U.S. Coast Guard Research and Development Center

1082 Shennecossett Road, Groton, CT 06340-6096

Report No. CG-D-19-00

COMPARATIVE LIFE CYCLE COSTS OF FUEL CELLS AND OTHER PROPULSION SYSTEMS

Final Report
January 2000

This document is available to the U.S. public through the
National Technical Information Service, Springfield, VA 22161

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Operations (G-O)
Washington, DC 20593-0001

N O T I C E

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.

Marc B. Mandler, Ph.D.
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No.	2. Government Accession Number	3. Recipient's Catalog No.
CG-D-19-00	ADA 385105	

4. Title and Subtitle	5. Report Date
COMPARATIVE LIFE CYCLE COSTS OF FUEL CELLS AND OTHER PROPULSION SYSTEMS	January 2000
	6. Performing Organization Code Project No. 3310.2

7. Author(s)	8. Performing Organization Report No.
Karni, Z., Willigan, R., Artze, C., Badal, M., Gordon, W., Haider, J., Levesque, R., and Forsyth, W.	R&DC-310-99

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
John J. McMullen Associates, Inc. 4300 King Street, Suite 400 Alexandria, VA 22302	
	11. Contract or Grant No. DTCG39-95-D-E99010 T.O. 98FE00260

12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
U.S. Department of Transportation United States Coast Guard Operations (G-O) U.S. Coast Guard Headquarters Washington, DC 20593-0001	Final
	14. Sponsoring Agency Code Commandant (G-OCU-1) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Robert D. Sedat, 860-441-2684, email: rsedat@rdc.uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

This is a report on the development of a Life Cycle Cost (LCC) model that compares costs for traditional propulsion systems to costs of marine propulsion systems that incorporate fuel cells. The Coast Guard is interested in applying fuel cell technology for shipboard applications where high efficiency and reduced pollution are critical. Similar cost comparisons are also made for ship service generators. The program sums acquisition costs of the machinery system of a vessel, the operational costs including fuel and maintenance, manning costs and disposal costs. An allowance for exhaust emission credits/penalties is included in the program. The description of the program and of all the major assumptions leading to the present and future cost figures is provided in this report. The Excel software used for this study is available from the technical point of contact listed above. A comparison of Life Cycle Costs for four marine propulsion systems is presented. A conventional diesel only system (CODAD) was compared to an Integrated Diesel Electric system (IDE) and then to the new powering systems, i.e., the Molten Carbonate (MC) and the Proton Exchange Membrane (PEM) fuel cell systems. The fuel cell models contained in this report are preliminary, as no historical shipboard data are yet available. Nonetheless, best estimates have been made, and all key variables can be altered to investigate sensitivity. This LCC model is expected to be refined as more accurate data, particularly with respect to fuel cells, becomes available.

17. Key Words	18. Distribution Statement
Life Cycle Cost (LCC), fuel cells, marine propulsion, Molten Carbonate Fuel Cell (MCFC), Proton Exchange Membrane Fuel Cell (PEMFC), Combined Diesel and Diesel (CODAD), Integrated Diesel Electric (IDE), net present value (NPV)	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Class (This Report)	20. Security Class (This Page)	21. No of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

[This page intentionally left blank.]

EXECUTIVE SUMMARY

Fuel cells offer the potential for substantially better fuel efficiency and cleaner emissions than marine diesels or gas turbines. However, the greatest technical barrier to their shipboard use remains the difficulty in extracting the hydrogen for the fuel cell from the marine diesel fuel. Together, the U.S. Navy and the Coast Guard (USCG) have been working to develop systems capable of purifying and reforming diesel fuel for use in marine fuel cells. As these technical barriers are overcome, costs are expected to decrease with mass production and economies of scale. The USCG has previously completed a Market Survey Report (September 1999) which showed that there is significant potential for a marine market for such fuel cells, providing that total life cycle costs (LCC) can be made competitive with traditional sources of marine power.

This study provides a tool to compare the total life cycle costs of various types of ship powering and electrical generator systems on a consistent basis. Each system includes the basic power plant, and all required auxiliaries (e.g., fuel treatment, intake and exhaust systems, cooling, etc.). Acquisition costs include basic hardware, foundations, fabrication and shipboard installation. Recurring costs include fuel, lubricants, manning and maintenance. Emission penalties and disposal costs are also considered. Thus, the study enables total costs of competing powering systems to be estimated and directly compared. This capability is essential for conducting cost/benefit analyses, and to assess the economic competitiveness of shipboard fuel cell systems. This capability will benefit the Coast Guard in establishing a business case for further fuel cell R&D, and in developing commercial fuel cell systems for future use on Coast Guard cutters and other marine vessels.

The LCC program allows the selection of the following propulsion plant alternatives to be compared:

- Combined Diesel and Diesel (CODAD)
- Combined Diesel or Gas Turbine (CODOG)
- Combined Diesel and Gas turbine (CODAG)
- Combined Gas Turbine and Gas Turbine (COGAG)
- Integrated Diesel Electric (IDE) with Alternating or Direct Current (AC/DC) Motors
- Integrated Gas Turbine Electric (IGTE) with AC or DC Motors
- Proton Exchange Membrane Fuel Cell (PEMFC) with AC or Direct Current (DC) Motors
- Molten Carbonate Fuel Cell (MCFC) with AC or DC Motors.

Just as there is a choice of propulsion systems, the LCC program also allows the selection of the following alternative Ship Service Generators to be compared:

- Medium Speed Diesel or High Speed Diesel depending on industry practices in the power rating considered
- Gas Turbine
- MCFC
- PEMFC

The LCC program permits the user to specify speeds and durations within the mission profile. The comparison of each system includes calculations for acquisition and operational costs for all required auxiliary components (e.g., fuel, lube oil, cooling systems, reformers, fuel cell stacks, power conditioners, reduction gearing, propulsion motors, etc.)

