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DRAFT REPORT: 77
APPLICATION OF ORGANIC RANKINE CYCLE
HEAT RECOVERY SYSTEMS
TO DIESEL POWERED MARINE VESSELS

for

Division of Transportation Energy Conservation
Non-Highway Transport Systems
Energy Research and Development Administration
20 Massachusetts Avenue
Washington, D.C. 20545

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August 22, 1977

Mr. Richard Alpaugh
Division of Transportation
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Subject: Draft Report—Application of Organic Rankine Cycle Heat
Recovery Systems to Diesel Powered Marine Vessels

Dear Dick:

We are pleased to submit our draft report entitled "Application of Organic Rankine Cycle Heat Recovery Systems to Diesel Powered Marine Vessels." We are enclosing five copies for your use. Three copies have been forwarded to Ms. E. Romo in ERDA in Oakland as required by the contract. Copies have also been forwarded to Mr. L. Fink, MarAd, Mr. S. Cohen, U.S. NRDC, Mr. J. Seelinger and Mr. J. Moore.

If you have any questions concerning this report or the conclusions reached as a result of the analysis please do not hesitate to call Mr. Leo Donovan or myself at (301) 656-2200.

Very truly yours,

Richard A. Tarkir

BOOZ • ALLEN & HAMILTON Inc.

Richard A. Tarkir

Approved:

Leo J. Donovan
Research Director

cc: E. Romo, ERDA, Oakland, California

Enclosures

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I. EXECUTIVE SUMMARY

I. EXECUTIVE SUMMARY

1. INTRODUCTION

This report describes the analysis and results of an investigation of the application of organic Rankine cycle heat recovery systems to diesel-powered marine vessels. The program under which this study was conducted was sponsored jointly by the U.S. Energy Research and Development Administration, the U.S. Navy, and the U.S. Maritime Administration.

The overall objective of this study was to investigate diesel bottoming energy recovery systems, currently under development by three U.S. concerns, to determine the potential for application to marine diesel propulsion and auxiliary systems. The study primarily focused on identifying the most promising vessel applications (considering vessel type, size, population density, operational duty cycle, etc.) so the relative economic and fuel conservation merits of energy recovery systems could be determined and assessed. Vessels in the current fleet and the projected 1985 fleet rated at 1,000 BHP class and above were investigated.

2. BACKGROUND

Since the oil embargo in 1974, considerable interest has been shown by industry, user organizations, and government in the organic Rankine cycle bottoming system (or diesel bottoming engine) as a means of capturing and utilizing waste heat to improve overall engine cycle efficiency. A bottoming cycle engine is an engine powered by heat that is rejected, and usually discarded, from another heat power cycle. For example, diesel or gas turbine engine exhaust or furnace or boiler flue gases could be utilized to drive a bottoming engine. The amount of recovered power that could be produced is dependent on the working fluid characteristics, cycle efficiency, the amount and temperature of the waste heat, and the space available for the sizing of the bottoming system components. Experience with existing units and experimental units has shown that the organic Rankine engine could produce an output power equal to a few percent to over 20 percent of the base diesel engine output power depending on component design. Fuel consumption of the base

diesel engine could be reduced by a comparative amount as an alternative to producing additional shaft horsepower.

Rankine cycle energy recovery systems utilizing organic fluids (i.e., Freon refrigerants, Fluorinal, Toluene, etc.) and heat energy supplied from various sources (i.e., waste steam, flue gases, hot process fluids, and engine exhaust gases) have been successfully developed and are currently used in a number of foreign manufacturing plants, chemical processing plants, and refineries. Industrial applications of the recovered power include electrical power generation, air conditioning, refrigeration, compressor, and pump drives. A small number of terrestrial energy recovery system applications are currently used in the United States. Various devices to utilize heat from marine engine exhaust gases and cooling system jacket water (in addition to engine radiant heat to keep the engine compartment warm) have been used. The most common applications are to heat water that can be used for heating crew cabins and ship compartment spaces, fuel heating, cargo heating, and fresh water distillation. Other marine vessel uses have been in the generation of steam for use in absorption refrigeration plants, space heaters, distillers, heat exchangers, and low pressure steam turbine drives.

A number of years ago closed-cycle energy recovery systems were tried on large foreign manufacture, diesel-powered ships for the generation of electricity but at the time it was concluded that energy recovery systems were cost effective only on ocean going vessels rated at ~15,000 horsepower and larger. No recent applications of closed-cycle energy recovery systems using diesel engine exhaust gas as the heat source, other than to supply auxiliary systems operating on a direct heat-exchange principal, are known to exist with the exception of one recent foreign development. This concern has developed a low pressure steam economizer turbo-generating plant with a power recovery effectiveness of ~6½ percent from a 13,000 horsepower twin bank, 2-cycle diesel marine engine.

Because of the sharp increase in fuel prices since the oil embargo and the desire to establish independence from a possible future embargo, both industry and the government have renewed interest in diesel engine bottoming cycle systems applied to marine vessels as a means of conserving energy. Although no known energy recovery systems for installation in marine vessels have been developed to date in the United States, several feasibility studies for marine application of energy recovery systems have been

conducted under ERDA sponsorship. However, because organic Rankine cycle bottoming systems are inherently simple and component design and construction are representative of state-of-the-art technology, it appears that transfer of design from terrestrial applications to marine applications could be accomplished with minimal risk. The three high-technology concerns who are actually engaged in the development of organic Rankine cycle energy recovery systems are Mechanical Technologies, Incorporated, Thermo Electron, Corporation, and Sundstrand Energy Systems.

3. SUMMARY

The results of this study indicate that the use of Rankine cycle diesel bottoming energy recovery systems is an effective means of reducing fuel consumption for some types of marine vessels. A Rankine cycle diesel bottoming system is capable of recovering the equivalent of a few percent to over 20 percent, of the base diesel engine output power, from the exhaust gas energy. Or, as a more desirable alternative to producing additional shaft horsepower, fuel consumption of the base diesel engine could be reduced by a comparative amount. The amount of energy recovery capability by the Rankine cycle engine is dependent on a number of factors including: working fluid type, cycle efficiency, available space, weight constraints, engine type, vessel operational characteristics, and system cost. Vessels equipped with most models of naturally aspirated and turbocharged 4-cycle diesel engines and blower-scavenged 2-cycle diesel engines appear to offer the best potential for the application of Rankine cycle energy recovery systems because they operate at higher exhaust reject gas temperatures.

The most promising marine application for organic Rankine cycle diesel bottoming energy recovery systems are concentrated among four types of inland and offshore vessels in three horsepower classes. These vessels are shown in Table I-1. The vessels exist in large population quantities, operate at relatively high duty-cycle/load-factors, are under operation a large number of hours annually, and dominate the fleet in the highest total number of operational horsepower/hours per year. However, strong evidence also exists to indicate that Rankine cycle bottoming energy recovery systems would also be cost effective for many other types of vessels that were dropped from consideration in this study only because they did not exist in large population quantities when compared to the candidate vessels selected.

TABLE I-1
Most Promising Marine Applications
for Energy Recovery Systems

Power Rating Range	Vessel Type
1,500-1,800 BHP	Push- Tow Boat Inland Tug Offshore Supply Boat
2,200-2,400 BHP	Push-Tow Boat Offshore Tug Offshore Supply Boat
3,000-3,200 BHP	Push-Tow Boat

The use of Rankine cycle energy recovery systems is cost-effective for the selected candidate vessels and can result in an equivalent reduction in initial required freight rate (I-RFR) of approximately 4 percent for vessels equipped with diesel bottoming systems with 10 percent effectiveness, to approximately 8 percent lower (I-RFR) for vessels equipped with bottoming systems with a 20 percent effectiveness.

The investment recapture period (years to pay back) for push-tow boats equipped with energy recovery systems is approximately 4½ years for systems with a 10 percent power recovery effectiveness, and about 4 years for systems with a 15 percent power recovery effectiveness. Although the pay back period for inland tugs, offshore tugs, and offshore supply boats equipped with a diesel bottoming system(s) is somewhat longer, they are also considered economically viable.

If fuel costs continue to escalate at a higher annual rate than other services, and/or at a higher rate than current time-frame escalation rates, the reduction in I-RFR for vessels equipped with energy recovery systems will be even greater. If the annual fuel cost escalation rate increases to 10 percent per year, for example, the pay-back period is reduced by an additional 15 percent or more.

Fuel savings for the candidate marine vessels in the projected 1985 fleet are estimated to be 3/4-million barrels if one-half of the fleet were equipped with energy recovery systems with a 15 percent effectiveness, or 1½-million barrels if all candidate vessels were comparably equipped. If all of the 1985 fleet of candidate vessels were equipped with an energy recovery system with a 20 percent power recovery effectiveness, almost 2 million barrels (84 million gallons) of fuel could be conserved annually.

Push-tow boats (all three horsepower classes) consume 70 percent of the total fuel used by all of the candidate vessels. Providing all push-tow boats (in the three horsepower classes) were equipped with energy recovery systems with a 20 percent power recovery effectiveness, 1,400,000 barrels of fuel could be conserved annually by this maritime segment alone.

Although Rankine cycle energy recovery systems have been used in a variety of industrial applications in Europe and in small numbers in the United States, no marine diesel applications are known to exist in the smaller class of vessels. But because organic Rankine cycle bottoming systems are reasonably conventional in state-of-the-art technology, the transfer of technology from terrestrial organic Rankine cycle systems and other machine technology to marine hardware could be accomplished with relatively little risk. Because of the relatively low electrical power demand of the candidate vessels, as compared to the power that is capable of being recovered, the most practical use of recovered power is augmentation of vessel propulsion.

Some concern exists with respect to the safety aspects of using certain fluids as the working medium in closed-cycle, high pressure, high temperature systems. The use of Freon as the working fluid in Rankine cycle energy recovery systems is one of the safest, from a fire or explosive potential but, system efficiency is greatly reduced compared with other fluids that can operate at higher temperatures. From an overall safety standpoint, it is believed that Fluorinal-85 poses no more of a hazard potential than engine diesel fuel (which is also pumped at high pressure, though much lower temperatures) in the event of a line rupture. The use of Toluene as a working fluid may be potentially more hazardous than Fluorinal-85 (and vessel diesel fuel) because of its lower flash point and fire point. All of the proposed working fluids (as well as diesel fuels) are considered to be toxic by OSHA/NIOSH standards. The use of both Fluorinal-85 and Toluene in Rankine cycle energy

recovery systems will be subject to U.S. Coast Guard regulations and American Bureau of Shipping rules. Good equipment design and installation practice must be adhered to, in addition to good vessel machinery operating procedures. The equipment must be designed and constructed to meet U.S.C.G. Coast Guard and American Bureau of Shipping rules.

The development of organic Rankine cycle diesel bottoming systems is currently being pursued by industry in a cautious manner. Development has been concentrated on terrestrial applications with shared (though not equal) funding by the system developer/manufacturer, the user, and the government (ERDA). Industry will pursue and implement programs with low technological risk and whose economic attractiveness is clearly determined. Consequently, higher risk programs that have a high potential benefit must be developed and demonstrated by joint ERDA/industry funding if they are to achieve industrial acceptance, implementation, and commercialization on a timely basis. The economic viability, as determined by return on investment on the projected capital cost of production units, must be clearly demonstrated to the potential end user. To circumvent these delays and barriers and hence development, it would be highly desirable for the government to provide aid to industry to quicken the pace and scope of development to accelerate earliest energy savings. A pilot demonstration program should be conducted to establish the economic viability of organic Rankine cycle bottoming systems on small marine vessels.

II. PROGRAM APPROACH

II. PROGRAM APPROACH

The approach used in this research effort on the application of organic Rankine cycle heat energy recovery systems to diesel marine vessels was conducted in the following manner.

1. MARINE DIESEL ENGINE CHARACTERISTICS

A survey of all major U.S. marine diesel engine manufacturers was conducted to collect data on engine performance, heat balance, and cost. An analysis of engine performance and operating characteristics was conducted, including:

- . Engine power performance
- . Power rating
- . Duty cycle/load factors
- . Fuel consumption
- . Heat balance
- . Exhaust gas temperature
- . Exhaust gas flow volume
- . Engine cost.

2. ORGANIC RANKINE CYCLE BOTTOMING SYSTEMS

Organic Rankine cycle energy recovery system concepts, under development by three companies, were investigated for application in diesel marine vessels. Three different organic working fluids have been proposed. Safety considerations and controls were investigated; system cost estimates including development costs, manufacturing production costs, installation costs, and operating costs were developed.

3. MARINE VESSEL APPLICATION STUDY

A survey was conducted to determine the number and horsepower rating of diesel powered vessels existing in the current (1976) and the projected 1985 maritime vessel fleet. Marine vessel operational characteristics were analyzed and typical duty cycle/load factors were developed for each type of vessel. Candidate vessels for the application of energy recovery systems were selected by the use of a

filtering process to identify those vessels that exist in large population densities, and operated at high power loading for long periods of time. A study of vessel hotel loads and auxiliary power requirements was conducted to determine the merits of utilizing waste heat energy to supply these demands compared to utilizing the recovered power in the vessel propulsion system.

4. ECONOMIC ANALYSIS

An economic analysis of Rankine cycle diesel bottoming systems was conducted. An analysis on the amortization of development costs was conducted to establish the system selling price, or purchase cost, to the customer. Vessel costs, incorporating energy recovery systems, and operating costs were developed for input to a computerized simulation model. A Maritime Transportation Energy Model which simulated vessel operation on actual trade routes was utilized to analyze the life-cycle cost performance for the selected candidate vessel types. Baseline vessels without energy recovery systems and current retrofitted and new construction vessels incorporating energy recovery systems with varying degrees of power recovery effectiveness were tested. The basic economic output indicators utilized from the marine simulation model to determine the effectiveness of vessels equipped with energy recovery systems are:

- . Change in required freight rate due to the reduced fuel consumption rate of vessels incorporating organic Rankine cycle bottoming systems
- . Annual fuel costs from which the number of years and return on investment in bottoming cycle systems can be derived.

Annual fuel consumption for each candidate vessel type was determined, and the total amount of fuel saved by the use of energy recovery systems for each maritime sector for both partial and full implementation of energy recovery systems was developed.

5. ENERGY RECOVERY SYSTEM CONCEPTUAL DESIGNS

Conceptual hardware configurations of organic Rankine cycle diesel bottoming systems and propulsion system machinery installations were developed for a typical push-towboat for both existing vessel retrofit installation and new vessel construction.

III. MARINE DIESEL ENGINE CHARACTERISTICS

III. MARINE DIESEL ENGINE CHARACTERISTICS

1. GENERAL

Discussion of diesel engine characteristics in this chapter will be limited to engines below 4,000 brake horsepower since the results of the marine vessel survey and selection analysis discussed in Chapter V indicate that the marine vessels with the highest operational fleet density and with high operating duty-cycles, in the primary market for application of diesel bottoming cycle systems, are all below the 4,000 brake horsepower class.

The results of the marine fleet survey analysis also indicate that the primary market for the application of the diesel bottoming cycle is concentrated in the medium size diesel-powered class of tow, tug, and supply boats ranging in power from 1,500 to 3,200 total installed horsepower, as shown in Table III-1. These boats are, almost without exception, powered by two engines for reasons of safety, reliability, maneuverability and control, propeller sizing and bottom clearance, and engine compartment space considerations.

TABLE III-1
Summary: Marine Market for
Diesel Bottoming Cycle Application

Vessel Type	Installed Total Horsepower Range Twin Engines	Installed Horsepower Range per Engine
<u>Primary Market</u>		
Push-tow Boat	3,000 - 3,200	1,500 - 1,600
Inland Tug & Push-Tow Boat	1,500 - 1,800	750 - 900
Supply Boat	1,500 - 1,800	750 - 900
Push-Tow Boat	2,200 - 2,400	1,100 - 1,200
Offshore Tug & Supply Boat	2,200 - 2,400	1,100 - 1,200

The diesel engines most popularly used in the above vessels are those manufactured by several prominent American concerns that include:

- . Alco (4-cycle)
- . Caterpillar (4-cycle)
- . Cummins (4-cycle)
- . Detroit Diesel (2-cycle)
- . Electro-Motive Div. (EMD) (2-cycle)
- . Fairbanks Morse (2-cycle)
- . Waukesha (4-cycle)

These engines are of both the 2-cycle design, available in naturally aspirated or turbocharged configuration, and the 4-cycle design, available in blower-scavenged or turbocharged configurations. Turbocharged engines have become increasingly popular due to the higher power output possible from a lighter and more compact engine and higher efficiency, particularly at their rated speed and power.

A small number of tow, tug, and supply boats have recently been delivered to operators in the U.S. with diesel engines of foreign manufacture.

Although there appears to be no unanimity among engine designers and operators as to the significance of engine speed and duty, it can generally be stated that all of the above marine engine makes used in the type/class of marine vessels in this analysis can be classified as medium- to high-speed medium-duty engines.

2. ENGINE PERFORMANCE CHARACTERISTICS

Marine diesel engines are generally rated by type of vessel service, such as pleasure boat or work boat service, or by continuous and intermittent power ratings to ensure satisfactory service performance. A pleasure boat or crew boat engine can be rated at the intermittent power rating because of the lighter duty-cycle operations where the engine is at high power levels only a part of the operating time.

In a push-tow boat or other heavy-duty work boat installation, more conservatism is exercised in rating the engine because of operation at high power levels for long periods of time. The continuous power rating reduction from the maximum rating varies from one application and manufacturer to another; however, the ratings and figures stated are representative. Figure III-1 illustrates typical marine

FIGURE III-1
Typical Manufacturers' Marine
Diesel Engine Performance Curves

diesel manufacturers' engine performance data for both intermittent and continuous power service for a blower scavenged, 2-stroke cycle diesel engine. The plot also includes the propeller load performance data for marine craft with fixed-pitch propellers. While the engine is capable of developing the rated shaft horsepower indicated, a fixed-pitch propeller cannot utilize it all below the maximum design point propeller speed. The power output at propeller load ratings represents a fixed-pitch propeller horsepower demand and approximates a cubic curve, i.e., speed varies in relation to the cube or third power of the horsepower. The fuel consumption also varies with the power ratings as shown, and is lower at the continuous power rating.

Fuel consumption characteristics of a typical marine diesel engine are shown in Figure III-2. The fuel performance curve shows the fuel consumption for maximum engine power and for the propeller load curve horsepower. A comparison of fuel consumption characteristics versus engine rated brake horsepower for 2-cycle engines is illustrated in Figure III-3, and for 4-cycle engines in Figure III-4. Figure III-3 includes fuel consumption (at propeller load) for both blower-scavenged and turbocharged 2-cycle engines. At a typical operating point of about 75 percent power the Brake Specific Fuel Consumption (BSFC) for a typical 2-cycle blower-scavenged engine is ~ 0.392 LB/BHP-HR, and ~ 0.380 for a typical 2-cycle turbocharged engine. Figure III-4

FIGURE III-2
Typical Marine Diesel Engine Fuel Consumption Map

FIGURE III-3
Fuel Consumption Characteristics of 2-Cycle Marine Diesel Engines

FIGURE III-4
Fuel Consumption Characteristics of 4-Cycle Marine Diesel Engines

includes fuel consumption (at propeller load) for both naturally aspirated and turbocharged 4-cycle engines. At the typical operating point of about 75 percent power, the BSFC for a typical 4-cycle naturally-aspirated engine is ~ 0.387 LB/BHP-HR, and ~ 0.385 LB/BHP-HR for a typical 4-cycle turbocharged engine. For analysis purposes, a fuel consumption rate of ~ 0.385 LB/BHP-HR at 70 to 80 percent power can be used as representative to generalize both 2-cycle and 4-cycle marine engines between 600 and 4,000 BHP rating.

3. DIESEL ENGINE THERMAL CHARACTERISTICS

Of all practical heat engine cycles, the diesel cycle is the most thermally efficient. Thermal efficiencies of modern diesel engines are on the order of 38 to 42 percent. However, some 58 to 62 percent of the fuel energy content is rejected in the form of heat. This heat is carried away by the various engine systems such as jacket water and lubricating oil, while approximately 30 percent is retained in the exhaust gas. This distribution is shown in the heat balance diagram in Figure III-5. The percentage of heat supplied that is converted to brake horsepower is fairly constant above 50 percent of maximum power. But as power is reduced below 50 percent, this percentage decreases at an increasing rate. The proportion of heat that goes to the exhaust, however remains reasonably constant over the whole power range.

FIGURE III-5

Typical Heat Balance Diagram of a 4-Cycle Naturally-Aspirated Diesel Engine Operating at Rated Speed

The thermal parameters of interest in heat recovery from reciprocating engines are the balance of heat between the different modes of heat rejection and exhaust temperatures. The behavior of these parameters varies significantly as a function of the following options available to the designer:

- . 2-stroke or 4-stroke cycle design
- . Combustion cycle
- . Jacket coolant temperature
- . Engine speed
- . Aspiration
- . Engine size.

Figure III-6 illustrates the heat balance of a typical 4-cycle, high-speed marine diesel engine. Figure III-7 shows the heat balance diagram of an opposed piston 2-cycle diesel engine superimposed on the heat balance of a 4-cycle diesel engine. Both of these engines operate as a fixed generator set installation with ebullient jacket water heat recovery. Although the jacket water operating temperature of 230°F is much higher than that of a typical marine diesel, which operates from about 175°F to 195°F, the relative differences would be similar in a marine installation. Both engines are similar in power and specific fuel consumption, and incorporate a similar heat recovery technique. The large differences in the heat balance result mainly from the excess air needed for scavenging in the 2-cycle engine. The increased air flow and resulting lower exhaust temperatures increase the removal of heat by the exhaust gases. The reduced cylinder temperatures, in turn, result in less heat being removed by the jacket coolant. Other variables being constant, 2-cycle engines tend to reject more heat through the lube oil because all strokes are power strokes.

The addition of a turbocharger to an engine substantially increases power output, and usually provides a reduction in specific fuel consumption under higher loads. Typically, a significant reduction occurs in the rejection of heat through jacket coolant and lube oil, while a greater relative amount of heat is lost through exhaust, radiation, and into the added aftercooler. In many engines, the aftercooler is included in the jacket coolant circuit, so that the reduced rejection of heat to the jacket is partially balanced by the added aftercooler heat.

FIGURE III-6
Heat Balance for a Typical
4-Cycle Marine Engine

FIGURE III-7
Comparative Heat Balances of a 2-Cycle
and 4-Cycle Diesel Engine

The extent to which exhaust heat is recoverable from an engine is a function of the absolute amount of heat available in the gases, which is a function of the engine heat balance, and of the exhaust temperature. Different engine types vary widely in their exhaust temperature characteristics. In the design of a heat recovery system, the effect of the following factors on exhaust temperature should be taken into account.

(1) 2-Stroke vs 4-Stroke Cycles

In general, the exhaust temperatures for a 2-cycle engine tend to be much lower than for a 4-cycle engine due to the excess air which is carried in the 2-cycle engine for scavenging. With 2-cycle engines operating at low loads, exhaust heat recovery is particularly problematic because the temperature drop across the heat exchanger is reduced severely at part loads. With 2-cycle diesel engines operating at low loads, the exhaust temperature approaches the 300°F minimum outlet temperature that is advisable with conventional heat exchangers made of corrodible materials. Consequently, the 2-cycle diesel engine, and to a lesser extent the 4-cycle diesel engine, operating at low power loads will be severely limited in exhaust gas heat recovery. Figure III-8 compares the exhaust temperatures of a conventional 4-cycle diesel engine and a conventional 2-cycle diesel. A comparison of exhaust gas temperatures for a number of marine diesel engines is shown in Figure III-9. Figure III-10 illustrates a comparison of exhaust gas flow volume for a number of marine diesel engines.

(2) Jacket Coolant Temperature

Raising the jacket coolant temperature causes a small rise in exhaust temperatures, generally of less than 50°F, in all engine types. More significant is the fact that varying the jacket coolant temperature causes the exhaust temperature to vary in the same direction as the exhaust heat content, so that exhaust heat recovery is always increased by raising the jacket temperature.

FIGURE III-8
Comparative Exhaust Temperatures of Typical
2-Cycle and 4-Cycle Engines

FIGURE III-9
Comparison of Exhaust Gas Temperature
for a Number of Marine Diesel Engines

FIGURE III-10
Comparison of Exhaust Gas Flow Volume
for a Number of Marine Diesel Engines

(3) Engine Speed

Increasing engine speed also increases exhaust temperature. Since exhaust heat also increases with engine speed, greater heat recovery is always achievable at higher engine speeds.

(4) Aspiration

The temperature of the exhaust from a turbocharged engine is determined by the exhaust turbine inlet temperature and the amount of heat removed from the exhaust by the turbine. In some conventional engines, stack temperature is changed little by turbocharging (50°F or less). However, in many cases exhaust gas temperature is reduced by about 200°F due to turbocharging. Thermodynamic data from an engine with one type of aspiration should not be assumed to be similar to that for an engine with different aspiration.

(5) Engine Size

Exhaust temperature does not change significantly as a function of engine size alone.

4. DIESEL ENGINE COST

A comparison of high-speed, medium-duty marine diesel engine costs are shown in Figure III-11. The costs for both the 2-cycle and the 4-cycle engines closely approximate each other because of a highly competitive market. A 2,000 BHP size, 4-cycle turbocharged marine diesel engine approximates \$65/BHP, and a 2,000 BHP size, 2-cycle turbocharged marine diesel approximates \$60/BHP. The cost per horsepower increases slightly for engines smaller than 2,000 BHP and decreases slightly for engines larger than 2,000 BHP.

FIGURE III-11
Typical Costs of High-Speed, Medium-Duty
Marine Diesel Engines

IV. ORGANIC RANKINE CYCLE BOTTOMING SYSTEMS

IV. ORGANIC RANKINE CYCLE BOTTOMING SYSTEMS

1. GENERAL

Considerable interest has been shown in recent years by industry, user organizations, and government in the organic Rankine cycle bottoming system, or diesel bottoming engine, as a means of capturing and utilizing waste heat to improve overall engine cycle efficiency. A bottoming cycle engine is an engine powered by heat that is rejected, and usually discarded, from another heat power cycle. For example, diesel or gas turbine engine exhaust, or furnace or boiler flue gases could be utilized to drive a bottoming engine. The amount of recovered power that could be produced is dependent on the working fluid characteristics, cycle efficiency, amount and temperature of the waste heat, and space available for the sizing of the bottoming system components. Industrial Rankine cycle units powered by diesel engine exhaust reject heat (or other sources such as flue gases) have been built and operated. These units are primarily engine-driven electrical generation plants. Experience with existing units and experimental units has shown that the organic Rankine engine could produce an output power equal to a few percent to over 20 percent of the base diesel engine output power, depending on component design. Fuel consumption of the base diesel engine could be reduced by a comparative amount as an alternative to producing additional shaft horsepower.

Individual engine design, in addition to the type of operating duty-cycle/load-factor, largely determines the practical upper limits of energy recovery. Most models of naturally-aspirated and turbocharged 4-cycle marine diesel engines, and blower-scavenged 2-cycle marine diesel engines appear to offer the best potential for the application of organic Rankine (ORC) cycle bottoming systems. These engines operate with high exhaust reject gas temperatures, and the 2-cycle blower-scavenged engines additionally produce a high gas flow volume. These characteristics are the ingredients for high efficiency organic Rankine cycle bottoming systems, which are able to recover a high percentage of the base engine exhaust energy. Available space, weight, and cost considerations also play a large part in the design of the bottoming system and energy recovery efficiency. If the ship's engine compartment space is at a premium, then

a bottoming system with less power recovery capability must be installed. On many vessels, where engine compartment space and exhaust stack size permit the installation of a large vapor generator, then a bottoming system with a higher percentage of power recovery may be installed.

As discussed in Chapter III, the amount of heat energy available from the engine exhaust gas begins to diminish rapidly below 50 percent engine load. Fuel savings could be significant for vessels such as push-tow boats, Great Lakes cargo ships, and ocean tugs, which operate at high duty-cycle/load-factors for a large number of hours annually. However, fuel savings may not be significant for vessels such as harbor tugs, research vessels, or yachts which operate at low duty-cycle/load-factors or for a small number of hours annually.

A schematic diagram of a closed-cycle organic Rankine bottoming system engine with a turbine expander and powered by diesel engine reject exhaust gases ($\geq 700^{\circ}\text{F}$) is illustrated in Figure IV-1. Heated, high pressure vapor (state 1) is expanded through the turbine engine and produces shaft-work. The expanded vapor (state 2) then passes through a regenerator (heat exchanger) where it is cooled (to state 3) by the transfer of heat to the liquid state of the working fluid. The working fluid exits the regenerator slightly superheated and enters the condenser where it is desuperheated and condensed to liquid (state 4), and enters the feedpump which raises the liquid pressure to expander inlet pressure (state 5). The working fluid is heated as it passes through the liquid side of the regenerator (state 6). The liquid enters the vapor generator where the transfer of heat into the working fluid from the heat source produces high-temperature vapor (state 1), completing the cycle. The system described above is illustrated on a pressure-enthalpy diagram of an organic working fluid, shown in Figure IV-2.

The relationship between the combined diesel/ORC system power output and the base diesel engine power output, and the method by which the addition of a bottoming cycle system improves the economy of a diesel engine, is shown in Figure IV-3. Shaft output power (P) can be produced entirely by the base diesel engine at a lower output power level (B); making up the difference in output power (between A and B) with the exhaust reject heat powered bottoming cycle system. The difference in the fuel consumption of the base diesel engine when operated at state points A and B results in fuel savings, or alternatively in increased engine plant efficiency. Also, additional power (represented by the

FIGURE IV-1
Schematic of an Organic Rankine Cycle Bottoming System

FIGURE IV-2
Rankine Cycle Overlaid on
Pressure-Enthalpy Diagram of an Organic Working Fluid

FIGURE IV-3
Relationship Between Diesel/ORC
Power Output and Base Diesel Engine Power Output

difference of A and C) can be produced and utilized at the same total fuel consumption rate of the base engine only at Point A power output.

2. INDUSTRY SURVEY

Three industrial concerns are most actively engaged in the development of organic Rankine cycle bottoming systems. They have all proposed, are developing, and demonstrating bottoming systems for various industrial applications. The system concepts of these companies were investigated for possible marine applications. These concerns are:

- . Mechanical Technology Incorporated (MTI)
Latham, New York
- . Thermo Electron Corporation (TECO)
Waltham, Massachusetts
- . Sundstrand Energy Systems (SES)
Sundstrand Corporation
Rockford, Illinois.

Mechanical Technology Inc. has been engaged in the development of both binary and single loop organic Rankine cycle bottoming systems for industrial applications. The binary systems utilize Freon R-11 and steam as the working mediums, and the single loop systems utilize Freon R-114 for use with diesel and gas turbine engine exhaust heat sources. Heat source supply has been varied and recovered energy has been primarily used to drive an electrical generator. MTI is currently engaged in the development of a binary bottoming cycle system utilizing the exhaust gas reject heat from a diesel engine of ~7,000 BHP as the heat source, to drive a generator set. Net recovered energy from this system is ~599HP, or 447 KW. MTI has also recently conducted several feasibility studies of bottoming systems for other applications. One, is for the power recovery from gas turbine exhaust heat for an oil pipeline pumping station and a gas pipeline pumping station. The other study is the application of shipboard heat recovery for merchant ships. This study involves the analysis of a base case 24,000 HP steam, marine powerplant, and alternate 24,000 HP diesel and gas turbine marine powerplants. The study also investigated a 2,875 HP inland waterway push-tow boat application, where 184 KW (2,247 BHP) was recovered from the vessel's exhaust reject heat.

