Potential of the Tractor- Trailer and Container Segments as Entry Markets for a Proposed Refrigeration Technology

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POTENTIAL OF THE TRACTOR-TRAILER AND
CONTAINER SEGMENTS AS ENTRY MARKETS
FOR A PROPOSED REFRIGERATION TECHNOLOGY

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SUMMARY

In this report the refrigerated trailer and container segments of the transportation industry are evaluated as potential entry markets for a proposed absorption refrigeration technology. To perform this analysis the existing transportation refrigeration industry is characterized; this includes a description of the current refrigeration technology, rating systems, equipment manufacturers, maintenance requirements, and sales trends. This information indicates that the current transportation refrigeration industry is composed of two major competitors, Thermo King and Carrier. In addition, it has low profit potential, some barriers to entry and low growth potential.

Data are also presented that characterize the transportation refrigeration consumers, specifically, major groups, market segmentation, consumer decision process, and buying criteria. This consumer information indicates that the majority of refrigerated trailer consumers are private carriers, and that the majority of refrigerated container consumers are shipping companies. Also, these consumers are primarily interested in buying reliable equipment at a low price, and are quite satisfied with existing refrigeration equipment.

The following conclusions and recommendations are made:

- Entry into the refrigerated container segment would be difficult and is not recommended.
- Entry into the refrigerated trailer segment would be possible if
 - an information transfer program is developed
 - a joint venture is formed with an existing refrigeration manufacturer.
- Evaluation of the potential of the truck bodies market segment is recommended.

CONTENTS

SUMMARY	iii
1.0 INTRODUCTION	1.1
2.0 TRANSPORTATION REFRIGERATION INDUSTRY	2.1
2.1 TRANSPORTATION REFRIGERATION TECHNOLOGIES	2.1
2.1.1 Mechanical Refrigeration Systems	2.1
2.1.2 Other Refrigeration Methods	2.3
2.2 REFRIGERATION EQUIPMENT DESIGN AND SELECTION	2.6
2.2.1 Temperature Requirements	2.6
2.2.2 Refrigeration Capacity	2.6
2.2.3 Air Circulation	2.9
2.2.4 Mobile Service Design Considerations	2.9
2.3 CURRENTLY AVAILABLE TRANSPORTATION REFRIGERATION EQUIPMENT	2.10
2.3.1 Technical Description	2.10
2.3.2 Rating Mechanical Refrigeration Systems	2.15
2.3.3 Costs of Transportation Refrigeration Units	2.17
2.3.4 Maintenance Schedules for Trailer and Container Refrigeration Units	2.18
2.4 TRANSPORTATION REFRIGERATION INDUSTRY SHIPMENTS	2.20
2.5 DESCRIPTION OF TRANSPORTATION REFRIGERATION MANUFACTURERS	2.23
2.5.1 Refrigeration Unit Manufacturers	2.24
2.6 SUMMARY	2.29
3.0 TRANSPORTATION REFRIGERATION CONSUMERS	3.1
3.1 TRANSPORTATION REFRIGERATION CONSUMERS	3.1

3.1.1	Refrigerated Trailer Consumers	3.1
3.1.2	Refrigerated Container Consumers	3.3
3.2	CURRENT AND FUTURE REFRIGERATION MARKETS	3.4
3.2.1	The Refrigerated Trailer Market	3.5
3.2.2	The Container Market	3.8
3.3	CONSUMER DECISION PROCESS	3.10
3.3.1	Principal Decision Maker	3.11
3.3.2	Buying Criteria	3.11
3.4	SHORTCOMINGS OF CURRENT REFRIGERATION EQUIPMENT	3.13
3.5	SUMMARY	3.14
4.0	EVALUATION OF BCS REFRIGERATION TECHNOLOGY	4.1
4.1	MINIMUM CRITERIA FOR CONTAINERS	4.1
4.2	MINIMUM CRITERIA FOR TRAILERS	4.3
5.0	EVALUATION OF THE TRAILER AND CONTAINER SEGMENTS AS ENTRY MARKETS	5.1
5.1	GROWING MARKET	5.1
5.2	PROFIT POTENTIAL	5.2
5.3	BARRIERS TO ENTRY	5.3
5.4	UNFILLED TECHNICAL NEEDS	5.4
5.5	SUMMARY	5.4
6.0	RECOMMENDATION	6.1
	REFERENCES	R.1
	APPENDIX A - TEMPERATURE RECOMMENDATIONS FOR SPECIFIC PERISHABLE PRODUCTS	A.1
	APPENDIX B - APPROXIMATE HEAT OF RESPIRATION OF VARIOUS PERISHABLE PRODUCTS BY TEMPERATURE	B.1

FIGURES

2.1	Taxonomy of Refrigeration Types for Containers	2.12
2.2	Value of Shipments of Refrigeration and Heating Equipment	2.21
2.3	U.S. Market Share for Trailer Refrigeration Equipment Manufacturers	2.23
2.4	U.S. Market Share for Container Refrigeration Equipment Manufacturers	2.24
3.1	Major Consumers of Trailer Refrigeration Units	3.2
3.2	Major Consumers of Container Refrigeration Units	3.3
3.3	Value of Shipments of Insulated Trailers	3.6
3.4	Value of Shipments of Containers	3.9

TABLES

2.1	General Temperature Ranges for Goods Shipped in Refrigerated Trucks, Trailers, and Containers	2.7
2.2	Refrigeration Units for Containers	2.11
2.3	One-Piece Refrigeration Units for Trailers	2.14
2.4	Two-Piece Refrigeration Units for Trailers	2.15
2.5	ARI Standard Rating Conditions	2.16
2.6	Typical Capacity Ranges of Existing Refrigeration Systems at 100°F Ambient	2.17
2.7	Standard Trailer Refrigeration Unit Maintenance	2.19
2.8	Standard Container Refrigeration Unit Maintenance	2.19
2.9	Value of Shipments of Refrigeration and Heating Equipment	2.20
2.10	Value of Shipments for Transportation Refrigeration Units	2.22
2.11	Westinghouse Electric Corporation Financial Highlights	2.25
2.12	Carrier Corporation Sales	2.26
2.13	United Technologies Corporation Financial Highlights	2.27
3.1	Value of Shipments of Insulated Trailers	3.5
3.2	Value of Shipments of Refrigerated Containers Manufactured in the U.S.	3.8
3.3	Important Refrigeration Unit Attributes Rated by Consumers of Refrigerated Containers and Trailers	3.12
4.1	Minimum Technical Criteria for Containers	4.2
4.2	Minimum Technical Criteria for Trailer Refrigeration Systems	4.4

1.0 INTRODUCTION

An important step in the successful transfer of a new technology from the research laboratory to the marketplace is to identify growing and profitable early market opportunities. Although these "entry" markets may not become the ultimate, long-term market for the new technology, they need to provide sufficient growth and profits so that the entrepreneur/commercializer can become more aware of the capabilities of the technology and further develop and refine it. These improvements will help the technology to capture a larger market share of the entry market and/or be introduced into additional markets or segments.

In 1985 the Office of Buildings and Community Systems (BCS) of the U.S. Department of Energy requested that Pacific Northwest Laboratory (PNL) evaluate the potential of the transportation industry as an entry market for a proposed BCS refrigeration technology. This study focused on the refrigerated tractor-trailer and intermodal container market sectors as potential entry markets. The trailer segment includes refrigeration units for 45 to 48 ft trailers that are used for transporting frozen or perishable foods or electronic equipment. Most of these trailers are hauled over long distances by Class 8 trucks.^(a) The container segment includes 20 to 40 ft containers that carry frozen or perishable foods and are transported by ship, rail, and/or Class 8 trucks.

Specifically, this report describes current transportation refrigeration equipment and the industry (Chapter 2.0), identifies the major consumers of transportation refrigeration systems (Chapter 3.0), describes the minimum technical requirements (Chapter 4.0), and evaluates the trailer/container segments as potential entry markets (Chapter 5.0).

(a) Class 8 trucks have a gross vehicular weight of greater than 33,000 lb.

2.0 TRANSPORTATION REFRIGERATION INDUSTRY

The objective of this section is to present information on existing transportation refrigeration equipment; the rating system used by the industry; the trends in the air-conditioning, heating and refrigeration industry; and the structure of the trailer and container market segments. This information will be used in evaluating the transportation industry as a potential entry market for the proposed BCS refrigeration technology.

2.1 TRANSPORTATION REFRIGERATION TECHNOLOGIES

A number of refrigeration systems are used to maintain product temperatures during transport. Mechanical systems far outnumber other refrigeration methods and account for about 90%^(a) of the current stock. Mechanical refrigeration systems, other refrigeration methods, and advanced transport refrigeration concepts are discussed below.

2.1.1 Mechanical Refrigeration Systems

Mechanical refrigeration systems consist basically of a compressor, drive and condenser combination; an evaporator; a blower; and a control device.

Reciprocating compressors with two, four or six cylinders are currently in use (Refrigerated Transporter 1985b). Compressors may be belt- or direct-driven through a crankshaft that extends through the housing, or the compressor and motor may be directly coupled and sealed in the housing (hermetic units). Finned tubes, pipe coils, plate surfaces and eutectic plates are used as evaporators. Finned-tube evaporators dominate use because they have the highest heat-transfer coefficients per unit weight (ASHRAE 1982). Finned coils are typically defrosted by reverse cycle operation at service temperatures above 32°F, and by either reverse operation or hot gas at temperatures below 32°F.

Mechanical systems are generally divided into two categories which are distinguished by the source of power used to drive the compressor. These

(a) Personal communication, Robert Guilfooy, U.S. Department of Agriculture, Beltsville, Maryland.

categories include: 1) speed-governed units, and 2) variable-speed units (ARI 1985). Speed-governed units are operated by independent engines and/or electric motors. These units operate at a constant, although adjustable, speed. Variable-speed refrigeration units derive power from the vehicle engine or the running gear of the vehicle. These units operate at variable speeds determined by the road speed of the vehicle.

2.1.1.1 Speed-Governed Units

Speed-governed units are the most common mechanical refrigeration device used in trucks, trailers and containers. Refrigeration capacities range from about 11,000 to 49,000 Btu/hr at a refrigeration temperature of 35°F and from about 6,000 to 31,000 Btu/hr at 0°F (Refrigerated Transporter 1985b).

Speed-governed units are operated by independent engines and/or electricity. The independent engine may operate on gasoline, diesel fuel, or liquified petroleum gas and may be either air- or liquid-cooled. Diesel engine use predominates. Diesel engines in new refrigeration systems range from 11 bhp at 2700 rpm to 27 bhp at 2200 rpm (Refrigerated Transporter 1985). Gasoline engines currently on the market range from 7.5 bhp at 2600 rpm to 11 bhp at 2700 rpm (Refrigerated Transporter 1985).

Independent engines require batteries for cranking, and fuel tanks and pumps if the engine cannot be connected to the vehicle fuel supply. Most independent engine-driven systems are fully automatic, with either thermostatically controlled start-stop operation or continuous, but adjustable speed operation.

