2b is an example of how the refrigerated loads inside the container can be at different temperatures during transit.

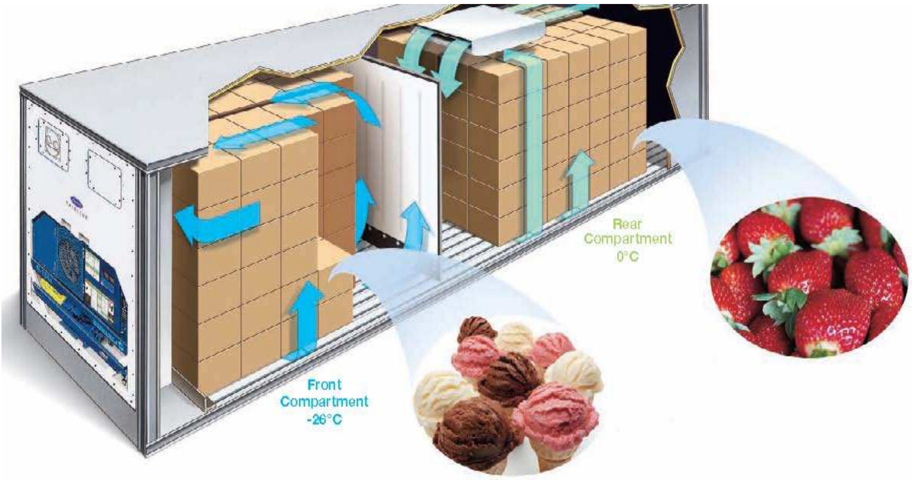


Figure 2b. Typical dual loads that can be used in a modern shipping container

The next page, Figure 3, of the appendix gives the specifications a typical modern refrigeration system used on shipping containers.

Host System
Cooling Capacities: Ambient @ 38°C (100°F) with Industry Standard Carrier 06D Reciprocating Compressor, HFC-134a

Temperature	Watts (up to)	Btu/hr (up to)
2°C (35°F)	10,260	35,000
-18°C (0°F)	6,008	20,500
-29°C (-20°F)	3,224	11,000

Remote Evaporator (Dual Discharge)
Cooling Capacity: Ambient @ 38°C (100°F)

Temperature	Watts	Btu/hr
0°C (32°F)	4,602	15,700

Dimensions:
H: 167 cm (6.6")
W: 1,049 cm (41.3")
D: 946 cm (37.2")
Weight: 40kg (88lbs)

Specifications are subject to change without notice.

Standard Features Include:
Advanced Carrier 06D semihermetic compressor
Enhanced MicroLink™ 3 modular controller with dual probes
DataCorder™ electronic data recorder
Exclusive dual backlit LCD displays
Time-delay motor start sequence
Zero-ODP HFC-134a
Current-limiting feature
Exclusive stepper-modulation capacity control
High-efficiency evaporator and condenser coils
Electrostatically coated all-copper condenser coil
System wired for 380/460volt-3ph-50/60Hz power
Safe 24-volt AC control circuit with fuse protection
Cool, Heat, Defrost, In-Range, Alarm indicator lights
Bottom air discharge
Main power circuit breaker
18m (60-ft) power cable with attached CEE-17 plug
Electric heat
Selectable timed electric defrost (3-, 6-, 9-, 12-, or 24-hour settings) or automatic defrost
Manual defrost initiation
Aluminum rear bulkhead
Removable front service panels
Single-phase dual-speed evaporator fan motors and vane-axial fans
ATO (Sprenger)-accepted adjustable fresh-air exchange
TIR
Energy-saving condenser pressure control
Forklift pockets
Refrigerant receiver with dual sight glass, electrostatically coated copper for superior corrosion prevention
Industry-leading low air leakage: less than 0.14 CMH (5 CFH) at 50.8 mm (2 in.) w.g.
Energy-saving Economy Mode evaporator motor logic
Composite control box
Provisioned for:
- Dehumidification control
- USDA cold treatment
- Water-cooled condenser
- Dual voltage (when applicable)
- Fresh-air vent position sensor

Accessories and Options:
USDA cold-treatment recording package
Rechargeable power-up battery pack
Chart recorder options
- Electronic Partlow chart recorder
- Saginomiya 31-day 203 mm (8.0 in.) chart recorder
- Simpson lead for calibration