Thermo Electron Corp. has been engaged in the development of organic Rankine cycle bottoming systems utilizing Fluorinol-50 and Fluorinol-85 as the working fluid mediums. Several demonstration programs are currently underway at TECO. One includes the design, build, and test of a bottoming system for a large over-the-road diesel tractor. The bottoming system is powered by the exhaust reject heat of a diesel engine rated at ~275 BHP. The recovered horsepower, amounting to about 19 percent for a total engine/bottoming system output of ~326 BHP, will be used to drive the vehicle. Or, fuel savings on the order of about 15 percent can be accomplished by throttling back. TECO is also currently involved in the design, fabrication, and demonstration of a 500 MW integrated diesel/organic Rankine cycle bottoming system for electric power generating stations. They are also developing a 620 BHP bottoming system, which will drive a 450 KW generator. This system is powered by the exhaust reject heat from a 3,600 BHP diesel engine, and operates at a power recovery effectiveness of ~17½ percent.

Sundstrand Energy Systems (SES) has been engaged in the development of organic Rankine cycle bottoming systems utilizing Toluene (among others) as the working fluid. They have developed several varied types of organic Rankine cycle systems below 6 KW in size. Their recent experience includes an 88 HP organic Rankine cycle bus engine, and 40 KW and 100 KW total energy systems. They are currently developing a 600 KW (~800 HP) organic Rankine cycle system to drive a generator. Six of these units are being fabricated that will be powered by the exhaust gas reject heat from a diesel engine rated at about 4,200 HP. Recovered horsepower is ~20 percent.

3. SAFETY CONSIDERATIONS

One of the major considerations associated with the operation of a vessel is that of safety. Any shipboard system whose operation creates the possibility of a safety hazard to crew and ship through inadequate design or by negligent operation must be considered very carefully before incorporation. The installed location of the organic Rankine cycle bottoming systems will be in the vicinity of shipboard operating personnel. Ventilation in ship engine compartments is usually limited. Therefore, it is imperative that the system working fluid does not present a hazard to the crew or vessel in the event of a leak. Because the working medium exists in both the liquid state and vapor

phase, and at high pressures and temperatures throughout various points in the bottoming system, a potential hazard exists from leakage, puncture, or explosion.

The characteristics of the organic working fluids used in the three manufacturers' organic Rankine cycle bottoming systems designs, Fluorinal-85, Toluene, and Freon R-114 are shown in Table IV-1, along with the characteristics of two marine diesel fuels; No. 2-D and No. 4-D. The threshold limit value (TLV) of toxicity indicates that Freon R-114 is the safest substance, requiring concentration levels of about 1,000 parts per million (PPM) (by volume). Toluene has a TLV of 200 PPM, which is equal to that of the marine diesel fuels. Fluorinal-85 requires the lowest value of concentration (10 PPM) and is the most toxic of the substances. All of the substances listed in the table are classed as toxic by OSHA/NIOSH.

Freon R-114, a fluorocarbon compound, is a nonflammable substance; however, a violent explosion may occur when in contact with highly reactive metals. Fluorinal-85, a mixture 85 mol. % trifluorethanol and 15 mol. % water; and Toluene, a petroleum derivative: both capable of working at high temperatures, present an explosive hazard in the event of a leak in the system. The auto-ignition point of both Fluorinal-85 and Toluene is approximately 400°F higher than that of the ship's diesel engine fuel. The products of combustion of all of the working fluids, as well as of the marine diesel comparison fuels, are toxic. Freon R-114, although nonflammable, decomposes when exposed directly to high temperatures. Flames and resistance heaters, for example, will cause pyrolysis of fluorocarbon vapors. These toxic vapors produce a pungent odor and tend to irritate the nose, eyes, and upper respiratory system, which will alert personnel in the vicinity of its presence. Freon has been safely used in home and industrial air conditioning and refrigeration equipment for many years.

The use of Freon R-114 as the working fluid in organic Rankine cycle bottoming systems on marine vessels appears to be the safest medium from a flammability or explosion standpoint. But, because the working temperature of this substance is much lower than that of the other fluids, the power recovery efficiency of the bottoming system will be lower for equivalent size components, i.e., vapor generator, etc. than that for systems using Fluorinal-85 or Toluene. From an overall safety standpoint, it is believed that Fluorinal-85 poses no more of a hazard potential than engine diesel fuel (which is also pumped at high pressure, though

TABLE IV-1
Characteristics of Three Organic Working Fluids
and Two Marine Diesel Fuels

Substances Characteristics	Fluorinal 85	Toluene (Methyl Benzene)	Freon (R-114) (Dichlorotetra fluoromethane)	No. 2-D (Marine Diesel Fuel Oil)	No. 4-D (Marine Diesel Fuel Oil)
<u>Toxicity</u> Threshold Limit Value (TLV)	10 PPM	200 PPM	1,000 PPM	200 PPM	200 PPM
OSHA/NIOSH Class	Toxic	Toxic	Toxic	Toxic	Toxic
<u>Availability</u> Quantity	Medium	Unlimited	Unlimited	-	-
Cost	~ \$35/gal.	~ \$2.50/gal.	~ \$0.52/lb.	-	-
<u>Flammability</u> Flash Point	108°F	40°F Closed Cup	Nonflammable	125°F Closed Cup	130°F Closed Cup
Fire Point	160°F	40°F	n/a	195°F	200°F
Auto Ignition Point	900°F	947°F	n/a	494°F	505°F
Products of Combustion	Toxic	Toxic	Toxic	Toxic	Toxic
Vapor Pressure PSIA @ 70°F	1.0	0.4588	~ 13.4	~ .019	~ .0019
Max. Operating Temp., °F	550-575	750-880	400	-	-

n/a—not applicable

much lower temperatures) in the event of a line rupture. The use of Toluene as a working fluid may be potentially more hazardous than Fluorinal-85 (and vessel diesel fuel) because of its lower flash point and fire point. All of the proposed working fluids (as well as diesel fuels) are considered to be toxic by OSHA/NIOSH standards. The use of both Fluorinal-85 and Toluene in Rankine cycle energy recovery systems will be subject of U.S. Coast Guard regulations and American Bureau of Shipping rules. Good equipment design and installation practice must be adhered to, in addition to good vessel machinery operating procedures and adequate compartment ventilation. The equipment must be designed and constructed to meet U.S. Coast Guard and American Bureau of Shipping rules.

4. CONTROLS

Operational control of a vessel equipped with a diesel bottoming system coupled into the main ship's propulsion system would require a minimum of extra effort on the part of the pilot because control functions are largely automatic. As the ship engines' throttles are advanced and power increases, power output from the Rankine bottoming system increases; as the throttle position is reduced, the output power from the bottoming system is correspondingly reduced since the performance of the bottoming system is dependent upon the quantity and temperature of the exhaust gases from the base engine. Governing of power turbine speed can be eliminated as a control requirement for the organic Rankine cycle system by direct coupling of the turbine assembly, through the reduction gearbox, to the diesel engine output shaft ahead of the marine transmission clutch assembly. Because of the low power output of the Rankine cycle power turbine assembly relative to that of the base diesel engine, the speed governing function is performed by the diesel engine using its standard governing system. To avoid back-driving of the turbine and gearbox assembly by the base diesel engine when it is throttled back (decelerating), or if the bottoming system is inoperative for some reason, an overrunning clutch assembly can be incorporated into the gearbox assembly and would perform its function automatically. An air- or hydraulic-actuated clutch assembly may be needed to uncouple the organic Rankine cycle system completely out of the power stream, at the option of the ship's pilot.

Throttling of the organic fluid flow rate into and out of the vapor generator to maintain proper pressure and temperature to the turbine over the approximate 40/50 percent

to 100 percent rated power operating range of the base diesel engine can be accomplished by modulating control valves, which utilize the fuel flow rate of the base diesel engine as an input to predict and select the proper organic fluid flow. This system positions feed pump displacement to supply the proper flow rate of the organic working fluid. These functions are completely automatic and require no action by the vessel's pilot. All system thermal and pressure protection sensors (regulators, valves, etc.) are fully automatic as are those required for system control and operating functions. In the event of a failure or malfunction in the Rankine cycle bottoming system, or for other reasons, where the system must be shut down without affecting operation of the ships diesel propulsion engine; a system to by-pass the bottoming system turbine and dumping the excess heat into the condenser; or an exhaust gas by-pass flap valve and duct assembly incorporated into the vapor generator assembly, must be considered in the system design.

5. SYSTEM COST

(1) General

The cost of organic Rankine cycle bottoming systems was developed from data on existing units, published data, data supplied by the three developers, and engineering analysis. Costing of Rankine cycle bottoming systems was difficult because of the great variance in system designs, heat sources, organic fluid types, system recovery efficiencies, type of heat rejection systems, single and dual heat source system designs, size of systems, and application of recovered power. In addition, current cost data available represent single unit systems under development or small quantities. Cost data on past systems are several years old and reflect construction of a single or limited number of units. Cost data on many units, past and present development, do not necessarily include all associated costs, such as development costs. Installation, maintenance, and operating costs vary greatly from one installation to another. Table IV-2 shows a cost comparison of several industrial organic Rankine cycle bottoming system installations, which vary in cost from \$300/KW to \$1,300/KW (\$224/BHP to \$970/BHP).

TABLE IV-2
Cost Comparison of Several Industrial
Organic Rankine Cycle Bottoming System Installations

Heat Energy Source	Rankine Cycle Bottoming System Output Power Desired	Rankine Cycle Bottoming System Recovery Power (% of heat source power)	System Cost (\$/KW)	System Cost (\$/BHP)
<u>Existing Installations</u>				
560°F Diesel Exhaust	Electric - 360-690KW	?	300-485*	224-362*
340°F Condensing Vapor	Electric - 1500 KW	?	390*	291*
875°F Engine Exhaust	Electric - 1100 KW	?	352*	263*
750°F Heater Stacks	Electric - 700 KW	?	748*	558*
450°F Turbine Exhaust	Electric - 1000 KW	?	618*	461*
<u>Recent Development Units</u>				
~800°F Diesel Exhaust	Electric - 450 KW	17.5	1300	970
~800°F Diesel Exhaust	Electric - 600 KW	20.0	1000	746

* 1974 Costs

(2) Cost Elements

The cost elements considered in the life-cycle cost of the energy recovery system to the purchaser/operator include development, production, installation, and operating costs.

1. Development Cost

Development cost is comprised of all costs leading to the development of a prototype organic Rankine cycle bottoming system, including feasibility analysis, engineering, drawing package, procurement, manufacturing, assembly, installation, and performance and safety testing. Development engineering cost of organic Rankine cycle diesel bottoming systems is shown in Figure IV-4. Fabrication and assembly cost of prototype/test Rankine cycle bottoming systems hardware is shown in Figure IV-5 and prototype testing cost is shown in Figure IV-6. The total development cost of Rankine cycle diesel bottoming systems is shown in Figure IV-7, and includes the costs of engineering (Figure IV-4), prototype test unit building (Figure IV-5), and hardware testing (Figure IV-6). Testing costs are higher for units of lower percentage of recovered power because of higher input heat requirements and hence higher fuel usage for recovered energy. These costs are also reflected in the total system development cost estimate, shown in Figure IV-7, where costs for 10 percent, 12.5 percent and 15 percent recovery are shown as being about equal.

2. Production Cost

The production cost is comprised of all costs leading to multiple unit production of organic Rankine cycle bottoming systems, and includes specification preparation, engineering changes resulting from prototype testing, production engineering, production drawing package, procurement, manufacturing, assembly, quality control, and operational testing. In this study and analysis of organic Rankine cycle bottoming systems for marine vessels, production costs of diesel bottoming systems, shown in Figure IV-8, are taken as installed costs and include initial system start-

FIGURE IV-4
Organic Rankine Cycle Diesel Bottoming System
Development Engineering Cost Estimate

FIGURE IV-5
Organic Rankine Cycle Diesel Bottoming System
Prototype/Test Unit Cost Estimates

FIGURE IV-6
Organic Rankine Cycle Diesel Bottoming System
Prototype Testing Cost Estimates

FIGURE IV-7
Organic Rankine Cycle Diesel Bottoming System
Total System Development Cost Estimates

FIGURE IV-8
Organic Rankine Cycle Diesel Bottoming System
Production Cost Estimates

up, operational check-out, and warranty costs. The costs are fully burdened (overhead and G&A) and include profit, but do not include the amortization of development costs and any tooling involved. This was done for convenience at this point, and amortization of development costs is discussed later in Chapter VII. Also shown in Figure IV-8 are cost estimates for organic Rankine cycle bottoming systems currently under development by Mechanical Technology Inc., Thermo Electron Corporation, and Sundstrand Energy Systems. The three specific bottoming cycle systems identified in this Figure are for specific designs, cycle efficiencies, and base diesel engines, and may not be representative of the maximum amount of power recovery capability for each particular system design. For example, the Thermo Electron unit is specifically designed for use with a 2-cycle turbocharged diesel engine rated at $\sim 3,600$ BHP. This particular diesel engine has an exhaust gas reject heat temperature of about 725°F . If this same Rankine cycle bottoming system were applied to a blower-scavenged 2-cycle engine of the same BHP rating, whose exhaust gas temperature would be more on the order of about 825°F to 850°F , the cycle efficiency would increase in the bottoming system. The recovery power effectiveness ratio, as a percent of base diesel engine power, would increase from $17\frac{1}{2}$ percent to approximately 20 percent. The same note of caution applies to the MTI and SES systems, which are designed for specific installations and conditions, and may not be optimal for other applications.

3. Installation Cost

The installation cost is comprised of all costs involved in the installation of organic Rankine cycle bottoming systems into a marine vessel, including initial start-up and operational checkout. These costs are included in the equipment production cost as discussed in the preceeding paragraph, Production Cost, and are valid for both new vessel construction and existing retrofit. However, the cost of any major tear-out or reinstallation of the main propulsion engine(s), marine reduction drive gearbox, shafting modifications, or exhaust stacks are not included in the unit-installed production costs. This was done for convenience at this point and is discussed later in Chapter VII.

4. Operating Cost

The operating cost is comprised of all costs associated with the organic Rankine cycle bottoming system during the equipment's useful economic operating life and includes maintenance, repair parts, and supplies. No additional labor should be required as the equipment is relatively straightforward and inherently simple in design, has few moving parts and controls, and operates at comparatively low pressures and temperatures. Ship's maintenance crew personnel should be able to perform routine inspections and maintenance work within their regular ship's machinery maintenance schedule and work shifts. Table IV-3 shows a comparison of typical operating and maintenance costs for electric plants and marine diesel engines.

TABLE IV-3
Comparison of Typical Operating and Maintenance Costs
for Electric Plants and Marine Diesel Engines

TYPE OF UNIT	O&M COST \$/KW-H	O&M COST \$/BHP-H
Average Electric Plant (100% Load Factor)	~0.0030	~0.00220
Well Managed New Electric Plant (100% Load Factor)	~0.0015	~0.00110
Small Electric Plants	~0.0013*	~0.00095*
Marine Diesel Engine, 4-Cycle	-	~0.00082*
Marine Diesel Engines, 2-Cycle	-	~0.00068*
Large Diesel Marine Engines	-	~0.00090*

*Based on 6,000-hours/year operation.

Costs factored to December 1976 dollars.

Figure IV-9 illustrates a comparison of maintenance and repair costs in \$/BHP/year versus installed BHP for typical industrial plants and marine engines. Figure IV-10 shows a comparison of annual maintenance and repair costs for several typical industrial plants and marine engines.

Table IV-4 shows a comparison of maintenance and repair costs for several proposed ORCBS and several current development ORC systems. Maintenance and repair (M&R) cost data for the generic ORC system used in this comparison are also shown, and is conservatively estimated to be $\sim \$0.0015/\text{KW-H}$, or $\sim \$0.0011/\text{BHP-H}$ ($\text{KW} \div 1.34 = \text{BHP}$). The M&R figure of $\$0.0011/\text{BHP-H}$ is generally supported by the three developers (MTI, TECO, and SES) as realistically attainable and is also supported by past operating data of electric plants, marine engines, and other similarly comparable equipment (Table IV-3, Figure IV-9, and Figure IV-10).

NOTE: ALL COSTS FACTORED TO 1976 DOLLARS (U.S. STAT. ABS. 1976 & S.C.A. 4TH QTR. 1976).

FIGURE IV-9
Comparison of Maintenance and Repair Costs
for Typical Industrial Plants and Marine Engines

NOTE: ALL COSTS FACTORED TO 1976 DOLLARS (U.S. STAT. AB. 1976 & S.C.A. 4TH QTR., 1976)
 SHP CONVERTED TO INSTALLED BHP.

FIGURE IV-10
 Comparison of Annual Maintenance and Repair Costs
 for Industrial Plants and Marine Engines

TABLE IV-4
Comparison of Maintenance and Repair Costs for Proposed
and Development Organic Rankine Cycle Bottoming Systems
and Generic Organic Rankine Cycle Bottoming System

ORCBS System	Diesel Engine/ Generator/ ORCBS Unit \$/KW-H	Diesel Engine/ Generator/ ORCBS Unit \$/BHP-H	Rankine Cycle Bottoming System Only \$/KW-H	Rankine Cycle Bottoming System Only \$/BHP-H
600 KW ORC Unit, Conservative Estimate (Sundstrand Energy Systems)	-	-	~0.0030	~0.0022
600 KW ORC Unit, Confidence Estimate (Sundstrand Energy Systems)	-	-	~0.0015*	~0.0011*
450 KW ORC Unit - 5.5 MW Diesel Eng./ Gen./ORC Unit (Thermo Electron Inc.)	~0.0030	~0.0022	~0.0015*	~0.0011*
184 KW ORC Unit (Proposed) (Mechanical Technology Inc.)	-	-	~0.0015 [†]	~0.0011 [†]
370 KW/500BHP ORC Unit (Proposed) 350°- 370°F Flue Gas Heat Source (MarAd sponsored study for energy recovery system for ships)	-	-	~0.0037 [‡]	~0.0028 [‡]
Generic Organic Rankine Cycle Diesel Bottoming System (M&R cost data used in this study)	-	-	~0.0015	~0.0011

Load Factor - 1.0; Oper. hrs/year ~6,000

* Estimated by company to be equal to an equivalent size diesel engine/generator plant.

† Estimated by company to be equal to base diesel engine, or an equivalent size diesel engine/generator plant.

‡ M&R cost approximately equal to 2%/year x installed or ORCBS unit cost.

Note: All costs factored to 1976 dollars where applicable

V. MARINE VESSEL APPLICATION STUDY

V. MARINE VESSEL APPLICATION STUDY

1. GENERAL

The potential market for the application of closed-cycle heat recovery systems to marine diesel propulsion systems and auxiliary systems is defined as those commercial and government owned vessels of 800 horsepower or greater. This chapter provides the results of a comprehensive survey and analysis of the entire maritime market and the selection of the most promising applications.

2. CURRENT (1976) FLEET SURVEY AND 1985 FLEET PROJECTION

(1) Current Maritime Fleet Survey

The current U.S. merchant, U.S. Navy, U.S. Coast Guard, and National Oceanographic and Atmospheric Administration (U.S. NOAA) marine vessel fleet was surveyed and broken down into 1,000 BHP increments. The results of this survey are summarized in Table V-1. The detailed fleet breakdown for each of the four maritime sectors, by vessel type and horsepower, is shown in Tables V-2, V-3, and V-4.

A fully-detailed breakdown of diesel engine-powered U.S. merchant vessels of the U.S. by horsepower versus vessel age distribution is provided in Appendix B.

The data concerning commercial vessels was obtained from the 1976 U.S. Coast Guard computer tapes of the publication "Merchant Vessels of the United States." Data on the number and types of U.S. Navy, U.S. Coast Guard, and U.S. NOAA vessels was extracted from "Jane's Fighting Ships, 1976-1977," and verified through interviews with appropriate representatives from each of the three government organizations.

The results of the survey and analysis show that the potential 1976 maritime market for the application of heat-recovery systems consists of slightly over 5,200 vessels above 800 brake horsepower in size.

TABLE V-1
Summary: Current (1976) U.S. Diesel-Powered Maritime Fleet

SECTOR	HORSEPOWER RANGE	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10000	10001+	TOTAL
NOAA		7	5	4	1	2							19
U.S.C.G.		16	100	30		15				1	4	3	169
U.S. NAVY		62	106	71	6		6	17			8	40	316
COMMERCIAL		1496	2120	459	333	136	73	40	25	16	19	19	4717
TOTAL		1581	2331	564	340	153	79	57	25	17	12	62	5221

TABLE V-2
Current (1976) U.S. Commercial, Diesel-Powered Merchant Fleet

<div style="display: inline-block; transform: rotate(-45deg);">VESSEL TYPE</div> <div style="display: inline-block; transform: rotate(45deg);">HORSEPOWER RANGE</div>	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10000	10001 & UP	TOTAL
TOWING VESSELS	631	1074	272	219	116	53	32	5	15		8	2425
OFFSHORE WORKBOATS	152	445	112	35	9	9	2	9			1	774
CARGO VESSELS	21	58	18	15	8	6	3	4	1		9	143
FISHING VESSELS	144	149	31	54	2	2						382
PASS./FERRY	133	162	16	9		3	3	7			1	334
MISC. SERVICE CRAFT	14	19	3									36
LARGE YACHTS	401	213	7	1	1							623
TOTAL	1496	2120	459	333	136	73	40	25	16		19	4717

TABLE V-3
Current (1976) U.S. Navy Diesel-Powered Fleet

Horsepower Range Vessel Type	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10000	10001+	TOTAL
AMPHIBIOUS											20	20
LANDING CRAFT	56											56
PATROL BOATS	5	16					17					38
MINE WARFARE			25									25
FLEET SUPPORT		3	41			5				1	7	57
SEALIFT SHIPS		3		1							13	17
RESEARCH SHIPS	1	3	5	5		1				7		22
SERVICE CRAFT		81										81
TOTAL	62	106	71	6		6	17			8	40	316

TABLE V-4
Current (1976) U.S. Coast Guard and U.S. NOAA Diesel-Powered Fleet

Horsepower Range Vessel Type	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10000	10001+	TOTAL
CUTTERS					15		12					27
PATROL BOATS		53	22									75
ICEBREAKERS		1								3	3	7
SEAGOING TENDER		36										36
COASTAL TENDER	1	8										9
RIVER TENDER	4	1	1									6
OCEAN TUGS		2	5									7
HARBOR TUGS	13											13
TRAINING CUTTER	1											1
NOAA	7	5	4	1	2							19
TOTAL	23	105	34	1	17		12		1	4	3	200

(2) 1985 Maritime Fleet Projection

The U.S. merchant, U.S. Navy, U.S. Coast Guard, and U.S. NOAA marine vessel fleet was projected to 1985 to determine the future potential market for heat recovery systems. The results of this projection analysis are summarized in Table V-5. The detailed 1985 fleet projections for each of the four maritime sectors, by vessel type and horsepower, are shown in Tables V-6, V-7, and V-8. The results of the projection analysis show that the potential 1985 maritime market for the application of heat recovery systems will consist of slightly over 6,000 vessels, above 800 brake horsepower in size. This is approximately 800 vessels more than the current diesel-powered fleet.

In order to project the present maritime fleet to 1985, as summarized in Table V-5, data was solicited from several sources. A survey of congressional appropriation hearings, supplemented by interviews with agency personnel, provided the basis for projecting U.S. Navy, U.S. Coast Guard, and U.S. NOAA vessels to 1985, and is shown in Tables V-6 and V-7.

In the U.S. commercial sector, shown in Table V-8, the number of towing vessels remains almost constant, but there is an upward shift in horsepower within each horsepower range. Historically, based on U.S. Army Corps of Engineers data, there has been an average annual increase in total horsepower of about six percent with very little fluctuation in the actual number of vessels. Based on conclusions made in Booz, Allen's "Study of Energy Use in the Marine Transportation Industry," there is a projected increase in offshore service craft requirements from 2.5 to 3.0 boats per drilling rig by 1985. No increase in the number of fishing vessels is projected because information received from fishing industry representatives indicate that a surplus of vessels now exists and new vessel additions to 1985 will be minimal. No data was available to form a basis of projecting the number of yachts to 1985. Current shipyard order books provided the information to project the increases in vessel numbers in the remaining categories of commercial vessels.

TABLE V-5
Summary: Projected 1985 U.S. Diesel-Powered Maritime Fleet

HORSEPOWER RANGE SECTOR	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10000	10001+	TOTAL
NOAA	7	7	4	1	2							21
USCG	3	100	43				39		1	9	3	198
U.S. NAVY	62	108	61	6	25	6	17			8	42	335
COMMERCIAL	1,598	2,509	616	370	149	84	43	33	17	1	38	5,458
TOTAL	1,670	2,724	724	377	176	90	99	33	18	18	83	6,012

TABLE V-6
Projected 1985 U.S. Navy Diesel-Powered Fleet

HORSEPOWER RANGE VESSEL TYPE	800- 1,000	1,001- 2,000	2,001- 3,000	3,001- 4,000	4,001- 5,000	5,001- 6,000	6,001- 7,000	7,001- 8,000	8,001- 9,000	9,001- 10,000	10,001+	TOTAL
AMPHIBIOUS											20	20
LANDING CRAFT	56											56
PATROL BOATS	5	19					17					41
MINE WARFARE			25									25
FLEET SUPPORT			31		13	5				1	9	59
SEALIFT SHIPS		3		1							13	17
RESEARCH SHIPS	1	3	5	5	12	1				7		34
SERVICE CRAFT		83										83
TOTAL	62	108	61	6	25	6	17			8	42	335

TABLE V-7
Projected 1985 U.S. Coast Guard and U.S. NOAA Diesel-Powered Fleet

<div><div>HORSEPOWER RANGE</div><div>VESSEL TYPE</div></div>	800-1000	1001-2000	2001-3000	3001-4000	4001-5000	5001-6000	6001-7000	7001-8000	8001-9000	9001-10000	10001 & UP	TOTAL
CUTTERS							39					39
PATROL BOATS		53	22									75
ICEBREAKER		1								8	3	12
SEAGOING TENDERS		36										36
COASTAL TENDERS	1	8										9
RIVER TENDERS	1		3						1	1		6
OCEAN TUGS		2	5									7
HARBOR TUGS			13									13
TRAINING CUTTER	1											1
NOAA	7	7	4	1	2							21
TOTAL	10	107	47	1	2		39		1	9	3	219

TABLE V-8
Projected 1985 U.S. Commercial Diesel-Powered Merchant Fleet

HORSEPOWER RANGE VESSEL TYPE	800- 1,000	1,001- 2,000	2,001- 3,000	3,001- 4,000	4,001- 5,000	5,001- 6,000	6,001- 7,000	7,001- 8,000	8,001- 9,000	9,001- 10,000	10,001+	TOTAL
TOWING	593	1,048	320	222	122	57	33	6	16	1	8	2,426
OFFSHORE	292	859	218	68	16	16	4	16			2	1,491
CARGO	21	58	18	16	8	6	3	4	1		27	162
FISHING	144	149	31	54	2	2						382
PASS/FERRY	133	163	18	9		3	3	7			1	337
MISC SERVICE	14	19	4									37
YACHTS	401	213	7	1	1							623
TOTAL	1,598	2,509	616	370	149	84	43	33	17	1	38	5,458

3. HEAT RECOVERY SYSTEM VESSEL APPLICATION SELECTION

(1) Marine Vessel Operational Characteristics

An analysis of the general operating characteristics and mission profiles for each vessel type within the U.S. merchant, Navy, Coast Guard, and NOAA fleets was conducted to establish the engine duty-cycle/load-factor. This analysis was conducted to identify those vessels whose potential diesel engine exhaust reject heat energy was available in sufficient quantity for viable operation of a closed-cycle bottoming system. Information on various types of commercial vessels operating duty cycles was extremely scarce, and does not exist, as far as is known, in any one source or convenient number of sources. Two of the most prominent marine diesel engine manufacturers were able to provide some insight into the operational characteristics of several types of commercial vessels. Therefore, the operational duty-cycle/load-factors were constructed from basic beginnings during the course of this study.

Information and data on the number of operating hours per year, mission profiles, power levels, and various other operating characteristics were obtained from a large number of operators, shipbuilders, engine manufacturers, various industry and government officials, and trade publications and journals. These data were analyzed and evaluated to provide vessel and engine operational duty-cycle/load-factor type scenarios.

The scarcity and the level of difficulty in obtaining operating data on government-owned vessels outweighed the potential of these vessels for heat recovery and energy savings compared to vessels in the commercial sector. The data obtained indicates that these vessels are operated a relatively small number of hours per year, that there is little full-power operation, and that the vessels represent a very small portion of the total maritime sector. However, several vessels that government representatives felt might demonstrate good heat recovery potential were included in the duty cycle analysis.

The duty cycle was constructed for each type of vessel in terms of percent of time versus percent power loading for that amount of time. The duty cycle is representative of operations of a "typical" vessel, while considering the operational characteristics of all vessels within a given type class. Certain vessels within a type class may experience somewhat different duty cycles. For example, push-tow boats operating on the lower Mississippi River and the Gulf Intercoastal waterway tend to operate at a higher duty cycle than those vessels operating on the upper reaches of the Mississippi, or on the Ohio River, because of the greater expanse of water and the fewer number of locks that must be traversed. Nevertheless, the duty cycles developed for all of the vessels are considered to be representative of typical vessels and operations. An overall weighted average duty cycle was developed from the average duty cycle data and represents the overall weighted average power loading on a 100 percent of the time basis that the engine is operating.

Because the engine exhaust reject heat decays at an accelerated rate below approximately 50 percent power loading on a diesel engine, as outlined in Chapter III, a weighted average power factor for engine operations at 50 percent and higher power level was developed as a function of percent of time at that weighted power level.

The results of the operational duty-cycle/load-factor analysis and evaluation are summarized in Table V-9 and graphically illustrated in Figure V-1 for a number of vessels. The comprehensive and detailed operational characteristics and duty-cycle/load-factors for these vessels are found in Appendix C.

(2) Selection of Candidate Vessels for the Application of Heat Recovery Systems

It became necessary to further separate some of the major categories of commercial vessels due to the diversity of operating characteristics. As shown in Table V-10, towing vessels were subdivided into ocean-going or coastal tugs, inland tugs, and push-tow boats.