2.1.1.2 Variable-Speed Units

Variable-speed systems are typically used on small trucks and vans. These systems derive power from the vehicle prime mover or running gear and are essentially precluded by practical considerations from trailer or container use.^(a) Variable-speed units operate only when the truck is running. Most units can be equipped with standby electric motor drives which can be connected to house current and some may store refrigeration capacity in eutectic plates

(a) A system which was developed to derive power from the trailer axle does not appear to have widespread application.

to provide temperature control during periods when the truck engine is not operating. The latter is typically used when frequent stops and door openings will be encountered during operation. Control systems range from manual to fully automatic.

Several methods are used to derive power from the vehicle engine:

- A belt-driven alternator operating from the engine crankshaft produces alternating current which is rectified to drive direct-current motors for fan and compressor operation.
- A belt-driven alternator operating from the engine crankshaft pulley provides power to an all-electric, self-contained unit.
- An engine-mounted compressor is belt-driven from the engine crankshaft pulley.
- A compressor is directly driven by power derived from the transmission (ASHRAE 1986).

The capacities of variable-speed units range from about 6,500 to 13,000 Btu/hr when operating at 35°F and from about 2,000 to 8,000 Btu/hr when operating at 0°F (Refrigerated Transporter 1985b, ARI 1985).

2.1.2 Other Refrigeration Methods

There are a wide variety of refrigeration techniques and systems in use beyond the mechanical systems described above. These may be used alone or in conjunction with mechanical systems. Product subcooling, ventilation, ice, cryogenic refrigerants, and eutectic plates are described below.

2.1.2.1 Product Subcooling

Improvements in vehicle body insulation have made it possible to ship some products without providing refrigeration to the truck or trailer. Instead, the product is subcooled prior to loading and the temperature is allowed to rise slowly during transit. The ambient temperature, the heat capacity of the product, the thermal conductivity of the insulated vehicle, and the time in transit

are the primary factors which determine whether this method is feasible. Bulk milk and orange juice are two products that are commonly subcooled.

2.1.2.2 Ventilation

Controlling the temperature of the cargo space through ventilation is the cheapest, yet most unreliable, system in use. Use of this technique is constrained by the ambient temperature. This technique may be used as a stop-gap measure in the event of a mechanical system failure.

2.1.2.3 Ice

Dry ice or water ice may be used to provide cooling during transit. Dry ice may be placed in bunkers while fans circulate the air across the bunker and throughout the cargo space. Water ice may be used in bunkers or a layer of crushed ice may be blown over the top of the load (top icing).

Dry ice is typically used with small retail trucks which deliver or sell frozen foods (e.g., ice cream trucks). Dry ice is only used in long-haul trucks or trailers as a temporary means of maintaining low temperatures during mechanical system failure.^(a) Maintaining a high relative humidity is as important as temperature in keeping produce fresh during transport. Water ice, in bunkers or as top icing, is often used in conjunction with mechanical refrigeration systems to maintain high humidity levels.

2.1.2.4 Cryogenic Liquids

A number of systems are available which inject nitrogen or carbon dioxide directly into the cargo space. The systems consist of a refrigerant storage tank located inside or outside the cargo space, a spray header located along the ceiling above the cargo, and a thermostat. The thermostat controls the release of the liquid refrigerant through the spray nozzles. Upon release, the refrigerant vaporizes and absorbs heat from the air. Some clip-on liquid refrigerant systems are used to provide land refrigeration for intermodal containers.

(a) It is becoming a trend to use carbon dioxide snow in bunkers for refrigerating railcars because of the simplicity and high reliability of the systems and because it places the responsibility for refrigeration on the shipper rather than the railroad (Tyree 1985, Burgener 1985).

Nitrogen systems have been in use since the 1960s. Recently, carbon dioxide systems have been replacing nitrogen systems because CO₂ vents more quickly thus reducing the lag time required before personnel can enter safely. Liquid CO₂ is also becoming more competitive with mechanical refrigeration systems; while the price of diesel fuel has increased about 700% in the last 15 years, the price of CO₂ has risen only 40%. Prototype liquid CO₂ systems are being tested in delivery trucks and trailers which supply fast food outlets. These vehicles typically have several compartments at different temperatures. Because it is desirable to make deliveries at night when parking lots are empty, the CO₂ systems are preferred over mechanical operation because they are quiet (Tyree 1985).

2.1.2.5 Eutectic Plates

These systems consist of a coil for the primary refrigerant mounted inside a thin plate containing a eutectic solution. Before loading, the eutectic solution is frozen by circulating a refrigerant through the coils. During transit, refrigeration is provided as the eutectic melts. Eutectic plates are used most often in trucks, although a few have been installed in trailers.

The refrigerant used to freeze the eutectic solution may be supplied by a stationary refrigerating plant or by a truck-mounted condensing unit. The latter may operate with power derived from the vehicle engine with an electric motor for standby operation, or it may have only the electric motor drive.

2.1.2.6 Advanced Systems

Several advanced systems have been proposed or have been used to a limited extent in prototype demonstrations. Of these, the Stirling cycle system continues to be studied as a viable option. A compact, efficient system developed for space use has been experimentally tested in a trailer. Cold water from the Stirling refrigeration system is distributed through enhanced surface pipes located along the walls near the ceiling and extending the length of the trailer. Natural convection air currents circulate down the walls, perpendicular to the main axis of the trailer. The test demonstrated a refrigeration

capacity of 25,000 Btu/hr at 0°F with a total power input of less than 7.5 kilowatts. The refrigerator and mounting brackets weighted 495 pounds (Malaker 1985).

2.2 REFRIGERATION EQUIPMENT DESIGN AND SELECTION

The refrigeration system must supply the required refrigeration capacity and provide accurate temperature control. In addition, mobile service imposes design restrictions not encountered in stationary applications. The following sections discuss temperature requirements, factors which impact refrigeration capacity, the importance of air circulation, and other mobile service design considerations.

2.2.1 Temperature Requirements

Trailers and containers used in highway and intermodal transport are designed to haul products requiring temperature control under ambient temperatures ranging from -60 to 130°F. Depending on ambient conditions, refrigeration or heating may be needed to maintain the product temperature within the recommended range. Heating may be provided by electric resistance heaters or through reverse operation of the refrigeration cycle.

There is often a need to maintain a certain relative humidity during transport of perishable produce. Mechanical refrigeration units tend to dehumidify by condensing water on the refrigeration coils and draining it to the outside of the vehicle. Top icing is the most common and reliable means of maintaining humidity level. Mechanical humidifiers are available, but have not been particularly reliable.

Goods transported in refrigerated trucks, trailers and containers can be grouped into the general temperature categories shown in Table 2.1. Transport temperature and relative humidity recommended for specific perishable products are listed in Appendix A.

2.2.2 Refrigeration Capacity

The actual cooling (or heating) load of a particular vehicle/cargo combination is a function of the vehicle design, the properties of the cargo, ambient conditions, and the use of the vehicle. The vehicle heat gain, which is

TABLE 2.1. General Temperature Ranges for Goods Shipped in Refrigerated Trucks, Trailers, and Containers

<u>Category</u>	<u>Temperature (°F)</u>	<u>Cargo</u>
Air-Conditioned	55-70	Electronic Gear, Flowers, Live Poultry
Cool	40-55	Produce (Melons, Citrus, Potatoes)
Chilled	32-40	Dairy Products and Produce (Lettuce, Apples, Stone Fruit)
Cold	28-32	Fresh Meats
Frozen	0 and below	Frozen Foods

used to determine the required refrigeration capacity, is established partly through testing and partly through calculations based on guidelines for particular products. Factors to be considered in determining the design refrigeration load include: 1) heat gain via conduction through the vehicle structure, 2) heat gain from air infiltration, and 3) product-dependent heat gains.

2.2.2.1 Heat Conduction

Heat is transferred into the cargo space via conduction through the vehicle structure. Conduction is minimized by using insulation within the constraints of minimizing vehicle weight and maximizing cargo space. In general, insulated trailers, which vary in length from about 39 to 46 ft have heat gain values ranging from 80 to 120 Btu/hr °F (ASHRAE 1986).

Usually the magnitude of the heat gain through the vehicle structure is determined for a particular truck, trailer or container model by a heat transmission test performed under controlled conditions.

2.2.2.2 Air Infiltration

Air infiltration occurs during transport through cracks in walls or leaks around doors and through door openings during loading and unloading. The first is a function of the manufacture of the vehicle, while the second is primarily dependent on the use of the vehicle (e.g., retail versus long-haul service).

Manufacturing techniques have been improved to minimize the air leakage rate resulting from manufacturing defects. A number of companies are beginning to establish a baseline air leakage rate through testing.

The number of times a door is opened during transport can significantly impact the refrigeration load. Typically, trucks used for short hauls and retail service have their doors opened more frequently. Trailers are typically used for long-haul applications and require fewer door openings.

2.2.2.3 Cargo-Dependent Loads

Refrigeration loads resulting from the type of product shipped are of two forms: 1) the residual heat in the product, and 2) in the case of perishable produce, the heat of respiration.

If the product is loaded at a temperature above the recommended transit temperature, an additional load will be imposed on the refrigeration system to remove this residual sensible heat. Although it is usually desirable to pre-cool perishable produce to remove field heat prior to transport, in practice this does not always occur, or precooling may be inadequate to reduce the product temperature to the transit temperature. At one time it was common practice to cool hanging meat in transit, rather than to precool prior to loading, thereby reducing the total time from slaughter to consumer. However, this practice has been largely abandoned as meat processors adopted shipping of boxed meat. Currently, about 75% of all meat is precooled, boxed and palletized prior to shipping.^(a)

After harvesting, produce continues to generate heat as the oxygen in the air combines with the plant sugars to produce carbon dioxide (respiration). The heat of respiration varies widely with the product and the ambient temperature. The heat of respiration is greater at higher temperatures and decreases as the temperature of the commodity approaches its freezing point.

Cooling and/or controlled atmospheres can be used to suppress respiration. Lowering the temperature of apples from 40°F to 32°F results in an almost 50% reduction in the heat of respiration. The impact of temperature on the heat of respiration for other perishable products is provided in Appendix B.

(a) Personal communication, American Meat Institute, Washington, D.C.

Introducing carbon dioxide or nitrogen gas directly to the cargo space reduces the amount of oxygen available for the respiration process. This practice has the added advantage of providing cooling.

2.2.3 Air Circulation

Regardless of the type of refrigeration system used, satisfactory product temperatures cannot be maintained if the air circulation system is inadequate. Air must be circulated around the load to provide a cushion of air between the cargo and the heat transferred through the walls of the vehicles. In addition, air must pass under and through the cargo to remove residual heat and heat of respiration. Inadequate air distribution is considered to be the primary cause of improper cargo refrigeration (Ciricillo 1979). Air circulation is one of the key areas of on-going research in transportation of perishables.

2.2.4 Mobile Service Design Considerations

Systems developed for stationary applications will likely require redesign to meet the requirements for mobile service. This section highlights some of these design considerations.

Increased attention to materials selection will be required to minimize weight, ensure durability to severe motion and vibration, and prevent corrosion. Lightweight materials and compact designs are preferred because each state sets a limit on the weight and dimensions of trailers that may operate on its highways, making it desirable to minimize the weight and size of the refrigeration system to maximize the cargo space and weight. The constant and often severe motion encountered on highways and in transferring containers from one transportation mode to another requires the use of high strength materials. Road grime and salt water or air that may contact refrigeration equipment surfaces require consideration of corrosion resistant materials.

