ELECTRIC POWER RESEARCH INSTITUTE

Electric Refrigerated Container Racks: Technical Analysis

Introduction

Refrigerated containers, also called reefers, are cold storage containers used in the shipping, trucking and rail industries to transport perishable items such as food and pharmaceuticals. These containers are capable of maintaining temperatures for frozen, chilled or even warm cargo through a refrigeration unit which is built into the nose of an insulated container. The power source for this unit can be a generator or electric power from the grid depending on whether the container is on wheels, grounded at a terminal or on a ship. Reefers are used extensively at ports and inter-modal facilities where goods movement occurs. Photo 1 below shows reefers (the white containers) as well as standard containers being transported by ship.

Small diesel engines have been used to maintain cold temperatures in reefers during some transport, but increasingly, electric motors—sometimes used in conjunction with a small portable diesel engine called a genset—are used when feasible. When sitting at the port awaiting transit, these electric reefers can be wheeled onto the terminal and plugged into grid power via ground outlets or stacked in refrigerated container racks, also called reefer racks. Reefer racks, a relatively new means of storage for reefer owners, may offer advantages over other strategies. Reefer rack costs and benefits, as well a market analysis of them, will be discussed in this technical analysis.

Photo 1: Container Ship with Reefers (Photo courtesy of Melissa Silva, Starcrest Consulting Group, LLC)

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Background

Many container terminals at any given time have hundreds or thousands of reefers awaiting a ship, truck or train for export or import out of or into the area. Typically these reefers will wait for 24–72 hours with their engines running in order to maintain cold temperatures for the goods inside. Depending on how they are transported, reefers are powered by diesel engines or electricity.

At a diesel price of $1.87 per gallon, a total of $4,123 is spent on fuel to run that reefer every year.[2]

Diesel Reefers

Diesel-powered reefers, or diesel reefers, have been the standard for perishable food truck transport in the U.S. With 2-liter engines ranging in size from 30 to 40 horsepower, these diesel engines are run anywhere from 1,000 hours to 7,200 hours per year depending on type of operation. For this study's purposes, we will assume an average use of 3,000 hours per year.

When powered by diesel generators, reefer containers can be major fuel consumers. At an average usage rate of 3,000 hours per year, annual diesel consumption would be 2,205 gallons per reefer per year (at an average rate of 0.735 gal/hr).[1] At a diesel price of $1.87 per gallon, a total of $4,123 is spent on fuel to run that reefer every year.[2]

Every gallon of diesel consumed is associated with harmful pollutants emitted by the diesel engines. Particulate matter (PM) from diesel exhaust has been of increasing concern because of respiratory issues linked to it. As of 2008, newly manufactured diesel reefer engines are becoming cleaner due to the U.S. Environmental Protection Agency's (EPA) Tier 4 engine standards, required for all transport refrigeration units (TRUs), the diesel engines that run diesel reefers. PM standards for a 25–50 horsepower engine, for example, were substantially reduced for Tier 4 engines, from 0.6 g/kWh to 0.03 g/kWh.[3] However, given the life cycle of an average TRU of 7-15 years, there are many Tier 2 TRUs still operating. For a facility operating 1,000 Tier 2 diesel reefers an average of 3,000 hours each year, annual PM emissions from these reefers are estimated to be 24.4 tons and annual carbon dioxide (CO_2) emissions are estimated to be 29,330 tons per year.[4] This compares quite significantly to the average passenger vehicle, which emits about 5 tons CO_2 per year.[5]

Diesel reefers can also be associated with inefficiencies, as a diesel engine is required to be in a constant state of operation in order to keep the container cool. Reefers have two primary cycles of operation:

- Pull-down mode—rapidly getting the reefer down to the desired temperature for pre-loading or when it is first loaded
- Maintenance mode—continuous maintenance of desired temperature

Pull-down mode accounts for a very small percentage of a reefer's operational cycle—as little as 5% according to some reports, yet requires the majority of the engine power.[6] During pull-down,

[1] Electric-Powered Trailer Refrigeration Unit Market Study and Technology Assessment. Prepared by Shurepower for NYSERDA. June 2005.