TABLE V-9
Summary: Typical Marine Duty-Cycle/Load-Factor
for Various Vessel Types

Vessel Type	Overall Weighted Average Power ____ % Power (for 100% annual engine hours)	Weighted Average Power for 50% Power Level and Higher ____ % Power/for ____ % Time (based on annual engine hours)
Inland river push-tow boats	71	78/89
Inland tugs	85	95/86
Ocean/coastal tugs	87	87/90
Offshore tugs (oil industry)	65	93/60
Offshore tug/supply boats (oil industry)	66	91/65
Offshore crew/crew supply boats (oil industry)	77	100/70
Offshore supply boats (oil industry)	69	100/60
Passenger/car ferries	65	81/80
Great Lakes cargo ships and tankers	87	95/89
Coastal tankers	87	95/90
Fishing seiner boats	71	86/79
Research/exploration/survey vessels	54	84/50
Harbor tugs	47	90/20
Large yachts	46	83/30
AD - Sealift tankers (Navy)	74	81/89
ATF - Fleet tugs (Navy)	66	76/83
MSO - Mine Sweeper (Navy)	54	56/95
AS - Sub tenders (Navy)	66	75/85
LST's (Navy)	51	53/95
High endurance cutter (Coast Guard)	40	68/45
Medium endurance cutters (Coast Guard)	45	63/60
Ice breakers (Coast Guard)	60	74/74

FIGURE V-1
 Duty-Cycle/Load-Factors for a Number of Vessels

TABLE V-10
Commercial Marine Vessel Types

TOWING VESSELS

Harbor tugs (miscellaneous service craft)
Ocean/coastal tugs
Push-towboats
Inland tugs

OFFSHORE WORK VESSELS

Supply boats
Tug/supply boats
Crew boats
Offshore tugs
Crew/supply boats*
Miscellaneous work boats*
Research/exploration/survey boats*

CARGO VESSELS

Coastal tankers
Great Lakes bulk carriers
Great Lakes tankers

FISHING VESSELS

Seiner boats
Trawler ships*

FERRY BOATS

Passenger/car ferries
Passenger ferries*
Car/railcar ferries*

YACHTS

Pleasure/private/corporate boats

MISCELLANEOUS SERVICE VESSELS

Fireboats*
Police/patrol boats*
Ice breakers (harbor)*
Pilot boats*

* Vessels consolidated with other vessel type or dropped from further consideration.

The actual number of towing vessels in each new category were estimated based on U.S. Army Corps of Engineers data, which separates towing vessels by area of operation. The oil exploitation vessels were separated into supply boats, tug/supply boats, crew boats, and offshore tugs. Diesel-powered cargo vessels are rare in the U.S. flag fleet, but some are in operation as small coastal tankers or Great Lakes bulk carriers and tankers. The category known as miscellaneous service craft (those vessels usually confined to local harbor areas) is represented by a typical harbor tug engaged primarily in assisting ocean liners. Harbor passenger vessels, which operate at low power levels over short distances, were dropped from consideration in favor of passenger/car ferries, which operate at a much high duty-cycle/load-factor. Tables V-11, V-12, and V-13 display the final population breakdown of commercial and government-owned vessels for further evaluation and candidate vessel selection.

For each of the vessel types listed in Tables V-11, V-12, and V-13, the horsepower hours per year were calculated for the weighted average power operations at 50 percent and higher power levels. Vessels operating at these higher power levels offer the best potential for exhaust reject heat bottoming cycle system application and fuel savings. The results of this analysis are compared in Table V-14, which indicates that towing vessels, oil exploitation vessels, fishing vessels, and ferries should be analyzed further.

Because almost all U.S. Navy, Coast Guard, and NOAA vessels operate at relatively low duty cycles over shorter numbers of yearly operating hours, and exist in smaller population quantities than a large number of commercial vessels, they were dropped from further consideration at this point in the study. However, this does not mean that all of these vessels are not good candidates for diesel bottoming cycle systems. Some types may be good candidates for the application of energy conservation systems and should be investigated further.

In order to establish the concentrations of engine horsepower size in these four groups, the U.S. Coast Guard tapes were programmed to provide a breakdown of vessel population numbers and characteristics by 100 horsepower increments. In addition, the tapes provided an age breakdown in five-year increments

TABLE V-11
Potential Maritime Market for Heat Recovery Bottoming Cycle Application
Commercial Fleet

Horsepower Vessel Type Range	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10,000	10,001 & up	Total
Push-towboats	364	620	156	126	70	30	14	5	10	0	5	1400
Ocean/coastal tugs	202	344	90	75	36	23	18	5	4	0	3	800
Inland tugs	27	46	12	10	5	0	0	0	0	0	0	100
Offshore tugs	12	34	36	44	41	22	20	7	24	0	0	240
Tug/supply boats	0	3	55	28	22	17	17	14	7	9	1	173
Supply boats	9	48	45	34	2	4	0	0	0	1	0	143
Crewboats	37	135	23	0	0	0	0	0	0	0	0	195
Great Lakes cargo vessels	1	6	10	6	2	3	4	0	0	1	3	36
Coastal tankers	9	20	5	2	0	0	0	0	0	0	0	36
Fishing seiners	144	149	31	54	2	2	0	0	0	0	0	382
Passenger/car ferries	13	15	5	3	0	3	3	7	0	0	1	50
Harbor tugs	27	46	12	10	5	0	0	0	0	0	0	100
Large yachts	401	213	7	1	1	0	0	0	0	0	0	623
Total	1246	1679	487	393	186	104	76	38	45	11	13	4278

TABLE V-12
Potential Maritime Market for Heat Recovery Bottoming Cycle Applications
U.S. Navy

Horsepower Range Vessel Type	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10,000	10,000 & up	Total
Miscellaneous ships	-	3	-	1	-	-	-	-	-	-	13	17
LST	-	-	-	-	-	-	-	-	-	-	20	20
(ATF) Fleet tugs	-	-	22	-	-	-	-	-	-	-	-	22
(AS) Sub tenders	-	-	-	-	-	-	-	-	-	-	9	9
(MSO) Mine sweepers	-	-	25	-	-	-	-	-	-	-	-	25
Total	-	3	47	1	-	-	-	-	-	-	42	93

TABLE V-13
Potential Maritime Market for Heat Recovery Bottoming Cycle Applications
U.S.C.G. and N.O.A.A.

Horsepower Range Vessel Type	800- 1000	1001- 2000	2001- 3000	3001- 4000	4001- 5000	5001- 6000	6001- 7000	7001- 8000	8001- 9000	9001- 10,000	10,000 & up	Total
Cutters	-	-	-	-	15	-	12	-	-	-	-	27
Icebreakers	-	1	-	-	-	-	-	-	-	6	3	10
All research ships	8	8	9	6	2	1	-	-	-	7	-	41
Total	8	9	9	6	17	1	12	-	-	13	3	78

TABLE V-14
Comparison of Yearly Developed Power
for Diesel Bottoming Cycle Candidate Applications

Vessel Type	Average Installed Brake Horsepower	Annual Engine(s) Operating Hours	Weighted Average Power for 50% Power Level & Higher - % Power for % Time (Based on yearly engine hours)	Total Number of Horsepower/Hours/Year Per Vessel for Operation at Weighted Average Power at 50% Power Level & Higher	Number of Vessels	Total Number of Horsepower/Hours/Year for All Vessels for Operation at Weighted Average Power at 50% Power Level & Higher x 10 ⁶
Ocean/Coastal Tugs	2,000	6,240	87/90	10,670,400	800	8,536
Coastal Tankers	1,560	6,500	95/90	8,669,700	36	313
Push-Tow Boats	1,350	8,280	78/89	7,759,768	1,400	10,864
Inland Tugs	1,350	5,568	95/86	6,141,226	100	614
Fishing Seiner Boats	1,670	4,560	86/79	5,173,767	382	1,976
Great Lakes Vessels	3,800	5,280	95/89	16,964,112	36	611
Harbor Tugs	1,350	2,800	90/20	850,500	100	85
Passenger/Car Ferries	3,350	7,000	81/80	15,195,600	50	760
Large Yachts	1,000	120	83/30	29,880	623	19
Research/Exploration/ Survey Vessels	4,000	4,560	84/50	7,660,800	50	383
Offshore Crew/ Crew Supply Boats	1,650	2,700	100/70	3,118,500	183	570
Offshore Tug/Supply Boats	4,000	4,900	91/65	11,593,400	170	1,970
Offshore Supply Boats	2,400	4,200	100/60	6,048,000	130	786
Offshore Tugs	4,500	4,200	93/60	10,546,200	240	2,530
MSC AO-Tankers	14,000	5,420	81/89	54,701,892	13	711
ATF-Fleet Tugs	3,000	1,607	76/83	3,041,087	22	67
MSO-Minesweepers	2,800	906	56/95	1,349,578	25	34
AS-Sub Tenders	15,000	550	75/85	5,259,375	9	47
LST's	16,500	1,714	53/95	14,239,483	20	285
High & Med. Endurance Cutters	5,900	4,320	68/45 63/60	15,382,008	27	415
Icebreakers	13,000	3,984	74/74	28,218,923	9	254

up to 20 years. It was assumed that any vessels over 20 years old would not fall into the potential market. Figure V-2 summarizes the population distribution of the four vessel types combined, and Figures V-3 through V-6 graphically illustrate the population distribution of each vessel type resulting from the second computer survey run for vessels 20 years old or less. The detailed output of this survey, for the four vessel types mentioned above, is contained within Appendices D and E.

The predominant power ranges, centered around the peaks in the preceding graphs, are associated with certain specific vessel types within each major group. For example, oil exploitation vessels in the 1,500 to 1,800 horsepower range are essentially offshore supply boats, whereas vessels in the 3,000 to 4,000 horsepower range would be the larger offshore tug/supply vessels. Using this approach, the horsepower hours-per-year for weighted average operations at 50 percent and higher power level were again calculated for the predominant power ranges, and are shown in Table V-15. The analysis indicates that three unique horsepower ranges emerge, namely the 3,000-3,200, 1,500-1,800, and 2,200-2,400 installed brake horsepower rating classes. The predominant vessels associated with the three horsepower ranges are essentially inland river and intercoastal push-tow boats, followed by offshore supply boats, offshore tugs, and inland tugs. Table V-16 summarizes the final selection of vessel types and horsepower ranges that represent the greatest potential for the application of heat recovery diesel bottoming cycle systems and potential fuel savings. They exist in large population quantities, operate at relatively high duty-cycle/load-factors, and operate a high number of hours yearly.

(3) Diesel Bottoming Cycle Energy Recovery Utilization

An analysis was conducted to determine the optimum utilization of recovered energy. Energy recovered from diesel engine exhaust (and water jacket) heat may be applied to many ship duties, the more common ones being:

- . Vacuum flash evaporator (fresh water production)
- . Accommodation heating

FIGURE V-2
Population Distribution Summary of Towing,
Oil Exploitation, Fishing Vessels, and Ferries
Number of Vessels vs Horsepower
(All Vessels ≤ 20 years old)

FIGURE V-3
Population Distribution of Towing Vessels
Number of Vessels vs Horsepower
(Includes Age Distribution, All Vessels ≤ 20 years old)

FIGURE V-4
Population Distribution of Oil Exploitation Vessels
Number of Vessels vs Horsepower
(All Vessels ≤ 20 years old)

FIGURE V-5
Population Distribution of Fishing Vessels
Number of Vessels vs Horsepower
(All Vessels ≤ 20 years old)

FIGURE V-6
Population Distribution of Ferries
Number of Vessels vs Horsepower
(All Vessels ≤ 20 years old)

TABLE V-15
Analysis of Predominant Vessel Horsepower Ranges

Vessel Type	Average Installed Brake Horsepower	Annual Engine(s) Operating Hours	Total Number of Horsepower/Hours/Year Per Vessel for Operation at Weighted Average Power at 50% Power Level & Higher	Number of Vessels	Total Number of Horsepower/Hours/Year For All Vessels For Operation at Weighted Average Power at 50% Power Level & Higher x 10 ⁶	Installed Brake Horsepower Range
Inland Tugs	1,587	5,568	7,219,352	63	455	1,501-1,600
Offshore Supply Boats	1,546	4,200	3,895,920	85	331	1,501-1,600
Fishing Vessels	1,550	4,560	4,801,999	26	125	1,501-1,600
TOTALS				174	911	-
Inland Tugs	1,693	5,568	7,701,552	63	485	1,601-1,700
Offshore Supply Boats	1,693	4,200	4,266,360	42	179	1,601-1,700
Fishing Vessels	1,700	4,560	5,266,709	2	11	1,601-1,700
TOTALS				107	675	-
Push-Tow Boats	1,795	8,280	9,157,680	91	833	1,701-1,800
Offshore Supply Boats	1,784	4,200	4,495,680	14	63	1,701-1,800
Fishing Vessels	1,800	4,560	5,576,515	10	56	1,701-1,800
Ferries	1,777	7,000	8,058,400	1	8	1,701-1,800
TOTALS				116	960	-
Push-Tow Boats	1,994	8,280	11,459,106	29	332	1,901-2,000
Offshore Tugs	1,995	4,200	5,064,150	19	96	1,901-2,000
Fishing Vessels	2,000	4,560	6,196,128	4	25	1,901-2,000
TOTALS				52	453	-
Push-Tow Boats	2,253	8,280	12,947,684	19	246	2,201-2,300
Offshore Tugs	2,250	4,200	5,273,100	50	264	2,201-2,300
Fishing Vessels	2,250	4,560	6,970,644	4	28	2,201-2,300
TOTALS				73	538	-
Push-Tow Boats	2,393	8,280	13,758,296	58	798	2,301-2,400
Offshore Tugs	2,365	4,200	5,544,000	13	72	2,301-2,400
Fishing Vessels	2,400	4,560	7,435,354	1	7	2,301-2,400
TOTALS				72	877	-
Push-Tow Boats	3,000	8,280	17,243,928	36	621	2,901-3,000
Offshore Tugs	3,000	4,200	7,030,800	12	84	2,901-3,000
Fishing Vessels	3,000	4,560	9,294,192	2	19	2,901-3,000
TOTALS				50	724	-
Push-Tow Boats	3,198	8,280	18,382,027	73	1,342	3,101-3,200
Tug/Supply Boats	3,200	4,900	9,274,720	4	37	3,101-3,200
TOTALS				77	1,379	-
Push-Tow Boats	3,585	8,280	20,506,493	11	227	3,501-3,600
Tug/Supply Boats	3,600	4,900	10,434,060	2	21	3,501-3,600
Fishing Vessels	3,599	4,560	11,149,428	39	435	3,501-3,600
TOTALS				52	683	-
Push-Tow Boats	3,999	6,240	22,984,534	23	529	3,901-4,000
Tug/Supply Boats	4,000	4,900	11,593,400	9	104	3,901-4,000
Fishing Vessels	4,000	4,560	12,392,256	5	62	3,901-4,000
Ferries	4,000	7,000	18,144,000	3	54	3,901-4,000
TOTALS				40	749	-

TABLE V-16

Summary: Most Promising Potential Market for Heat Recovery
Diesel Bottoming Cycle Applications

Vessel Type	Installed Rated Brake Horsepower Range	Number of Vessels in Present (1976) Fleet (all vessels $\leq$ 20 years old)	Projected Number of New Vessel Construction to 1985
Push-tow boats	3,000 - 3,200	109	20
Push-tow boats and Inland tugs	1,500 - 1,800	217	49
Offshore supply boats	1,500 - 1,800	141	23
Push-tow boats	2,200 - 2,400	77	25
Offshore tugs and Offshore supply boats	2,200 - 2,400	63	33

- . Accommodation air conditioning
- . Feed water heating
- . Fuel heating
- . Cargo temperature regulation
- . Domestic services
- . Deicing services
- . Electrical power generation (which could also service some of the above equipment)
- . Vessel propulsion augmentation.

It appears that the only practical uses for energy recovered through the use of a diesel bottoming cycle (organic Rankine cycle) system are for the ship's service electrical power generation or to augment vessel propulsion. Consequently, vessel electrical service requirements for the vessel types selected for the application of energy recovery systems in the previous section of this report were analyzed. Figure V-7 shows a comparison of main electrical generation capacity for a number of vessel types. The data plots show that U.S. Coast Guard vessels have high electrical generation capacity in relation to the ship's main propulsion engine size. Passenger/car ferries also have a high electrical generation capacity because they have high ship's service requirements. However, the electrical requirements for a ferry boat are nearly the same when the vessel is at the dock in the loading and unloading mode (when engines are at idle, hence exhaust mass flow is low) as when it is under way at design speed and at approximately 80 percent power. Large fishing seiner vessels also have a high electrical generation capacity due to fish storage refrigeration requirements. These vessels travel several thousand miles to and from the fishing grounds; a typical trip off the southwestern coast of Africa may last 50 to 80 days. When in the fish-finding mode the engine power varies from about 25 to 50% load, and when in the seining or haul mode, power fluctuates from idle up to approximately 50 percent power. The main engines are generally shut down over night. Main engine power fluctuates enough that electrical power generation from a bottoming cycle unit may not be practical for these vessels.

FIGURE V-7
Comparison of Electrical Generator Capacity
for Various Types of Marine Vessels

A quick look at Figure V-7 illustrates that for the type vessels of interest; push-tow boats, offshore tugs, offshore supply boats, offshore tug/supply boats, and inland tugs, the electrical generation capacity of the main generator plant in terms of KW horsepower is relatively small in comparison to the main engine(s) horsepower. Almost all of these vessels have a backup or auxiliary generator set of generally the same capacity as the main plant. In addition, some vessels incorporate a similar size or smaller unit for emergencies. However, discussions with a number of the operators of these vessels revealed that the majority of the time the main generator plant is operating at between 40 to 60 percent capacity. As an example, a typical push-tow boat, or offshore supply boat rated at 2,300 total installed brake horsepower (from two engines), has a main electrical generation capacity of approximately 75 to 100 kilowatts (KW). Larger vessels of this type require an even lower percentage of electrical power in relation to main engine horsepower. At 50 percent load utilization to satisfy electrical demand requirements, the output is about 38 to 50 KW, or approximately 51 to 67 BHP. A generally modest designed bottoming cycle system with a recovery effectiveness of 10 percent (in relation to prime engine power) would yield 230 BHP from the 2,300 BHP main engines. The bottoming cycle unit would have to be sized to supply full electrical requirements of 75 to 100 KW when needed, but this is considered poor utilization of recovery energy. In addition, the operational nature of these vessels is such that many times during daily operations the main engines are at idle, standby or part-load for maneuvering purposes, albeit for short durations. However, because the main engine's exhaust energy is severely depleted at this load condition, the bottoming cycle system power is also severely depleted and hence so is the electrical generation power capacity. This interruption of electrical services for even short periods of time make this use of bottoming cycle energy impractical.

It is concluded that the only practical use of recovery power from a diesel bottoming cycle system, for push-tow boats, tugs, and supply vessels, is to input the power into the main propulsion system. The above vessels operate at relatively high duty-cycle/load-factors for a large number of annual operating hours and, therefore, could maximize utilization of recovered energy. To conserve fuel the main engines could be throttled (or raked) down so that the combined

power from the engine shaft and the bottoming cycle system is equal to the initial engine power, resulting in a decrease in fuel consumption. Or, the additional power could be utilized, in which case fuel consumption would remain the same but vessel speed, and hence productivity, would increase.

VI. ECONOMIC ANALYSIS

VI. ECONOMIC ANALYSIS

1. GENERAL

The economic analysis of the use of organic Rankine cycle bottoming systems for marine application is based primarily on the utilization of the Marine Transportation Energy Model (MTEM) developed by Booz, Allen under ERDA contract. The MTEM model simulates the United States maritime transportation industries activities on an annual basis. Cargo movements for the year 1974 are specified for 27 foreign and 16 domestic trade routes. A series of 35 generic vessels were developed and are contained within the model. Each of these vessels is described in terms of application to trade routes, speed, horsepower, fuel consumption, cargo carrying capacity, acquisition costs, and operating costs, all of which can be varied to represent a diversity of vessel designs within any vessel type category. The model is capable of analyzing the life-cycle cost performance of any generic vessel, or a specific vessel design. This analysis is accomplished first by determining all operating costs on an annual basis for the vessel's operational lifetime. Annual required revenues and freight rates are calculated based on costs, annualized capitalization expense, and return on investment or profit margin. In this manner the model may be used to determine the change in required freight rates due to proposed technological or operational improvements or innovations.

The vessels analyzed were those identified in Table V-16 of Chapter V, Marine Vessel Application Study. Cost inputs were those developed in Chapter IV, Organic Rankine Cycle Bottoming Systems, modified to include amortization of development costs. Vessel costs were adjusted to reflect an equivalent new construction vessel cost, and cost of vessels retrofitted with organic Rankine cycle bottoming systems. Fuel consumption rates, maintenance and repair costs, and insurance costs, were adjusted to reflect the percentage of recovery power for bottoming systems with varying power recovery effectiveness. Operational characteristics of the vessels were based on the duty-cycle/load-factor data and annual operation hours as developed in Chapter V. The basic economic output indicators from the marine simulation model are:

- . Change in required freight rate due to the reduced fuel consumption of vessels incorporating organic Rankine cycle bottoming systems
- . Annual fuel costs from which the number of years for return on investment in bottoming cycle systems can be derived.

2. EQUIPMENT COST

As discussed in Chapter IV, Section 5, System Cost, the production costs of organic Rankine cycle bottoming systems did not include amortization of development costs and hence did not represent actual selling price, or purchase cost, to the customer. The true market selling price, or purchase cost to customer, can only be developed by first conducting a market analysis to determine the actual number of vessels that represent a potential market for the application of Rankine cycle bottoming systems; Secondly, projecting the number of bottoming cycle systems that can be sold in a given period of time; and thirdly, by determining over what period of time, or sale of what number of units, the manufacturer desires to recover his development costs. It is this last number of units over which development costs must be amortized by the manufacturer.

The vessels identified in Chapter V (Table V-16) that represent the most promising potential market for heat recovery bottoming systems applications were subjected to a simplified market evaluation process as shown in Table VI-1. Since the lead time required for bottoming cycle system development, test, procurement, and production precludes market availability of Rankine cycle bottoming systems before 1980, an initial 5-year market span exists to 1985. The vessels in each horsepower category were combined to yield the total number of existing vessels and projected new vessel construction by the year 1985. An assumption was made that it appears reasonable to expect a 50 percent market penetration for bottoming cycle systems (providing they prove economically viable and are accepted by the vessel operators). The three bottoming cycle systems developers expressed a desire to recover their development costs over the first year of production sales. The extreme right hand column in Table VI-1 reflects the above conditions and lists the number of vessels for which the sale of bottoming cycle systems could be expected annually over a five-year period.

TABLE VI-1
Potential Primary Market for
Diesel Engine Bottoming-Cycle Systems
1980 - 1985

Vessel Power Rating (Population Power Range)	Vessel Type	Present Fleet (1976) No. Vessels (20 years old & newer)	Projected New Building to 1985 No. Vessels	Total No. Vessels to 1985	Combined Total No. Vessels to 1985	Market for Bottom-Cycle System No. Vessels 1980 - 1985 (Assumes 50% Market Penetration)	Bottom-Cycle Market No. Vessels Per Year 1980 - 1985
1650 BHP (1500-1800)	Push-Tow Boat	} (130)* 217 (87)*	(30)* 49	266	} 430	215	43
	Inland Tug		(19)*				
	Offshore Supply Boat	141	23	164			
2300 BHP (2200-2400)	Push-Tow Boat	} 77 (13)* 63 (50)*	25 (7)* 33 (26)*	102 96	} 198	99	20
	Offshore Tug						
	Offshore Supply Boat						
3100 BHP (3000-3200)	Push-Tow Boat	109	28	137	137	68	14

Note: Numbers above represent vessels. Since almost all of the above vessels incorporate twin engines, the actual number of engine/Rankine cycle bottoming system units is twice that of the number of vessels listed in each column, but at a rated horsepower of one-half the total vessel horsepower in the extreme left hand column.

* Estimated breakdown.

It also appears reasonable to expect that if bottoming cycle systems were developed for vessels in the primary market, then a probable market could exist for vessels considered as being in the secondary market. The annual sales of bottoming cycle units would be increased slightly, as shown in Table VI-2, and would allow amortization of development costs to be spread among a slightly greater number of units, resulting in a reduction in the selling price for the first year's production. Table VI-3 summarizes the potential combined primary and secondary marine market for diesel engine bottoming cycle systems between the years 1980 and 1985.

In the 1,650 BHP size vessel category, the potential first year's production market (and annual market to 1985) is 50 vessels. Almost all of the vessels in this category incorporate twin engines, with the exception of fishing vessels, which are generally powered by a single engine. The actual number of engine/Rankine cycle bottoming system units is approximately twice that of the number of vessels listed in each column, but at a rated horsepower of one-half the total vessel rated horsepower, or ~825 BHP per engine. Therefore, with fishing vessels temporarily excluded from this category, development costs can be amortized over 86 bottoming cycle units, or the first year's production.

In the 2,300 BHP size vessel category, the first year's production market is 21 vessels. As above, almost all of the vessels in this category incorporate twin engines, with the exception of fishing vessels. The actual number of engine/Rankine cycle bottoming system units is approximately twice that of the number of vessels listed in each column, but at a rated horsepower of one-half the total vessel rated horsepower, or ~1,150 BHP per engine. Fishing vessels with a single engine in the 2,200 to 2,400 BHP class do not fit into any category or horsepower class among the three power classes of vessels and consequently are dropped from further consideration in this analysis. Development costs can be amortized over 40 bottoming cycle units or the first year's production.

In the 3,100 BHP size vessel category, the first year's production market is 18 vessels. Again, almost all of the vessels in this category incorporate twin engines, with the exception of fishing vessels. The actual number of engine/Rankine cycle bottoming system units is approximately twice that of the number of vessels listed in each column, but at a rated horsepower of one-half the total vessel rated horsepower, or ~1,550 BHP per engine. Fishing vessels with

TABLE VI-2
Potential Secondary Market for
Diesel Engine Bottoming-Cycle Systems
1980 - 1985

Vessel Power Rating (Population Power Range)	Vessel Type	Present Fleet (1976) No. Vessels (20 Years Old & Newer)	Projected New Building to 1985 No. Vessels	Total No. Vessels to 1985	Combined Total No. Vessels to 1985	Market for Bottom-Cycle System No. Vessels 1980 - 1985 (Assumes 50% Market Penetration)	Bottom-Cycle Market No. Vessels Per Year 1980 - 1985
1650 BHP (1500-1800)	Fishing Boat	38	-(?)	38	} 66	33	7
	Coastal Tanker	20	-(?)	20			
	Pass./Car Ferry	8	-(?)	8			
2300 BHP (2200-2400)	Fishing Boat	9	-(?)	9	9	5	1
3100 BHP (3000-3200)	Fishing Boat	7	-(?)	7	} 40	20	4
	Tug/Supply Boat	23	10	33			

Note: Numbers above represent vessels. Since almost all of the above vessels incorporate twin engines with the exception of fishing vessels, which are generally powered by a single engine, the actual number of engine/Rankine cycle bottoming system units is twice that of the number of vessels listed in each column; but at a rated horsepower of one-half the total vessel horsepower in the extreme left hand column.

TABLE VI-3
Potential Combined Primary and Secondary Market for
Diesel Engine Bottoming-Cycle Systems
1980 - 1985

Vessel Power Rating (Population Power Range)	Vessel Type	Fleet Total to 1985 No. Vessels	Combined Total to 1985 No. Vessels	Combined Total No. Vessels Primary & Secondary Market to 1985	Diesel Bottom-Cycle Market 1980-1985 No. Vessels (Assumes 50% Market Penetration)	Annual Diesel Bottom-Cycle Market No. Vessels Per Year for 5-Year Period (1980-1985) and First Year Market for Amortization of Development Costs No. of Vessels
1650 BHP (1500-1800)	<u>Primary Market</u>			496	248	50 (86 Bottoming cycle units rated for ~ 825 BHP base engine. Does not include fishing vessels.)
	Push-Tow Boat	266	430			
	Inland Tug					
	Offshore Supply Boat	164				
	<u>Secondary Market</u>					
	Fishing Boat	38	66			
Coastal Tanker	20					
Pass./Car Ferry	8					
2300 BHP (2200-2400)	<u>Primary Market</u>			207	104	21 (40 Bottoming cycle units rated for ~ 1150 BHP engine. Does not include fishing vessels.)
	Push-Tow Boat	102	198			
	Offshore Tug	96				
	Offshore Supply Boat					
	<u>Secondary Market</u>					
Fishing Boat	9	9				
3100 BHP (3000-3200)	<u>Primary Market</u>			177	89	18 (34 Bottoming cycle units rated for ~ 1550 BHP engine. Plus 4 bottoming cycle units rated for ~ 1650 BHP base engine for fishing vessels. Does not include fishing vessels in 3100 BHP category.)
	Push-Tow Boat	137	137			
	<u>Secondary Market</u>					
	Fishing Boat	7	40			
Offshore Tug/Supply Boat	33					

Note: Numbers above represent vessels. Since almost all of the above vessels incorporate twin engines, with the exception of fishing vessels which are generally powered by a single engine, the actual number of engine/Rankine cycle bottoming system units is twice that of the number of vessels listed in each column; but at a rated horsepower of one-half the total vessel horsepower in the extreme left hand column.

single engines from the 1,650 BHP category can also benefit from bottoming cycle units developed for vessels with two engines in the 3,100 BHP category. Development costs can be amortized over 34 bottoming cycle units in the 3,100 BHP vessel class, plus 4 units for 4 fishing vessels from the 1,650 BHP vessel class, for a total of 38 units, or the first year's production run. Fishing vessels with a single engine in the 3,000 to 3,200 BHP class do not fit into any category or horsepower class among the three power classes of vessels and consequently are dropped from further consideration in this analysis.

The selling price, or purchase cost, of organic Rankine cycle bottoming systems is shown in Tables VI-4 and VI-5 in the form of equivalent vessel cost that reflects the cost of the bottoming system equipment installed. Development costs were amortized over the first year's production quantities, as shown in Table VI-3. The costs were developed for bottoming systems at five levels of power recovery effectiveness for both new construction vessels and existing vessels retrofitted with bottoming cycle systems. Baseline vessel costs shown in the table were obtained from a number of boat manufacturers and vessel operators, and represent average costs for typical vessels of their type.

3. COST INPUTS

The detailed vessel data, operational data, and cost data input to the MTEM model is included in Appendix F. The rated brake horsepower for each vessel type was corrected to reflect the weighted average number of horsepower hours of operation per year. Since the MTEM model is based on 330 24-hour days of operation per year, the hour-year operation of each vessel was factored up or down to correct for this fixed operational time characteristic in the model. The corrected vessel brake horsepower is equal to the product of the rated brake horsepower of the vessel, the weighted average power factor, and the annual number of engine(s) operating days (24-hour), divided by 330. For example, the corrected vessel BHP for the 1,650 BHP rated push-tow boat that operates for an average of 345 24-hour days per year at a weighted average duty-cycle/load-factor of 0.71 is equal to 1,225 BHP ($1,650 \times 0.71 \times \frac{345}{330} = 1,225$).