Stationary absorption refrigeration systems, heat pumps, and air conditioners have been designed with gravity feed distributors and falling film heat

exchangers. These design features are not appropriate for an over-the-road product that will be required to operate on inclines as well as on level surfaces.

2.3 CURRENTLY AVAILABLE TRANSPORTATION REFRIGERATION EQUIPMENT

The following sections provide information on the operation and costs of currently available mechanical refrigeration equipment. Information on these units was gleaned from product brochures provided by refrigeration manufacturers and from discussions with transportation refrigeration dealers.

2.3.1 Technical Description

Technical descriptions of mechanical refrigeration units used with trailers and containers are provided below.

2.3.1.1 Refrigeration Units for Intermodal Containers

Refrigeration systems for intermodal containers are designed to provide temperatures ranging from about -22°F to 77°F. Intermodal containers may be equipped with individual refrigeration units or they may be refrigerated by a central system while on shipboard and by a clip-on mechanical or liquid nitrogen system during land operation (Guilfooy 1973). The most common individual refrigerating units for containers are electric-motor-driven, with or without a companion engine-driven generator. Models are available for both 20 ft and 40 ft containers. Characteristics of the various container refrigeration models are summarized in Table 2.2.

A taxonomy of the types of refrigeration units used with containers is provided in Figure 2.1. Refrigeration systems can be classified as integral units or as clip-on units. Integral units are permanently incorporated within the frame of the container. Clip-on units are separate units which are attached outside of the container frame during land transport. Most refrigerated containers are the integral type (Mitsubishi 1980). Integral units may be either built-in units or plug-in units. The plug-in units, which are most common, provide for removal of the evaporator and condenser for service and repair. With some built-in units, access to the evaporator section must be from the inside of the container. Plug-in units are further characterized as

TABLE 2.2. Refrigeration Units for Containers

Model	Type ^(a)	Cooling Capacity @ 35°/0°F (Btu/hr)	Heating Capacity (Btu/Hr)	Dimensions (h x w x l)	Weight (lb)	Dual Voltage System ^(b)
20-FT CONTAINER UNITS:						
<u>CARRIER</u>						
NT-20	F	25,500/ 11,500	16,000	88"x79"x17"	1130	D, T
69NP	C	17,500/ 10,500	13,000	95"x95"x18"	1520	D, T
<u>DAIKIN</u>						
LKEN580	F	na/ ^(c) 9,900	13,300	88"x80"x13"	1232	D
LKAS5	F	na/ ^(c) 9,900	13,300	87"x82"x17"	1080	--
LKE58	F	na/ ^(c) 10,300	13,300	88"x80"x13"	1166	D
<u>MITSUBISHI</u>						
CPE51	F	20,800/ 10,300	17,900	88"x80"x13"	1102	T
<u>THERMO KING</u>						
CF-II	F	23,500/ 9,000	18,430	88"x74"x15"	1150	T
<u>KLINGE</u>						
TNE 550	F	19,000/ 9,500	12,000	88"x79"x13"	1125	T
40-FT CONTAINER UNITS:						
<u>CARRIER</u>						
NT-40	F	29,000/ 16,000	18,000	88"x79"x17"	1180	D, T
RN-40	N	34,000/ 16,000	22,000	54"x82"x23"	1075	D, T
<u>DAIKIN</u>						
LKE8CD	F	na/ ^(c) 17,400	20,500	88"x80"x17"	1485	D
LK8AD	F	na/ ^(c) 15,900	20,500	87"x82"x17"	1389	D
<u>MITSUBISHI</u>						
CPE10	F	30,600/ 17,900	19,500	88"x80"x13"	1235	T
<u>THERMO KING</u>						
CD-II	N	32,000/ ^(d) 15,500 36,500/ ^(e) 17,000	10,000 12,800T	46"x71"x58"	1726	
CE-II	B	36,000/ 18,000	16,380	54"x82"x24"	1200	T
CF-II	F	29,000/ 15,000	18,430	88"x74"x15"	1175	T
<u>KLINGE</u>						
TNE 255	N	35,000/ 18,000	18,750	49"x82"x25"	1195	T
TNE 400 or 500	F	34,000/ 17,500	18,000	88"x79"x16"	1450	T

(a) Type of Unit: F = Flush-Mounted, C = Clip-On, B = Built-In, N = Nose-Mounted.

(b) Type of dual-voltage system: D = Dual-Rated Motor, T = Transformer

(c) Daikin reports only one refrigeration capacity. It is assumed to be for 0°F.

(d) Capacity when diesel-driven.

(e) Capacity when electric-motor-driven.

FIGURE 2.1. Taxonomy of Refrigeration Types for Containers
(Mitsubishi 1980)

either flush-mounted units or nose-mounted units. With nose-mounted units, a part of the evaporator section protrudes into the cargo space. Flush-mounted units do not protrude into the cargo space.

For 20-ft containers, the cooling capacity of refrigeration units ranges from about 9,000 to 11,500 Btu/hr at 0°F and from 17,500 to 25,500 Btu/hr at 35°F. For 40-ft containers, refrigeration capacities range from 15,500 to 18,000 Btu/hr at 0°F and from about 29,000 to 36,500 Btu/hr at 35°F. All of the existing systems appear to use R-12 as the refrigerant. Air-cooled condensers are standard equipment with water-cooled condensers available as an option. Water-cooled condensers are designed to accommodate either fresh or sea water.

The all-electric units use electric resistance heaters for defrost and heating. The electric- and engine-driven units can defrost and heat using electric resistance heaters or, when operating in the engine-driven mode, they defrost and heat by reverse cycle operation of the refrigeration system.

All of the container refrigeration units operate on electricity while on shipboard. Some models provide the option of connecting to a diesel generator set during land operation, and one model (Thermo King CD-II) integrates a diesel engine in the design of the refrigeration unit. The latter has the disadvantage of weighing more than the other container refrigeration units.

The height and width of the refrigeration units are limited by the height and width of the container. The critical dimension of interest is the thickness of the unit. Every attempt is made to minimize thickness in order to maximize cargo space. The thickness of flush-mounted units varies from about 13 in. to 17 in. Nose-mounted units, by definition, protrude much further into the cargo space.

Refrigeration unit weights vary from about 1075 to 1726 lb. Again, the heaviest unit has an integral diesel engine. Options such as water-cooled condensers and dual-voltage equipment add weight beyond the standard weights listed in Table 2.2.

Because power supplies differ from ship to ship and from country to country, most companies provide optional dual-voltage capability. Two methods are used to provide the dual capability: one method uses a transformer integrated with the refrigeration system and the other uses dual-rated motors. Containers which will be limited in application to one type of power supply will typically be designed to accommodate only that power source. Daikin provides both single- and dual-rated motors. Mitsubishi, Thermo King and Klinge use transformers to provide dual ratings and Carrier provides either option. Reportedly, the transformer option is more reliable although it may weigh as much as 150 lb more than systems using the dual-rated motors (Mitsubishi 1980).

2.3.1.2 Refrigeration Units for Trailers

Mechanical units used on refrigerated trailers may be a one- or two-piece design. The one-piece^(a) units are mounted on the front wall of the trailer, with the compressor, condensing unit, engine, and fuel tank on the outside and the evaporator coils and air-circulation fans inside the cargo space. Most trailer refrigeration models are the one-piece design. Table 2.3 summarizes characteristics of the one-piece refrigeration systems. For two-piece (under-mount)^(b) units, the condenser and engine are located under the frame of the trailer and the evaporator and coils are inside the front end of the trailer.

(a) Also referred to as "single-package units."

(b) Also referred to as "remote-condensing units."

TABLE 2.3. One-Piece Refrigeration Units for Trailers

<u>Model</u>	<u>Type^(a)</u>	<u>Cooling Capacity at 35°F/0°F (Btu/hr)</u>	<u>Heating Capacity Engine/ Standby (Btu/hr)</u>	<u>Dimensions (h x w x l)</u>	<u>Weight (lb)</u>
<u>CARRIER</u>					
NDJ-425	F	42,000/ 21,000	40,000/ 19,000	79"x74"x23"	1745
NDJ-40	F	41,000/ 21,000	none	79"x74"x23"	1620
NDF-425	F	42,000/ 21,000	40,000/ 19,000	88"x74"x23"	1976
NDJ-468	F	46,500/ 23,500	none	--	1620
NDB-405	N	41,000/ 21,000	none	72"x50"x21"	1430
NDS-405	N	41,000/ 21,000	40,000/ 19,000	72"x50"x21"	1595
NDB-468	N	46,500/ 23,500	none	--	1460
NEE-49	N	49,000/ 31,000	--		
<u>THERMO KING</u>					
Sentry 1500/ 3000	N	39,500/ 19,500	38,500/ 18,500	66"x46"x22"	1350
SB-II 1500	N	43,500/ 21,000	37,000/ 17,850	82"x75"x22"	1685

(a) Type of Unit: F = Flush-mounted, N = Nose-mounted.

The undermount units are also used for land transport of intermodal containers. Table 2.4 provides information for undermount diesel units.

There are two basic configurations for one-piece units: nose-mounted units and flush-mounted units. The evaporator section of nose-mounted units protrudes into the cargo space, whereas it is flush with the front wall of the trailer in the flush-mounted models.

Trailers and long-haul trucks typically use refrigeration units powered by independent engines and/or electric motors. Diesel-powered cooling capacities

TABLE 2.4. Two-Piece Refrigeration Units for Trailers

<u>Company</u>	<u>Model</u>	<u>Type</u>	<u>Cooling Capacity at 35°F/0°F (Btu/hr)</u>
CARRIER	UOE-405	Diesel	38,500/ 18,500
THERMO KING	RMU-IISVI	Diesel	37,500/ 17,500

range from about 38,500 to 42,000 Btu/hr at 35°F and from 18,500 to 23,500 at 0°F. When the unit is operating on electric standby, cooling capacities are slightly lower. All independent-engine units currently on the market provide heat or defrost by reverse operation of the refrigeration cycle.

The weights of trailer units are larger than those listed previously for intermodal containers simply because the trailer unit weight includes the weight of the diesel engine.

2.3.2 Rating Mechanical Refrigeration Systems

Mechanical refrigeration systems are rated according to their ability to remove heat (i.e., their refrigeration capacity expressed in Btu/hr). The Air-Conditioning and Refrigeration Institute (ARI) has developed Standard 1110-77 for mechanical transport refrigeration units. The standard specifies the test method, the standard rating conditions, and the tolerances that are to be used to obtain ARI certification. Testing is performed for ARI on a contract basis by ETL Testing Laboratories, Courtland, New York.

The testing program is voluntary; participating manufacturers are allowed to display the ARI certification symbol on certified models and associated literature and advertising. Currently, the only participants in the program are the Carrier Corporation and Thermo King Corporation. Although not all models produced by these two companies are certified under the program, ARI publishes a directory of certified models along with their refrigeration

capacity at standard conditions. A survey of users of mechanical transport refrigeration equipment indicates that for a majority of companies an ARI rating is not a significant factor in their buying decisions.