Dehumidification control
Quick-connect 190/230volt-50/60Hz dual-voltage transformer module
Optional 230-volt plug (specify)
Optional 460-volt plug
Electronic power line communication module (RMU)
Water-cooled condenser system
Low-position air-exchange control, 0-75 CMH (0-44 CFM)
Cable retainer
- Bungee cord
- Door with catch

Remote monitoring receptacle (ISO 4-wire)
Certification: ABS, BV, KRS, GL
Hinged rear bulkhead panel with quick-release fasteners
Thermometer insertion ports
- Supply air
- Return air

Suction and Discharge mechanical pressure gauge set
System temperature sensors
- Suction
- Discharge

Pressure transducers
- Suction
- Discharge

Convenience handles
- Center
- Left and right

Rain gutters
CE marking
Fresh-air vent position sensor
Emergency Bypass System (EBS)
LED display

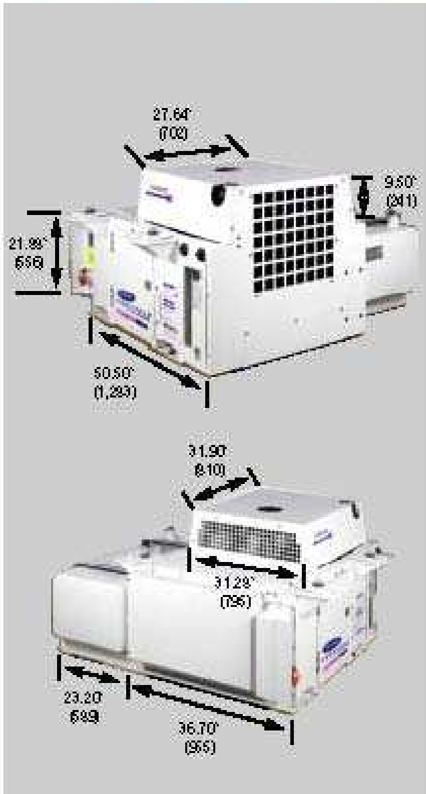
Figure 3. Specifications of a typical refrigeration system for a refrigerated shipping container

The generator-sets that are used to drive the refrigeration system are diesel engine powered, and these diesel engines are essentially identical to those used to power large TRUs in the California market. The specifications for a typical system are shown in Figure 4 below.

POWERLINE Specifications

UG15 Gen Set

Standard Features Include:
CT4-134DI 4-cylinder, water-cooled, 2.2-liter direct-injection diesel engine
Nominal 15 kW brushless, self-regulated generator 460V output
All-steel fabricated frame construction with 4-point PlateMount hangers



Fuel tank lengths:
50 gallon = 51.50" (1,308)
68 gallon = 57.75" (1,467)

Oil-bath air cleaner
Full-flow spin-on oil filter
Spin-on fuel filter with water separator
Self-bleeding fuel system
Stainless steel exhaust
Waterproof control box
Stainless steel hinges and hardware
Driver-side controls
Large aluminum service access door with quick-release latch
Enclosed forklift pockets, both sides
12V DC maintenance-free battery
Safety stop controls for low oil pressure and high water temperature
Epoxy-dipped tube and fin radiator
Large oil pan capacity for 2,000 running hours between oil changes
Fuel gauge with protective shield
DC ammeter
Power output circuit breaker
Preheat and Run/Stop/Start switches
Coolant overflow bottle
Engine hourmeter
50-gallon (189-liter) integral fuel tank
Installation kit
Operating instruction labels (English and Spanish)
Maintenance plate and schematic labels
Oil pressure and water temperature gauges
Fuel filter with built-in electric fuel warmer
Solid-state battery charger

Accessories and Options:
Four-point QuickMount installation system (w/single captive bolts)
Service-Free-For-Three extended maintenance package
Auto Restart
68-gallon (257-liter) integral fuel tank
80-gallon (303-liter) remote fuel tank
110-gallon (416-liter) remote fuel tank
230V output (in lieu of 460V)

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Figure 4. Specification for a diesel engine generator set used to drive a shipping container refrigeration system