Cargo haul tonnage for all three horsepower classes of push-tow boats was developed by using a 20 standard barge tow, 5 long x 4 wide, with a load capacity of ~ 947 short tons each. The speed of each power class of push-tow boat was varied to reflect the power rating. Cargo haul

TABLE VI-4
VESSEL COST

New Construction Vessels Equipped with Organic Rankine Cycle
Diesel Bottoming Systems with Varying Energy Recovery Effectiveness

Vessel Power Rating (Population Power Range)	Vessel Type	Baseline Vessel Cost (millions of dollars)	Vessel Cost Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 10% Energy Recovery Effectiveness (millions of dollars)	Vessel Cost Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 12.5% Energy Recovery Effectiveness (millions of dollars)	Vessel Cost Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 15.0% Energy Recovery Effectiveness (millions of dollars)	Vessel Cost Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 17.5% Energy Recovery Effectiveness (millions of dollars)	Vessel Cost Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 20.0% Energy Recovery Effectiveness (millions of dollars)
1650 BHP (1500-1800)	Push-Tow Boat	0.980	1.091	1.107	1.123	1.143	1.168
	Inland Tug	0.880	0.991	1.007	1.023	1.043	1.068
	Offshore Supply Boat	1.080	1.191	1.207	1.223	1.243	1.268
2300 BHP (2200-2400)	Push-Tow Boat	1.310	1.485	1.506	1.525	1.554	1.589
	Offshore Tug	2.500	2.675	2.696	2.715	2.744	2.779
	Offshore Supply Boat	2.000	2.175	2.196	2.215	2.244	2.279
3100 BHP (3000-3200)	Push-Tow Boat	1.640	1.850	1.877	1.902	1.938	1.985

TABLE VI-5
VESSEL COST

Vessels Retrofitted with Organic Rankine Cycle
Diesel Bottoming Systems with Varying Energy Recovery Effectiveness

Vessel Power Rating (Population Power Range)	Vessel Type	Baseline Vessel Cost (millions of dollars)	Vessel with Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 10% Energy Recovery Effectiveness (millions of dollars)	Vessel with Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 12.5% Energy Recovery Effectiveness (millions of dollars)	Vessel with Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 15.0% Energy Recovery Effectiveness (millions of dollars)	Vessel with Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 17.5% Energy Recovery Effectiveness (millions of dollars)	Vessel with Engine(s) Equipped with Rankine Cycle Bottoming System(s) with 20.0% Energy Recovery Effectiveness (millions of dollars)
1650 BHP (1500-1800)	Push-Tow Boat	0.980	1.119	1.141	1.162	1.188	1.219
	Inland Tug	0.880	1.019	1.041	1.062	1.088	1.119
	Offshore Supply Boat	1.080	1.219	1.241	1.262	1.288	1.319
2300 BHP (2200-2400)	Push-Tow Boat	1.310	1.527	1.556	1.581	1.619	1.664
	Offshore Tug	2.500	2.717	2.746	2.771	2.809	2.854
	Offshore Supply Boat	2.000	2.217	2.246	2.271	2.309	2.354
3100 BHP (3000-3200)	Push-Tow Boat	1.640	1.903	1.940	1.975	2.022	2.080

Note: Includes machinery modification and rearrangement cost.

tonnage for inland tugs are typical average load hauls. Offshore tugs were assigned a "dummy" load for model simulation purposes. Offshore supply boats were loaded with deck haul cargo to rated vessel capacity. Vessel speed averages were obtained from a number of sources and represent operation under average sea weather conditions.

The vessel fuel consumption rates were adjusted to reflect the power recovery effectiveness of the organic Rankine cycle bottoming system(s).

Vessel operational data, and duty-cycle/load-factors were derived from Appendix C.

Operating costs, crew wages, stores and subsistence, maintenance and repair, and insurance were obtained from several sources including U.S. Coast Guard, operators, and various articles and papers.

Fuel cost was established at \$0.40 per gallon (April-May 1977) for No. 2-D marine diesel fuel, based on information received from numerous sources in the United States. Costs actually varied from \$0.385 to \$0.41 per gallon in large bulk quantity lots. Normal annual fuel cost escalation rate was set at 5 percent.

The capitalization/financing scheme used in the MTEM model was the Federal Ship Financing Program Title XI of the Merchant Marine Act of 1936. The Maritime Administration guarantees the principal and interest, in the event of a default by the ship owner, on commercially-placed mortgages and loans used to finance the construction, conversion, and reconditioning of vessels and certain marine equipment. The annual interest rate on debt was 8.0 percent and corporate tax rate was 48 percent.

4. SYSTEM ECONOMICS

The economics of a waste heat energy recovery system are a function of capital costs, operating costs, vessel operational characteristics, energy recovery system effectiveness, and fuel costs. Since the operating costs of energy recovery systems are small in comparison with the capital cost, which is also independent of inflation, and assuming all other factors are fixed, dollar savings will increase in direct proportion to increases in fuel cost. Consequently, all vessels tested in the MTEM marine simulation model were subjected to the effects of an annual fuel cost escalation

rate of 5 and 10 percent. In order to keep the number of computer runs and data analysis in manageable proportions, baseline vessels, vessels retrofitted with energy recovery systems with recovery effectiveness of 10 and 15 percent, and new construction vessels incorporating energy recovery systems with recovery effectiveness of 10 and 15 percent were run in the model. A sample of typical results of the MTEM computerized analysis are shown in Appendix G.

The results of the MTEM simulation analysis are shown in Tables VI-6 and VI-7, which tabulate the changes in initial required freight rates (I-RFR) for the vessels under consideration equipped with energy recovery systems; for a 5 and 10 percent fuel cost escalation rate respectively. The I-RFR indicator is expressed in dollars per ton per trip. In the case of inland river push-tow boats, the typical trip length is equal to 358 statute miles. The use of I-RFR, in absolute terms, as an economic indicator for offshore supply boats and offshore tugs, is not entirely valid in this analysis. The type of service in which these vessels engage is widely varied, and the handling of cargo and charges for vessel use on strictly a tonnage measure basis is not representative of actual operations: (for example, specialized cargo hauling, emergency supply service of small loads, standby service, empty runs, rig towing, anchor handling, etc.). However, the use of the I-RFR data to determine trends and magnitude of economic effectiveness of energy recovery systems is valid. Figures VI-1 and VI-2 graphically illustrate the magnitude of change in I-RFR for push-towboats and inland tugs respectively. For all vessel cases, the I-RFR declines as the effectiveness of the energy recovery system increases. This indicates a definite advantage in lower I-RFR for energy recovery systems with the highest percentage of power recovery effectiveness, even though the cost is considerably higher than with a lower point recovery effectiveness.

The investment recapture period (years to pay back) for vessels equipped with energy recovery systems, is shown in Tables VI-8 and VI-9 for a 5 and 10 percent fuel cost escalation rate respectively. The investment recapture period for new construction push-tow boats incorporating energy recovery systems with a 15 percent power recovery effectiveness at a 5 percent/year fuel cost escalation rate is 4 years. At a 10 percent/year fuel cost escalation rate, the pay back period is 3½ years. The pay back period for vessels equipped with energy recovery systems with a 10 percent power recovery effectiveness is slightly longer than for vessels equipped with systems with a 15 percent

TABLE VI-6
Initial Required Freight Rates for Baseline Vessels and
Vessels Equipped with Energy Recovery Systems for
5% Fuel Cost Escalation Rate

Vessel Power Rating (Population Power Range)	Vessel Type	Initial Required Freight Rate - Dollars/Ton				
		Baseline Vessel (No Energy Recovery)	Vessels Retrofitted with Energy Recovery System		New Construction Vessels Incorporating Energy Recovery System	
		Energy Recovery Effectiveness - 0%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%
1650 BHP (1500-1800)	Push-Tow Boat	1.0448	1.0188	1.0027	1.0165	0.9997
	Inland Tug	2.5802	2.5248	2.4903	2.5186	2.4823
	Offshore Supply Boat	37.3933	37.2720	37.1586	37.1300	36.9574
2300 BHP (2200-2400)	Push-Tow Boat	1.1505	1.1164	1.0953	1.1135	1.0917
	Offshore Tug	3.6380	3.5957	3.5630	3.5852	3.5474
	Offshore Supply Boat	31.1784	~31.1420*	31.1195	31.0405	30.9088
3100 BHP (3000-3200)	Push-Tow Boat	1.3312	1.2856	1.2590	1.2824	1.2542

*Estimated

TABLE VI-7
Initial Required Freight Rates for Baseline Vessels and
Vessels Equipped with Energy Recovery Systems for
10% Fuel Cost Escalation Rate

Vessel Power Rating (Population Power Range)	Vessel Type	Initial Required Freight Rate - Dollars/Ton				
		Baseline Vessel (No Energy Recovery)	Vessels Retrofitted with Energy Recovery System		New Construction Vessels Incorporating Energy Recovery System	
		Energy Recovery Effectiveness - 0%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%
1650 BHP (1500-1800)	Push-Tow Boat	1.3012	1.2496	1.2206	1.2473	1.2177
	Inland Tug	3.1359	3.0249	2.9627	3.0187	2.9547
	Offshore Supply Boat	42.9921	42.3488	41.9723	42.1972	41.7619
2300 BHP (2200-2400)	Push-Tow Boat	1.4785	1.4116	1.3741	1.4087	1.3705
	Offshore Tug	4.2882	4.1810	4.1158	4.1705	4.1002
	Offshore Supply Boat	36.6012	36.1610	35.8083	35.9624	35.5843
3100 BHP (3000-3200)	Push-Tow Boat	1.7491	1.6617	1.6143	1.6585	1.6094

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FIGURE VI-2
Comparison of Reduction in Initial Required Freight Rate Versus Rankine Cycle Bottoming System Power Recovery Effectiveness for Inland Water Tugs 1,650 BHP Rating

TABLE VI-8
Investment Recapture (Years to Pay Back) for
Vessels Equipped with Energy Recovery Systems for
5% Fuel Cost Escalation Rate

Vessel Power Rating (Population Power Range)	Vessel Type	Investment Recapture Period (Years to Pay Back)			
		Vessels Retrofitted with Energy Recovery System		New Construction Vessels Incorporating Energy Recovery System	
		Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%
1650 BHP (1500-1800)	Push-Tow Boat	5½	4½	4½	4
	Inland Tug	6½	6	5½	4½
	Offshore Supply Boat	10	9	8½	7½
2300 BHP (2200-2400)	Push-Tow Boat	6	5	5	4
	Offshore Tug	11½	9	9	7½
	Offshore Supply Boat	11½	10*	9½	8
3100 BHP (3000-3200)	Push-Tow Boat	5½	4½	4½	4

*Estimated

TABLE VI-9
Investment Recapture (Years to Pay Back) for
Vessels Equipped with Energy Recovery Systems for
10% Fuel Cost Escalation Rate

Vessel Power Rating (Population Power Range)	Vessel Type	Investment Recapture Period (Years to Pay Back)			
		Vessels Retrofitted with Energy Recovery System		New Construction Vessels Incorporating Energy Recovery System	
		Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 10%	Organic Rankine Cycle Bottoming System Energy Recovery Effec- tiveness - 15%
1650 BHP (1500-1800)	Push-Tow Boat	5	4	4	3½
	Inland Tug	5½	5	4½	4
	Offshore Supply Boat	8	7½	7	6
2300 BHP (2200-2400)	Push-Tow Boat	5	4½	4½	3½
	Offshore Tug	8½	7½	7	6
	Offshore Supply Boat	9	8	7½	6½
3100 BHP (3000-3200)	Push-Tow Boat	4½	4	4	3½

power recovery effectiveness. The pay back period for vessels retrofitted with energy recovery systems, as opposed to new construction installations, is also slightly longer. Based on the results listed in Tables VI-8 and VI-9, it is estimated that the pay back period for vessels equipped with energy recovery systems with a 20 percent power recovery effectiveness is proportionally less than for a system with a 15 percent power recovery effectiveness, or about $3\frac{1}{2}$ years at a 5 percent/year fuel cost escalation rate and about 3 years at a 10 percent/year fuel cost escalation rate for push-tow boats.

5. FUEL SAVINGS

The estimated annual fuel consumption for each candidate vessel is shown in Table VI-10. The fuel consumption estimates are based on the duty-cycle/load-factors and yearly vessel operating hours developed in Chapter V and included in Appendix C. The overall weighted average horsepower/hours/year of each vessel was based on the overall weighted average power factor because all of the vessels have some operation at 40 to 50 percent power levels, and some amount of energy can be recovered at this power loading, depending on engine type. Fuel consumption was based on an overall BSFC rate of 0.385 lbs/BHP-HR across the engine operating load spectrum. The table also summarizes the total amount of fuel used by all vessels per year for this projected 1985 fleet—almost 10 million barrels annually.

The estimated annual fuel savings for the candidate marine vessels in the projected 1985 fleet equipped with organic Rankine cycle bottoming systems (with varying degrees of power recovery effectiveness) is shown in Table VI-11. The table lists the total yearly fuel savings possible per vessel for each candidate vessel equipped with an energy recovery system, and also the total yearly fuel savings possible if one-half of all vessels were equipped with energy recovery systems and if all vessels were equipped with energy recovery systems. Of significance here is the fact that a total of $3\frac{3}{4}$ -million barrels of fuel can be conserved annually if just one-half of the candidate vessels were equipped with an organic Rankine cycle bottoming system with a power recovery effectiveness of 15 percent. If all of the 1985 fleet of candidate vessels were equipped with the same system, $1\frac{1}{2}$ million barrels

TABLE VI-10
Estimated Annual Fuel Consumption for
Candidate Marine Vessels

Vessel Power Rating (Population Power Range)	Vessel Type	Present Fleet (1976) No. Vessels (20 years old and newer)	Present Fleet (1976) No. Vessels (20 years old and newer)	Projected New Building to 1985 No. Vessels	Total No. Vessels to 1985	Overall Weighted Average Power & Power (for 100% annual engine hours)	Annual Engine(s) Operating Hours (Per Vessel)	Overall Weighted Average Horsepower/Hours/Year Per Vessel $\times 10^6$	Fuel Used Per Vessel/Year (BSFC = 0.385 lb/hp-hr) BBLS/Year	Total Amount of Fuel Used by All Vessels/Year 1985 Fleet (Vessels ≤ 20 yrs old (BSFC = 0.385 lb/hp-hr) BBLS/Year
1650 BHP (1500-1800)	Push-Tow Boat	217	130*	30*	160	71	8,280	9.70	12,524	2,003,840
	Inland Tug		87*	19*	106	85	5,568	7.81	10,082	1,068,692
	Offshore Supply Boat		141	23	164	69	4,200	4.78	6,174	1,012,536
2300 BHP (2200-2400)	Push-Tow Boat	77	77	25	102	71	8,280	13.52	17,457	1,780,614
	Offshore Tug	63	13*	7*	20	65	4,200	6.28	8,107	162,140
	Offshore Supply Boat		50*	26*	76	69	4,200	6.67	8,606	654,056
3100 BHP (3000-3200)	Push-Tow Boat	109	109	28	137	71	8,280	18.22	23,529	3,223,473
TOTAL										9,905,351

*Estimated Breakdown

TABLE VI-11
Estimated Annual Fuel Savings for Candidate Marine Vessels
Equipped with Energy Recovery Systems

Vessel Power Rating (Population Power Range)	Vessel Type	Total Yearly Fuel Savings Per Vessel			Total Yearly Vessel (1985 Fleet) Fuel Savings Assuming 50% of All Vessels (≤ 20 years old) Equipped with Energy Recovery Systems			Total Yearly Vessel (1985 Fleet) Fuel Savings Assuming 50% of All Vessels (≤ 20 years old) Equipped with Energy Recovery Systems		
		Rankine Cycle Bottoming System Power Recovery Effectiveness = 10%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 15%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 20%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 10%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 15%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 20%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 10%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 15%	Rankine Cycle Bottoming System Power Recovery Effectiveness = 20%
		BBLS/Yr	BBLS/Yr	BBLS/Yr	BBLS/Yr	BBLS/Yr	BBLS/Yr	BBLS/Yr	BBLS/Yr	BBLS/Yr
1650 BHP (1500-1800)	Push-Tow Boat	1,252	1,878	2,504	100,160	150,240	200,320	200,320	300,480	400,640
	Inland Tug	1,008	1,512	2,016	53,424	80,136	106,848	106,848	160,272	213,696
	Offshore Supply Boat	617	925	1,234	50,594	75,932	101,188	101,188	151,864	202,376
2300 BHP (2200-2400)	Push-Tow Boat	1,746	2,619	3,492	89,046	133,569	178,092	178,092	267,138	356,184
	Offshore Tug	811	1,217	1,622	8,110	12,170	16,220	16,220	24,340	32,440
	Offshore Supply Boat	861	1,292	1,722	32,718	49,096	65,436	65,436	98,192	130,872
3100 BHP (3000-3200)	Push-Tow Boat	2,353	3,530	4,706	161,181	134,140	322,361	322,361	268,280	644,722
TOTALS					495,233	742,850	990,466	990,466	1,485,699	1,980,932

of fuel can be conserved annually. If all of the 1985 fleet of candidate vessels were equipped with an energy recovery system with a 20 percent power recovery effectiveness, almost 2 million barrels (84 million gallons) of fuel can be saved annually.

Also of significance is the fact that the candidate push-tow boats, in all three horsepower classes, consume 70 percent of the total fuel used by all of the candidate vessels. If one-half of the push-tow boats were equipped with energy recovery systems with a 15 percent power recovery effectiveness, then 418,000 barrels of fuel can be saved annually. Providing all push-tow boats in the three horsepower classes were equipped with energy recovery systems with a 20 percent power recovery effectiveness, 1,400,000 barrels of fuel can be conserved annually.

VII. ORGANIC RANKINE CYCLE DIESEL
BOTTOMING SYSTEM CONCEPTION DESIGN

VII. ORGANIC RANKINE CYCLE DESIGN BOTTOMING SYSTEM CONCEPTION DESIGN

1. GENERAL

Chapter V, Marine Vessel Application Study, and Chapter VI, Economic Analysis, concluded that push-tow boats (among others) were rated as one of the most promising potential markets for heat recovery, diesel bottoming cycle applications. Based on the results of these analyses, representative machinery installation layout drawings were developed for a "typical" 2,300 BHP push-tow boat for both retrofitted and new construction installation. Sizing of organic Rankine cycle bottoming system components was conducted from data supplied by the Thermo Electron Corporation in a report entitled "A Study of Organic Rankine Cycle Systems for Waste Heat Recovery from Tugboat Diesel Engines."

2. RETROFITTED VESSEL ORGANIC RANKINE CYCLE BOTTOMING SYSTEM INSTALLATION

A system concept machinery installation layout for a typical 2,300 BHP rated twin-screw push-tow boat, retrofitted with an organic Rankine cycle bottom system which uses a high temperature working fluid, is shown in Figure VII-1. Vessel characteristics are:

- . Vessel/Engine(s) BHP rating - 2,300 (2,200-2,400 BHP range)
- . Number of engines - 2
- . BHP rating (each) - 1,150
- . Overall vessel length - ~100'
- . Overall width - ~30'
- . Hull depth - ~10'1"
- . Draft - ~7'7"

The engines are a popular make V-8, 2-cycle, turbocharged design.

FIGURE VII-1
System Concept Machinery Layout
2,300 BHP Push-Tow Boat
Retrofitted Organic Rankine Cycle Bottoming System Installation

The organic Rankine cycle bottoming system shown retrofitted into this vessel has approximately 10 percent power recovery effectiveness as a percentage of base engine power. Had the engine been a blower-scavenged version instead of a turbocharged version, an additional ~1 percent of recovered horsepower might have been achieved due to the higher temperature exhaust reject gas available. A bottoming system designed for a 10 percent energy recovery effectiveness was chosen as a conservative approach for a retrofit installation because of space considerations and a desire to minimize the amount of tear-out modifications and rearrangement of the engine room equipment. However, it appears that in many vessels, retrofit installations of Rankine cycle bottoming systems approaching 15 percent power recovery effectiveness can be achieved. Higher percentages could be achieved in some cases depending on the engine used and available space. Although the vessel horsepower rating increases by the percentage of power recovery effectiveness of the Rankine cycle bottoming system, the vessel power rating remains at 2,300 BHP because it is assumed that the operator will use a lower engine throttle position to affect fuel savings. However, the additional power is available if needed or desired, and fuel consumption will be the same at full power as that of the base engine before addition of the Rankine cycle bottoming system.

In this installation the engine positions remained intact. The Rankine cycle turbine reduction gearbox was installed in the space occupied by the driveshaft from the engine to the marine reduction drive gearbox. In addition, the marine drive gearbox was moved aft approximately 6 inches. It is possible that the Rankine cycle turbine gearbox could be designed in such a manner so that neither the marine transmission or the engine would require repositioning. As discussed in the section on controls in Chapter IV, a disengagement clutch for this turbine gearbox and a vapor generator exhaust gas bypass valve may be required. However, these components are not included in the installation layout. A cooperative analysis between the Rankine cycle bottoming system developer and the vessel manufacturers, and possibly the vessel operators, would determine the need or requirement of these two components for compatible operation of the engine and diesel bottoming system.

3. NEW CONSTRUCTION VESSEL ORGANIC RANKINE CYCLE BOTTOMING SYSTEM INSTALLATION

A system concept machinery installation layout for a typical new construction 2,300 BHP rated twin-screw push-tow boat incorporating an organic Rankine cycle bottoming system, which uses a high temperature working fluid, is shown in Figure VII-2. Vessel characteristics in this case remain the same as for the retrofitted vessel installation. These characteristics are:

- . Vessel/Engine(s) BHP rating - 2,300 (2,200-2,400 BHP range)
- . Number of engines - 2
- . BHP rating (each) - 1,150
- . Overall vessel length - ~100'
- . Overall width - ~30'
- . Hull depth - ~10'1"
- . Draft - ~7'7"

The engines are a popular make V-8, 2-cycle, turbocharged design. However, the use of a lower power blower-scavenged version of this engine may be possible in new construction vessels.

The organic Rankine cycle bottoming system shown incorporated into the design of this new construction vessel has approximately 15 percent power recovery effectiveness, as a percentage of base engine power. A bottoming system designed for a 15 percent energy recovery effectiveness was chosen as a conservative approach for a new installation in this study because of space considerations and because detailed vessel construction and machinery installation drawings were not available. It appears that in many vessels where the Rankine cycle bottoming system is allowed for an integrated into the machinery arrangement, Rankine cycle bottoming systems approaching 18 percent power recovery effectiveness can be achieved. Higher percentages could be achieved in some cases depending on the engine used and available space. In the new vessel installation, it may be possible to use a blower-scavenged lower-power version of the base diesel engine. If this were possible (through a detailed analysis of heat available from a specific engine) then the total combined horsepower rating of each diesel engine and Rankine

FIGURE VII-2
System Concept Machinery Layout
2,300 BHP Push-Tow Boat
New Construction Organic Rankine Cycle Bottoming System Installation

cycle bottoming system unit would be 1,150 BHP, with a fuel consumption equal to that of the lower-powered base diesel engine at full power rating.

In this installation the engine has been moved forward about one foot to accommodate a more gentle transition section from the engine exhaust outlet to the vapor generator inlet. However, there appears to be no reason why the vapor generator cannot be installed at an angle (inclined forward at the top) for both new and retrofitted installations to obtain a more favorable exhaust gas flow transition section. As discussed in the section on controls in Chapter IV, a disengagement clutch for the turbine gearbox and a vapor generator exhaust gas bypass valve may be required. However, these components are not included in the installation layout. As mentioned in the previous discussion on retrofitted vessels, a cooperative analysis between the Rankine cycle bottoming system developer and the vessel manufacturers, and possibly the operators, would determine the need or requirement of these two components for compatible operation of the engine and diesel bottoming system.

VIII. CONCLUSIONS AND RECOMMENDATIONS

VIII. CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The most promising marine applications for organic Rankine cycle diesel bottoming energy recovery systems are concentrated among four types of inland and offshore vessels in three rated brake horsepower ranges, as shown in Table VIII-1.

TABLE VIII-1
Most Promising Marine Applications
for Energy Recovery Systems

Power Rating Range	Vessel Type
1,500-1,800 BHP	Push-Tow Boat Inland Tug Offshore Supply Boat
2,200-2,400 BHP	Push-Tow Boat Offshore Tug Offshore Supply Boat
3,000-3,200 BHP	Push-Tow Boat

The above vessels in the specified horsepower ranges exist in large population quantities, operate at relatively high duty-cycle/load-factors, are under operation a large number of hours annually and dominate the fleet in the highest total number of operational horsepower/hours per year.

The use of organic Rankine cycle bottoming energy recovery systems is cost effective for the above specified vessels. The initial required freight rate (I-RFR) for new construction push-tow boats equipped with an energy recovery system with a 10 percent power recovery effectiveness is about 3 to 4 percent lower than that for

vessels not so equipped. The I-RFR for push-tow boats equipped with energy recovery systems with a 15 percent power recovery effectiveness is about 5 to 6 percent lower than that of unequipped vessels. It is projected that the I-RFR for vessels equipped with systems of 20 percent power recovery effectiveness is approximately 7 to 8 percent lower than that of conventional vessels. The reduction in I-RFR for vessels retrofitted with energy recovery systems, and the other vessel types (i.e., inland tugs, offshore tugs, offshore supply boats), is slightly lower than that for push-tow boats. If fuel costs escalate at an annual rate higher than 5 percent, reduction in I-RFR for vessels equipped with energy recovery systems is even greater.

The investment recapture period (years to pay back) for push-tow boats equipped with energy recovery systems is approximately $4\frac{1}{2}$ years for systems with a 10 percent power recovery effectiveness, and about 4 years for systems with a 15 percent power recovery effectiveness. Although the pay back period for the other vessel types equipped with energy recovery systems is somewhat longer, they are still economically viable. Higher fuel costs will effect a substantial reduction in investment pay back period. The pay back period is reduced by an additional 15 percent (approximate) if the annual fuel cost escalation rate increases to 10 percent.

The approach used in the economic analysis reflects conservatism. Since the projected production and selling prices of organic Rankine cycle bottoming systems are projected from limited experience, and are based on developmental installations or proposed units, no accurate cost data exist. It is believed that production costs of the energy recovery system could be reduced if large scale production occurred. Costs could also be reduced if industry was willing to amortize development costs over a 2 to 3 year period instead of the first year's production. Also, no equipment investment tax credit was considered in the analysis. Any one, or a combination, of the three factors would lower the true selling price of the equipment to the vessel operator and reduce the investment recapture period.

Strong evidence exists to indicate that Rankine cycle bottoming energy recovery systems would also be cost effective for many other types of vessels that were dropped from consideration in this study only because they did not exist in large population quantities when compared with the candidate vessels selected.

The annual fuel savings for the candidate marine vessels in the projected 1985 fleet is estimated to be 3/4-million barrels if one-half of the fleet were equipped with energy recovery systems with a 15 percent effectiveness, or 1½-million barrels if all candidate vessels were comparably equipped. If all of the 1985 fleet of candidate vessels were equipped with an energy recovery system with a 20 percent power recovery effectiveness, almost 2 million barrels (84 million gallons) of fuel can be saved annually. Push-tow boats, in all three horsepower classes, consume 70 percent of the total fuel used by all of the candidate vessels. Providing all push-tow boats in the three horsepower classes were equipped with energy recovery systems with a 20 percent power recovery effectiveness, 1.4 million barrels of fuel could be conserved annually by this segment alone.

The use of Freon R-114 as the working fluid in organic Rankine cycle bottoming systems on marine vessels appears to be the safest medium from a flammability or explosion standpoint. But, because the working temperature of this substance is much lower than that of the other fluids, the power recovery efficiency of the bottoming system will be lower for equivalent size components, i.e., vapor generator, etc. than that for systems using Fluorinal-85 or Toluene. From an overall safety standpoint, it is believed that Fluorinal-85 poses no more of a hazard potential than engine diesel fuel (which is also pumped at high pressure, though much lower temperatures) in the event of a line rupture. The use of Toluene as a working fluid may be potentially more hazardous than Fluorinal-85 (and vessel diesel fuel) because of its lower flash point and fire point. All of the proposed working fluids (as well as diesel fuels) are considered to be toxic by OSHA/NIOSH standards. The use of both Fluorinal-85 and Toluene in Rankine cycle energy recovery systems will be subject to U.S. Coast Guard regulations and American Bureau of Shipping rules. Good equipment design and installation practice must be adhered to, in addition to good vessel machinery operating procedures and adequate compartment ventilation. The equipment must be designed and constructed to meet U.S. Coast Guard and American Bureau of Shipping rules.

Energy recovery systems have been used in industrial applications in Europe for a number of years. A small number of terrestrial applications are found in the United States; however, no known marine applications exist. Because organic Rankine cycle bottoming systems are reasonably conventional in state-of-the-art technology, the transfer of technology from terrestrial organic Rankine cycle systems and other machine technology to marine hardware could be accomplished with minimal risk.

It appears that the only practical uses for energy recovered through the use of a diesel bottoming cycle system are for the ships' service electrical power generation, or to augment vessel propulsion. Because of the relatively low electrical power that is capable of being recovered, the most practical use of recovered power is to input the power into the main propulsion system.

A potential problem may exist with the design of the turbine reduction drive gearbox and its coupling to the diesel engine output drive. Extreme care must be exercised in the design and coupling of a relatively small, smoothly rotating high-speed mass (Rankine cycle turbine) to a large, slow-speed reciprocating mass (main diesel engine) to minimize torsional vibration effects on the turbine unit. A "flex-plate" drive, or other type of dampened drive coupling, will be required to control torsional effects.

2. RECOMMENDATIONS

The development of organic Rankine cycle diesel bottoming systems is currently being pursued by industry in a cautious manner. Development has been concentrated on terrestrial applications with shared (though not equal) funding by the system developer/manufacturer, the user, and the government (ERDA). Three major factors are involved in the introduction of new energy technologies: risk, cost and benefit. Since the feasibility of a new technology product depends not only on its technical merit but on its economics of introduction, risk and cost are closely related. Similarly, benefit and cost are related since the energy saved (or benefit) per unit of output determines the reduction in operating costs and hence is a major detriment in return on investment (ROI). Additionally, risk is related to benefit in that the higher the benefit the more willing industry would be to accept a risk. In light of the above factors, industries are extremely reluctant to introduce new design and product technologies unless they are well proven in production environment, unless they do not significantly increase the capital investment per unit product, and unless they save production costs to the extent that internal return on investment is very high.

Industry will pursue and implement programs when technological risk is low and whose economic attractiveness is clearly determined. Consequently, higher risk programs, which have a high potential benefit, must be developed and demonstrated by joint ERDA/industry funding if they are to

achieve industrial acceptance, implementation, and commercialization on a timely basis. The economic viability, as determined by return on investment on the projected capital cost of production units, must be clearly demonstrated to the potential end user. To circumvent these delays and barriers, and hence development, it would be highly desirable for the government to provide aid to industry to quicken the pace and scope of development to accelerate earliest energy savings.