Certification tests are conducted under the standard conditions shown in Table 2.5. To be ARI-certified, any production unit selected at random must have a cooling capacity not less than 95% of the certified rating. The standard requires that ratings include the compressor speed during testing. For variable-speed units, the refrigeration capacity is determined for high- and low-temperature service at two compressor speeds: 600 and 1800 rpm. Speed-governed units are tested at the governed speed listed on their nameplate.

In testing, the unit is mounted on an insulated box, with the condenser on the outside and the evaporator on the inside. The insulated box is calibrated to determine the heat input due to air leakage from the outside. The refrigeration system is operated to bring the inside temperature of the box to the test service temperature (35°F or 0°F). When the box is at the appropriate temperature, electric strip heaters inside the box are activated to counteract the cooling input of the equipment and to keep the interior temperature of the box at the test temperature. The power to the electric heaters is measured over a two-hour period at the steady-state test temperature. The measured heat input via the electric heaters is added to the heat input through leakage to obtain the capacity of the unit. The ARI rating does not consider the energy efficiency ratio (EER) or coefficient of performance (COP) of the equipment. Although the power input to electric-driven units is recorded (from which an

TABLE 2.5. ARI Standard Rating Conditions (ARI 1985)

	Cargo Space Dry-Bulb Temperature (°F)	Ambient Dry-Bulb Temperature (°F)	Barometric Pressure (in. Hg)
High-Temperature Service	35	100	29.92
Low-Temperature Service	0	100	29.92

EER or COP could be calculated), fuel use data are not collected during testing. The ETL Testing Laboratories indicated that, no one has ever shown an interest in efficiency ratings for transportation refrigeration units.^(a)

Table 2.6 shows the typical range of refrigeration capacity associated with existing variable-speed and speed-governed units. Again, variable-speed units are typically limited to truck applications, whereas speed-governed units can be used with trucks, trailers, and containers.

2.3.3 Costs of Transportation Refrigeration Units

Information on the costs of refrigeration units for trailers and containers was requested from refrigeration manufacturers. Most manufacturers were reluctant to provide this information because the industry is very competitive and the price of a refrigeration unit is not only a function of the type of unit but also the quantity purchased. Discounts are usually available to customers who purchase multiple units since the transaction costs to the manufacturer are lower.

Due to the limited number of firms in the industry and their price competitiveness, company-specific prices will not be presented in this report.

TABLE 2.6. Typical Capacity Ranges of Existing Refrigeration Systems at 100°F Ambient (ARI 1985)

	<u>Btu/hr @ 35°F</u>	<u>Btu/hr @ 0°F</u>
Variable-Speed Units	8,000-13,000	4,000-8,000
Speed-Governed Units		
• Trucks	11,000-26,000	6,000-19,500
• Trailers	35,000-49,000	17,000-31,000
• Intermodal		
20-ft container	17,500-25,500	9,000-11,500
40-ft container	29,000-36,500	15,500-18,000

(a) Personal communication with Larry Smith, ETL Testing Laboratories, Courtland, New York, January 23, 1986.

However, the prices received for installed refrigeration units for both trailers and containers ranged from \$8500 to \$14,000 (in 1985 dollars) per unit depending upon the particular features. The average price for all refrigeration units was approximately \$11,500.

The cost of the refrigeration unit represents a significant portion of the initial cost of both trailers and containers. Information from trailer manufacturers indicates that the range of prices for unrefrigerated trailers is \$22,000 to \$32,000, with the average being about \$24,000. Therefore, the installation of the refrigeration unit represents approximately 30% of the final cost of a refrigerated trailer.

Unrefrigerated containers are relatively less expensive than trailers since the containers do not have a chassis. Prices of unrefrigerated containers ranged from \$10,000 to \$16,000, with the average price being about \$15,000 for a 40-ft container. Therefore, the installation of a refrigeration unit represents approximately 40% of the final cost of a refrigerated container.

2.3.4 Maintenance Schedules for Trailer and Container Refrigeration Units

Trailer and container refrigeration units undergo both regular and pre-trip and maintenance. Pre-trip maintenance inspections are performed whenever a trailer or container returns to the carrier's home base, or before the unit leaves on a long-haul. Trailer pre-trip inspections consist of checking operating pressures, solenoid valves, oil and water levels, and test running the system (Table 2.7). Trailer refrigeration units owned by large shipping companies may receive three pre-trip inspections per month, depending upon their shipping schedules. In general, units belonging to owner/operator shippers receive pre-trip inspections less frequently.

Pre-trip inspections of container refrigeration units are similar to that of trailers (Table 2.8); however, the container inspections are much more detailed since containers are not at their home bases as frequently as trailers

TABLE 2.7. Standard Trailer Refrigeration Unit Maintenance

<u>Normal Pre-Trip Inspection</u> (Approx. time = 1 hr)	<u>Normal Full Maintenance Tune-Ups</u>
Check:	Perform pre-trip
operating pressures	Change oil
solenoid valves	Inspect radiation fluid
oil level	Test run system
water level	
Test run system	

TABLE 2.8. Standard Container Refrigeration Unit Maintenance

<u>Normal Pre-Trip Checks</u> (Approx. time = 1 hr)	<u>Normal Full Maintenance Tune-Ups</u>
Check:	Perform pre-trip
floor panels and ducts	Change oil
condenser coil for cleanliness	Inspect radiation fluid
sight glass for freon levels	Evaluate overall condition
condenser fans	Test run system
oil level	
water level	
solenoid valves	
operating pressures	
Run through all cycles	
Replace recording document	

and since fewer repair facilities are available along container routes. Pre-trip inspections container refrigeration units owned by large shipping companies receive about one pre-trip inspection per month. Since a large number of containers are leased, units undergo thorough pre- and post-lease maintenance checks and tune-ups.

Refrigeration equipment manufacturers also specify the frequency and routine for formal maintenance checks of trailer and container refrigeration units. Manufacturers recommend that trailer units be maintained every

500 hours for gasoline engines and every 1000 hours for diesels. The formal maintenance includes performing pre-trip inspection, changing oil, inspecting fluids and test running the system. The formal maintenance requirements are similar to those for trailer units.

2.4 TRANSPORTATION REFRIGERATION INDUSTRY SHIPMENTS

Information on the value of shipments of refrigeration units for trailers and containers is presented under the Standard Industrial Classification (SIC) Code 3585, titled Air-Conditioning, Refrigeration and Heating Equipment. This product class includes information on residential, commercial and industrial heating and refrigeration units, as well as information on transportation refrigeration units.

Although this industry was impacted by the recession of 1982, the value of shipments has increased in recent years as the overall economy improved. In 1984, the value of shipments was \$5,690 million (in 1972 dollars) (Table 2.9 and Figure 2.2). This sector is forecasted to grow at an average annual rate

TABLE 2.9. Value of Shipments of Refrigeration and Heating Equipment (SIC 3585) (millions)

<u>Year</u>	<u>Current Dollars</u>	<u>Constant 1972 Dollars^(a)</u>
1985	--	--
1984	12,720	5,690
1983	12,000	5,570
1982	10,812	5,210
1981	11,514	5,890
1980	10,253	5,750
1979	10,939	6,690
1978	10,158	6,750
1977	8,502	6,070
1976	7,563	5,710
1975	6,151	4,890

(a) Deflated using the implicit price deflator.

FIGURE 2.2. Value of Shipments of Refrigeration and Heating Equipment (SIC 3585)

of 3.5% through 1989 (Department of Commerce 1985) compared to the Gross National Product which is forecasted to grow at a rate of 4% during the same time. The future growth in the value of shipments of refrigeration equipment could change significantly as the overall U.S. economy changes, since most air-conditioning, refrigeration and heating equipment is affected by building construction as well as passenger car and truck production.

A more detailed breakdown of the value of shipments of refrigeration units is provided under SIC 35851, Mechanical Refrigeration Systems for Mobile Vehicles. This category of equipment includes refrigeration units for use on truck, trailer, containers and vans, and had a total value of shipments of \$117.9 million in 1984 (Department of Commerce 1984). Since 1980, sales in this subsector have grown at an average annual rate of 3.7% (see Table 2.10). Unfortunately, further disaggregation of refrigeration equipment is not provided by the Department of Commerce, and therefore, detailed information on the value of shipments of refrigeration units exclusively for trailers and containers, is not available.

TABLE 2.10. Value of Shipments for Transportation Refrigeration Units (SIC 35851) (millions)

<u>Year</u>	<u>Current Dollars</u>	<u>Constant 1972 dollars</u>
1984	263	117
1983	231	107
1982	222	107
1981	196	100
1980	182	102
1979	188	115
1978	172	114
1977	158	113
1976	135	102
1975	113	90

2.5 DESCRIPTION OF TRANSPORTATION REFRIGERATION MANUFACTURERS

The transportation refrigeration industry has fairly unique industry characteristics. Specifically, the products supplied are fairly homogeneous, the pricing is extremely competitive, sales are large; however, only a few firms are involved in the industry.

For trailer refrigeration, Carrier Transicold and Thermo King are the principle companies in the U.S. with an approximate 95% market share (Figure 2.3). According to industry experts, Thermo King's U.S. market share for trailer refrigeration is approximately 60% and Carrier Transicold's about 35%, with the remaining 5% made up by various small companies. Carrier Transicold's share of the market has increased substantially since the company was acquired by United Technologies Corporation in 1979.

Thermo King and Carrier Transicold are strong competitors in the international as well as the U.S. container markets. However, in the container market, Carrier Transicold controls about 50% of the market while Thermo King has 30% of the U.S. market (Figure 2.4). One other U.S. company, Klinge Corporation, also manufactures container refrigeration units and markets them under the York trademark. Klinge Corporation controls about 15% of U.S. container sales. Internationally, these three U.S. companies contribute approximately 60% to worldwide container refrigeration sales. However, it is more difficult to determine individual manufacturer market shares worldwide.

FIGURE 2.3. U.S. Market Share for Trailer Refrigeration Equipment Manufacturers

FIGURE 2.4. U.S. Market Share for Container Refrigeration Equipment Manufacturers

Since the container refrigeration industry is worldwide, foreign competitors must also be recognized. The major foreign manufacturers of container refrigeration units are Daikin and Mitsubishi both of which have recently expanded their distribution networks through a joint marketing venture in the U.S. These two companies contribute approximately 25% to total container refrigeration sales internationally.

Overall, these trailer and container refrigeration unit manufacturers have realized economies of scale in their production process and continue to stress research and development of more efficient and advanced cooling equipment. Worldwide distribution networks have been established to provide customers with sales and service support, and most are a part of large, financially strong parent companies. The following section describes each of these companies in more detail.

2.5.1 Refrigeration Unit Manufacturers

2.5.1.1 Thermo King Corporation

Thermo King Corporation began as a partnership in 1939 and was incorporated by Westinghouse Electric Corporation in 1961. Thermo King manufactures refrigeration units for trailers, trucks, and seagoing containers, as well as air-conditioning units for buses (Westinghouse 1984). In recent years, the principal market for their refrigeration units has been the trailer industry.