[2] based on the 2009 national average for commercial/institutional ultra low sulfur no. 2 diesel at $1.87 per gallon. www.tonto.eia.doe.gov

[3] www.epa.gov/nonroaddiesel

[4] Sam Wells, Starcrest Consulting Group, LLC

[5] www.epa.gov/oms/climate

[6] Electric-Powered Trailer Refrigeration Unit Market Study and Technology Assessment. Prepared by Shurepower for NYSERDA. June 2005.

a diesel engine on a reefer will consume an estimated 1.4 gallons of diesel per hour. Maintenance mode accounts for the majority of a reefer's operation. During this phase, a diesel reefer engine will consume an estimated 0.7–0.9 gallons of diesel per hour depending on the reefer model and use.

There can be several advantages to electric reefers compared to diesel, including reduced operational costs, lower emissions, and reduced maintenance costs.

Electric/Hybrid Electric

Electrically powered reefers, or electric reefers, used extensively in the shipping industry, are powered by electrically driven components, which are in turn powered by electricity. When stationary at the dock, these units are plugged into grid power at an electrical terminal, and when in motion on a ship, they are powered by a ship's electricity generators. When moving over the road, reefer containers require a mobile power source, or genset. An alternative to a full electric reefer is the hybrid electric reefer in which a small diesel engine serves as the source of power when electric power is not available.

Electric reefers typically operate on 400 volt, 32 AMP, 3-phase, 60 Hz power with a maximum electrical load of 18 kVA. Step up power transformers can be used if either 308 VAC or 230/240 VAC power sources are present. Depending on cargo and temperatures, a high capacity electric reefer uses, on average, 12–15 kWh of electricity in pull-down mode and 2.25 kWh during normal operation, for an average of 2.8875 kWh per hour.[7]

There can be several advantages to electric reefers compared to diesel, including:

- Reduced operational costs
- Lower emissions
- Reduced maintenance costs

Although the capital costs of electric compared to diesel reefers may be higher—as much as 10% higher when comparing the purchase prices of the two—this cost premium has been estimated to be recouped quickly with operating cost savings, depending on electricity and diesel pricing. At the 2009 national average commercial/institutional price of no. 2 ultra low sulfur diesel at $1.87 per gallon of diesel[8] and the July 2010 national average commercial retail price of electricity at 10.70 cents/kWh,[9] annual fuel costs associated with reefer operations can be four times as high with diesel compared to electricity (Table 1).

Table 1. Annual Fuel Costs: Electric verses Diesel Reefer

	Diesel Reefer	Electric Reefer
Average Fuel/Electricity Usage	0.735 Gal./Hour	2.8875 kWh/Hour
Average Hours Operated/Year	3,000	3,000
Price	$1.87/Gal.	$0.107/kWh
Cost to Operate Annually	$4,123	$927

Assumption: 95% maintenance and 5% pull-down

[7] Ibid.

[8] www.eia.doe.gov

[9] www.eia.doe.gov

In addition to fuel costs, there are land and lift costs associated with reefer operations at ports and inter-modal facilities. These costs, as they relate to electric reefers and the storage strategies that may be employed to keep cargo cold while reefers are awaiting transport at ports, will be discussed in the next section.

This strategy allows for approximately two dozen electric reefers to be stacked in a rack, sharing electrical infrastructure and allowing for land space efficiencies.

Electric Reefer Storage

Traditionally, electric reefers awaiting transport are parked lined up side-by-side at a port terminal, each plugged into their own electrical outlet. These containers typically have been wheeled into the terminal via truck chassis, or off-loaded from a ship by a crane and then wheeled to a parking spot by a yard truck where they are then plugged into grid power while they await further transport.