A pilot demonstration program should be conducted to establish the economic viability of organic Rankine cycle bottoming systems on small marine vessels. Two systems should be developed and tested. First, an organic Rankine cycle using Fluorinal-85 as the working fluid should be developed for use with 2- or 4-cycle marine diesel engines rated at ~1,550 BHP. A program should be implemented by ERDA to develop a set of specifications, hardware design and fabrication, and laboratory verification testing of a single unit for a 1,550 BHP marine diesel engine. The unit should be tested for a period of time to establish operational design verification, performance, reliability and durability, and operational safety. At this point, a second unit should be fabricated and both units installed in a push-tow boat (either retrofitted into an existing vessel or incorporated into a new construction vessel). The vessel should be operated by a private operator for approximately one year as a demonstration project to prove the cost savings and fuel conservation to the inland river towing industry. A third unit should be constructed and installed in a single-engined fishing boat, or single-engined inland tug rated at ~1,550 BHP, to verify the potential of energy recovery systems for this marine segment. It may also be highly desirable to equip a second push-tow boat, owned by a different operator, with a diesel bottoming system to obtain a more accurate operational data base from two diverse trade route sectors.

Second, an organic Rankine cycle diesel bottoming system using Freon R-114 as the working fluid should be developed for use with 2- or 4-cycle marine diesel engines rated at ~325 BHP. A program should be implemented by ERDA to develop a set of specifications, hardware design and fabrication, and laboratory verification testing of a single unit for a 1,550 BHP marine diesel engine. The unit should be tested for a period of duration to establish operational design verification, performance, reliability and durability, and operational safety. At this point, a second unit should be fabricated and both units installed in a push-tow boat (either retrofitted into an existing vessel or incorporated

into a new construction vessel). The vessel should be operated by a private operator for approximately one year as a demonstration project to prove the cost savings and fuel conservation to the inland river towing industry. It may also be highly desirable to equip a second push-tow boat, owned by a different operator, with a diesel bottoming system to obtain a more accurate operational data base from two diverse trade route sectors.

In addition, a small engineering study program should be implemented at the earliest possible date in conjunction with, or preferably prior to, the above programs to optimize the overall operational and design concept of the Rankine cycle bottoming system turbine reduction drive gearbox when used in conjunction with a diesel engine for marine drive applications.

APPENDIX A

DIESEL ENGINE POWERED
MERCHANT VESSELS OF THE UNITED STATES
(HORSEPOWER VS VESSEL SIZE)

TOWING VESSELS - DIESEL

	800	1001	2001	3001	4001	5001	6001	7001	8001	9001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
NO. OF SHIPS	631.	1074.	272.	219.	116.	53.	32.	5.	15.	0.
AVG GRT	121.	194.	328.	400.	532.	568.	601.	1074.	967.	0.
AVG NRT	74.	120.	179.	254.	340.	388.	374.	710.	655.	0.
AVG HP	906.	1460.	2467.	3429.	4556.	5558.	6698.	7440.	8547.	0.
AVG LENGTH	70.6	87.2	109.8	122.9	137.6	135.2	146.7	184.4	172.3	0.0
AVG REAM	22.3	25.8	30.5	33.7	38.2	41.4	42.8	50.9	49.7	0.0
AVG DEPTH	8.6	9.9	11.1	10.7	10.5	11.3	11.1	11.3	10.7	0.0

TOW SHIPS OVER 10000 HP - DIESEL

	HP	GRT	NRT	LENGTH	BEAM	DEPTH
1	11000.	989.	672.	129.1	46.1	28.8
2	11000.	920.	625.	129.1	46.1	28.8
3	14840.	1578.	1073.	141.0	54.3	25.8
4	10100.	972.	660.	176.1	54.1	9.0
5	10100.	972.	660.	176.1	54.1	9.0
6	10100.	963.	650.	176.7	54.1	9.0
7	14000.	1360.	924.	112.7	90.8	31.5
8	10100.	1022.	695.	176.1	54.1	9.0

OIL EXPLOITATION VESSELS-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	152.	445.	112.	35.	9.
AVG GRT	99.	159.	375.	235.	2107.
AVG NRT	66.	109.	249.	157.	1402.
AVG HP	928.	1378.	2333.	3516.	4700.
AVG LENGTH	81.7	104.7	150.8	161.7	234.3
AVG BEAM	23.2	26.3	36.6	38.4	46.9
AVG DEPTH	8.2	9.5	12.0	13.4	17.5

OIL EXPLOITATION SHIPS-DIESEL-OVER 5000 HP

	HP	GRT	NRT	LENGTH	BEAM	DEPTH
1	5100.	5926.	4001.	374.0	65.2	26.8
2	7080.	298.	203.	180.0	40.0	18.0
3	5750.	292.	198.	170.0	40.1	16.0
4	7080.	298.	203.	180.0	40.0	18.0
5	7080.	298.	203.	180.0	40.0	18.0
6	5600.	280.	190.	171.5	40.0	16.4
7	7080.	298.	203.	180.0	40.0	18.0
8	6160.	294.	200.	180.0	40.0	18.0
9	5600.	280.	190.	171.5	40.0	16.4
10	5750.	292.	198.	170.0	40.1	16.0
11	5600.	265.	180.	172.0	40.1	16.4
12	6160.	296.	201.	180.0	40.0	18.0
13	6000.	288.	196.	168.0	38.1	13.0
14	8000.	491.	129.	188.5	42.1	15.0
15	8000.	491.	129.	188.5	42.1	15.0
16	12750.	8300.	7934.	255.1	191.1	24.3
17	5750.	292.	198.	170.0	40.1	16.0
18	7180.	295.	201.	171.8	40.0	16.5
19	6000.	295.	201.	181.0	40.0	12.5
20	7180.	295.	201.	171.8	40.0	16.5
21	7180.	296.	201.	171.8	40.0	16.5

FERRYS-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	13.	15.	5.	3.	0.
AVG GRT	522.	793.	1582.	1869.	0.
AVG NRT	374.	484.	1033.	1158.	0.
AVG HP	920.	1492.	2496.	4000.	0.
AVG LENGTH	153.9	193.4	312.0	260.5	0.0
AVG BEAM	50.3	50.9	65.7	64.0	0.0
AVG DEPTH	11.2	13.4	19.0	15.6	0.0

FERRYS-DIESEL-OVER 5000 HP

	HP	GRT	NRT	LENGTH	BEAM	DEPTH
1	6000.	2713.	1287.	347.9	56.2	19.2
2	8000.	2928.	1253.	375.1	73.5	18.4
3	8000.	2458.	1093.	319.1	73.5	18.4
4	8000.	2458.	1093.	319.1	73.5	18.4
5	6400.	2109.	1434.	277.0	69.0	19.1
6	6400.	2109.	1434.	277.0	69.0	19.1
7	6400.	2109.	1434.	277.0	69.0	19.1
8	7200.	2704.	1214.	369.0	73.2	20.7
9	8000.	2704.	1214.	369.0	73.2	20.7
10	8000.	2704.	1214.	369.0	73.2	20.7
11	7200.	2704.	1214.	369.0	73.2	20.7
12	5750.	3246.	1198.	429.5	86.8	14.8
13	5750.	3246.	1198.	429.5	86.8	14.8
14	18000.	3946.	2683.	379.6	85.1	19.5

FISH VESSELS-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	144.	149.	31.	54.	2.
AVG GRT	276.	465.	690.	1052.	1363.
AVG NRT	167.	291.	355.	545.	751.
AVG HP	902.	1427.	2606.	3597.	4375.
AVG LENGTH	118.3	143.0	146.3	191.7	212.4
AVG BEAM	26.1	29.9	31.2	38.8	41.2
AVG DEPTH	10.6	11.8	15.0	16.3	16.7

FISH SHIPS-DIESEL-OVER 5000 HP

	HP	GRT	NRT	LENGTH	BEAM	DEPTH
1	6000.	1568.	855.	234.3	45.0	20.3
2	5750.	1308.	781.	213.9	41.3	20.0

TANKER-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	10	10	10	10	10
	1000	2000	3000	4000	5000
NO. OF SHIPS	9.	20.	5.	2.	0.
AVG GRT	963.	1647.	1967.	2874.	0.
AVG NRT	680.	1244.	1514.	2024.	0.
AVG HP	855.	1527.	2318.	3200.	0.
AVG LENGTH	212.1	253.0	291.4	327.5	0.0
AVG BEAM	35.4	43.0	44.2	50.7	0.0
AVG DEPTH	13.0	16.8	17.9	18.3	0.0

TANKER-DIESEL-OVER 5000 HP

	HP	GRT	NRT	LENGTH	BEAM	DEPTH
1	15000.	20751.	16954.	641.9	89.0	47.0
2	15000.	20751.	16954.	641.9	89.0	47.0
3	15000.	20751.	16954.	641.9	89.0	47.0
4	15000.	20751.	16954.	641.9	89.0	47.0

RECORD NO. 1847 540413 STS FRT 41127 25389 0120M 08922
 1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
 ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
 CALLED FROM KRAKER= AT ADDRESS 000345
 CALLED FROM INPC= AT ADDRESS 000075
 CALLED FROM OSSER AT LINE 17

RECORD NO. 1857 542200 STS FRT 41127 25389 0120M 08922
 1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
 ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
 CALLED FROM KRAKER= AT ADDRESS 000345
 CALLED FROM INPC= AT ADDRESS 000075
 CALLED FROM OSSER AT LINE 17

RECORD NO. 1867 545200 STS FRT 41127 25389 0120M 08922
 1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
 ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
 CALLED FROM KRAKER= AT ADDRESS 000345
 CALLED FROM INPC= AT ADDRESS 000075
 CALLED FROM OSSER AT LINE 17

RECORD NO. 1868 545201 STS FRT 41127 25389 0120M 08922
 1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
 ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
 CALLED FROM KRAKER= AT ADDRESS 000345
 CALLED FROM INPC= AT ADDRESS 000075
 CALLED FROM OSSER AT LINE 17

RECORD NO. 1871 546383 STS FRT 41127 25389 0120M 08922
 1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
 ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
 CALLED FROM KRAKER= AT ADDRESS 000345
 CALLED FROM INPC= AT ADDRESS 000075
 CALLED FROM OSSER AT LINE 17

FREIGHTER-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	12.	38.	13.	13.	8.
AVG GRT	178.	985.	3624.	5607.	4591.
AVG NRT	107.	659.	2677.	3989.	3524.
AVG HP	912.	1439.	2614.	3533.	4494.
AVG LENGTH	104.1	166.4	337.8	430.2	357.2
AVG BEAM	26.8	34.3	47.9	52.5	53.8
AVG DEPTH	9.5	13.1	20.7	23.0	20.6

APPENDIX A (6B)