Although Westinghouse Corporation provides no sales or earnings information for its Thermo King subsidiary, it does provide information on its commercial group of which Thermo King is a member. The commercial group is made up of companies whose operations include beverage bottling, community development, elevators and escalators, insulating and plastic materials, furniture systems, watches, and educational and language products. In 1984, these companies contributed \$1.8 billion (18%) to Westinghouse's 1984 overall sales of \$10.264 billion. Operating profit for the commercial group rose to \$194 million in 1984, compared to \$144 million in 1981. According to the 1984 Westinghouse Annual Report, "Thermo King paced the Commercial Groups' strong performance and continues to lead the transport refrigeration industry."

The parent company is financially sound and has sufficient income to support the subsidiary in lean times, such as the 1982 recession. On December 31, 1984, Westinghouse reported total sales of \$10.2 billion, and a tangible net worth on a consolidated basis of \$3.1 billion (Table 2.11). The company's condition was stated as "good," and trend "up," by Dun and Bradstreet, Inc. on December 26, 1985.

TABLE 2.11. Westinghouse Electric Corporation Financial Highlights
(in millions except common share data) (Westinghouse 1984)

	1984	1983
Sales and Operating Revenues	\$10,264.5	\$9,532.6
Operating Profit	610.0	477.8
Net Income	535.9	449.0
Common Share Data:		
Net Income	3.04	2.54
Dividends	.975	.90
Year End Book Value	21.40	19.48
Market Price at Year End	26 1/8	27 3/8
Capital Expenditures	662.0	716.0
Depreciation and Amortization	426.0	383.0

2.5.1.2 Carrier Corporation

Carrier Corporation manufactures a wide range of air-conditioning equipment for residential and commercial use and refrigeration units for trailers and containers. Refrigeration systems are marketed under the Carrier Transicold trademark. Although unitary residential air-conditioning is their primary market, refrigeration equipment for the transportation industry has recently become an increasingly important portion of their business.

Specific information on the Carrier Transicold portion of Carrier corporation is not available. However, Carrier Corporation is financially strong with reported sales of \$2.3 billion in 1984 and projected sales of \$2.5 billion in 1985 (Kidder, Peabody and Company 1984) (Table 2.12).

Carrier Corporation's parent company, United Technologies, is a broad-based designer and manufacturer of high-technology products with global headquarters in Hartford, Connecticut. The corporation is among the 35 largest industrial companies in the world, and the fifth largest manufacturer in the United States (United Technologies Annual Report 1984). Sales are balanced

TABLE 2.12. Carrier Corporation Sales
(dollars in millions, current)

<u>Year</u>	<u>Sales</u>
1986E ^(a)	2.700
1985E	2.500
1984 ^(b)	2.298
1983	1.838
1982	1.613
1981	1.976

(a) Estimates for 1985 and 1986 from Kidder, Peabody, and Company Research Abstracts, 1983.

(b) Sales for 1981 to 1984 were taken from United Technologies Form 10K, 1984.

among four industries: building systems, aerospace, electronics, and automotive. Carrier is a member of the building system group. United Technologies' condition was stated as "good" and its trend "up" by Dun and Bradstreet, Inc., on January 6, 1986. Sales for United Technologies in 1984 were \$16.3 billion compared to \$14.6 billion in 1983 (Table 2.13).

2.5.1.3 Klinge Corporation

Klinge Corporation of York, Pennsylvania, was established in 1984 when the company assumed responsibility for the transportation equipment department of the York Division of Borg-Warner Corporation. Borg-Warner had operated the division for 18 years.

The 1984 agreement allowed for the transfer of all equipment, know-how, designs and engineering data, as well as the trademark license to the York name. York's main products are transportation refrigeration units for use on containers, rail cars, trucks, and barges, as well as air-conditioning units for rail coaches. The most important line has been the refrigeration units for 10-ft, 20-ft, and 40-ft containers.

Production facilities are located in York, Pennsylvania, and at sister companies in Denmark, with total production capacity of 15 units per day. Klinge Corporation offers service, maintenance, and repair facilities in all major ports and several other locations around the world (Klinge Corporation 1984).

TABLE 2.13. United Technologies Corporation Financial Highlights
(dollars in millions) (United Technologies Corporation 1984)

	<u>1984</u>	<u>1983</u>
Sales	16,332	14,670
Net Income	645	509
Common Share Data:		
Net Income	4.90	3.97
Dividends	1.37	1.27
Capital Expenditures	825	675
Research and Development	1,012	971

Klinge Corporation's parent company, Paul Klinge A/S, Copenhagen, Denmark, is the parent company of a number of firms within the iron and metal industry, plus a publishing company and an advertising agency. Starting capital of \$950,000 for the partial acquisition of the York Division of Borg-Warner consisted of \$500,000 savings and a \$450,000 loan from Borg-Warner, which has since been paid off. Sales for 1986 are projected to be about \$4 million. On February 10, 1986, Dun and Bradstreet Inc. rated the company's financing as "secured" and its history "clear."

2.5.1.4 Daikin Industries

Daikin Industries is a large Japanese company founded in 1924, and centered around five major areas of business; oil hydraulics and lubrication, air-conditioning and refrigeration, fluorochemicals, defense, and most recently, robotics and electronics (Daikin 1984). Daikin entered the marine container refrigeration market in 1966 and is currently one of the leading manufacturers of container refrigeration units in the world. Daikin also supplies over half of the container refrigeration units sold in the Japanese market.

In 1981, Daikin America was established and now supplies a relatively small but growing number of container refrigeration units in the United States. Daikin markets their refrigeration units along with Mitsubishi in a joint effort to tap the U.S. container refrigeration market.

2.5.1.5 Mitsubishi Corporation

Mitsubishi Corporation was founded in 1870 as a shipping business and has developed into one of the world's largest conglomerates. The corporation handles over 25,000 product categories and employs over 51,000 workers. Sales totaled \$1,683,636 million in 1984.

Mitsubishi Corporation is organized into nine business divisions, each composed of several companies. Container refrigeration units are produced by Mitsubishi Heavy Industries Ltd., which is the largest heavy machinery manufacturer in Japan. This division's strengths lie in shipbuilding, nuclear power,

aircraft, and space fields. Mitsubishi Heavy Industries Ltd. is marketing its container refrigeration units in the U.S. in a joint effort with Daikin Industries.

2.6 SUMMARY

This chapter presented information on existing transportation refrigeration equipment; the industry rating system; trends in the air-conditioning, heating, and refrigeration industry; refrigeration equipment design and selection; the structure of the trailer and container market segments; and the major manufacturers of trailer and container refrigeration equipment.

Although a number of refrigeration systems are used by the transportation industry, mechanical refrigeration units far outnumber other types of systems. Systems powered by an independent (usually diesel) engine are the most common and may be used with trucks, trailers or containers. Independent-engine systems are available with refrigeration capacities ranging from 11,000 to 49,000 Btu/hr at 35°F. Systems which derive power from the vehicle engine generally have smaller capacities (6,500 to 13,000 Btu/hr at 35°F) than the independent-engine systems (6,500 to 13,000 Btu/hr at 35°F) and are restricted to truck use.

Important design considerations include refrigeration capacity, weight, dimensions, durability, and air circulation. The latter is seen as the most prevalent cause of improper cargo refrigeration.

The major U.S. manufacturers of refrigeration units for trailers and containers are Carrier Transicold and Thermo King. Together these two manufacturers control 95% of the U.S. trailer and container refrigeration market. These two companies operate in a highly competitive environment where increases in market share are normally obtained only at the other company's expense.

Both companies market similar transportation refrigeration products whose average price is \$11,500. The cost of the refrigeration unit represents over one-third of the total cost of an insulated trailer or container.

aircraft and space fields. Mississippi Heavy Industries Ltd. is marketing its container refrigeration units in the U.S. in a joint effort with Olin Industries.

2.2 SUMMARY

This chapter presents information on existing transportation refrigeration equipment; the industry testing system; trends in the air-conditioning, heating, and refrigeration industries; refrigeration equipment design and safety; the structure of the trailer and container body segments; and the major manufacturers of trailer and container refrigeration equipment.

Although a number of refrigeration systems are used by the transportation industry, mechanical refrigeration units (an auxiliary power unit or APU) are the most common and may be used with trucks, trailers or containers. Independent-engine systems are available with refrigeration capacities ranging from 11,000 to 40,000 Btu/hr at 35°F. Systems which derive power from the vehicle engine generally have smaller capacities (5,000 to 13,000 Btu/hr at 35°F) and are restricted to truck use.

Important design considerations include refrigeration capacity, weight, dimensions, durability, and air circulation. The latter is seen as the most prevalent cause of improper cargo refrigeration.

The major U.S. manufacturers of refrigeration units for trailers and containers are Carrier, Frigoscold and Thermo King. Together these two manufacturers control 95% of the U.S. trailer and container refrigeration market. These two companies operate in a highly competitive environment where increased market share is normally obtained only at the other company's expense.

Both companies market similar transportation refrigeration products whose average price is \$11,500. The cost of the refrigeration unit represents over one-third of the total cost of an installed trailer or container.

3.0 TRANSPORTATION REFRIGERATION CONSUMERS

In this section, the consumers of transportation refrigeration equipment are described. Specifically, this section defines the categories of consumers, assesses the potential markets, describes the decision process, and identifies the primary decision maker and important buying criteria. Finally, any shortcomings of the existing refrigeration equipment that were identified by the various consumers is noted.

The methodology used to gather the information presented in this section involved first requesting customer lists from transportation refrigeration manufacturers. These lists not only provided information on specific refrigeration consumers, but they also helped to define the major consumer groups. The lists were supplemented with the names and addresses of major trailer and container manufacturers as well as ports, shippers, and leasing companies.

A sample was taken from the customer lists. Then consumers were contacted to gather additional information on each company's purchasing process, key decision maker(s), and selection criteria. Consumers were also asked to note any problems or shortcomings of existing refrigeration equipment. Although the sample size was not statistically significant in terms of the number of contacts made, we feel that the results of this sampling are fairly representative of the industry's decision process and of major criteria used by most transportation refrigeration consumers.

3.1 TRANSPORTATION REFRIGERATION CONSUMERS

This section provides a breakdown of refrigerated trailer and container consumers. Although the commodities hauled by these consumers differ, their refrigeration needs are quite similar.

3.1.1 Refrigerated Trailer Consumers

Manufacturers of trailer refrigeration equipment identify their major customers as 1) private carriers, 2) food cooperatives, 3) owner-operator, and

4) others. Some variation occurred in the dispersion of market share between the consumer groups; however, all manufacturers agreed that the private carriers were the largest group (Figure 3.1).

3.1.1.1 Private Carriers

Private carriers are made up primarily of large, food-oriented companies that own their own trucks and trailers for product distribution. Large food chains, restaurants, and food manufacturers, such as McDonalds, Safeway, and Anheiser Bush, make up the majority of this segment. These companies usually own a large number of refrigerated trailers, as well as their own service shops for maintenance. Some companies with large refrigeration fleets have maintenance personnel specifically for their refrigeration units. Private carriers represent approximately 75% of the total market for trailer refrigeration equipment.

3.1.1.2 Food Cooperatives

Food cooperatives such as Associated Grocers, Darigold, and Western Grocers own their own trucks and trailers for distributing their products. Food cooperatives vary widely in size and number of trucks. This segment represents approximately 15% of the market.