A relatively new alternative to wheeled reefer operations has come into play at some ports—the refrigerated container rack system, known simply as reefer racks. This strategy allows for approximately two dozen electric reefers to be stacked—commonly four high by six or seven wide—in a rack, sharing electrical infrastructure and allowing for land space efficiencies. Both of these strategies will be discussed further below.

Wheeled Reefer Storage System

In a wheeled reefer export operation, refrigerated containers are delivered to the port or inter-modal facility by truck or train, are parked and plugged into an electrical outlet (Photo 2) at a parking slot on terminal for later pick up by a yard truck and ultimate loading onto a ship by a crane. A wheeled reefer import operation is similar, but actions are reversed. The wheeled operation requires relatively few movements of the container, from truck/rail to ship or vice versa, translating into lower operating expenses.

Photo 2: Wheeled Reefers Plugged in (Photo courtesy of John Ryan)

In this type of operation, the port owns the land that the parking slots occupy and is responsible for developing and maintaining the electrical infrastructure associated with these slots. Typically ports charge for electrical usage at each slot, in addition to “rent”, a fee for the use of these parking slots on a per day basis.

While operationally efficient, the wheeled electric reefer strategy is land-intensive, requiring a 10x40 foot land footprint for each 40-foot container parked. In the port industry, where land is often expensive and in short supply, any means of reducing land requirements translates to lower operating expenses.

Rack Storage System

The rack’s electrical system is centralized at one end of each rack, simplifying access for maintenance and hook up.

The reefer rack system (Photo 3), an alternative reefer storage system, may offer such a savings, depending on land costs and type of operation. In an electric reefer rack system, instead of being driven to a parking spot by a truck, the electric reefer to be exported is dropped off by the truck/train and then placed by a container handler (e.g., top pick or rubber tired gantry crane) into one of two dozen spaces in a custom-built rack that may hold 22–26 electric reefers. The reefer is then plugged in and awaits loading onto a ship. Later, it is removed from the rack by a container handler and transferred to yard truck and then to a crane which then loads it onto ship.

The reefer rack, because it is custom built, can accommodate any sized refrigerated container. The rack’s electrical system is centralized at one end of each rack, simplifying access for maintenance and hook up. Each of the rack parking slots has its own electrical hookup, which workers access via platforms and ladders.

Although it requires additional handling compared to the wheeled system, the reefer rack has the advantage of being land efficient, taking up a footprint of 320 square feet for four 40 foot containers, compared to a 400 square foot per container footprint associated with a wheeled system. Where land costs are high, this footprint savings can translate into cost reductions for reefer owners who pay rent on reefer parking spaces.

Photo 3: Reefer Rack System (Photo courtesy of John Ryan)

Storage System Costs

In any reefer storage strategy, typically a port will own the parking spot—whether it be in a rack or on the ground—and will charge shipping companies a storage fee in addition to passing on electricity costs associated with running the reefers on grid power. As such, capital costs to develop and supply electrical infrastructure to these parking slots are generally the responsibility of the port.

In addition to capital costs, every reefer entering or exiting a port or inter-modal facility has operating costs associated with it. These costs are related to how many lifts—and thus labor—it takes to move a container onto or off of a ship. Both the capital and operating costs associated with reefers will be discussed further below.

In general, electrical infrastructure for the rack and wheeled systems are similar.

Capital Costs

Purchase prices for the reefer rack system are not published, and are dependent on specifications of each use. At the Port of Savannah, $2.3 million was spent on its first 10 reefer racks.[10] This included electrical infrastructure associated with the racks. These numbers are consistent with costs at the Port of Oakland, where bids to complete their racks ranged in price from $120,000 to $216,000 each.[11] On the low end of this scale, this equates to $4,286 per slot if the rack system has 28 spaces.

In a wheeled operation, installation costs of approximately $1,250 per electrical outlet have been estimated,[12] including basic electrical infrastructure but not major electrical upgrades such as transformers, etc. Lower capital costs for a wheeled operation compared to a rack operation are primarily due to there being no need for structural framing as in a rack system. In general, electrical infrastructure for the rack and wheeled systems are similar, with substation, switch gear, plugs, enclosures and other ancillary equipment for both modes of operation.