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* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
CALLED FROM KRAKER= AT ADDRESS 000345
CALLED FROM INPC= AT ADDRESS 000075
CALLED FROM KRAKER= AT ADDRESS 000075
AT LINE 17
```

RECORD NO. 546383 STS FRT 41127 25389 0120M 08922
1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
CALLED FROM KRAKER= AT ADDRESS 000345
CALLED FROM INPC= AT ADDRESS 000075
CALLED FROM DSSER AT LINE 17

10	12000.	15544.	11582.	622.0	77.8	45.4
11	5400.	10343.	6477.	612.1	68.2	34.4
12	7200.	15674.	12482.	665.3	78.1	42.8

RECORD NO. 1888 550721 STS FRT 41127 25389 0120M 08922
1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
CALLED FROM KRAKER= AT ADDRESS 000345
CALLED FROM INPC= AT ADDRESS 000075
CALLED FROM DSSER AT LINE 17

RECORD NO. 1889 550722 STS FRT 41127 25389 0120M 08922
1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
CALLED FROM KRAKER= AT ADDRESS 000345
CALLED FROM INPC= AT ADDRESS 000075
CALLED FROM DSSER AT LINE 17

RECORD NO. 1890 550723 STS FRT 41127 25389 0120M 08922
1234567890123456789012345678901234567890.+.1234567890123456789012345678901234567890

* ERROR DATA INPUT * ILLEGAL DATA IN FIELD **
ERROR NUMBER 78 DETECTED BY INCOM= AT ADDRESS 000207
CALLED FROM KRAKER= AT ADDRESS 000345
CALLED FROM INPC= AT ADDRESS 000075
CALLED FROM DSSER AT LINE 17

13	7000.	13862.	9712.	666.8	78.1	42.7
14	5400.	10343.	6477.	612.1	68.2	34.4
15	7000.	21815.	17665.	690.8	78.1	42.7
16	5600.	539.	171.	128.0	42.0	9.5
17	5400.	10037.	6269.	612.1	68.2	34.4
18	7200.	251.	171.	171.4	40.0	16.5

PATROL BOAT-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	0.	1.	0.	0.	0.
AVG GRT	0.	57.	0.	0.	0.
AVG NRT	0.	38.	0.	0.	0.
AVG HP	0.	1240.	0.	0.	0.
AVG LENGTH	0.0	60.4	0.0	0.0	0.0
AVG BEAM	0.0	17.5	0.0	0.0	0.0
AVG DEPTH	0.0	7.0	0.0	0.0	0.0

PILOT BOAT-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	2.	10.	0.	0.	0.
AVG GRT	170.	310.	0.	0.	0.
AVG NRT	116.	198.	0.	0.	0.
AVG HP	900.	1335.	0.	0.	0.
AVG LENGTH	93.5	101.7	0.0	0.0	0.0
AVG BEAM	21.8	23.2	0.0	0.0	0.0
AVG DEPTH	10.1	11.4	0.0	0.0	0.0

POLICE BOAT-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	1.	0.	0.	0.	0.
AVG GRT	162.	0.	0.	0.	0.
AVG NRT	127.	0.	0.	0.	0.
AVG HP	800.	0.	0.	0.	0.
AVG LENGTH	112.8	0.0	0.0	0.0	0.0
AVG BEAM	18.0	0.0	0.0	0.0	0.0
AVG DEPTH	8.5	0.0	0.0	0.0	0.0

FIREBOAT-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	11.	8.	3.	0.	0.
AVG GRT	144.	168.	321.	0.	0.
AVG NRT	85.	108.	196.	0.	0.
AVG HP	932.	1366.	2900.	0.	0.
AVG LENGTH	85.4	85.6	125.9	0.0	0.0
AVG BEAM	22.3	23.0	29.7	0.0	0.0
AVG DEPTH	10.0	10.6	12.6	0.0	0.0

ICE BREAKER-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	0.	0.	0.	0.	0.
AVG GRT	0.	0.	0.	0.	0.
AVG NRT	0.	0.	0.	0.	0.
AVG HP	0.	0.	0.	0.	0.
AVG LENGTH	0.0	0.0	0.0	0.0	0.0
AVG BEAM	0.0	0.0	0.0	0.0	0.0
AVG DEPTH	0.0	0.0	0.0	0.0	0.0

PASSENGER VESSELS-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	120.	147.	11.	6.	0.
AVG GRT	81.	128.	223.	1176.	0.
AVG NRT	54.	87.	193.	712.	0.
AVG HP	894.	1249.	2343.	3417.	0.
AVG LENGTH	68.1	81.2	125.1	217.9	0.0
AVG BEAM	19.8	22.9	30.8	46.5	0.0
AVG DEPTH	7.1	7.8	7.5	14.0	0.0

YACHTS-DIESEL

	800	1001	2001	3001	4001
HORSEPOWER	TO	TO	TO	TO	TO
	1000	2000	3000	4000	5000
NO. OF SHIPS	401.	213.	7.	1.	1.
AVG GRT	62.	81.	343.	792.	186.
AVG NRT	47.	62.	225.	633.	126.
AVG HP	882.	1179.	2371.	3200.	4050.
AVG LENGTH	60.5	68.9	127.5	220.0	116.7
AVG BEAM	16.5	17.9	22.2	30.0	27.0
AVG DEPTH	8.2	8.7	11.4	18.0	5.7

APPENDIX B

DIESEL ENGINE POWERED
MERCHANT VESSELS OF THE UNITED STATES
(HORSEPOWER VS VESSEL AGE)

1.1 OIL EXPLOITATION-DIESEL

	0	51	101	501	1001	5001	10001	20001	
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO	
	50	100	500	1000	5000	10000	20000	OVER	
NUMBER OF SHIPS	4.	19.	987.	433.	601.	20.	1.	0.	
AVERAGE AGE	28.0	32.0	14.7	11.9	7.2	2.7	2.0	0.0	
01 - 09 YRS OLD	1.	0.	276.	173.	417.	20.	1.	0.	
10 - 19 YRS OLD	0.	1.	461.	192.	172.	0.	0.	0.	
20 - 29 YRS OLD	1.	8.	194.	57.	4.	0.	0.	0.	
30 - 39 YRS OLD	1.	6.	37.	9.	6.	0.	0.	0.	
40 - 49 YRS OLD	1.	2.	12.	1.	2.	0.	0.	0.	
50 - 59 YRS OLD	0.	2.	7.	1.	0.	0.	0.	0.	
60 - 69 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.	
YR BUILT UNKNOWN	0.	1.	2.	0.	0.	0.	0.	0.	

NUMBER OF SHIPS 2065

YEAR BUILT UNKNOWN 3

1.1 TOWING-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	22.	143.	2734.	1479.	1680.	105.	8.	0.
AVERAGE AGE	35.2	39.2	26.6	21.3	19.1	6.0	2.8	0.0
01 - 09 YRS OLD	2.	5.	380.	408.	613.	83.	8.	0.
10 - 19 YRS OLD	2.	8.	632.	428.	393.	20.	0.	0.
20 - 29 YRS OLD	6.	28.	673.	263.	297.	1.	0.	0.
30 - 39 YRS OLD	4.	35.	616.	235.	235.	1.	0.	0.
40 - 49 YRS OLD	3.	30.	183.	40.	40.	0.	0.	0.
50 - 59 YRS OLD	1.	15.	103.	22.	30.	0.	0.	0.
60 - 69 YRS OLD	4.	18.	72.	33.	45.	0.	0.	0.
70 - 79 YRS OLD	0.	3.	39.	30.	16.	0.	0.	0.
80 - 89 YRS OLD	0.	1.	24.	10.	6.	0.	0.	0.
90 - OVER YEARS	0.	0.	12.	10.	5.	0.	0.	0.
YR BUILT UNKNOWN	0.	2.	16.	0.	1.	0.	0.	0.

NUMBER OF SHIPS 6171

YEAR BUILT UNKNOWN 19

1.11 FISH-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	390.	2602.	13369.	608.	236.	2.	0.	0.
AVERAGE AGE	35.4	32.2	19.5	16.2	14.3	3.0	0.0	0.0
01 - 09 YRS OLD	38.	213.	4931.	291.	125.	2.	0.	0.
10 - 19 YRS OLD	31.	312.	2628.	84.	39.	0.	0.	0.
20 - 29 YRS OLD	49.	577.	2358.	94.	11.	0.	0.	0.
30 - 39 YRS OLD	112.	776.	2127.	111.	59.	0.	0.	0.
40 - 49 YRS OLD	83.	390.	600.	17.	2.	0.	0.	0.
50 - 59 YRS OLD	61.	225.	454.	6.	0.	0.	0.	0.
60 - 69 YRS OLD	11.	78.	203.	5.	0.	0.	0.	0.
70 - 79 YRS OLD	4.	20.	48.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	10.	10.	0.	0.	0.	0.	0.
90 - OVER YEARS	1.	1.	10.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	11.	53.	69.	1.	0.	0.	0.	0.

NUMBER OF SHIPS 17207

YEAR BUILT UNKNOWN 134

1.21 COD-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	0.	0.	2.	0.	0.	0.	0.	0.
AVERAGE AGE	0.0	0.0	21.0	0.0	0.0	0.0	0.0	0.0
01 - 09 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
10 - 19 YRS OLD	0.	0.	1.	0.	0.	0.	0.	0.
20 - 29 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
30 - 39 YRS OLD	0.	0.	1.	0.	0.	0.	0.	0.
40 - 49 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
50 - 59 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
60 - 69 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	0.	0.	0.	0.	0.	0.	0.	0.

NUMBER OF SHIPS 2

YEAR BUILT UNKNOWN 0

1.31 OYSTER-DIESEL

	* 0	* 51	* 101	* 501	* 1001	* 5001	* 10001	* 20001	
	* TO	* TO	* TO	* TO	* TO	* TO	* TO	* TO	
HORSEPOWER	* 50	* 100	* 500	* 1000	* 5000	* 10000	* 20000	* OVER	
NUMER OF SHIPS	* 7.	* 48.	* 207.	* 1.	* 0.	* 0.	* 0.	* 0.	
AVERAGE AGE	* 39.7	* 41.8	* 27.0	* 18.0	* 0.0	* 0.0	* 0.0	* 0.0	
01 - 09 YRS OLD	* 0.	* 1.	* 38.	* 0.	* 0.	* 0.	* 0.	* 0.	
10 - 19 YRS OLD	* 2.	* 5.	* 63.	* 1.	* 0.	* 0.	* 0.	* 0.	
20 - 29 YRS OLD	* 1.	* 9.	* 30.	* 0.	* 0.	* 0.	* 0.	* 0.	
30 - 39 YRS OLD	* 1.	* 11.	* 31.	* 0.	* 0.	* 0.	* 0.	* 0.	
40 - 49 YRS OLD	* 0.	* 6.	* 14.	* 0.	* 0.	* 0.	* 0.	* 0.	
50 - 59 YRS OLD	* 1.	* 3.	* 12.	* 0.	* 0.	* 0.	* 0.	* 0.	
60 - 69 YRS OLD	* 1.	* 7.	* 6.	* 0.	* 0.	* 0.	* 0.	* 0.	
70 - 79 YRS OLD	* 1.	* 5.	* 8.	* 0.	* 0.	* 0.	* 0.	* 0.	
80 - 89 YRS OLD	* 0.	* 0.	* 1.	* 0.	* 0.	* 0.	* 0.	* 0.	
90 - OVER YEARS	* 0.	* 1.	* 4.	* 0.	* 0.	* 0.	* 0.	* 0.	
YR BUILT UNKNOWN	* 0.	* 0.	* 0.	* 0.	* 0.	* 0.	* 0.	* 0.	

NUMBER OF SHIPS 263

YEAR BUILT UNKNOWN 0

1.41 WHALE-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	0.	0.	1.	1.	0.	0.	0.	0.
AVERAGE AGE	0.0	0.0	34.0	32.0	0.0	0.0	0.0	0.0
01 - 09 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
10 - 19 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
20 - 29 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
30 - 39 YRS OLD	0.	0.	1.	1.	0.	0.	0.	0.
40 - 49 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
50 - 59 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
60 - 69 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	0.	0.	0.	0.	0.	0.	0.	0.

NUMBER OF SHIPS 2

YEAR BUILT UNKNOWN 0

1.11 PLEASURE-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	4.	6.	21.	1.	0.	0.	0.	0.
AVERAGE AGE	14.8	33.7	28.4	40.0	0.0	0.0	0.0	0.0
01 - 09 YRS OLD	3.	1.	5.	0.	0.	0.	0.	0.
10 - 19 YRS OLD	0.	1.	3.	0.	0.	0.	0.	0.
20 - 29 YRS OLD	0.	0.	3.	0.	0.	0.	0.	0.
30 - 39 YRS OLD	0.	1.	5.	0.	0.	0.	0.	0.
40 - 49 YRS OLD	0.	2.	1.	1.	0.	0.	0.	0.
50 - 59 YRS OLD	1.	0.	2.	0.	0.	0.	0.	0.
60 - 69 YRS OLD	0.	1.	1.	0.	0.	0.	0.	0.
70 - 79 YRS OLD	0.	0.	1.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	0.	0.	1.	0.	0.	0.	0.	0.

NUMBER OF SHIPS 32

YEAR BUILT UNKNOWN 1

1.21 YACHT-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	5571.	1665.	5009.	2917.	222.	0.	0.	0.
AVERAGE AGE	9.0	15.6	16.5	8.9	8.5	0.0	0.0	0.0
01 - 09 YRS OLD	4044.	833.	2247.	1966.	177.	0.	0.	0.
10 - 19 YRS OLD	1041.	376.	1241.	816.	24.	0.	0.	0.
20 - 29 YRS OLD	193.	128.	568.	61.	2.	0.	0.	0.
30 - 39 YRS OLD	119.	149.	442.	42.	14.	0.	0.	0.
40 - 49 YRS OLD	121.	104.	309.	21.	4.	0.	0.	0.
50 - 59 YRS OLD	36.	49.	141.	8.	1.	0.	0.	0.
60 - 69 YRS OLD	11.	13.	45.	2.	0.	0.	0.	0.
70 - 79 YRS OLD	6.	9.	12.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	3.	2.	1.	0.	0.	0.	0.
90 - OVER YEARS	0.	1.	2.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	11.	7.	16.	1.	0.	0.	0.	0.

NUMBER OF SHIPS 15384

YEAR BUILT UNKNOWN 35

1.11 FREIGHTER-DIESEL

	0	51	101	501	1001	5001	10001	20001	
	TO	TO	TO	TO	TO	TO	TO	TO	
	50	100	500	1000	5000	10000	20000	OVER	
NUMBER OF SHIPS	22.	87.	497.	47.	72.	14.	3.	1.	
AVERAGE AGE	28.7	41.3	35.1	27.3	30.3	12.7	4.3	9.0	
01 - 09 YRS OLD	3.	3.	21.	3.	14.	9.	3.	1.	
10 - 19 YRS OLD	7.	5.	82.	10.	16.	2.	0.	0.	
20 - 29 YRS OLD	1.	10.	96.	6.	3.	0.	0.	0.	
30 - 39 YRS OLD	2.	24.	138.	24.	19.	2.	0.	0.	
40 - 49 YRS OLD	6.	19.	50.	2.	5.	0.	0.	0.	
50 - 59 YRS OLD	2.	15.	54.	1.	6.	1.	0.	0.	
60 - 69 YRS OLD	1.	9.	33.	0.	3.	0.	0.	0.	
70 - 79 YRS OLD	0.	0.	13.	1.	6.	0.	0.	0.	
80 - 89 YRS OLD	0.	1.	4.	0.	0.	0.	0.	0.	
90 - OVER YEARS	0.	1.	6.	0.	0.	0.	0.	0.	
YR BUILT UNKNOWN	0.	0.	2.	1.	0.	0.	0.	0.	

NUMBER OF SHIPS 743

YEAR BUILT UNKNOWN 3

1.21 REFRIGERATOR-DIESEL

	0	51	101	501	1001	5001	10001	20001	
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO	
	50	100	500	1000	5000	10000	20000	OVER	
NUMBER OF SHIPS	0.	0.	0.	0.	0.	0.	0.	0.	
AVERAGE AGE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
01 - 09 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
10 - 19 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
20 - 29 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
30 - 39 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
40 - 49 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
50 - 59 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
60 - 69 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.	
YR BUILT UNKNOWN	0.	0.	0.	0.	0.	0.	0.	0.	

NUMBER OF SHIPS 0

YEAR BUILT UNKNOWN 0

1.31 TANKER-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	5.	10.	47.	18.	27.	0.	9.	0.
AVERAGE AGE	22.8	29.8	36.2	31.3	28.0	0.0	2.9	0.0
01 - 09 YRS OLD	1.	1.	3.	1.	5.	0.	9.	0.
10 - 19 YRS OLD	2.	1.	2.	3.	3.	0.	0.	0.
20 - 29 YRS OLD	1.	2.	10.	2.	6.	0.	0.	0.
30 - 39 YRS OLD	0.	4.	10.	9.	6.	0.	0.	0.
40 - 49 YRS OLD	1.	2.	16.	0.	4.	0.	0.	0.
50 - 59 YRS OLD	0.	0.	5.	3.	2.	0.	0.	0.
60 - 69 YRS OLD	0.	0.	0.	0.	1.	0.	0.	0.
70 - 79 YRS OLD	0.	0.	1.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	0.	1.	0.	0.	0.	0.	0.	0.

NUMBER OF SHIPS 116

YEAR BUILT UNKNOWN 1

1.11 PASSENGER-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	176.	334.	3049.	645.	164.	0.	0.	0.
AVERAGE AGE	18.4	27.4	20.2	11.5	10.6	0.0	0.0	0.0
01 - 09 YRS OLD	82.	59.	717.	334.	111.	0.	0.	0.
10 - 19 YRS OLD	33.	58.	966.	234.	27.	0.	0.	0.
20 - 29 YRS OLD	11.	64.	616.	33.	5.	0.	0.	0.
30 - 39 YRS OLD	24.	92.	521.	35.	13.	0.	0.	0.
40 - 49 YRS OLD	16.	30.	144.	4.	5.	0.	0.	0.
50 - 59 YRS OLD	7.	15.	61.	0.	2.	0.	0.	0.
60 - 69 YRS OLD	3.	14.	15.	3.	1.	0.	0.	0.
70 - 79 YRS OLD	0.	1.	4.	1.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	0.	3.	0.	0.	0.	0.	0.
90 - OVER YEARS	0.	1.	2.	1.	0.	0.	0.	0.
YR BUILT UNKNOWN	0.	3.	29.	1.	0.	0.	0.	0.

NUMBER OF SHIPS 4368

YEAR BUILT UNKNOWN 33

1.21 FERRY-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	5.	18.	63.	34.	23.	13.	1.	0.
AVERAGE AGE	37.4	32.4	25.3	25.3	27.0	12.7	2.0	0.0
01 - 09 YRS OLD	0.	1.	9.	10.	4.	6.	1.	0.
10 - 19 YRS OLD	0.	1.	19.	7.	5.	6.	0.	0.
20 - 29 YRS OLD	2.	5.	14.	2.	6.	0.	0.	0.
30 - 39 YRS OLD	1.	8.	11.	7.	2.	0.	0.	0.
40 - 49 YRS OLD	0.	3.	3.	3.	4.	0.	0.	0.
50 - 59 YRS OLD	2.	0.	7.	4.	2.	1.	0.	0.
60 - 69 YRS OLD	0.	0.	0.	1.	0.	0.	0.	0.
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	0.	0.	0.	0.	0.	0.	0.	0.

NUMBER OF SHIPS 157

YEAR BUILT UNKNOWN 0

1.11 PILE DRIVING.WELDING.WRECKING-DIESEL

	0	51	101	501	1001	5001	10001	20001	
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO	
	50	100	500	1000	5000	10000	20000	OVER	
NUMBER OF SHIPS	1.	3.	28.	1.	2.	0.	0.	0.	
AVERAGE AGE	34.0	28.3	29.3	22.0	37.0	0.0	0.0	0.0	
01 - 09 YRS OLD	0.	1.	2.	0.	0.	0.	0.	0.	
10 - 19 YRS OLD	0.	0.	3.	0.	0.	0.	0.	0.	
20 - 29 YRS OLD	0.	0.	6.	1.	0.	0.	0.	0.	
30 - 39 YRS OLD	1.	1.	13.	0.	1.	0.	0.	0.	
40 - 49 YRS OLD	0.	1.	2.	0.	1.	0.	0.	0.	
50 - 59 YRS OLD	0.	0.	2.	0.	0.	0.	0.	0.	
60 - 69 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.	
YR BUILT UNKNOWN	0.	0.	0.	0.	0.	0.	0.	0.	

NUMBER OF SHIPS 35

YEAR BUILT UNKNOWN 0

1.21 FIRE BOAT, ICE BREAKER, PILOT, POLICE, PATROL-DIESEL

	* 0	* 51	* 101	* 501	* 1001	* 5001	* 10001	* 20001	
	* TO	* TO	* TO	* TO	* TO	* TO	* TO	* TO	
HORSEPOWER	* 50	* 100	* 500	* 1000	* 5000	* 10000	* 20000	* OVER	
NUMBER OF SHIPS	2.	6.	100.	49.	22.	0.	0.	0.	
AVERAGE AGE	44.5	20.0	18.0	14.3	22.7	0.0	0.0	0.0	
01 - 09 YRS OLD	0.	1.	33.	16.	7.	0.	0.	0.	
10 - 19 YRS OLD	0.	2.	29.	22.	5.	0.	0.	0.	
20 - 29 YRS OLD	0.	2.	19.	8.	2.	0.	0.	0.	
30 - 39 YRS OLD	1.	1.	13.	2.	2.	0.	0.	0.	
40 - 49 YRS OLD	0.	0.	3.	1.	4.	0.	0.	0.	
50 - 59 YRS OLD	1.	0.	2.	0.	1.	0.	0.	0.	
60 - 69 YRS OLD	0.	0.	1.	0.	1.	0.	0.	0.	
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.	
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.	
YR BUILT UNKNOWN	0.	0.	0.	0.	0.	0.	0.	0.	

NUMBER OF SHIPS 179

YEAR BUILT UNKNOWN 0

1.31 LIGHTERING-DIESEL

	0	51	101	501	1001	5001	10001	20001
HORSEPOWER	TO	TO	TO	TO	TO	TO	TO	TO
	50	100	500	1000	5000	10000	20000	OVER
NUMBER OF SHIPS	0.	0.	1.	0.	1.	0.	0.	0.
AVERAGE AGE	0.0	0.0	18.0	0.0	32.0	0.0	0.0	0.0
01 - 09 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
10 - 19 YRS OLD	0.	0.	1.	0.	0.	0.	0.	0.
20 - 29 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
30 - 39 YRS OLD	0.	0.	0.	0.	1.	0.	0.	0.
40 - 49 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
50 - 59 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
60 - 69 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
70 - 79 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
80 - 89 YRS OLD	0.	0.	0.	0.	0.	0.	0.	0.
90 - OVER YEARS	0.	0.	0.	0.	0.	0.	0.	0.
YR BUILT UNKNOWN	0.	0.	0.	0.	0.	0.	0.	0.

NUMBER OF SHIPS 2

YEAR BUILT UNKNOWN 0

APPENDIX C

MARINE VESSEL OPERATING DUTY-CYCLE/LOAD-FACTORS

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: INLAND RIVER PUSH-TOW BOATS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>345</u>
Average No. of Hours Operation per Year	Vessel <u>8,280</u>
	Main Engine <u>8,280</u>

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>49</u>	<u>100</u>
<u>40</u>	<u>50</u>
<u>5</u>	<u>25</u>
<u>3</u>	<u>10</u>
<u>3</u>	<u>Idle</u>
<u> </u>	<u> </u>
<u> </u>	<u> </u>

WEIGHTED AVERAGE DUTY CYCLE/LOAD FACTOR

▽ Overall Weighted Average Power	<u>71</u> %
□ Weighted Average Power for 50% Power Level and Higher:	
<u>78</u> % Power for <u>89</u> % Time	
(Based on Yearly Engine Hours)	

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: INLAND TUGS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 300
 Average No. of Hours Operation per Year Vessel 7,200
 Main Engine 5,568

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

50
32
4
4
5
5

100
90
80
40
20
10 <

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

Overall Weighted
 Average Power . . . 85 %

Weighted Average Power
 for 50% Power Level and Higher:

95 % Power for 86 % Time
 (Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: OCEAN/COASTAL TUGS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 300
 Average No. of Hours Operation per Year Vessel 7,200
 Main Engine 6,240

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>50</u>	<u>100</u>
<u>36</u>	<u>90</u>
<u>4</u>	<u>80</u>
<u>2</u>	<u>40</u>
<u>4</u>	<u>20</u>
<u>4</u>	<u>10 <</u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

Overall Weighted
 Average Power . . . 87 %
 Weighted Average Power
 for 50% Power Level and Higher:
87 % Power for 90 % Time
 (Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: OFFSHORE TUGS (Oil Industry)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>300</u>
Average No. of Hours Operation per Year	Vessel <u>7,200</u>
	Main Engine <u>4,200</u>

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

<u>50</u>
<u>10</u>
<u>15</u>
<u>10</u>
<u>15</u>

<u>100</u>
<u>60</u>
<u>40</u>
<u>20</u>
<u>10 <</u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR Overall Weighted
Average Power . . . 65 % Weighted Average Power
for 50% Power Level and Higher:

93 % Power for 60 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: OFFSHORE TUG/SUPPLY BOATS (Oil Industry)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>350</u>
Average No. of Hours Operation per Year Vessel	<u>8,400</u>
Main Engine	<u>4,900</u>

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>50</u>	<u>100</u>
<u>15</u>	<u>60</u>
<u>10</u>	<u>40</u>
<u>10</u>	<u>20</u>
<u>15</u>	<u>10 <</u>
<u> </u>	<u> </u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

▽ Overall Weighted
Average Power . . 66 %

□ Weighted Average Power
for 50% Power Level and Higher:

91 % Power, for 65 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: OFFSHORE CREW/CREW-SUPPLY BOATS (Oil Industry)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>12</u>
Average No. of Hours Operation per Year	<u>300</u>
Average No. of Hours Operation per Year Vessel	<u>3,600</u>
Main Engine	<u>2,700</u>

○ AVERAGE DUTY CYCLE

Percent of Time Percent Power

<u>70</u>	<u>100</u>
<u>10</u>	<u>40</u>
<u>10</u>	<u>20</u>
<u>10</u>	<u>10<</u>
<u> </u>	<u> </u>
<u> </u>	<u> </u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR▽ Overall Weighted
Average Power . . . 77 %□ Weighted Average Power
for 50% Power Level and Higher:

100 % Power for 70 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: OFFSHORE SUPPLY BOATS (Oil Industry)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 350
 Average No. of Hours Operation per Year Vessel 8,400
 Main Engine 4,200

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

60
10
20
10

100
40
20
10 <

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

Overall Weighted
 Average Power . . . 69 %

□ Weighted Average Power
 for 50% Power Level and Higher:

100 % Power for 60 % Time
 (Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: PASSENGER/CAR FERRIES

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>350</u>
Average No. of Hours Operation per Year	Vessel <u>8,400</u>
	Main Engine <u>7,000</u>

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>3</u>	<u>100</u>
<u>77</u>	<u>80</u>
<u>2</u>	<u>10</u>
<u>18</u>	<u>Idle</u>
<u> </u>	<u> </u>
<u> </u>	<u> </u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

▽ Overall Weighted
Average Power . . . 65 %

□ Weighted Average Power
for 50% Power Level and Higher:

81 % Power for 80 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: GREAT LAKES CARGO SHIPS & TANKERS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>270</u>
Average No. of Hours Operation per Year	Vessel <u>6,480</u>
	Main Engine <u>5,280</u>

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

<u>50</u>	<u>100</u>
<u>35</u>	<u>90</u>
<u>4</u>	<u>80</u>
<u>2</u>	<u>40</u>
<u>4</u>	<u>20</u>
<u>5</u>	<u>10 <</u>

WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR Overall Weighted
Average Power . . . 87 % Weighted Average Power
for 50% Power Level and Higher:

95 % Power for 89 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: COASTAL TANKERS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day		<u>24</u>
Average No. of Hours Operation per Year		<u>300</u>
Average No. of Hours Operation per Year	Vessel	<u>7,200</u>
	Main Engine	<u>6,500</u>

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

<u>50</u>
<u>36</u>
<u>4</u>
<u>2</u>
<u>4</u>
<u>4</u>

<u>100</u>
<u>90</u>
<u>80</u>
<u>40</u>
<u>20</u>
<u>10</u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR Overall Weighted
Average Power . . . 87 % Weighted Average Power
for 50% Power Level and Higher:

95 % Power for 90 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: FISHING SEINER BOATS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 300
 Average No. of Hours Operation per Year Vessel 7,200
 Main Engine 4,560

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

<u>49</u>	<u>100</u>
<u>15</u>	<u>75</u>
<u>15</u>	<u>50</u>
<u>15</u>	<u>20</u>
<u>6</u>	<u>10 <</u>
<u> </u>	<u> </u>

WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR Overall Weighted
Average Power . . . 71 % Weighted Average Power
for 50% Power Level and Higher:

86 % Power for 79 % Time
 (Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: RESEARCH/EXPLORATION/SURVEY VESSELS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>190</u>
Average No. of Hours Operation per Year	Vessel <u>4,560</u>
	Main Engine <u>4,560</u>

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

<u>10</u>
<u>40</u>
<u>20</u>
<u>10</u>
<u>20</u>

<u>100</u>
<u>80</u>
<u>40</u>
<u>20</u>
<u>10 <</u>

WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR▽ Overall Weighted
Average Power . . . 54 %□ Weighted Average Power
for 50% Power Level and Higher:

<u>84</u> % Power for	<u>50</u> % Time
(Based on Yearly Engine Hours)	

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: HARBOR TUGS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>350</u>
Average No. of Hours Operation per Year	Vessel <u>8,400</u>
	Main Engine <u>2,800</u>

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

259050452510 < WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR Overall Weighted
Average Power . . . 47 % Weighted Average Power
for 50% Power Level and Higher:

90 % Power for 25 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: LARGE PLEASURE YACHTS

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 10
 Average No. of Hours Operation per Year 12
 Average No. of Hours Operation per Year Vessel 120
 Main Engine 120

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>10</u>	<u>100</u>
<u>20</u>	<u>75</u>
<u>40</u>	<u>40</u>
<u>20</u>	<u>20</u>
<u>10</u>	<u>10 <</u>
<u> </u>	<u> </u>

WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

▽ Overall Weighted
Average Power . . . 46 %
 □ Weighted Average Power
for 50% Power Level and Higher:
83 % Power for 30 % Time
 (Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: AO-SEALIFT TANKERS (Navy)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>270</u>
Average No. of Hours Operation per Year	Vessel <u>6,480</u>
	Main Engine <u>5,420</u>

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>5</u>	<u>100</u>
<u>84</u>	<u>80</u>
<u>2</u>	<u>40</u>
<u>4</u>	<u>20</u>
<u>5</u>	<u>10 <</u>
<u> </u>	<u> </u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

▽ Overall Weighted
Average Power . . . 74 %

□ Weighted Average Power
for 50% Power Level and Higher:

81 % Power for 89 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: ATF-FLEET TUGS (Navy)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 81
 Average No. of Hours Operation per Year Vessel 1,954
 Main Engine 1,607

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>5</u>	<u>100</u>
<u>78</u>	<u>75</u>
<u>2</u>	<u>40</u>
<u>5</u>	<u>20</u>
<u>10</u>	<u>10 <</u>
<u> </u>	<u> </u>

▽ WEIGHTED AVERAGE DUTY CYCLE/LOAD FACTOR

Overall Weighted Average Power . . . 66 %
 Weighted Average Power for 50% Power Level and Higher:
76 % Power for 83 % Time
 (Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: MSO-MINE SWEEPERS (Navy)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 98
 Average No. of Hours Operation per Year Vessel 2,361
 Main Engine 906

○ AVERAGE DUTY CYCLE

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

Percent of Time

Percent Power

Overall Weighted
Average Power . . . 54 %5809055510< Weighted Average Power
for 50% Power Level and Higher:56 % Power for 95 % Time

(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: AS-SUB TENDERS (Navy)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 348
 Average No. of Hours Operation per Year Vessel 8,352
 Main Engine 550

○ AVERAGE DUTY CYCLE

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

Percent of Time

Percent Power

Overall Weighted
Average Power . . . 65 % Weighted Average Power
for 50% Power Level and Higher:

75 % Power for 85 % Time
 (Based on Yearly Engine Hours)

5
80
15

80
75
10<

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: LST's (Navy)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>83</u>
Average No. of Hours Operation per Year	<u>1,995</u>
Vessel	<u>1,995</u>
Main Engine	<u>1,714</u>

○ AVERAGE DUTY CYCLE

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

Percent of Time

Percent Power

Overall Weighted
Average Power . . . 51 % Weighted Average Power
for 50% Power Level and Higher:

53 % Power for 95 % Time
(Based on Yearly Engine Hours)

10808550510 <

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: HIGH ENDURANCE CUTTERS (Coast Guard)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day 24
 Average No. of Hours Operation per Year 350
 Average No. of Hours Operation per Year Vessel 8,400
 Main Engine 4,320

○ AVERAGE DUTY CYCLE

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

Percent of Time

Percent Power

Overall Weighted

Average Power . . . 40 %101001080255040201510 < Weighted Average Power
for 50% Power Level and Higher:68 % Power for 45 % Time

(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: MEDIUM ENDURANCE CUTTERS (Coast Guard)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	24
Average No. of Hours Operation per Year	350
Average No. of Hours Operation per Year	Vessel 8,400
	Main Engine 4,800

○ AVERAGE DUTY CYCLE

Percent of Time

Percent Power

<u>10</u>	<u>100</u>
<u>10</u>	<u>80</u>
<u>40</u>	<u>50</u>
<u>25</u>	<u>20</u>
<u>15</u>	<u>10<</u>
<u> </u>	<u> </u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

▽ Overall Weighted
Average Power . . . 45 %

□ Weighted Average Power
for 50% Power Level and Higher:

63 % Power for 60 % Time
(Based on Yearly Engine Hours)

TYPICAL MARINE DUTY CYCLE/LOAD FACTOR

VESSEL TYPE: ICE BREAKERS (Coast Guard)

OPERATIONAL CHARACTERISTICS

Average No. of Hours Operation per Day	<u>24</u>
Average No. of Hours Operation per Year	<u>215</u>
Average No. of Hours Operation per Year	Vessel <u>5,160</u>
	Main Engine <u>3,984</u>

○ AVERAGE DUTY CYCLE

Percent of Time	Percent Power
<u>6</u>	<u>100</u>
<u>60</u>	<u>75</u>
<u>8</u>	<u>50</u>
<u>8</u>	<u>30</u>
<u>8</u>	<u>20</u>
<u>10</u>	<u>10<</u>

▽ WEIGHTED AVERAGE
DUTY CYCLE/LOAD FACTOR

▽ Overall Weighted
Average Power . . . 60 %

□ Weighted Average Power
for 50% Power Level and Higher:

74 % Power for 74 % Time
(Based on Yearly Engine Hours)

APPENDIX D

DIESEL ENGINE POWERED
MERCHANT VESSELS OF THE UNITED STATES
HORSEPOWER VS VESSEL SIZE
(IN 100 BHP INCREMENTS)

- . Towing Vessels
- . Oil Exploitation Vessels
- . Fishing Vessels
- . Ferry Vessels

-----G-DIESEL-OVER 800 HP

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
<hr/>																
NO. OF SHIPS	199.	270.	162.	226.	55.	66.	64.	145.	86.	197.	9.	64.	9.	47.	43.	76.
AVE GRT	124.	133.	132.	160.	184.	198.	203.	202.	208.	240.	275.	276.	220.	243.	575.	265.
AVE NRT	74.	81.	88.	102.	103.	126.	117.	122.	131.	147.	136.	174.	122.	138.	198.	164.
AVE HP	877.	991.	1050.	1185.	1278.	1375.	1485.	1587.	1693.	1795.	1877.	1994.	2085.	2168.	2253.	2393.
AVE LENGTH	72.5	74.1	70.8	81.0	87.1	84.2	90.9	92.5	89.2	95.9	109.1	105.2	90.9	100.0	132.0	101.6
AVE BEAM	22.4	22.9	23.2	24.5	25.5	26.0	25.9	25.9	27.6	27.6	31.0	28.3	27.5	28.3	32.8	29.3