FIGURE 3.1. Major Consumers of Trailer Refrigeration Units

3.1.1.3 Owner/Operator

This segment is made up of individuals who own one or a few trucks for use in their small business. This segment also includes persons or small companies that lease-out their hauling services. This segment represents approximately 7% of the market.

3.1.1.4 Other

This segment includes all other companies, which are primarily non-food transporters of blood, chemicals, etc., and represents approximately 3% of the market.

3.1.2 Refrigerated Container Consumers

Manufacturers of container refrigeration units describe their consumers as primarily shipping and leasing companies. Since only a small number (1,054 units in 1984) of containers are currently manufactured in the U.S., we relied primarily on the manufacturers for the breakdown of consumers (Figure 3.2).

3.1.2.1 Shipping Companies

Shippers are the main purchasers of containers which are used to transport products for their clients. Containers owned by a single company can number into the hundreds of thousands. This segment represents approximately 70% of the market.

FIGURE 3.2. Major Consumers of Container Refrigeration Units

3.1.2.2 Container Leasing Companies

These companies purchase containers and lease them mainly to shippers. This allows many shipping companies, especially the smaller ones, to operate or carry more containers without having to purchase them. This segment represents approximately 25% of the market.

3.1.2.3 Others

This category includes the remainder of companies which purchase containers. These may include ports and certain manufacturing companies. This segment represents approximately 5% of the market.

3.2 CURRENT AND FUTURE REFRIGERATION MARKETS

Private carriers purchase about 75% of the trailer refrigeration market, and the shipping companies purchase about 70% of the container refrigeration units. An important factor in determining the potential of the trailer and container segments as entry markets is their potential for growth. In this section, the transportation refrigeration market is assessed in terms of its potential as an entry market for the BCS refrigeration technology. The assessment is based on information on industries which directly impact the mobile refrigeration market, along with information presented in Section 2.4 on refrigeration and heating equipment SIC 3585, and information on mobile refrigeration SIC 35851.

Trailer refrigeration unit sales are influenced by sales of insulated trailers; sales of both refrigeration units and trailers are dependent upon demand created by consumers of refrigerated trailers identified earlier in this chapter. These consumers operate in a variety of industries including the fast food industry, the grocery industry, and the chemical manufacturing industry. Rather than assessing each individual industry, this section will focus on evaluating the insulated trailer market.

To provide more insight into the market for containers the shipping industry will be evaluated since this sector represents the major end-use of containers.

3.2.1 The Refrigerated Trailer Market

The insulated trailer industry has made considerable progress since the setback in shipments experienced in the early 1980s. Shipments have increased constantly from declines experienced in 1981 and 1982, with the 1984 value of shipments of more than \$2290 million being the highest in the last 9 years (Table 3.1 and Figure 3.3). The value of 1985 shipments is expected to reach \$185 million which is well below the 1984 peak but is still significant when compared to sales during the early 1980s.

Several factors have contributed to the recent increase in refrigerated trailer shipments. The recovery in sales of Class 8 (heavy duty) trucks that developed in mid-1983 has led to increased sales of trailer units. Probably the greatest contributing factor, however, was the passage of the 1982 Surface Transportation Assistance Act (STAA) that increased the maximum length of a trailer from 45 to 48 ft, and increased the maximum width of a trailer from 96 to 102 in. The STAA resulted in a surge of new trailer orders as carriers took advantage of the opportunity for greater productivity in their shipments.

TABLE 3.1. Value of Shipments of Insulated Trailers (millions)

<u>Year</u>	<u>Value of Shipments of Trailer Units (current dollars)</u>	<u>Value of Shipments Insulated Trailers (constant 1972 dollars)</u>
1985	425.4	185.7
1984	511.6	229.0
1983	336.3	156.3
1982	319.7	154.2
1981	254.8	130.2
1980	253.0	141.8
1979	330.9	202.5
1978	263.8	175.4
1977	208.1	148.6
1976	193.4	146.1
1975	156.6	124.5

Source: Truck Trailer Manufacturers Association (1984).

FIGURE 3.3. Value of Shipments of Insulated Trailers

One unwanted side effect of the change in the regulations has been the surplus of used trailers which have flooded the market. Increasingly low residual values for the 45/96 (45 ft long by 96 in. wide) trailers caused some carriers to accelerate their purchases of 48/102 trailers in 1985 while their 45/96's had any trade-in value at all. Most large carriers have completed their conversion from 45/96 trailers to the longer and wider 48/102 trailers approved by STAA (Refrigerated Transporter November 1985c), indicating that the growth in this market is expected to level off.

Trailer demand for 1986 is expected to decline as the trend toward intermodalism continues and as the near-term surge in demand caused by STAA legislation levels out. However, opportunities exist for improvements in the design of the recently approved longer and wider trailers, especially in the area of air flow for insulated trailers. Overall, the long-term annual growth in the trailer industry is expected to average about 2.5% over the next 5 years (U.S. Department of Commerce 1985).

One other area of interest is the growing trend toward intermodalism, that is, the transportation of goods using ocean carriers, railroads, and truck lines. This trend may have negative impact on commercial trailer manufacturers (Refrigerated Transporter, September 1985) as carriers opt for intermodal containers. George Malley, president of Fruehauf Division, stated that, "Intermodalism is here, and it doesn't bode well for the commercial trailer business. Shippers are substituting containers for trailers. It's the hottest topic in the industry right now."^(a)

The two leading manufacturers of insulated trailers are Utility Trailer Corporation with about 35% of the U.S. insulated trailer market, and Great Dane Trailers with about 25% of this market. Other manufacturers of insulated trailers are American Trailers, Inc.; Comet Trailer Corporation; Fruehauf Corporation; Theurer, Incorporated; Timpco Industries, Incorporated.

(a) "Trends and Outlook." Refrigerated Transporter, September 1985. p. 80.

3.2.2 The Container Market

The major end-use of refrigerated containers is the shipping industry. The value of shipments of insulated containers manufactured in the U.S. has fallen from \$8.9 million in 1982 to \$0.2 million in 1985 (constant 1972 dollars) (Table 3.2 and Figure 3.4). The principal cause of this significant decline in sales has been the strength of the U.S. dollar relative to foreign currencies. Since most containers are used to ship U.S. goods overseas, the demand for refrigerated containers is influenced by the demand for U.S. products. The purchase of U.S. goods by foreign countries requires that foreign currency be exchanged for U.S. dollars. As the U.S. dollar strengthens relative to foreign currencies, fewer dollars are received in exchange for a given amount of foreign currency. Consequently, the demand for U.S. exports decreases.

This decrease in the demand for U.S. exports has had a severe impact on many container manufacturers. Since containers last approximately 10 years,

TABLE 3.2. Value of Shipments of Refrigerated Containers Manufactured in the U.S. (millions)

Year	Value of Shipments of Containers Units (current dollars)	Value of Shipments of Insulated Containers (constant 1972 dollars)
1985	0.5	0.2
1984	2.1	0.9
1983	3.0	1.4
1982	18.6	8.9
1981	10.9	5.6
1980	11.8	6.6
1979	11.2	6.9
1978	8.11	5.4
1977	7.2	5.2
1976	5.7	4.3
1975	5.1	4.0

Source: Truck Trailer Manufacturers Association (1984).

FIGURE 3.4. Value of Shipments of Containers

manufacturers are currently facing a saturated market. A company that had been the largest manufacturer of refrigerated containers in the U.S. has not manufactured a container in the past 4 1/2 years.

The Jones Act of 1920 requires that all commerce carried between points in the U.S. be carried in U.S. vessels. This provision has helped the U.S. container industry significantly in recent years. Deep sea trade between the mainland, Alaska, Hawaii, Puerto Rico, and trust territories, as well as coastal trade, has continued to grow with the overall U.S. economy.

However, the U.S. container industry is not expected to achieve the level of shipments of the late 1970s and early 1980s unless the U.S. dollar weakens relative to other foreign currency. U.S. companies may continue to purchase foreign-built containers and to install U.S.-made refrigeration systems. However, no information is available on the value of shipments of foreign-made containers. As a result, the size of the worldwide container market cannot be adequately estimated nor can the trend in the worldwide market be assessed.

3.3 CONSUMER DECISION PROCESS

The decision process used in selecting and installing a refrigeration unit begins when the consumer identifies the need for a refrigerated trailer or container. The consumer must then decide on the trailer/container size and the refrigerator capabilities needed. Insulated trailer/container manufacturers and refrigeration unit manufacturers are then contacted. The consumer also contacts the refrigeration equipment manufacturers, and provides them with information on the number and types of units required. The refrigeration equipment manufacturers then submit bids to the customer. The bids are reviewed and the refrigeration units are chosen. Installation of the units occurs either at the trailer or container manufacturer's factory, or at the refrigeration unit dealership. The process is similar for both small and large purchases although the single unit purchase usually does not involve the submission of formal bids from refrigeration manufacturers. Insulated trailer and containers are usually purchased through a similar bidding process.

This section identifies the principal decision-making groups within consumer's organizations. This section also describes the primary buying criteria

used by Consumers of Transportation refrigeration units as identified in PNL's discussions with consumers.

3.3.1 Principal Decision Maker

The principal decision maker(s) at companies that purchase transportation refrigeration units were identified through information obtained through contacting consumers of refrigeration units for trailer and container applications. Since a properly cared for refrigeration unit normally lasts the life of the trailer or container, the decision to purchase a new refrigeration unit usually is made when a new refrigerated container or trailer is required.

The majority of large trucking and shipping companies contacted stated that the decision to purchase a refrigeration unit is made by three key persons or departments at the firm: engineering, finance, and maintenance. The engineering department decides on the technical specifications or requirements of the unit depending on its intended application; the maintenance department provides input based on their experience with the particular brands and models; and the finance department approves the funding for the unit which is usually budgeted for on a yearly basis. At this point, a purchasing agent may accept bids from refrigeration companies. These bids are then evaluated using input from all three departments.

In smaller companies, of course, the decision process is much less detailed and is usually made by the president with input from others who operate or work on the units. Owner/operators normally decide on the unit they wish to purchase and negotiate the sale with the dealer themselves.

3.3.2 Buying Criteria

The objective of this section is to identify important criteria or attributes of refrigeration units that are considered by decision makers when purchasing a transportation refrigeration unit. In order to obtain this information, the principal decision makers identified in Section 3.2.1 were contacted. Each decision maker was asked to list the criteria or attributes considered most important to their company in selecting a refrigeration unit. This sample of consumers is not statistically representative of the population

because of the limited number of consumers contacted. However, this information provides valuable insight into the criteria the BCS technology will have to meet in order to be accepted by its intended consumers.

All questions were presented in an open-ended fashion and the participant was encouraged to respond freely. This technique was used to gain responses that were not biased by preconceptions of what refrigeration unit attributes are most important. One problem in using the open-ended format is that it causes differences in the number of attributes listed between individuals responding to the question.

Thirteen trucking companies were contacted with truck fleets ranging in size from 2 to 250 units. Five of the largest U.S. container shipping companies were also contacted. Table 3.3 summarizes the results of these contacts by listing the various attributes and the distribution of responses between shipping and container companies.