In addition to the above capital costs, major electrical infrastructure upgrades may be required in some cases for both the wheeled and rack systems, depending on the existing conditions and new specifications.

Operating Costs—Lift

As described above, in a wheeled operation, three primary container movements are required to move a reefer from the truck/train to, ultimately, the ship or vice versa (Table 2). Each of these movements is associated with a labor cost, for which the terminal itself is responsible for only the latter two movements, averaging $200 per container.[13]

In a rack operation, two additional moves are necessary on the terminal end (Table 2), for a total of four container moves that the terminal itself is responsible for. These two additional moves bring the terminal container handling cost per container to $290, an increase of 45% compared to wheeled operation.[14]

Operating Costs—Land

Although lift costs for wheeled operations have the advantage over rack operations, the other portion of operating costs—land—may give rack operations the advantage. Land costs in a reefer

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[10] Rich Cox, Georgia Ports Authority.

[11] Electric Technology Feasibility Study, California Air Resources Board, August 2009.

[12] Electric-Powered Trailer Refrigeration Unit Market Study and Technology Assessment. Prepared by Shurepower for NYSERDA. June 2005.

[13] Steve Hessenauer, Nautical Systems, Inc.

[14] Ibid.

Table 2. Container Moves Required for Wheeled verses Rack Export Electric Reefer Operation

Wheeled	Rack
1) Truck to Parking Spot 2) Yard Truck to Crane 3) Crane to Ship	1) Truck to Container Handler 2) Container Handler to Rack 3) Container Handler from Rack to Yard Truck 4) Yard Truck to Crane 5) Crane to Ship

operation are incurred when each electric reefer is parked and plugged in. Reefers occupy premium land and for that space, users are charged "rent", as well as utility fees for electricity used. At ports where land is in short supply, rent can be charged at a premium. On average, reefer spaces are charged out at $0.21 per square foot per day.[15] In an export operation, a reefer has a layover, or is parked, for an average of three days. In a wheeled export operation, the land requirement for each container is 400 square feet (for a 40 foot container), for an average rent of $84/day/container or $252 per container for its three-day stay. In a rack operation, the land footprint efficiencies can make this side of the operating expense equation much more economical compared to wheeled systems. For each four containers (due to vertical stacking), a footprint of 320 square feet (for a 40 foot container) is required. For these four containers over a three-day stay, then, average rent would be $201.60, or $50.40 per container (Table 3).

Operating Costs—Summary

When looking at combined operating costs, including both lift and land expenses for an export operation, a reefer rack system can offer substantial cost savings. At the land rental price suggested above ($0.21 per square foot), a wheeled export container would incur costs, including both lift and land, of $452 over its three-day stay compared to a racked export container, with costs of $340.40.

For terminals operators with thousands of reefers exported every year, this could mean substantial savings over the 15 year life of a reefer (Table 4). It is important to note, though, that although there may be savings realized in a reefer rack system for exports, imports may tell a different story.

Table 3. Average Land Costs: Wheeled verses Rack Electric Export Reefer

	Wheeled	Rack
Land Cost Per Square Foot	$0.21	$0.21
Number of Days Parked	3	3
Square Foot Requirement Per Container	400	80
Average Land Costs Per Container for Three-Day Stay	$252	$50.40

Based on three day stay for 40′ container at $0.21/square foot

[15] Steve Hessenauer, Nautical Systems, Inc.

Table 4. Life Cycle Costs—A Single Electric Reefer Wheeled verses Rack

	Electric Reefer—Wheeled	Electric Reefer—Rack
Capital Costs		
Purchase Price	$20,000	$20,000
Parking Infrastructure/Space	$1,250	$4,286
Total Over 15 Years	$21,250	$24,286
Operational Costs		
Fuel Costs/Year	$927	$927
Land and Lift Costs/Year	$55,000	$41,415
Total Over 15 Years	$860,000	$659,000

Assumptions: 40 foot container with a purchase price of $20,000, operating 3,000 over a 365 day year; 15 year life; electricity costs of $0.107; land price of $0.21/square feet/day and three days stay; rack prices based on 28 slot rack at $120,000; no inflation; 2.887 kW/hour electricity usage.