AVE DEPTH	8.6	9.0	8.4	9.9	10.1	9.6	10.6	10.4	10.0	10.2	11.0	10.5	11.0	10.7	13.2	10.5

POWER-DIESEL-OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	15.	12.	5.	12.	13.	39.	6.	106.	14.	10.	7.	26.	0.	15.	8.	27.
AVE GRT	319.	467.	333.	403.	325.	244.	325.	414.	424.	383.	222.	384.	0.	389.	293.	451.
AVE NRT	203.	346.	186.	257.	219.	157.	221.	259.	288.	242.	133.	236.	0.	258.	192.	288.
AVE HP	2476.	2571.	2663.	2796.	2881.	3000.	3080.	3198.	3277.	3384.	3500.	3585.	0.	3800.	3891.	3999.
AVE LENGTH	111.9	126.6	106.6	119.5	119.1	106.5	97.0	123.3	124.3	118.5	112.4	124.8	0.0	119.0	119.7	132.2
AVE BEAM	30.3	34.8	31.4	33.7	32.8	30.9	31.3	33.3	36.3	33.6	32.3	32.8	0.0	34.0	33.3	35.3
AVE DEPTH	9.2	8.9	11.3	10.4	10.4	12.0	8.9	10.0	11.1	11.4	12.5	11.2	0.0	10.9	12.3	11.5

TOTAL RECORDS READ = 6184

EXPLOITATION-DIESEL-OVER 800 HP

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
NO. OF SHIPS	33.	93.	132.	52.	12.	46.	32.	85.	44.	16.	7.	19.	22.	5.	50.	13.
AVE AGE	11.2	12.6	9.5	8.9	10.5	8.3	6.4	10.3	8.2	10.4	7.4	7.9	3.5	9.0	6.0	3.7
00 - 05 YRS OLD	8.0	11.0	20.0	16.0	4.0	16.0	15.0	8.0	11.0	4.0	2.0	7.0	22.0	1.0	21.0	12.0
06 - 10 YRS OLD	11.0	20.0	53.0	18.0	4.0	11.0	11.0	24.0	28.0	8.0	3.0	5.0	0.0	1.0	29.0	1.0
11 - 15 YRS OLD	7.0	44.0	57.0	15.0	3.0	17.0	6.0	53.0	3.0	1.0	2.0	7.0	0.0	3.0	0.0	0.0
16 - 20 YRS OLD	2.0	6.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
21 - 25 YRS OLD	28	81	131	50	11	45	32	85	42	14	7	19	22	5	50	13
26 - OVER	4.0	6.0	1.0	1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YR BUILT UNKN	1.0	6.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0

XPLOITATION-DIESEL-OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	2.	5.	0.	0.	2.	13.	5.	5.	0.	9.	4.	2.	0.	0.	1.	9.
AVE AGE	17.5	6.6	0.0	0.0	7.0	7.5	3.2	8.8	0.0	3.8	5.5	2.5	0.0	0.0	5.0	6.0
00 - 05 YRS OLD	1.0	1.0	0.0	0.0	0.0	6.0	5.0	4.0	0.0	9.0	2.0	2.0	0.0	0.0	1.0	3.0
06 - 10 YRS OLD	0.0	4.0	0.0	0.0	2.0	5.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	6.0
11 - 15 YRS OLD	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 - 20 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<u>1</u>	<u>5</u>	<u>0</u>	<u>0</u>	<u>2</u>	<u>12</u>	<u>5</u>	<u>4</u>	<u>0</u>	<u>9</u>	<u>4</u>	<u>2</u>	<u>0</u>	<u>0</u>	<u>1</u>	<u>9</u>
21 - 25 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 - OVER	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YR BUILT UNKN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TOTAL RECORDS READ = 2065

TOTAL RECO AD = 157

(X)

FERRY-DIESEL-OVER 800 HP

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
NO. OF SHIPS	1.	9.	2.	3.	0.	2.	0.	1.	1.	6.	0.	0.	1.	0.	0.	0.
AVE AGE	18.0	24.3	11.0	34.0	0.0	34.5	0.0	54.0	30.0	40.8	0.0	0.0	20.0	0.0	0.0	0.0
00 - 05 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
06 - 10 YRS OLD	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 - 15 YRS OLD	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 - 20 YRS OLD	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
21 - 25 YRS OLD	1	4	2	0	0	0	0	0	0	1	0	0	1	0	0	0
26 - OVER	0.0	4.0	0.0	2.0	0.0	2.0	0.0	1.0	1.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX D (5)

YR BUILT UNKN 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

FERRY-DIESEL-OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	3.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.
AVE AGE	20.0	0.0	0.0	0.0	33.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
00 - 05 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
06 - 10 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 - 15 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 - 20 YRS OLD	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21 - 25 YRS OLD	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
26 - OVER	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

FISHING DIESEL OVER 800 HP

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
NO. OF SHIPS	47.	64.	17.	38.	8.	11.	8.	31.	5.	25.	1.	5.	1.	0.	5.	7.
AVE AGE	13.6	24.4	16.8	18.0	20.6	23.5	22.1	14.1	24.0	22.8	33.0	14.0	3.0	0.0	13.2	30.6
00 - 05 YRS OLD	23.0	4.0	2.0	15.0	0.0	0.0	1.0	2.0	0.0	6.0	0.0	0.0	1.0	0.0	0.0	0.0
06 - 10 YRS OLD	6.0	1.0	3.0	1.0	2.0	1.0	1.0	10.0	0.0	1.0	0.0	4.0	0.0	0.0	4.0	1.0
11 - 15 YRS OLD	0.0	6.0	6.0	0.0	0.0	4.0	2.0	13.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
16 - 20 YRS OLD	2.0	15.0	2.0	4.0	2.0	0.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
21 - 25 YRS OLD	31	26	13	20	4	5	4	26	2	10	0	4	1	0	4	1
26 - OVER	2.0	12.0	2.0	5.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YR BUILT UNKN	14.0	26.0	2.0	13.0	2.0	5.0	4.0	5.0	3.0	15.0	1.0	1.0	0.0	0.0	1.0	6.0
	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

(X)

FISHING DIESEL OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	1.	1.	0.	7.	7.	2.	5.	0.	0.	0.	3.	39.	0.	0.	1.	6.
AVE AGE	40.0	35.0	0.0	7.9	11.7	8.5	6.0	0.0	0.0	0.0	5.3	4.9	0.0	0.0	7.0	8.8
00 - 05 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	25.0	0.0	0.0	0.0	5.0
06 - 10 YRS OLD	0.0	0.0	0.0	7.0	6.0	2.0	5.0	0.0	0.0	0.0	1.0	14.0	0.0	0.0	1.0	0.0
11 - 15 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 - 20 YRS OLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21 - 25 YRS OLD	0	0	0	7	6	2	5	0	0	0	3	39	0	0	1	5
26 - OVER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
YR BUILT UNKN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

APPENDIX E

DIESEL ENGINE POWERED MERCHANT VESSELS OF THE UNITED STATES HORSEPOWER VS VESSEL AGE (IN 100 BHP INCREMENTS)

- . Towing Vessels
- . Oil Exploitation Vessels
- . Fishing Vessels
- . Ferry Vessels

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
NO. OF SHIPS	199.	270.	162.	226.	55.	66.	64.	145.	86.	197.	9.	64.	9.	47.	43.	76.
AVE AGE	28.1	24.1	17.9	25.4	24.0	20.2	26.2	26.5	16.5	24.5	23.3	26.9	19.0	16.4	21.2	14.3
00 - 05 YRS OLD	22.0	25.0	27.0	31.0	5.0	17.0	3.0	12.0	7.0	30.0	1.0	4.0	1.0	4.0	5.0	19.0
06 - 10 YRS OLD	34.0	39.0	47.0	32.0	2.0	8.0	11.0	11.0	49.0	21.0	0.0	12.0	0.0	14.0	13.0	13.0
11 - 15 YRS OLD	18.0	41.0	26.0	16.0	2.0	7.0	12.0	26.0	3.0	17.0	3.0	8.0	1.0	12.0	1.0	15.0
16 - 20 YRS OLD	15.0	30.0	9.0	29.0	17.0	1.0	3.0	14.0	4.0	23.0	0.0	5.0	4.0	3.0	0.0	11.0
21 - 25 YRS OLD	23.0	43.0	12.0	22.0	7.0	14.0	3.0	20.0	4.0	21.0	1.0	3.0	2.0	7.0	1.0	7.0
26 - OVER	87.0	92.0	41.0	96.0	22.0	19.0	32.0	62.0	19.0	85.0	4.0	31.0	1.0	7.0	23.0	11.0
YR BUILT UNKN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.

3-DIESEL-OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	15.	12.	5.	12.	13.	39.	6.	106.	14.	10.	7.	26.	0.	15.	8.	27.
AVE AGE	18.9	20.3	19.8	17.0	14.6	10.3	3.7	17.0	10.4	15.6	9.0	20.8	0.0	8.2	9.6	13.7
00 - 05 YRS OLD	3.0	0.0	0.0	3.0	1.0	8.0	5.0	15.0	7.0	1.0	1.0	1.0	0.0	6.0	2.0	5.0
06 - 10 YRS OLD	1.0	2.0	1.0	1.0	7.0	18.0	1.0	19.0	1.0	3.0	2.0	4.0	0.0	6.0	5.0	9.0
11 - 15 YRS OLD	2.0	0.0	2.0	3.0	1.0	8.0	0.0	17.0	2.0	3.0	4.0	5.0	0.0	2.0	0.0	4.0
16 - 20 YRS OLD	2.0	3.0	0.0	2.0	0.0	2.0	0.0	22.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	5.0
	8	5	3	9	9	36	6	73	10	7	7	11	0	14	7	23
21 - 25 YRS OLD	1.0	5.0	0.0	0.0	0.0	0.0	0.0	11.0	4.0	0.0	0.0	5.0	0.0	1.0	0.0	0.0
26 - OVER	6.0	2.0	2.0	3.0	4.0	3.0	0.0	22.0	0.0	3.0	0.0	10.0	0.0	0.0	1.0	4.0
YR BUILT UNKN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TOTAL RECORDS READ = 6184

EXPLOITATION-DIESEL-OVER 800 HP

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
NO. OF SHIPS	33.	93.	132.	52.	12.	46.	32.	85.	44.	16.	7.	19.	22.	5.	50.	13.
AVE GRT	115.	102.	76.	101.	111.	112.	123.	191.	330.	356.	126.	411.	96.	171.	211.	192.
AVE NRT	76.	69.	50.	66.	75.	75.	84.	129.	209.	269.	80.	346.	65.	116.	143.	131.
AVE HP	883.	979.	1054.	1192.	1261.	1383.	1491.	1546.	1693.	1784.	1863.	1995.	2025.	2148.	2250.	2365.
AVE LENGTH	83.1	85.0	70.9	91.1	98.1	93.9	102.6	136.8	155.3	123.4	110.6	130.8	89.7	120.5	158.2	164.6
AVE BEAM	24.2	23.8	19.7	23.2	23.7	23.0	24.1	32.7	37.2	26.9	26.1	39.9	21.2	28.9	37.3	38.0
AVE DEPTH	8.6	8.1	8.1	7.7	8.4	8.2	8.9	11.7	12.5	10.4	8.8	11.2	8.2	9.7	12.1	12.6

PLOITATION-DIESEL-OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	2.	5.	0.	0.	2.	13.	5.	5.	0.	9.	4.	2.	0.	0.	1.	9.
AVE GRT	2849.	272.	0.	0.	192.	1428.	199.	333.	0.	195.	196.	298.	0.	0.	291.	238.
AVE NRT	1891.	185.	0.	0.	130.	924.	135.	211.	0.	133.	133.	203.	0.	0.	198.	162.
AVE HP	2475.	2590.	0.	0.	2900.	3000.	3080.	3200.	0.	3400.	3488.	3600.	0.	0.	3900.	4000.
AVE LENGTH	264.9	170.8	0.0	0.0	166.3	195.9	151.4	168.1	0.0	171.0	148.0	165.9	0.0	0.0	171.5	158.5
AVE BEAM	54.1	39.0	0.0	0.0	38.2	57.4	38.0	39.2	0.0	39.1	37.1	38.0	0.0	0.0	40.1	37.9
AVE DEPTH	20.0	11.2	0.0	0.0	13.4	16.9	13.0	11.8	0.0	13.5	13.4	13.5	0.0	0.0	16.0	14.1

TOTAL RECORDS READ = 2065

FERRY-DIESEL-OVER 800 HP

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
NO. OF SHIPS	1.	9.	2.	3.	0.	2.	0.	1.	1.	6.	0.	0.	1.	0.	0.	0.
AVE GRT	229.	564.	80.	744.	0.	610.	0.	631.	937.	1119.	0.	0.	2255.	0.	0.	0.
AVE NRT	156.	392.	41.	453.	0.	198.	0.	429.	425.	761.	0.	0.	1533.	0.	0.	0.
AVE HP	900.	962.	1075.	1187.	0.	1400.	0.	1600.	1610.	1777.	0.	0.	2100.	0.	0.	0.
AVE LENGTH	119.6	160.7	82.3	209.2	0.0	187.9	0.0	189.5	217.9	220.9	0.0	0.0	362.4	0.0	0.0	0.0
AVE BEAM	32.1	50.0	22.3	45.1	0.0	51.8	0.0	36.1	60.0	63.9	0.0	0.0	59.1	0.0	0.0	0.0
AVE DEPTH	9.8	11.6	7.2	14.0	0.0	10.8	0.0	14.7	12.4	15.9	0.0	0.0	15.1	0.0	0.0	0.0

FERRY-DIESEL-OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	3.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.
AVE GRT	1388.	0.	0.	0.	1492.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1869.
AVE NRT	944.	0.	0.	0.	799.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1158.
AVE HP	2500.	0.	0.	0.	2880.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4000.
AVE LENGTH	296.7	0.0	0.0	0.0	307.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	260.5
AVE BEAM	73.1	0.0	0.0	0.0	50.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.0
AVE DEPTH	23.2	0.0	0.0	0.0	10.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.6

FISHING DIESEL OVER 800 HP

HORSEPOWER	801 TO 900	901 TO 1000	1001 TO 1100	1101 TO 1200	1201 TO 1300	1301 TO 1400	1401 TO 1500	1501 TO 1600	1601 TO 1700	1701 TO 1800	1801 TO 1900	1901 TO 2000	2001 TO 2100	2101 TO 2200	2201 TO 2300	2301 TO 2400
NO. OF SHIPS	47.	64.	17.	38.	8.	11.	8.	31.	5.	25.	1.	5.	1.	0.	5.	7.
AVE GRT	247.	326.	214.	241.	337.	319.	565.	560.	1746.	579.	630.	927.	99.	0.	754.	217.
AVE NRT	146.	201.	142.	142.	180.	215.	377.	353.	1109.	363.	428.	548.	67.	0.	401.	125.
AVE HP	964.	978.	1064.	1161.	1281.	1359.	1479.	1550.	1700.	1800.	1900.	2000.	2025.	0.	2250.	2400.
AVE LENGTH	103.8	127.5	111.1	117.3	135.9	136.0	146.7	159.7	218.8	165.5	176.2	168.0	96.0	0.0	144.6	108.4
AVE BEAM	26.8	26.5	22.8	27.6	27.7	27.7	31.5	33.2	37.5	32.6	33.1	35.2	21.6	0.0	33.9	20.6
AVE DEPTH	10.3	11.1	9.7	10.2	11.1	10.7	13.9	12.7	17.6	12.3	14.3	17.9	6.8	0.0	15.9	10.8

FISHING DIESEL OVER 800 HP

HORSEPOWER	2401 TO 2500	2501 TO 2600	2601 TO 2700	2701 TO 2800	2801 TO 2900	2901 TO 3000	3001 TO 3100	3101 TO 3200	3201 TO 3300	3301 TO 3400	3401 TO 3500	3501 TO 3600	3601 TO 3700	3701 TO 3800	3801 TO 3900	3901 TO 4000
NO. OF SHIPS	1.	1.	0.	7.	7.	2.	5.	0.	0.	0.	3.	39.	0.	0.	1.	6.
AVE GRT	14.	872.	0.	850.	855.	1593.	1236.	0.	0.	0.	1209.	1033.	0.	0.	1558.	862.
AVE NRT	10.	426.	0.	438.	452.	693.	674.	0.	0.	0.	649.	531.	0.	0.	863.	426.
AVE HP	2500.	2600.	0.	2800.	2858.	3000.	3100.	0.	0.	0.	3500.	3599.	0.	0.	3900.	4000.
AVE LENGTH	41.3	172.9	0.0	154.5	161.3	267.4	207.2	0.0	0.0	0.0	201.0	188.1	0.0	0.0	238.6	189.7
AVE BEAM	13.0	37.0	0.0	34.3	36.0	44.3	40.1	0.0	0.0	0.0	40.2	38.8	0.0	0.0	43.8	35.6
AVE DEPTH	4.6	15.4	0.0	18.8	17.0	15.9	17.4	0.0	0.0	0.0	16.7	16.4	0.0	0.0	17.9	14.6

345 VESSELS of 378

TOTAL RECORDS READ = 17336

APPENDIX F

MARINE TRANSPORTATION ENERGY MODEL
VESSEL, OPERATIONAL, AND COST INPUT DATA

BASELINE VESSELS

Vessel TYPE	Rated BRAKE HORSEPOWER (Population Range)	TYPE OF Cargo HAUL	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consumption Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. Operatl. Duty-Cycle @ 50% Power & HIGHER % Power-% Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	Vessel Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No Hours Opern. Per Day	Avg. No. Days Opern. Per Year	Avg. No. Hours Opern. Per Year	Avg. No. Hours Main Eng. Operating Hours Per Year			Crew Wages	Stores & Subsist- ance & Misc.	M \$ R	Insur- ance
(16) Push-Tow Boat	1225 1650 (1500-1800)	Barge, Push-Tow	18944	16914	(6.4)	D	0.3850	71	78/89	24	345	8280	8280	0.945	0.980	689	76	49	27
(11) Inland Tug	986 1650 (1500-1800)	Barge, Tow	6300	5625	(9.0)	D	0.3850	85	95/86	24	300	7200	5568	0.636	0.880	689	76	49	24
(14) Offshore Supply Boat	604 1650 (1500-1800)	Deck	~600	~535	13.0	D	0.3850	69	100/60	24	350	8400	4200	0.479	1.080	689	76	49	30
(16) Push-Tow Boat	1707 2300 (2200-2400)	Barge, Push-Tow	18944	16914	(7.2)	D	0.3850	71	78/89	24	345	8280	8280	0.945	1.310	689	85	66	36
(15) Offshore Tug	793 2300 (2200-2400)	Assistance & Towing	12768	11400	8.0 (13.0 in transit)	D	0.3850	65	93/60	24	300	7200	4200	0.479	2.500	689	85	66	68
(14) Offshore Supply Boat	842 2300 (2200-2400)	Deck	~800	~715	14.0	D	0.3850	69	100/60	24	350	8400	4200	0.479	2.000	689	85	66	55
(16) Push-Tow Boat	2301 3100 (3000-3200)	Barge, Push-Tow	18944	16914	(7.8)	D	0.3850	71	78/89	24	345	8280	8280	0.945	1.640	740	93	86	45

ENERGY
VESSELS RETROFITTED WITH BOTTOM-CYCLE SYSTEM WITH 10% RECOVERY

Vessel TYPE	Rated BRAKE Horsepower (Population Range)	TYPE OF Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consump- tion Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. Operatl. Duty-Cycle @ 50% Power & HIGHER % Power / % Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	VESSEL Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours OPRTN. Per DAY	Avg. No. Days OPRTN. Per YEAR	Avg. No. Hours OPRTN. PER YEAR	Avg. No. MAIN ENG. OPERATING Hours Per YEAR			Crew WAGES	Stores & Subsist- ance & MISC.	M & R	INSUR- ANCE
(16) Push-Tow BOAT	1225 ⁺ 1650 ⁺ (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3465	71	78/89	24	345	8280	8280	0.945	1.119	689	76	53	31
(11) Inland TUG	986 ⁺ 1650 ⁺ (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3465	85	95/86	24	300	7200	5568	0.636	1.019	689	76	52	28
(14) OFFSHORE Supply BOAT	604 ⁺ 1650 ⁺ (1500-1800)	Deck	~595	~531	13.0	D	0.3465	69	100/60	24	350	8400	4200	0.479	1.219	689	76	51	33
(16) Push-Tow BOAT	1707 ⁺ 2300 ⁺ (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3465	71	78/89	24	345	8280	8280	0.945	1.527	689	85	72	42
(15) OFFSHORE TUG	793 ⁺ 2300 ⁺ (2200-2400)	ASSISTANCE & TOWING	12768	11400	8.0 (13.0 IN Transit)	D	0.3465	65	93/60	24	300	7200	4200	0.479	2.717	689	85	69	74
(19) OFFSHORE Supply BOAT	842 ⁺ 2300 ⁺ (2200-2400)	Deck	~792	~707	14.0	D	0.3465	69	100/60	24	350	8400	4200	0.479	2.217	689	85	69	61
(16) Push-Tow BOAT	2301 ⁺ 3100 ⁺ (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3465	71	78/89	24	345	8280	8280	0.945	1.903	740	93	94	52

+ Utilized Horsepower; Available power is 10% Greater

ENERGY

VESSELS RETROFITTED WITH BOTTOM-CYCLE SYSTEM WITH 15% RECOVERY

Vessel TYPE	Rated BRAKE Horsepower (Population Range)	TYPE OF Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consump- tion Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. OPRNTL. Duty-Cycle @ 50% Power & HIGHER % Power / % Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	VESSEL Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No Hours OPRTN. Per Day	Avg. No. Days OPRTN. Per Year	Avg. No. Hours OPRTN. Per Year	Avg. No. Main Eng. Operating Hours Per Year			Crew Wages	Stores & Subsist- ance	M & R	INSUR- ANCE
(10) Push-Tow Boat	1225 1650 ⁺ (1500-1800)	Barge, Push-Tow	18944	16914	(6.4)	D	0.3273	71	78/89	24	345	8280	8280	0.945	1.162	689	76	55	32
(11) Inland Tug	986 1650 ⁺ (1500-1800)	Barge, Tow	16300	5675	(9.0)	D	0.3273	85	95/86	24	300	7200	5568	0.636	1.062	689	76	53	29
(14) Offshore Supply Boat	604 1650 ⁺ (1500-1800)	Deck	~593	~529	13.0	D	0.3273	69	100/60	24	350	8400	4200	0.479	1.262	689	76	52	35
(16) Push-Tow Boat	1707 2300 ⁺ (2200-2400)	Barge, Push-Tow	18944	16914	(7.2)	D	0.3273	71	78/89	24	345	8280	8280	0.945	1.581	689	85	75	43
(15) Offshore Tug	793 2300 ⁺ (2200-2400)	Assistance & Towing	12768	11400	8.0 (13.0 in Transit)	D	0.3273	65	93/60	24	300	7200	4200	0.479	2.771	689	85	71	76
(14) Offshore Supply Boat	842 2300 ⁺ (2200-2400)	Deck	~788	~703	14.0	D	0.3273	69	100/60	24	350	8400	4200	0.479	2.271	689	85	71	62
(16) Push-Tow Boat	2301 3100 ⁺ (3000-3200)	Barge, Push-Tow	18944	16914	(7.8)	D	0.3273	71	78/89	24	345	8280	8280	0.945	1.975	740	93	98	54

+ Utilized Horsepower; Available Power is 15% Greater

ENERGY

NEW VESSELS CONSTRUCTED WITH BOTTOM-CYCLE SYSTEM WITH 10% RECOVERY

Vessel TYPE	Rated BRAKE Horsepower (Population Range)	Type of Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consump- tion Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. Opern. Duty-Cycle @ 50% Power & HIGHER % Power / % Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	VESSEL Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours Opern. Per Day	Avg. No. Days Opern. Per Year	Avg. No. Hours Opern. Per Year	Avg. No. Main Eng. Operating Hours Per Year			Crew Wages	Stores & Subsist- ance	M & R	Insur- ance
(16) Push-Tow Boat	1225 1650 (1500-1800)	Barge, Push-Tow	18944	16914	(6.4)	D	0.3465	71	78/89	24	345	8280	8280	0.945	1.091	689	76	53	30
(11) Inland Tug	986 1650 (1500-1800)	Barge, Tow	16300	5625	(9.0)	D	0.3465	85	95/86	24	300	7200	5568	0.636	0.991	689	76	52	27
(14) Offshore Supply Boat	604 1650 (1500-1800)	Deck	~596	~532	13.0	D	0.3465	69	100/60	24	350	8400	4200	0.479	1.191	689	76	51	33
(16) Push-Tow Boat	1707 2300 (2200-2400)	Barge, Push-Tow	18944	16914	(7.2)	D	0.3465	71	78/89	24	345	8280	8280	0.945	1.485	689	85	72	41
(15) Offshore Tug	793 2300 (2200-2400)	Assistance & Towing	12768	11410	8.0 (13.0 in transit)	D	0.3465	65	93/60	24	300	7200	4200	0.479	2.675	689	85	69	73
(14) Offshore Supply Boat	842 2300 (2200-2400)	Deck	~794	~709	14.0	D	0.3465	69	100/60	24	350	8400	4200	0.479	2.175	689	85	69	60
(16) Push-Tow Boat	2301 3100 (3000-3200)	Barge, Push-Tow	18944	16914	(7.8)	D	0.3465	71	78/89	24	345	8280	8280	0.945	1.850	740	93	94	51

ENERGY

NEW VESSELS CONSTRUCTED WITH BOTTOM-CYCLE SYSTEM WITH 15% RECOVERY

VESSEL TYPE	Rated BRAKE HORSEPOWER (Population Range)	TYPE OF Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consumption Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. Operatl. Duty-Cycle @ 50% Power & HIGHER % Power / % Time	OPERATIONAL DATA				YEARLY ENGINE OPERATIONAL Factor	VESSEL Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours Opern. Per DAY	Avg. No. Days Opern. Per YEAR	Avg. No. Hours Opern. Per YEAR	Avg. No. Hours Main Eng. Operating Per YEAR			Crew WAGES	Stores & Subsistence	M & R	Insurance
(16) Push-Tow BOAT	1225 1650 (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3273	71	78/89	24	345	8280	8280	0.945	1.123	689	76	55	31
(11) Inland Tug	986 1650 (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3273	85	95/86	24	300	7200	5568	0.636	1.023	689	76	53	28
(14) Offshore Supply Boat	604 1650 (1500-1800)	Deck	~594	~530	13.0	D	0.3273	69	100/60	24	350	8400	4200	0.479	1.223	689	76	52	34
(16) Push-Tow BOAT	1707 2300 (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3273	71	78/89	24	345	8280	8280	0.945	1.525	689	85	75	42
(15) Offshore Tug	793 2300 (2200-2400)	Assistance & Towing	12768	11400	8.0 (13.0 in transit)	D	0.3273	65	93/60	24	300	7200	4200	0.479	2.715	689	85	71	74
(14) Offshore Supply Boat	842 2300 (2200-2400)	Deck	~790	~705	14.0	D	0.3273	69	100/60	24	350	8400	4200	0.479	2.215	689	85	71	61
(16) Push-Tow BOAT	2301 3100 (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3273	71	78/89	24	345	8280	8280	0.945	1.902	740	93	98	52

ENERGY
VESSELS RETROFITTED WITH BOTTOM-CYCLE SYSTEM WITH 12½% RECOVERY

Vessel TYPE	Rated BRAKE Horsepower (Population Range)	Type of Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consump- tion Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. Oprtl. Duty-Cycle @ 50% Power- & HIGHER % Power/% Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	Vessel Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours OPRTN. Per DAY	Avg. No. Days OPRTN. Per YEAR	Avg. No. Hours OPRTN. Per YEAR	Avg. No. Hours Main Eng. Operating Hours Per YEAR			Crew Wages	Stores & Subsist- ance	M & R	Insur- ance
Push-Tow BOAT	1650 ⁺ (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3369	71	78/89	24	345	8280	8280	0.945	1.141	689	76	54	31
Inland Tug	1650 ⁺ (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3369	85	95/86	24	300	7200	5568	0.636	1.041	689	76	53	29
Offshore Supply Boat	1650 ⁺ (1500-1800)	Deck	~594	~530	13.0	D	0.3369	69	100/60	24	350	8400	4200	0.479	1.241	689	76	52	34
Push-Tow BOAT	2300 ⁺ (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3369	71	78/89	24	345	8280	8280	0.945	1.556	689	85	73	43
Offshore Tug	2300 ⁺ (2200-2400)	Assistance & Towing	-	-	8.0 (13.0 in Transit)	D	0.3369	65	93/60	24	300	7200	4200	0.479	2.746	689	85	70	75
Offshore Supply Boat	2300 ⁺ (2200-2400)	Deck	~790	~705	14.0	D	0.3369	69	100/60	24	350	8400	4200	0.479	2.246	689	85	70	62
Push-Tow BOAT	3100 ⁺ (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3369	71	78/89	24	345	8280	8280	0.945	1.940	740	93	96	53

⁺ Utilized Horsepower; Available Power is 12½% Greater

ENERGY
VESSELS RETROFITTED WITH BOTTOM-CYCLE SYSTEM WITH $17\frac{1}{2}\%$ RECOVERY

Vessel TYPE	Rated BRAKE Horsepower (Population Range)	Type of Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consump- tion Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. OPRNTL. Duty-Cycle @ 50% Power & HIGHER % Power / % Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	VESSEL Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No Hours OPRTN. Per DAY	Avg. No. Days OPRTN. Per YEAR	Avg. No. Hours OPRTN. PER YEAR	Avg. No. Main Eng. Operating Hours Per YEAR			Crew WAGES	Stores & Subsist- ANCE	M \$ R	INSUR- ANCE
Push-Tow Boat	1650 ⁺ (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3176	71	78/89	24	345	8280	8280	0.945	1.188	689	76	56	33
Inland Tug	1650 ⁺ (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3176	85	95/86	24	300	7200	5568	0.636	1.088	689	76	54	30
Offshore Supply Boat	1650 ⁺ (1500-1800)	Deck	~592	~529	13.0	D	0.3176	69	100/60	24	350	8400	4200	0.479	1.288	689	76	53	35
Push-Tow Boat	2300 ⁺ (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3176	71	78/89	24	345	8280	8280	0.945	1.619	689	85	76	44
Offshore Tug	2300 ⁺ (2200-2400)	Assistance & Towing	-	-	8.0 (13.0 in transit)	D	0.3176	65	93/60	24	300	7200	4200	0.479	2.809	689	85	71	77
Offshore Supply Boat	2300 ⁺ (2200-2400)	Deck	~786	~702	14.0	D	0.3176	69	100/60	24	350	8400	4200	0.479	2.309	689	85	71	63
Push-Tow Boat	3100 ⁺ (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3176	71	78/89	24	345	8280	8280	0.945	2.022	740	93	100	55

+ Utilized Horsepower; Available Power is $17\frac{1}{2}\%$ Greater

ENERGY
VESSELS RETROFITTED WITH BOTTOM-CYCLE SYSTEM WITH 20% RECOVERY

Vessel TYPE	Rated BRAKE Horsepower (Population Range)	Type of Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consumption Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. Oprtl. Duty-Cycle @ 50% Power & HIGHER % Power / % Time	OPERATIONAL DATA				YEARLY ENGINE OPERATIONAL Factor	VESSEL Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours OPRTN. Per DAY	Avg. No. Days OPRTN. Per YEAR	Avg. No. Hours OPRTN. Per YEAR	Avg. No. Main Eng. Operating Hours Per YEAR			Crew WAGES	Stores & Subsist- ANCE	M & R	INSUR- ANCE
(16) Push-Tow BOAT	1225 + 1650 + (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3080	71	78/89	24	345	8280	8280	0.945	1.219	689	76	57	33
(11) Inland Tug	986 + 1650 + (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3080	85	95/86	24	300	7200	5568	0.636	1.119	689	76	55	31
(14) Offshore Supply BOAT	604 + 1650 + (1500-1800)	Deck	~591	~528	13.0	D	0.3080	69	100/60	24	350	8400	4200	0.479	1.319	689	76	53	36
(16) Push-Tow BOAT	1707 + 2300 + (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3080	71	78/89	24	345	8280	8280	0.945	1.664	689	85	78	46
(15) Offshore Tug	793 + 2300 + (2200-2400)	Assistance & Towing	12768	11400	8.0 (13.0 in Transit)	D	0.3080	65	93/60	24	300	7200	4200	0.479	2.854	689	85	72	78
(14) Offshore Supply BOAT	842 + 2300 + (2200-2400)	Deck	~784	~700	14.0	D	0.3080	69	100/60	24	350	8400	4200	0.479	2.354	689	85	72	64
(16) Push-Tow BOAT	2301 + 3100 + (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3080	71	78/89	24	345	8280	8280	0.945	2.080	740	93	102	57

+ Utilized Horsepower; Available Power is 20% Greater

NEW VESSELS CONSTRUCTED WITH BOTTOM-CYCLE SYSTEM WITH 12½% ENERGY RECOVERY

VESSEL TYPE	Rated Brake Horsepower (Population Range)	Type of Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consumption Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	Weighted Avg. Opernl. Duty-Cycle @ 50% Power & Higher % Power / % Time	OPERATIONAL DATA				Yearly Engine Operational Factor	Vessel Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours Opern. Per Day	Avg. No. Days Opern. Per Year	Avg. No. Hours Opern. Per Year	Avg. No. Hours Main Eng. Operating Hours Per Year			Crew Wages	Stores & Subsistence	M \$ R	Insurance
Push-Tow Boat	1650 (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3369	71	78/89	24	345	8280	8280	0.945	1.107	689	76	54	30
Inland Tug	1650 (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3369	85	95/86	24	300	7200	5568	0.636	1.007	689	76	53	28
Offshore Supply Boat	1650 (1500-1800)	Deck	~595	~531	13.0	D	0.3369	69	100/60	24	350	8400	4200	0.479	1.207	689	76	52	33
Push-Tow Boat	2300 (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3369	71	78/89	24	345	8280	8280	0.945	1.506	689	85	73	41
Offshore Tug	2300 (2200-2400)	Assistance & Towing	-	-	8.0 (13.0 in transit)	D	0.3369	65	93/60	24	300	7200	4200	0.479	2.696	689	85	70	74
Offshore Supply Boat	2300 (2200-2400)	Deck	~792	~707	14.0	D	0.3369	69	100/60	24	350	8400	4200	0.479	2.196	689	85	70	60
Push-Tow Boat	3100 (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3369	71	78/89	24	345	8280	8280	0.945	1.877	740	93	96	51

NEW VESSELS CONSTRUCTED WITH BOTTOM-CYCLE SYSTEM WITH 17 1/2 % ENERGY RECOVERY

Vessel TYPE	Rated BRAKE Horsepower (Population Range)	TYPE OF Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consump- tion Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. OPRNTL. Duty-Cycle @ 50% Power & HIGHER % Power / % Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	Vessel Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours OPRTN. Per DAY	Avg. No. Days OPRTN. Per YEAR	Avg. No. Hours OPRTN. Per YEAR	Avg. No. Main Eng. Operating Hours Per YEAR			Crew WAGES	Stores & Subsist- ANCE	M \$ R	INSUR- ANCE
Push-Tow Boat	1650 (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3176	71	78/89	24	345	8280	8280	0.945	1.143	689	76	56	31
Inland Tug	1650 (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3176	85	95/86	24	300	7200	5568	0.636	1.043	689	76	54	29
Offshore Supply Boat	1650 (500-1800)	Deck	~593	~530	13.0	D	0.3176	69	100/60	24	350	8400	4200	0.479	1.243	689	76	53	34
Push-Tow Boat	2300 (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3176	71	78/89	24	345	8280	8280	0.945	1.554	689	85	76	43
Offshore Tug	2300 (2200-2400)	Assistance & Towing	-	-	8.0 (13.0 in transit)	D	0.3176	65	93/60	24	300	7200	4200	0.479	2.744	689	85	71	75
Offshore Supply Boat	2300 (2200-2400)	Deck	~788	~704	14.0	D	0.3176	69	100/60	24	350	8400	4200	0.479	2.244	689	85	71	61
Push-Tow Boat	3100 (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3176	71	78/89	24	345	8280	8280	0.945	1.938	740	93	100	53

ENERGY

NEW VESSELS CONSTRUCTED WITH BOTTOM-CYCLE SYSTEM WITH 20% RECOVERY

Vessel TYPE	Rated BRAKE HORSEPOWER (Population Range)	TYPE OF Cargo Haul	DWT Short Tons	DWT Long Tons	Vessel Speed Knots (MPH)	Fuel Type	Fuel Consump- tion Rate lb/BHP-hr	Weighted Average Operational Duty-Cycle % Power	WEIGHTED Avg. Opernl. Duty-Cycle @ 50% Power or % HIGHER % Power/% Time	OPERATIONAL DATA				YEARLY ENGINE OPERAT- IONAL Factor	Vessel Cost Millions of Dollars	OPERATING COSTS - \$/DAY (NOT INCLUDING FUEL)			
										Avg. No. Hours Opern. Per Day	Avg. No. Days Opern. Per Year	Avg. No. Hours Opern. Per Year	Avg. No. Main Eng. Operating Hours Per Year			Crew Wages	Stores & Subsist- ance	M \$ R	Insur- ance
(16) Push-Tow Boat	1225 1650 (1500-1800)	BARGE, Push-Tow	18944	16914	(6.4)	D	0.3080	71	78/89	24	345	8280	8280	0.945	1.168	689	76	57	32