Several differences in responses were found between trailer and container consumers, but the main attributes considered most important by both were price, reliability, and energy efficiency. Container consumers stated that availability of spare parts, service outlets, and current brands in the fleet

TABLE 3.3. Important Refrigeration Unit Attributes Rated by Consumers of Refrigerated Containers and Trailers

<u>Attribute</u>	<u>Total Responses</u>	<u>Trailer Consumer</u>	<u>Container Consumer</u>
Reliability	8	6	2
Price	8	4	4
Energy Efficiency	7	4	3
Durability	4	3	1
Fuel Type	3	3	0
Low Maintenance Costs	3	2	1
Service Quality	2	1	1
Availability of Spare Parts	2	0	2
Service Outlets	2	0	2
Current Brands in Fleet	2	0	2

were important whereas trailer consumers did not. This is probably because of the worldwide scope of container use. Fuel type (diesel preferred) was mentioned only by trailer consumers.

Important refrigeration unit attributes listed in Table 3.3 are fairly consistent with what we expected to be important qualities in refrigeration units. These attributes should be kept in mind as criteria which the BCS technology will have to meet in order to be successful, and will be used to evaluate the technology in Chapter 4.0.

3.4 SHORTCOMINGS OF CURRENT REFRIGERATION EQUIPMENT

The same 18 trailer and container consumers contacted concerning important refrigeration unit attributes were also asked if they had experienced any problems or recognized any shortcomings in current refrigeration equipment. Two maintenance shops which repair container refrigeration units, and two ports which are in charge of container and trailer units were also contacted.

The majority of consumers contacted did not identify any significant problems or shortcomings with current refrigeration equipment and often were quick to add that they are quite satisfied with the quality of the equipment. Strong points of current refrigeration equipment and/or the manufacturers mentioned by consumers included: strong research and development being conducted by refrigeration unit manufacturers which has resulted in continual equipment improvements, technically sound units, high quality of service, low maintenance, high reliability, and long life spans. Of the 18 trailer and container consumers contacted, 15 were very satisfied with their current refrigeration units.

The remaining three, two trailer consumers and one container consumer, identified areas where they have experienced problems. Trailer consumers found electrical problems and had problems in diagnosing breakdowns in units. The container consumer mentioned problems with corrosion of container refrigeration units.

Shipping ports were contacted to provide further insight into possible equipment shortcomings. Most found the equipment to be very reliable. While the service manager at the Port of Portland stated that he had no problems with

the refrigeration units themselves, he did, however, state that some container chassis do not have precut holes for the refrigeration unit wires. As a result wires must be routed around the unit and this causes some of the wires to be severed.

Two container maintenance shops contacted both stated that the major cause of refrigeration unit problems is a lack of proper maintenance. For example, operators neglect the refrigeration manufacturer's maintenance schedules and they also do not clean the condensers on a regular basis. Also, problems often result when the unit is not hooked up to the proper power source causing the electronic controller to burn-out.

Current refrigeration equipment for trailers and containers seems to be satisfying the majority of customers according to our investigations. The three refrigeration equipment problems identified were not deemed severe by consumers, and were not encountered by other consumers of refrigeration equipment contacted. Also, the competitive nature of the refrigeration equipment industry has increased the research and development being conducted by manufacturers to improve the refrigeration systems. It appears that consumer needs are being fairly well met by current refrigeration equipment.

3.5 SUMMARY

This chapter identified the major market segments of consumers, assessed trailer- and container-related industries, outlined the consumer decision process, and identified refrigeration unit buying criteria and shortcomings of current refrigeration equipment.

The major market segments of trailer refrigeration units were identified as private carriers, owner-operators, and food cooperatives. For container refrigeration units, the major market segments identified were shipping companies and container-leasing companies. The insulated trailer market and the shipping industry were assessed to gain further insight into the current status and potential growth of the refrigeration unit market.

The consumer decision process, buying criteria, and equipment shortcomings were identified by contacting consumers of refrigeration units for trailers and

containers. In larger companies, the decision process is quite involved and depends upon interaction between the engineering, maintenance, and finance departments. At smaller companies, the decision is usually made by the president of the company who is involved with all aspects of the business. The major buying criteria are price, reliability, and energy efficiency. Consumers contacted were generally satisfied with the current refrigeration equipment available, and no major equipment shortcomings were identified.

4.0 EVALUATION OF BCS REFRIGERATION TECHNOLOGY

New refrigeration concepts proposed for transportation applications will have to meet certain technical and economic criteria in order to compete with established technologies. The minimum criteria a new technology must meet or exceed were established by assessing the characteristics of existing technologies. Maintenance of cargo quality and the desire to maximize cargo space and weight (i.e., minimize refrigeration system weight and volume) are the key considerations in refrigeration system design. These considerations determine the acceptable range on cooling and heating capacities, physical dimensions and weight.

The minimum technical and economic criteria are discussed below for containers and trailers.

4.1 MINIMUM CRITERIA FOR CONTAINERS

Table 4.1 summarizes the major technical criteria that are recommended for market acceptance of new container refrigeration technologies. Criteria are presented for both 20-ft and 40-ft containers.

The dimension limitations are the same for both 20- and 40-ft containers. The height and width restrictions are important because the system must be flush with the frame of the container to allow for stacking both dock-side and on shipboard. The length restriction is critical because it is desirable to minimize refrigeration system thickness in order to maximize cargo space.

With containers, the weight restriction is particularly important because of the lifting and stacking involved in moving containers from one transportation mode to another. The container structure is designed to accommodate the stresses involved in these operations and the structure designed is based on a particular weight limitation. Therefore, every pound saved in refrigeration system weight is an extra pound available for the cargo.

The required refrigeration and heating capacities will vary depending on the container design, the cargo, ambient conditions, and the time in transit.

TABLE 4.1. Minimum Technical Criteria for Containers

	<u>20-ft Containers</u>	<u>40-ft Containers</u>
Dimensions (in.)		
height	<88	<88
width	<82	<82
length	<17	<17
Weight (lb)	1,100-1,250	1,175-1,500
Cooling Capacity (Btu/hr)		
@35°F	19,000-25,500	29,000-36,500
@0°F	9,000-11,500	15,000-18,000
Heating Capacity (Btu/hr)	12,000-18,500	18,000-20,500
Other Desirable Features:		
• Zone Temperature Capability		
• Flush Mounting		
• Corrosion Resistant Materials		
• Capability for Dual-Voltage Operation		

It is assumed that a new technology would be most competitive if the heating/defrosting capability is provided through reverse cycle operation of the system.

Other features that should be incorporated into the design of an advanced refrigeration concept include: flush mounting, use of corrosion resistant materials, and provision for dual-voltage operation. To maximize cargo space it is desirable that the system be mounted flush with the front wall of the container, rather than protrude into the cargo space. Because the containers may come in contact with sea water and salt air, corrosion resistant materials should be used in construction. A means of allowing system operation from different power supplies, should be included as an integral part of the system.

4.2 MINIMUM CRITERIA FOR TRAILERS

Table 4.2 provides a summary of the minimum criteria recommended for refrigeration systems designed for the trailer market. Criteria are provided for nose-mounted and flush-mounted refrigeration units.

Each state specifies by law the maximum weight and dimensions of trailers that may operate on its highways. Thus, as with containers, minimizing the dimensions and weight of the refrigeration systems are important in order to maximize the space and weight available for the cargo.

Cooling and heating capacity requirements tend to be greater for trailers than for containers, primarily due to the larger size. Again, these capability requirements are dependent on trailer size, the cargo, the ambient conditions, and the operation of the trailer. Heating and defrosting should be provided through reverse cycle operation of the refrigeration system.

Other features that may be important to market acceptance of a new refrigeration concept in the trailer segment include use of corrosion resistant materials and zone temperature capability. Although not as corrosive as sea water, water and dirt splashed from road surfaces can also have a corrosive effect on refrigeration components. A growing number of trailers, particularly those servicing the fast food industry, are using multiple zones in the cargo space, each operated at different temperatures.

TABLE 4.2. Minimum Technical Criteria for Trailer Refrigeration Systems

	<u>Nose-Mounted</u>	<u>Flush-Mounted</u>
Dimensions (in.)		
height	<82	<88
width	<75	<74
length	<22	<23
Weight (lb)	1,620-1,976	1,350-1,685
Cooling Capacity (Btu/hr)		
@35°F	39,500-46,500	41,000-46,500
@0°F	21,000-23,500	21,000-23,500
Heating Capacity (Btu/hr)		
Reverse Cycle Operation	37,000-40,000	19,000
Other Features:		
• Reverse Cycle Operation		
• Corrosion Resistant Materials		
• Zone Temperature Capability		

5.0 EVALUATION OF THE TRAILER AND CONTAINER SEGMENTS AS ENTRY MARKETS

The chapter evaluates the potential of the trailer and container segments of the transportation industry as entry markets for the proposed BCS refrigeration technology. This evaluation is performed by comparing the characteristics of an entry market to the characteristics of the trailer/container market segments as were identified in chapters 2.0 and 3.0. Characteristics of an entry market include:

- growing market
- high profit potential
- low barriers to entry
- unfilled technical needs.

5.1 GROWING MARKET

A good entry market for a new technology should be a growing market in terms of dollar sales. It may be possible to find successful opportunities in stable markets; however, sales will have to be taken away from established competitors. Establishing market share by attracting sales from a competitor can be extremely difficult and costly if customers have developed long-term relationships with competitors.

Information presented in Chapter 3.0 indicated that refrigerator trailer sales have increased at an average annual (real) growth rate of 4% between 1975-85. Forecasts suggest and industry experts concur that trailer sales (of both refrigerated and unrefrigerated units) will increase at an average annual rate of 2.5% between 1985-90. It is also expected that the refrigerated trailer sales will continue to represent about 10% of total trailer sales.

The outlook for refrigerated containers is not as optimistic as it is for trailers. The sales of refrigerated containers fell at an average annual rate of -27% between 1975-85. Since 1982, the sales of refrigerated containers has fallen at a rate of -73% per year. The primary cause of this dramatic drop has been the strength of the U.S. dollar overseas and, consequently, the drop in U.S. exports. Since the demand for all containers is a function of the level

of U.S. exports, the sales of containers has decreased. In addition, U.S. shippers are moving towards purchasing containers from lower-priced foreign sources.

U.S. container manufacturers are not optimistic about the near term growth in container sales and positive growth is not forecasted for the next several years.

5.2 PROFIT POTENTIAL

An effective entry market must provide sufficient profits to enable entrepreneurs to further develop and refine the new technology. These technological improvements will allow the technology to be introduced into additional, long term markets. Profits must be sufficient to allow adequate research and development of the technology and should be in excess of the normal profits received in competitive markets.

Information is not available from refrigeration manufacturers nor from published sources on the level of profits received by refrigeration manufacturers from selling units to the trailer/container market segments. However, refrigeration dealers state that they receive about a 4% mark-up on single unit refrigeration sales. Dealers were not sure of the level of mark-ups that manufacturers placed on the units before they were sold to the dealers.