Whereas the average export layover for a reefer is three days, an import reefer may have a shorter stay, typically 24 hours. This shorter stay results in lower land rental costs for import reefers compared to export reefers, and it is more difficult to offset the higher lift costs associated with rack operations when land costs come down substantially. Additionally, for ports that are not land constrained and where rent prices for reefer parking spaces are not as high as $0.21/square foot, the cost benefits of reefer racks compared to wheeled systems may be less.

Energy Use

Although in the past, reefer connections were not standardized, today an international reefer standard—ISO 1496—exits that is 440 volt, 32 AMP.[16] Average electrical demand, depending on reefer specifications and use, is 3 kWh/hr during maintenance mode and 15 kWh/hr for pull down mode, with a maximum load of 18 kVA. Older reefer models may be 230 volt, 50 AMP.

Reefer Population

Internationally, the fleet of shipping containers has been estimated to be 26 million twenty-foot equivalents (TEUs); approximately 6%, or 1.5 million TEUs, of these are electric reefers.[17]

Domestically, based on Year 2000 data and a conservative 1.3% growth rate, today's population of container truck-trailer units with refrigeration is approximately 300,000.[18] Though increasing, a very small fraction of these are hybrid electric.[19]

[16] http://www.iso.org/iso/catalogue_detail.htm?csnumber=3047

[17] Mike Stark, Thermo King

[18] California Air Resources Board. Airborne Toxic Control Measures for In-Use Diesel Fuel Transport Refrigeration Units (TRUs) and TRU Generator Sets, and Facilities where TRUs Operate. October 2003.

[19] Hartley, Paul. "Diesel-Electric Hybrid Reefers". Fleet Equipment. September 22, 2010.

Although diesel powered refrigerated containers are still the overwhelming majority in the trucking industry, containers capable of operating in electric mode are becoming more common as new models phase out older models and reefer operators are increasingly looking for cost savings and fuel flexibility as the price of diesel fluctuates. In the shipping industry, electric reefers are the norm, and as the refrigerated transport industry grows, so will the need for more reefers and more places to store them.

Snapshot

Georgia Ports Authority, Port of Savannah

Reefer Racks

- Cargo volume at the Port of Savannah is up 120% in the past 6 years
- To better handle the refrigerated container portion of this growth, Savannah installed 44 reefer racks
- Savannah plans a total of 93 reefer racks at full build out
- Savannah spent $2.3M on its first 10 racks
- The 44 racks hold 1,056 containers in 84,000 square feet of terminal space, compared to 422,000 square feet for a wheeled operation
- With 44 racks the switch from diesel to electric saves Savannah 2.4 million gallons of diesel annually

Reefer Racks at Georgia Ports Authority, Port of Savannah

Reefer racks can play an important role in this increasing electric reefer market share. Ports, partners with terminal operators in the goods movement industry, pass on potential cost savings to their tenants with more efficient container storage systems like the reefer rack. Today, electric reefer racks can be seen at several ports, including the Port of Savannah, the Port of Oakland, and the Port of New York/New Jersey.

Conclusions

As the refrigerated cargo industry grows over the next decade as expected, there will be more reefers in use and a greater demand for reefer infrastructure. Ports, some facing land constraints and air quality pressures, will need to respond accordingly, by providing additional dedicated reefer storage. Reefer racks—with their benefits of land efficiency, centralized electrical infrastructure and potential cost savings—offer some ports and their tenants an advantage as they face this growth. Possible good candidates for an electric reefer rack system include ports facing land constraints, those with an export focus or those with longer reefer wait times for its imports.

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