(11) Inland Tug	986 1650 (1500-1800)	BARGE, Tow	6300	5625	(9.0)	D	0.3080	85	95/86	24	300	7200	5568	0.636	1.068	689	76	55	29
(14) Offshore Supply Boat	604 1650 (1500-1800)	Deck	~592	~529	13.0	D	0.3080	69	100/60	24	350	8400	4200	0.479	1.268	689	76	53	35
(16) Push-Tow Boat	1707 2300 (2200-2400)	BARGE, Push-Tow	18944	16914	(7.2)	D	0.3080	71	78/89	24	345	8280	8280	0.945	1.589	689	85	78	44
(15) Offshore Tug	793 2300 (2200-2400)	Assistance & Towing	12768	11400	8.0 (13.0 in transit)	D	0.3080	65	93/60	24	300	7200	4200	0.479	2.779	689	85	72	76
(14) Offshore Supply Boat	842 2300 (2200-2400)	Deck	~786	~702	14.0	D	0.3080	69	100/60	24	350	8400	4200	0.479	2.279	689	85	72	62
(16) Push-Tow Boat	2301 3100 (3000-3200)	BARGE, Push-Tow	18944	16914	(7.8)	D	0.3080	71	78/89	24	345	8280	8280	0.945	1.985	740	93	102	54

APPENDIX G
SAMPLE MTEM ANALYSIS OUTPUT

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)

TYPE TUG/TOW US FLAG (Push-Tow Boat)

Baseline Vessel

SERVICE AREA

INLAND

No Energy Recovery System

DWT 16914. LONG TONS

HORSEPOWER 1225.

Rated BHP = 1650

TYPE OF FUEL DIESEL

FUEL CONSUMP AT DESIGN SPEED

5. LTON/DAY (.39 LR/SHP-HR) (.385 actual)

SERVICE CHARACTERISTICS

SERVICE AREA INLAND

SPEED, MI/HR 6.4

ROUND TRIP TIME, DAYS 6.3

AVERAGE DISTANCE, MI 358.

CARGO PER HAUL, LT 16914.

SUMMARY FOR ONE VOYAGE

FUEL CONSUMED, LTONS

AT SEA 32.

IN PORT 0.

TOTAL 32. (1379.593 MBTU)

COST SUMMARY

VESSEL COSTS 8980.

PORT COSTS 0.

CARGO COSTS 0.

TOTAL DIRECT COST 8980.

GEN + ADMIN 2245.

TOTAL OPERATING COST 11226.

SUMMARY FOR ONE YEAR

VOYAGES 52.1

CARGO HAULED, LT 882034.

FUEL USED, LT 1668.

TOTAL OPERATING COSTS 585395.

CAPITALIZATION SCHEME		(Push-Tow Boat)		Baseline Vessel	
METHOD	TITLE XI			No Energy Recovery System	
FULL CAPITAL COST	472500.				
INITIAL INVESTMENT	94500.				
DEBT SERVICE/LEASE PMT	38500.				
ANNUAL INTEREST RATE	.080				
CORPORATE TAX RATE	.48				

OPERATING COSTS												
YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL (SEA)	FUEL (PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	227370.	25080.	16170.	8910.	200325.	0.	0.	0.	477855.	119464.	38500.	635819.
2	238739.	26334.	16979.	9355.	210341.	0.	0.	0.	501748.	125437.	38500.	665685.
3	250675.	27651.	17827.	9823.	220858.	0.	0.	0.	526835.	131709.	38500.	697044.
4	263209.	29033.	18719.	10314.	231901.	0.	0.	0.	553177.	138294.	38500.	729971.
5	276370.	30485.	19655.	10830.	243496.	0.	0.	0.	580836.	145209.	38500.	764545.
6	290188.	32009.	20637.	11372.	255671.	0.	0.	0.	609878.	152469.	38500.	800847.
7	304698.	33610.	21669.	11940.	268455.	0.	0.	0.	640371.	160093.	38500.	838964.
8	319932.	35290.	22753.	12537.	281877.	0.	0.	0.	672390.	168097.	38500.	878988.
9	335929.	37055.	23890.	13164.	295971.	0.	0.	0.	706009.	176502.	38500.	921012.
10	352725.	38907.	25085.	13822.	310770.	0.	0.	0.	741310.	185327.	38500.	965138.
11	370362.	40853.	26339.	14513.	326308.	0.	0.	0.	778375.	194594.	38500.	1011469.
12	388880.	42895.	27656.	15239.	342624.	0.	0.	0.	817294.	204324.	38500.	1060118.
13	408324.	45040.	29039.	16001.	359755.	0.	0.	0.	858159.	214540.	38500.	1111199.
14	428740.	47292.	30491.	16801.	377743.	0.	0.	0.	901067.	225267.	38500.	1164834.
15	450177.	49657.	32015.	17641.	396630.	0.	0.	0.	946120.	236530.	38500.	1221150.
16	472686.	52140.	33616.	18523.	416461.	0.	0.	0.	993426.	248357.	38500.	1280283.
17	496320.	54746.	35297.	19449.	437284.	0.	0.	0.	1043098.	260774.	38500.	1342372.
18	521136.	57484.	37062.	20422.	459149.	0.	0.	0.	1095252.	273813.	38500.	1407566.
19	547193.	60358.	38915.	21443.	482106.	0.	0.	0.	1150015.	287504.	38500.	1476019.
20	574553.	63376.	40861.	22515.	506211.	0.	0.	0.	1207516.	301879.	38500.	1547895.

REQUIRED REVENUES		
PRESENT VALUE OF INCOME STREAM		9772108.
AVERAGE/INITIAL ANNUAL REVENUE		921584.
AVERAGE/INITIAL RFR		1.0448

ANNUAL CASH FLOW											
YEAR	DIR. OP. COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR NET REVENUE	NPV-NI	RV
1	477855.	38500.	129718.	94500.	765537.	23780.	30240.	921584.	1.	156048.	156048.
2	501748.	38500.	115699.	0.	781384.	23780.	29579.	921584.	1.	140200.	285862.
3	526835.	38500.	100989.	0.	798033.	23780.	28866.	921584.	1.	123551.	391787.
4	553177.	38500.	85554.	0.	815525.	23780.	28095.	921584.	1.	106059.	475980.
5	580836.	38500.	69358.	0.	833903.	23780.	27262.	921584.	1.	87681.	540428.
6	609878.	38500.	52365.	0.	853212.	23780.	26363.	921584.	1.	68372.	586961.
7	640371.	38500.	34535.	0.	873499.	23780.	25392.	921584.	1.	48085.	617262.
8	672390.	38500.	15827.	0.	894814.	23780.	24344.	921584.	1.	26770.	632882.
9	706009.	38500.	-3801.	0.	917211.	23780.	23211.	921584.	1.	4373.	635245.
10	741310.	38500.	-24394.	0.	940743.	23780.	21988.	921584.	1.	-19159.	625660.
11	778375.	38500.	-46000.	0.	965470.	23780.	20667.	921584.	1.	-43886.	605333.
12	817294.	38500.	-68666.	0.	991452.	23780.	19240.	921584.	1.	-69868.	575368.
13	858159.	38500.	-92445.	0.	1019753.	23780.	17700.	921584.	1.	-97169.	536781.
14	901067.	38500.	-117391.	0.	1047442.	23780.	16036.	921584.	1.	-125858.	490503.
15	946120.	38500.	-143561.	0.	1077590.	23780.	14239.	921584.	1.	-156006.	437389.
16	993426.	38500.	-171013.	0.	1109270.	23780.	12298.	921584.	1.	-187686.	378222.
17	1043098.	38500.	-199809.	0.	1142563.	23780.	10201.	921584.	1.	-220979.	313721.
18	1095252.	38500.	-230016.	0.	1177550.	23780.	7937.	921584.	1.	-255966.	244541.
19	1150015.	38500.	-261700.	0.	1214319.	23780.	5492.	921584.	1.	-292735.	171284.
20	1207516.	38500.	-294933.	0.	1252962.	23780.	2852.	921584.	1.	-331378.	94500.

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APPENDIX G (1B)

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)			
TYPE	TUG/TOW	US FLAG (Push-Tow Boat)	New Construction Vessel Equipped with
SERVICE AREA	INLAND		ORC's Bottoming System = 15% Effectiveness
DWT	16914. LONG TONS		
HORSEPOWER	1225.	Rated BHP = 1650	
TYPE OF FUEL	DIESEL		
FUEL CONSUMP AT DESIGN SPEED	4. LTON/DAY	.33 LR/SHP-HR	(.3273 actual)

SERVICE CHARACTERISTICS		
SERVICE AREA	INLAND	
SPEED, MI/HR	6.4	
ROUND TRIP TIME, DAYS	6.3	
AVERAGE DISTANCE, MI	358.	
CARGO PER HAUL, LT	16914.	

SUMMARY FOR ONE VOYAGE		
FUEL CONSUMED, LTONS		
AT SEA	27.	
IN PORT	0.	
TOTAL	27.	(1172.833 MATON)

COST SUMMARY		
VESSEL COSTS	8495.	
PORT COSTS	0.	
CARGO COSTS	0.	
TOTAL DIRECT COST	8495.	
GEN + ADMIN	2124.	
TOTAL OPERATING COST	10619.	

SUMMARY FOR ONE YEAR		
VOYAGES	52.1	
CARGO HAULED, LT	882034.	
FUEL USED, LT	1418.	
TOTAL OPERATING COSTS	553778.	

CAPITALIZATION SCHEME

METHOD	TITLE XI
FULL CAPITAL COST	561500.
INITIAL INVESTMENT	112300.
DEBT SERVICE/LEASE PMT	45752.
ANNUAL INTEREST RATE	.080
CORPORATE TAX RATE	.48

(Push-Tow Boat)

New Construction Vessel Equipped with
ORC's Bottoming System = 15% Effectiveness

OPERATING COSTS

YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL (SEA)	FUEL (PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	227370.	25980.	18150.	10230.	170302.	0.	0.	0.	451132.	112783.	45752.	609667.
2	238739.	26334.	19058.	10742.	178817.	0.	0.	0.	473689.	118422.	45752.	637863.
3	250675.	27651.	20010.	11279.	187758.	0.	0.	0.	497373.	124343.	45752.	667469.
4	263209.	29033.	21011.	11843.	197146.	0.	0.	0.	522242.	130561.	45752.	698555.
5	276370.	30485.	22061.	12435.	207003.	0.	0.	0.	548354.	137089.	45752.	731195.
6	290188.	32009.	23165.	13056.	217354.	0.	0.	0.	575772.	143943.	45752.	765467.
7	304698.	33610.	24323.	13709.	228221.	0.	0.	0.	604560.	151140.	45752.	801453.
8	319932.	35290.	25539.	14395.	239632.	0.	0.	0.	634788.	158697.	45752.	839238.
9	335929.	37055.	26816.	15114.	251614.	0.	0.	0.	666528.	166632.	45752.	878912.
10	352725.	38917.	28157.	15870.	264195.	0.	0.	0.	699854.	174964.	45752.	920570.
11	370362.	40853.	29564.	16664.	277404.	0.	0.	0.	734847.	183712.	45752.	964311.
12	388880.	42895.	31043.	17497.	291275.	0.	0.	0.	771589.	192897.	45752.	1010239.
13	408324.	45040.	32595.	18372.	305838.	0.	0.	0.	810169.	202542.	45752.	1058463.
14	428740.	47292.	34225.	19290.	321130.	0.	0.	0.	850677.	212669.	45752.	1109099.
15	450177.	49657.	35936.	20255.	337187.	0.	0.	0.	893211.	223303.	45752.	1162266.
16	472686.	52140.	37733.	21267.	354046.	0.	0.	0.	937872.	234468.	45752.	1218092.
17	496320.	54746.	39619.	22331.	371749.	0.	0.	0.	984765.	246191.	45752.	1276708.
18	521136.	57484.	41600.	23447.	390336.	0.	0.	0.	1034003.	258501.	45752.	1338256.
19	547193.	60358.	43680.	24620.	409853.	0.	0.	0.	1085704.	271426.	45752.	1402882.
20	574553.	63376.	45864.	25851.	430345.	0.	0.	0.	1139989.	284997.	45752.	1470738.

REQUIRED REVENUES

PRESENT VALUE OF INCOME STREAM	9350227.
AVERAGE/INITIAL ANNUAL REVENUE	881797.
AVERAGE/INITIAL RFR	.5997

ANNUAL CASH FLOW

YEAR	DIR OP COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR NET REVENUE	NPV-NI RV
1	451132.	45752.	121774.	112300.	731441.	28251.	35936.	881797.	1.	150356.
2	473689.	45752.	108617.	0.	746480.	28251.	35151.	881797.	1.	135318.
3	497373.	45752.	94813.	0.	762282.	28251.	34303.	881797.	1.	119516.
4	522242.	45752.	80332.	0.	778886.	28251.	33387.	881797.	1.	102911.
5	548354.	45752.	65139.	0.	796334.	28251.	32397.	881797.	1.	85464.
6	575772.	45752.	49201.	0.	814668.	28251.	31329.	881797.	1.	67129.
7	604560.	45752.	32482.	0.	833935.	28251.	30175.	881797.	1.	47863.
8	634788.	45752.	14943.	0.	854181.	28251.	28929.	881797.	1.	27617.
9	666528.	45752.	-3454.	0.	875458.	28251.	27583.	881797.	1.	6340.
10	699854.	45752.	-22752.	0.	897817.	28251.	26130.	881797.	1.	-16020.
11	734847.	45752.	-42995.	0.	921316.	28251.	24560.	881797.	1.	-39519.
12	771589.	45752.	-64226.	0.	946012.	28251.	22865.	881797.	1.	-64215.
13	810169.	45752.	-86495.	0.	971968.	28251.	21034.	881797.	1.	-90171.
14	850677.	45752.	-109851.	0.	999248.	28251.	19056.	881797.	1.	-117450.
15	893211.	45752.	-134346.	0.	1027920.	28251.	16920.	881797.	1.	-146122.
16	937872.	45752.	-160035.	0.	1058056.	28251.	14614.	881797.	1.	-176259.
17	984765.	45752.	-186976.	0.	1089733.	28251.	12123.	881797.	1.	-207935.
18	1034003.	45752.	-215227.	0.	1123029.	28251.	9433.	881797.	1.	-241232.
19	1085704.	45752.	-244853.	0.	1158029.	28251.	6527.	881797.	1.	-276231.
20	1139989.	45752.	-275918.	0.	1194820.	28251.	3389.	881797.	1.	-313023.

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)

TYPE	TUG	US FLAG	Inland Tug
SERVICE AREA	GR. LAKES		
DWT	5625. LONG TONS		
HORSEPOWER	986.	Rated BHP =	1650
TYPE OF FUEL	DIESEL		
FUEL CONSUMP AT DESIGN SPEED	4. LTON/DAY (	.39 LB/SHP-HR)	(.385 actual)

Baseline Vessel

No Energy Recovery System

SERVICE CHARACTERISTICS

SERVICE AREA	GR. LAKES
SPEED, MI/HR	9.0
ROUND TRIP TIME, DAYS	5.7
AVERAGE DISTANCE, MI	540.
CARGO PER HAUL, LT	5625.

SUMMARY FOR ONE VOYAGE

FUEL CONSUMED, LTONS	
AT SEA	23.
IN PORT	0.
TOTAL	23. (994.420 MBTU)

COST SUMMARY

VESSEL COSTS	7386.	
PORT COSTS	0.	
CARGO COSTS	0.	
TOTAL DIRECT COST		7386.
GEN + ADMIN	1847.	
TOTAL OPERATING COST		9233.

SUMMARY FOR ONE YEAR

VOYAGES	58.2	
CARGO HAULED, LT	327554.	
FUEL USED, LT	1342.	
TOTAL OPERATING COSTS		517629.

CAPITALIZATION METHOD	TITLE XI	(Inland Tug)	Baseline Vessel
FULL CAPITAL COST	440000.		No Energy Recovery System
INITIAL INVESTMENT	88000.		
DEBT SERVICE/LEASE PMT	35852.		
ANNUAL INTEREST RATE	.080		
CORPORATE TAX RATE	.48		

OPERATING COSTS

YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL (SEA)	FUEL (PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	227370.	25080.	16170.	7920.	161241.	0.	0.	0.	437781.	109445.	35852.	583078.
2	238739.	26334.	16979.	8316.	169303.	0.	0.	0.	459670.	114918.	35852.	610440.
3	250675.	27651.	17827.	8732.	177769.	0.	0.	0.	482654.	120663.	35852.	639169.
4	263209.	29033.	18719.	9168.	186657.	0.	0.	0.	506786.	126697.	35852.	669335.
5	276370.	30485.	19655.	9627.	195990.	0.	0.	0.	532126.	133031.	35852.	701009.
6	290188.	32009.	20637.	10108.	205789.	0.	0.	0.	558732.	139683.	35852.	734267.
7	304698.	33610.	21669.	10614.	216079.	0.	0.	0.	586669.	146667.	35852.	769188.
8	319932.	35290.	22753.	11144.	226883.	0.	0.	0.	616002.	154001.	35852.	805855.
9	335929.	37055.	23890.	11701.	238227.	0.	0.	0.	646802.	161701.	35852.	844355.
10	352725.	38907.	25085.	12287.	250138.	0.	0.	0.	679142.	169786.	35852.	884780.
11	370362.	40853.	26339.	12901.	262645.	0.	0.	0.	713099.	178275.	35852.	927226.
12	388880.	42895.	27656.	13546.	275777.	0.	0.	0.	748754.	187189.	35852.	971795.
13	408324.	45040.	29039.	14223.	289566.	0.	0.	0.	786192.	196548.	35852.	1018592.
14	428740.	47292.	30491.	14934.	304044.	0.	0.	0.	825502.	206375.	35852.	1067729.
15	450177.	49657.	32015.	15681.	319247.	0.	0.	0.	866777.	216694.	35852.	1119323.
16	472686.	52140.	33616.	16465.	335209.	0.	0.	0.	910116.	227529.	35852.	1173497.
17	496320.	54746.	35297.	17288.	351969.	0.	0.	0.	955621.	238905.	35852.	1230379.
18	521136.	57484.	37062.	18153.	369568.	0.	0.	0.	1003403.	250851.	35852.	1290105.
19	547193.	60358.	38915.	19060.	388046.	0.	0.	0.	1053573.	263393.	35852.	1352818.
20	574553.	63376.	40861.	20013.	407448.	0.	0.	0.	1106251.	276563.	35852.	1418666.

REQUIRED REVENUES

PRESNT VALUE OF INCOME STREAM	8961701.
AVERAGE/INITIAL ANNUAL REVENUE	845157.
AVERAGE/INITIAL RFR	2.5802

ANNUAL CASH FLOW

YEAR	DIR OP COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR NET REVENUE	NPV-NT RV
1	437781.	35852.	118930.	88000.	702008.	22000.	28160.	845157.	3.	143148.
2	459670.	35852.	106092.	0.	716531.	22000.	27545.	845157.	3.	128625.
3	482654.	35852.	92620.	0.	731790.	22000.	26880.	845157.	3.	113367.
4	506786.	35852.	78485.	0.	747820.	22000.	26162.	845157.	3.	97336.
5	532126.	35852.	63654.	0.	764663.	22000.	25387.	845157.	3.	80493.
6	558732.	35852.	48092.	0.	782359.	22000.	24550.	845157.	3.	62798.
7	586669.	35852.	31764.	0.	800952.	22000.	23646.	845157.	3.	44205.
8	616002.	35852.	14633.	0.	820487.	22000.	22669.	845157.	3.	24669.
9	646802.	35852.	-3341.	0.	841014.	22000.	21615.	845157.	3.	4143.
10	679142.	35852.	-22199.	0.	862581.	22000.	20476.	845157.	3.	-17425.
11	713099.	35852.	-41982.	0.	885244.	22000.	19246.	845157.	3.	-40087.
12	748754.	35852.	-62738.	0.	909057.	22000.	17917.	845157.	3.	-63901.
13	786192.	35852.	-84512.	0.	934080.	22000.	16482.	845157.	3.	-88924.
14	825502.	35852.	-107354.	0.	960376.	22000.	14933.	845157.	3.	-115219.
15	866777.	35852.	-131315.	0.	988008.	22000.	13259.	845157.	3.	-142851.
16	910116.	35852.	-156451.	0.	1017045.	22000.	11452.	845157.	3.	-171889.
17	955621.	35852.	-182818.	0.	1047561.	22000.	9500.	845157.	3.	-202405.
18	1003403.	35852.	-210474.	0.	1079631.	22000.	7392.	845157.	3.	-234474.
19	1053573.	35852.	-239484.	0.	1113334.	22000.	5115.	845157.	3.	-268178.
20	1106251.	35852.	-269910.	0.	1148756.	22000.	2656.	845157.	3.	-303599.

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)		
TYPE	TUG	US FLAG Inland Tug
SERVICE AREA	GR. LAKES	New Construction Vessel Equipped with
DWT	5625. LONG TONS	ORC's Bottoming System = 15% Effectiveness
HORSEPOWER	986.	Rated BHP = 1650
TYPE OF FUEL	DIESEL	
FUEL CONSUMP AT DESIGN SPEED	3. LTON/DAY (.33 LR/SHP-HR) (.3273 actual)	

SERVICE CHARACTERISTICS

SERVICE AREA	GR. LAKES
SPEED, MI/HR	9.0
ROUND TRIP TIME, DAYS	5.7
AVERAGE DISTANCE, MI	540.
CARGO PER HAUL, LT	5625.

SUMMARY FOR ONE VOYAGE

FUEL CONSUMED, LTONS	
AT SEA	20.
IN PORT	0.
TOTAL	20. (845.386 MPTU)

COST SUMMARY

VESSEL COSTS	7036.	
PORT COSTS	0.	
CARGO COSTS	0.	
TOTAL DIRECT COST		7036.
GEN + ADMIN	1759.	
TOTAL OPERATING COST		8795.

SUMMARY FOR ONE YEAR

VOYAGES	58.2	
CARGO HAULED, LT	327554.	
FUEL USED, LT	1141.	
TOTAL OPERATING COSTS		512161.

CAPITALIZATION SCHEME

METHOD	TITLE XI	Inland Tug	New Construction Vessel Equipped with
FULL CAPITAL COST	511500.		ORC's Bottoming System = 15% Effectiveness
INITIAL INVESTMENT	102300.		
DEBT SFRVICF/LEASE PMT	41678.		
ANNUAL INTEREST RATE	.080		
CORPORATE TAX RATE	.48		

OPERATING COSTS

YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL (SEA)	FUEL (PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	227370.	25080.	17490.	9240.	137076.	0.	0.	0.	416256.	104064.	41678.	561998.
2	238739.	26334.	18365.	9702.	143930.	0.	0.	0.	437069.	109267.	41678.	588014.
3	250675.	27651.	19283.	10187.	151126.	0.	0.	0.	458922.	114731.	41678.	615331.
4	263209.	29033.	20247.	10696.	158683.	0.	0.	0.	481868.	120467.	41678.	644013.
5	276370.	30485.	21259.	11231.	166617.	0.	0.	0.	505962.	126490.	41678.	674130.
6	290188.	32009.	22322.	11793.	174948.	0.	0.	0.	531260.	132815.	41678.	705753.
7	304698.	33610.	23438.	12382.	183695.	0.	0.	0.	557823.	139456.	41678.	738956.
8	319932.	35290.	24610.	13002.	192880.	0.	0.	0.	585714.	146428.	41678.	773820.
9	335929.	37055.	25841.	13652.	202524.	0.	0.	0.	615000.	153750.	41678.	810427.
10	352725.	38907.	27133.	14334.	212650.	0.	0.	0.	645750.	161437.	41678.	848865.
11	370362.	40853.	28489.	15051.	223282.	0.	0.	0.	678037.	169509.	41678.	889224.
12	388880.	42895.	29914.	15804.	234446.	0.	0.	0.	711939.	177985.	41678.	931602.
13	408324.	45040.	31410.	16594.	246169.	0.	0.	0.	747536.	186884.	41678.	976098.
14	428740.	47292.	32980.	17423.	258477.	0.	0.	0.	784913.	196228.	41678.	1022819.
15	450177.	49657.	34629.	18295.	271401.	0.	0.	0.	824158.	206040.	41678.	1071876.
16	472686.	52140.	36360.	19209.	284971.	0.	0.	0.	865366.	216342.	41678.	1123386.
17	496320.	54746.	38178.	20170.	299220.	0.	0.	0.	908635.	227159.	41678.	1177471.
18	521136.	57484.	40087.	21178.	314181.	0.	0.	0.	954066.	238517.	41678.	1234261.
19	547193.	60358.	42092.	22237.	329890.	0.	0.	0.	1001770.	250442.	41678.	1293890.
20	574553.	63376.	44196.	23349.	346384.	0.	0.	0.	1051858.	262965.	41678.	1356501.

REQUIRED REVENUES

PRESNT VALUE OF INCOME STREAM	8621831.
AVERAGE/INITIAL ANNUAL REVENUE	813104.
AVERAGE/INITIAL RFR	2.4823

ANNUAL CASH FLOW

YEAR	DIR OP COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR NET REVENUE	NPV-NT RV
1	416256.	41678.	112547.	102300.	674545.	25575.	32736.	813104.	2.	138559.
2	437069.	41678.	100403.	0.	688417.	25575.	32021.	813104.	2.	124687.
3	458922.	41678.	87662.	0.	702992.	25575.	31248.	813104.	2.	110112.
4	481868.	41678.	74294.	0.	718308.	25575.	30414.	813104.	2.	94796.
5	505962.	41678.	60271.	0.	734401.	25575.	29513.	813104.	2.	78703.
6	531260.	41678.	45559.	0.	751312.	25575.	28539.	813104.	2.	61792.
7	557823.	41678.	30126.	0.	769082.	25575.	27488.	813104.	2.	44022.
8	585714.	41678.	13936.	0.	787757.	25575.	26353.	813104.	2.	25348.
9	615000.	41678.	-3047.	0.	807381.	25575.	25127.	813104.	2.	5723.
10	645750.	41678.	-20861.	0.	828004.	25575.	23803.	813104.	2.	-14900.
11	678037.	41678.	-39547.	0.	849677.	25575.	22373.	813104.	2.	-36573.
12	711939.	41678.	-59147.	0.	872455.	25575.	20829.	813104.	2.	-59350.
13	747536.	41678.	-79705.	0.	896393.	25575.	19161.	813104.	2.	-83289.
14	784913.	41678.	-101266.	0.	921553.	25575.	17359.	813104.	2.	-108449.
15	824158.	41678.	-123880.	0.	947996.	25575.	15414.	813104.	2.	-134892.
16	865366.	41678.	-147596.	0.	975790.	25575.	13313.	813104.	2.	-162686.
17	908635.	41678.	-172468.	0.	1005004.	25575.	11043.	813104.	2.	-191899.
18	954066.	41678.	-198550.	0.	1035711.	25575.	8593.	813104.	2.	-222606.
19	1001770.	41678.	-225902.	0.	1067988.	25575.	5946.	813104.	2.	-254884.
20	1051858.	41678.	-254583.	0.	1101918.	25575.	3087.	813104.	2.	-288814.

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)		
TYPE	166-	US FLAG Offshore Supply Boat
SERVICE AREA	COASTWISE	Baseline Vessel
DWT	535. LONG TONS	No Energy Recovery System
HORSEPOWER	604.	Rated BHP = 1650
TYPE OF FUEL	DIESEL	
FUEL CONSUMP AT DESIGN SPEED	2. LTON/DAY (.39 LR/SHP-HR) (.385 actual)	

SERVICE CHARACTERISTICS

SERVICE AREA	COASTWISE
SPEED, MI/HR	13.0
ROUND TRIP TIME, DAYS	8.9
AVERAGE DISTANCE, MI	1383.
CARGO PER HAUL, LT	535.

SUMMARY FOR ONE VOYAGE

FUEL CONSUMED, LTONS	
AT SEA	22.
IN PORT	0.
TOTAL	22. (952.959 MBTU)

COST SUMMARY

VESSEL COSTS	10010.	
PORT COSTS	0.	
CARGO COSTS	0.	
TOTAL DIRECT COST		10010.
GEN + ADMIN	2502.	
TOTAL OPERATING COST		12512.

SUMMARY FOR ONE YEAR

VOYAGES	37.2	
CARGO HAULED, LT	19915.	
FUEL USED, LT	822.	
TOTAL OPERATING COSTS		465736.

CAPITALIZATION SCHEME

METHOD	TITLE XI	Offshore Supply Boat	Baseline Vessel
FULL CAPITAL COST	540000.		No Energy Recovery System
INITIAL INVESTMENT	108000.		
DEBT SERVICE/LEASE PMT	44000.		
ANNUAL INTEREST RATE	.080		
CORPORATE TAX RATE	.48		

OPERATING COSTS

YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL (SEA)	FUEL (PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	227370.	25080.	16170.	9900.	98772.	0.	0.	0.	377292.	94323.	44000.	515616.
2	238739.	26334.	16979.	10395.	103711.	0.	0.	0.	396157.	99039.	44000.	539197.
3	250675.	27651.	17827.	10915.	108897.	0.	0.	0.	415965.	103991.	44000.	563956.
4	263209.	29013.	18719.	11460.	114342.	0.	0.	0.	436763.	109191.	44000.	589954.
5	276370.	30485.	19655.	12034.	120059.	0.	0.	0.	458601.	114650.	44000.	617252.
6	290188.	32009.	20637.	12635.	126062.	0.	0.	0.	481531.	120383.	44000.	645914.
7	304698.	33610.	21669.	13267.	132365.	0.	0.	0.	505608.	126402.	44000.	676010.
8	319932.	35290.	22753.	13930.	138983.	0.	0.	0.	530888.	132722.	44000.	707611.
9	335929.	37055.	23890.	14627.	145932.	0.	0.	0.	557433.	139358.	44000.	740791.
10	352725.	38907.	25085.	15358.	153229.	0.	0.	0.	585304.	146326.	44000.	775631.
11	370362.	40853.	26339.	16126.	160890.	0.	0.	0.	614570.	153642.	44000.	812212.
12	388480.	42895.	27656.	16932.	168934.	0.	0.	0.	645298.	161325.	44000.	850623.
13	408324.	45040.	29039.	17779.	177381.	0.	0.	0.	677563.	169391.	44000.	890954.
14	428740.	47292.	30491.	18668.	186250.	0.	0.	0.	711441.	177860.	44000.	933302.
15	450177.	49657.	32015.	19601.	195563.	0.	0.	0.	747013.	186753.	44000.	977767.
16	472686.	52140.	33616.	20581.	205341.	0.	0.	0.	784364.	196091.	44000.	1024455.
17	496320.	54746.	35297.	21610.	215608.	0.	0.	0.	823582.	205896.	44000.	1073478.
18	521136.	57484.	37062.	22691.	226388.	0.	0.	0.	864761.	216190.	44000.	1124952.
19	547193.	60358.	38915.	23826.	237708.	0.	0.	0.	907999.	227000.	44000.	1178999.
20	574553.	63376.	40861.	25017.	249593.	0.	0.	0.	953399.	238350.	44000.	1235749.

REQUIRED REVENUES

PRESENT VALUE OF INCOME STREAM	7896189.
AVERAGE/INITIAL ANNUAL REVENUE	744671.
AVERAGE/INITIAL RFR	37.3933

ANNUAL CASH FLOW

YEAR	DIR OP COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR NET REVENUE	NPV-NI RV
1	377292.	44000.	101457.	108000.	617073.	27126.	34560.	744671.	37.	127598.
2	396157.	44000.	90501.	0.	629697.	27126.	33805.	744671.	37.	114973.
3	415965.	44000.	79007.	0.	642964.	27126.	32989.	744671.	37.	101707.
4	436763.	44000.	66951.	0.	656905.	27126.	32108.	744671.	37.	87765.
5	458601.	44000.	54305.	0.	671557.	27126.	31157.	744671.	37.	73114.
6	481531.	44000.	41040.	0.	686955.	27126.	30129.	744671.	37.	57716.
7	505608.	44000.	27127.	0.	703137.	27126.	29020.	744671.	37.	41534.
8	530888.	44000.	12534.	0.	720145.	27126.	27821.	744671.	37.	24526.
9	557433.	44000.	-2772.	0.	738020.	27126.	26527.	744671.	37.	6651.
10	585304.	44000.	-18824.	0.	756807.	27126.	25129.	744671.	37.	-12137.
11	614570.	44000.	-35658.	0.	776554.	27126.	23620.	744671.	37.	-31884.
12	645298.	44000.	-53312.	0.	797310.	27126.	21989.	744671.	37.	-52640.
13	677563.	44000.	-71826.	0.	819128.	27126.	20228.	744671.	37.	-74457.
14	711441.	44000.	-91240.	0.	842061.	27126.	18326.	744671.	37.	-97391.
15	747013.	44000.	-111598.	0.	866169.	27126.	16273.	744671.	37.	-121499.
16	784364.	44000.	-132943.	0.	891512.	27126.	14054.	744671.	37.	-146841.
17	823582.	44000.	-155324.	0.	918154.	27126.	11659.	744671.	37.	-173483.
18	864761.	44000.	-178790.	0.	946162.	27126.	9071.	744671.	37.	-201491.
19	907999.	44000.	-203391.	0.	975608.	27126.	6277.	744671.	37.	-230937.
20	953399.	44000.	-229183.	0.	1006566.	27126.	3259.	744671.	37.	-261896.

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)		
TYPE	TUG	US FLAG Offshore Supply Boat
SERVICE AREA	COASTWISE	New Construction Vessel Equipped with
DWT	530. LONG TONS	ORC's Bottoming System = 15% Effectiveness
HORSEPOWER	604.	Rated BHP = 1650
TYPE OF FUEL	DIESEL	
FUEL CONSUMP AT DESIGN SPEED	2. LTON/DAY (.33 LR/SHP-HR) (.3273 actual)	

SERVICE CHARACTERISTICS

SERVICE AREA	COASTWISE
SPEED, MI/HR	13.0
ROUND TRIP TIME, DAYS	8.9
AVERAGE DISTANCE, MI	1383.
CARGO PER HAUL, LT	530.

SUMMARY FOR ONE VOYAGE

FUEL CONSUMED, LTONS	
AT SEA	19.
IN PORT	0.
TOTAL	19. (810.139 MBTU)

COST SUMMARY

VESSEL COSTS	9693.	
PORT COSTS	0.	
CARGO COSTS	0.	
TOTAL DIRECT COST		9693.
GEN + ADMIN	2423.	
TOTAL OPERATING COST		12116.

SUMMARY FOR ONE YEAR

VOYAGES	37.2	
CARGO HAILED, LT	19728.	
FUEL USED, LT	699.	
TOTAL OPERATING COSTS		451001.

CAPITALIZATION SCHEME

METHOD	TITLE XI	Offshore Supply Boat	New Construction Vessel Equipped with ORC's Bottoming System = 15% Effectiveness
FULL CAPITAL COST	611500.		
INITIAL INVESTMENT	122300.		
DEBT SERVICE/LEASE PMT	49826.		
ANNUAL INTEREST RATE	.080		
CORPORATE TAX RATE	.48		

OPERATING COSTS

YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL (SEA)	FUEL (PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	227370.	25080.	17160.	11220.	83969.	0.	0.	0.	364799.	91200.	49826.	505825.
2	238739.	26334.	18018.	11781.	88168.	0.	0.	0.	383039.	95760.	49826.	528625.
3	250675.	27651.	18919.	12370.	92576.	0.	0.	0.	402191.	100548.	49826.	552565.
4	263209.	29033.	19865.	12989.	97205.	0.	0.	0.	422301.	105575.	49826.	577702.
5	276370.	30485.	20858.	13638.	102065.	0.	0.	0.	443416.	110854.	49826.	604096.
6	290188.	32009.	21901.	14320.	107169.	0.	0.	0.	465587.	116397.	49826.	631810.
7	304698.	33610.	22996.	15036.	112527.	0.	0.	0.	488866.	122217.	49826.	660909.
8	319932.	35290.	24146.	15788.	118153.	0.	0.	0.	513309.	128327.	49826.	691463.
9	335929.	37055.	25353.	16577.	124061.	0.	0.	0.	538975.	134744.	49826.	723545.
10	352725.	38907.	26621.	17406.	130264.	0.	0.	0.	565924.	141481.	49826.	757231.
11	370362.	40853.	27952.	18276.	136777.	0.	0.	0.	594220.	148555.	49826.	792601.
12	388880.	42895.	29349.	19190.	143616.	0.	0.	0.	623931.	155983.	49826.	829740.
13	408324.	45040.	30817.	20150.	150797.	0.	0.	0.	655127.	163782.	49826.	868735.
14	428746.	47292.	32358.	21157.	158337.	0.	0.	0.	687884.	171971.	49826.	909681.
15	450177.	49657.	33976.	22215.	166254.	0.	0.	0.	722278.	180569.	49826.	952674.
16	472686.	52140.	35674.	23326.	174566.	0.	0.	0.	758392.	189598.	49826.	997816.
17	496320.	54746.	37458.	24492.	183295.	0.	0.	0.	796311.	199078.	49826.	1045215.
18	521136.	57484.	39331.	25716.	192460.	0.	0.	0.	836127.	209032.	49826.	1094985.
19	547193.	60358.	41298.	27002.	202682.	0.	0.	0.	877933.	219483.	49826.	1147243.
20	574553.	63376.	43362.	28352.	212187.	0.	0.	0.	921830.	230458.	49826.	1202114.

REQUIRED REVENUES

PRESNT VALUE OF INCOME STREAM	7731192.
AVERAGE/INITIAL ANNUAL REVENUE	729110.
AVERAGE/INITIAL RFR	36.9574

ANNUAL CASH FLOW

YEAR	DIR OP COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR	NET REVENUE	NPV-NT RV
1	364799.	49826.	97561.	122300.	603387.	30722.	39136.	729110.	37.	125723.	125723.
2	383039.	49826.	87028.	0.	615653.	30722.	38281.	729110.	37.	113457.	230776.
3	402191.	49826.	75980.	0.	628545.	30722.	37357.	729110.	37.	100565.	316994.
4	422301.	49826.	64393.	0.	642095.	30722.	36360.	729110.	37.	87015.	386069.
5	443416.	49826.	52241.	0.	656337.	30722.	35282.	729110.	37.	72773.	439559.
6	465587.	49826.	39497.	0.	671307.	30722.	34119.	729110.	37.	57803.	478899.
7	488866.	49826.	26133.	0.	687042.	30722.	32862.	729110.	37.	42069.	505410.
8	513309.	49826.	12118.	0.	703581.	30722.	31505.	729110.	37.	25529.	520306.
9	538975.	49826.	-2578.	0.	720967.	30722.	30039.	729110.	37.	8143.	524705.
10	565924.	49826.	-17987.	0.	739244.	30722.	28457.	729110.	37.	-10134.	519636.
11	594220.	49826.	-34144.	0.	758457.	30722.	26747.	729110.	37.	-29347.	506043.
12	623931.	49826.	-51085.	0.	778655.	30722.	24901.	729110.	37.	-49545.	484794.
13	655127.	49826.	-68845.	0.	799890.	30722.	22907.	729110.	37.	-70780.	456686.
14	687884.	49826.	-87465.	0.	822215.	30722.	20753.	729110.	37.	-93105.	422451.
15	722278.	49826.	-106986.	0.	845688.	30722.	18427.	729110.	37.	-116578.	382761.
16	758392.	49826.	-127448.	0.	870368.	30722.	15915.	729110.	37.	-141258.	338231.
17	796311.	49826.	-148898.	0.	896318.	30722.	13202.	729110.	37.	-167208.	289425.
18	836127.	49826.	-171381.	0.	923604.	30722.	10273.	729110.	37.	-194494.	236859.
19	877933.	49826.	-194946.	0.	952297.	30722.	7108.	729110.	37.	-223187.	181007.
20	921830.	49826.	-219647.	0.	982470.	30722.	3691.	729110.	37.	-253360.	122300.

APPENDIX G (6B)

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