Contacts with consumers of multiple refrigeration units stated that the market for transportation refrigeration equipment is quite competitive. Most multiple unit sales are transacted through a competitive bid process. Although the selection of refrigeration units is based on several criteria, the technical similarities of existing equipment usually reduces the final selection to one of price.

The moderately growing trailer and the declining container industries are also good indicators that the profit potential of selling refrigeration units to these sectors is probably modest. The two principle transportation refrigeration manufacturers have been able to survive the downturns of the trailer and container markets due to their diversity and through the financial support of their parent companies.

5.3 BARRIERS TO ENTRY

Several factors could prevent new firms from entering a profitable, growing industry including the requirements that the firm have:

- large production facilities
- specially-trained personnel
- extensive distribution and service network.

Large Production Facilities

Current transportation refrigeration units are composed of several components such as compressors, and evaporators that are manufactured at one or two plants per company. The production of these components is capital intensive and economies of scale are achieved by building a few large production facilities. Establishing several smaller production facilities through the U.S. would probably not allow a company to compete with firms that have single production facilities, due to higher production costs.

Specially Trained Personnel

The technology used to manufacture current refrigeration equipment is fairly well established. Although the design of these units requires a skilled refrigerator engineer, the manufacturing and assembly requires only semi-skilled labor. It is expected that the proposed BCS technology will require about the same skill level for manufacture and assembly.

Extensive Distribution and Service Networks

All five companies currently selling transportation refrigeration units in the U.S. have dealers and/or service facilities located throughout the U.S. (for trailers) or throughout the world (for containers). Most of the dealer/service facilities are independently-owned and operated under an exclusive dealership arrangement with one of the refrigeration equipment manufacturers. A new technology trying to enter the trailer/container refrigeration industry would have to establish a similar network or would have to join with a company that had already established this network. In addition, service personnel at these dealerships would have to be trained to repair the BCS equipment.

5.4 UNFILLED TECHNICAL NEEDS

The majority of the refrigerated container and trailer consumers indicated that existing refrigeration units meet their performance and reliability requirements. While no major unfilled technical needs were identified for the refrigeration unit itself, a need for better air circulation through the cargo space to ensure adequate cooling of the entire load is recognized. The industry is currently conducting a great deal of research in this area. New technologies designed to rely on natural draft circulation will not likely find acceptance in the market.

Relative to product quality considerations and restrictions on the weight and volume of the refrigeration system, the energy consumption of the refrigeration unit is insignificant. Currently, COP or EER ratings are not reported for transportation refrigeration systems as part of the ARI certification rating. As mentioned previously, ETL Testing Laboratories, which performs the tests, indicated that no one has ever indicated an interest in efficiency ratings for transportation refrigeration units. Therefore, we conclude that an improvement in efficiency alone would not be sufficient for a new technology to enter the market.

5.5 SUMMARY

This chapter compares the characteristics of an entry market with the characteristics of the trailer/container market segments. This comparison was made to determine the potential of the trailer/container segment as an early market opportunity for the proposed BCS technology. This evaluation was made in terms of:

- growth potential
- profit potential
- barriers to entry
- unfilled technical needs.

The trailer segment provides only a modestly growing market segment with sales expected to increase at an average annual rate of 2.5% through 1990.

Sales in the container segment have fallen significantly during the 1982-85 period, and industry experts and manufacturers are not optimistic about near term prospects.

The profit potential of these two market segments are currently poor as evidenced by declining sales and comments on the competitiveness of the industry. The need to establish a large manufacturing facility and distribution network may prevent a firm from industry.

6.0 RECOMMENDATIONS

The objective of this report is to assess the trailer and container segments of the transportation industry as potential entry markets for the proposed absorption refrigeration technology. The previous sections have characterized the current transportation refrigeration technology, rating system, manufacturers, consumers, and decision process. Based on the information contained in the previous section the following recommendations are made.

Entry into the refrigerated container market segment would be difficult at this time because of the poor growth potential. Consequently, entry into this segment is not recommended at this time.

Entry into the refrigerated trailer market segment may be difficult because of the modest growth rate of refrigeration sales (4%/year), the low profit potential, some barriers to entry and general consumer satisfaction with existing equipment. If entry is considered the following would increase the probability that this market segment would adopt the proposed refrigeration technology.

- Develop an information transfer program directed towards refrigeration equipment consumers highlighting the technical advantages of the proposed technology over existing equipment.
- Form a joint venture with an existing manufacturer of transportation refrigeration equipment to produce, distribute and service the new refrigeration technology. Such a venture would significantly reduce the barriers to entry into this market segment.

The potential of unitary refrigerated delivery trucks (i.e., truck bodies) as a potential entry market for the proposed technology should be evaluated. This particular market segment may be an attractive alternative to the container and trailer markets since a single unit air conditions the cab and refrigerates the cargo

space. Also, the absorption refrigeration unit could be operated from the exhaust gases of the truck engine, thus eliminating the need for an additional heat source.

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APPENDIX A

TEMPERATURE RECOMMENDATIONS FOR SPECIFIC PERISHABLE PRODUCTS (USDA 1970, unless otherwise noted)

APPENDIX A. Temperature Recommendations for Specific Perishable Products (USDA 1970, unless otherwise noted)

Product	Transit Temp. (°F)	% Relative Humidity	Product	Transit Temp. (°F)	% Relative Humidity
Fresh Fruits and Vegetables:			Fresh Fruits and Vegetables (Cont.):		
Apples	30-40	90	Pineapples, ripe	45	85-90
Apricots	31-32	90	Plums/Prunes	31-32	90-95
Artichokes	32	90-95	Potatoes	40-70	90
Asparagus	32	90-95	Radishes	32	90-95
Avocados	40-55	85-90	Raspberries	31-32	90-95
Bananas	55-60	90-95	Rhubarb	32	95
Beans, Green	45-50	90-95	Romaine	32	90-95
Beans, Lima	32-40	90	Spinach	32	90-95
Beets	32	90-95	Squash, winter	50-55	50-75
Blackberries	31-32	90-95	Squash, summer	32-50	90
Blueberries	32	90-95	Strawberries	32	90-95
Broccoli	32	90-95	Sweetpotatoes	55-70	85-90
Cabbage	32	90-95	Tangerines	32-38	85-90
Cantaloups	32-34	85-90	Tomatoes	45-50	85-90
Carrots	32	80-95	Watermelons	55-70	80-85
Cauliflower	32	90-95			
Celery	32	90-95	Fresh Meat and Poultry:		
Cherries	31-32	90	Beef	32-34	88-92
Corn	32	90-95			
Cranberries	36-40	90-95	Lamb	32-34	85-90
Cucumbers	36-40	90-95	Pork	32-34	85-90
Eggplants	45-50	90	Poultry	28-34	90-95
Endive	32	90-95	Veal	32-34	90-95
Grapefruit	50-60	85-90			
Grapes	30-32	85-95	Processed Meat:		
Kale	32	90-95	Bacon, slab	26-28	70-80
Lemons	50-55	85-90	Bacon, sliced	32-35	90-95
Lettuce	32	95	Cold cuts	26-28	70-80
Limes	48-50	85-90	Dried Beef	38-45	70-85
Melons	45-50	85-90	Hams	26-30	70-85
Mushrooms	32	90			
Okra	45-50	90-95	Dairy Products and Eggs:		
Onions, Dry	32	65-70	Eggs	35-40	80-85
Onions, Green	32	90-95	Butter	32-40	80-85
Oranges	40-44	85-90	Margarine	35	60-70
Parsley	32	90-95	Cheese	30-45	65-70
Parsnips	32	90-95	Milk ^(a)	32-40	
Peaches/					
Nectarines	31-32	90	Frozen Foods:		
Pears	29-31	90-95	All	below 0	
Peas	32	90-95			
Peppers	45-50	90-95			
Pineapples, green	50-60	85-90			

(a) (International Institute of Refrigeration 1974).

APPENDIX B

APPROXIMATE HEAT OF RESPIRATION OF VARIOUS
PERISHABLE PRODUCTS BY TEMPERATURE

APPENDIX B. Approximate Heat of Respiration of Various
Perishable Products by Temperature
(Adapted from USDA 1970)

Product	Heat of Respiration (Btu per ton per 24 hours)				
	32°F	40°F	60°F	70°F	80°F
Apples	700	1,350	4,900	5,700	--
Apricots	--	5,050	11,700	20,350	--
Artichokes	7,700	10,450	26,400	40,700	50,050
Asparagus	9,700	18,050	38,500	48,750	93,250
Avocados	--	5,500	24,050	46,250	60,050
Bananas	--	--	4,850	7,400	--
Beans, Green	7,250	10,300	38,100	49,200	--
Beans, Lima	4,450	6,100	24,700	34,300	--
Beets	2,700	4,100	7,200	--	--
Blackberries	4,100	7,950	--	38,350	--
Blueberries	1,400	2,350	10,550	15,300	22,250
Broccoli	4,400	21,400	56,500	68,100	158,400
Cabbage	1,200	2,200	4,900	8,450	12,350
Cantaloupe	1,200	2,050	7,950	12,000	14,700
Carrots	3,300	4,300	8,750	15,500	--
Cauliflower	3,900	4,500	10,100	17,700	24,650
Celery	1,600	2,400	8,200	14,200	--
Cherries	1,050	2,600	7,700	--	--
Corn	8,950	13,850	35,850	63,700	78,900
Cranberries	650	950	--	3,200	--
Cucumbers	--	--	5,300	6,850	8,050
Endive	--	2,650	12,350	16,700	21,000
Grapefruit	--	1,000	3,100	4,250	--
Grapes	600	1,200	3,500	7,200	8,500
Kale	4,700	8,900	30,250	49,600	--
Leeks	2,900	5,350	21,950	--	24,850
Lemons	700	1,250	3,650	4,850	5,350
Lettuce	2,500	3,650	8,450	12,200	14,700
Limes	--	800	--	4,650	--
Mushrooms	7,900	15,600	46,000	63,800	--
Okra	--	12,250	32,050	57,400	75,900
Onions:					
Dry	650	750	2,400	3,650	6,200
Green	3,600	9,400	17,950	25,800	33,800
Oranges	750	1,200	4,000	6,200	7,150
Parsnips	3,000	2,900	8,250	--	--
Peaches	1,150	1,700	8,300	17,750	22,350
Pears	1,100	1,650	8,250	11,000	--
Peas	8,500	14,450	41,900	66,750	79,200
Peppers	--	2,900	8,500	9,650	12,100
Pineapples	--	400	3,450	7,050	10,800
Plums	550	1,450	2,700	4,700	10,900
Potatoes	--	2,600	4,850	6,950	--
Radishes	1,400	2,100	7,100	11,250	16,400
Raspberries	4,700	7,650	20,200	--	--
Rhubarb	2,350	3,200	8,700	10,650	--
Romaine	--	4,550	9,750	15,100	23,850
Spinach	4,550	10,150	39,350	50,550	--
Squash:					
Summer	2,700	3,600	18,250	20,050	--
Winter	--	--	--	--	20,650
Strawberries	3,300	5,450	17,950	32,800	41,800
Sweetpotatoes	--	--	6,300	--	14,000
Tomatoes	--	1,300	5,850	7,500	9,050
Turnips	1,900	2,150	5,000	5,400	--
Watermelons	--	800	--	4,650	--

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