The LCC model employs cost estimating relationships (CERs) based on the use of relationships between weights of equipment to be installed and the cost of the equipment and the installation activity required. The program contains a CER screen that shows the cost relationship for a propulsion system by ship work breakdown structure (SWBS). The screen shows the SWBS number, description of the SWBS category, weight of equipment, labor hours, material required (cost), labor rate, and total procurement cost for the SWBS category.

A standalone User's Manual is appended to this report (Appendix A). The program was validated for trends and for preliminary comparison between systems. Results of the comparison are provided in Appendix B. The actual software is written in Excel, and is available from Robert Sedat of the USCG R&D Center at (860) 441-2684, or e-mail: rsedat@rdc.uscg.mil.

A comparison of Life Cycle Costs for four marine propulsion systems is presented. A conventional Diesel only system (CODAD) was compared to an Integrated Diesel Electric system (IDE) and then to the new powering systems, i.e., the MC and the PEM fuel cell systems.

The initial cost of a 5475 kW integrated diesel-electric (IDE) system (including propulsion motors and installation) is $24,825,269, or $4534/kW. This compares to an initial cost of $36,118,681, or $6597/kW for a MCFC propulsion system. The annual operating costs of the MCFC system are lower than those of the IDE system. For the operational scenario studied, the annual fuel and lube oil cost savings with the MCFC system amount to $162,000 ($441,000 vs. $603,000) and a saving of $131,000 for maintenance ($794,000 vs. $925,000). This annual savings of almost $300,000 in operational costs is not sufficient to compensate for the difference in the initial costs. It is quite clear, however, that a change in fuel costs could make the fuel cell system economically feasible. If the diesel fuel cost were increased by a factor of 2.14 to $582/tonne (from current $272/tonne), roughly $1.93 per gallon, which is less than the cost of the diesel oil sold at gas stations in Europe, the net present value (NPV) of both systems, for the period of analysis, equalizes.

It must be admitted that certain parts of the LCC program require further verification before they can be used with confidence. In particular, all of the fuel cell costs, except fuel consumption and pollution reduction credits, lack service experience. It would also be useful to benchmark some of the diesel costs against installations that were not in the original database. Lacking definitive costs for maintenance (including fuel cell stack replacement), manning, and disposal, these costs are tentatively considered to be similar for both the fuel cell and the diesel electric powering systems discussed. The maintenance costs for fuel cell systems were modified to include the latest estimate of actual fuel stack replacement costs for replacement intervals of five years.

Emission penalties, once enacted and enforced, could add another $50,000 to the annual operating costs of a 5475 kW diesel propulsion system. This, by itself, may not be sufficient to equalize annualized costs, but added scrubbing requirements for the diesel electric system and increased fuel costs can do so.

The results presented here are subject to numerous assumptions, but give some idea of the comparative economics of a diesel electric system relative to a fuel-cell electric system. The fuel cell models contained in this report are preliminary, as no historical shipboard data are yet available. Nonetheless, best estimates have been made, and all key variables can be altered to investigate sensitivity. This LCC model provides a consistent tool to compare fuel cell economics to those of traditional marine powering systems.

[This page intentionally left blank.]

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE **PAGE**

LIST OF TABLES

TABLE **PAGE**

LIST OF ACRONYMS AND ABBREVIATIONS

ACRONYM	DEFINITION
AC	Alternating Current
C	Centigrade (degrees)
CER	Cost Estimating Relationship
CFIP	California Federal Implementation Plan
CODAD	Combined Diesel And Diesel
CODAG	Combined Diesel and Gas Turbine
CODOG	Combined Diesel or Gas Turbine
COGAG	Combined Gas Turbine and Gas Turbine
CSIP	California State Implementation Plan
DC	Direct Current
FCE	Fuel Cell Energy, Inc. formerly Energy Research Corp. (ERC)
g	gram (s)
hr	Hour
IDE	Integrated Diesel Electric
IFCE	Integrated Fuel Cell Electric
IGTE	Integrated Gas Turbine Electric
kg	Kilogram
kt	knot (nautical mile/hour)
kW	Kilowatt
kWe (or ekW)	kilowatt electric
LCC	Life Cycle Cost
LHV	Lower Heating Value
m	Meter
MC	Molten Carbonate
MCFC	Molten Carbonate Fuel Cell
MCR	Maximum Continuous Rating
MEL	Major Equipment Lists
mm	Millimeter
MT	metric ton (tonne)
MW	Megawatt
NPV	Net Present Value
O&S	Operating and Support
PEM	Proton Exchange Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
SFC	Specific Fuel Consumption
skW	shaft kilowatt

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

SSDG	Ship Service Diesel Generator
SSGTG	Ship Service Gas Turbine Generator
SWBS	Ship Work Breakdown Structure
USCG	United States Coast Guard
w.g.	Water Gauge
Yr	Year

1.0 INTRODUCTION

1.1 Background

The U.S. Navy and Coast Guard (USCG) have been working together to develop systems capable of purifying and reforming diesel fuel for use in marine fuel cells. Possible applications for such fuel cells include energy for main propulsion, and for ship service requirements. While many principal technical barriers have been overcome, fuel cells are still developmental. Costs are in a state of flux while mass production techniques are developed and economies of scale are realized. The USCG has previously completed a Market Survey Report (July 1999) which showed that there is significant potential for a marine market for such fuel cells, providing that total life cycle costs (LCC) can be made competitive with traditional sources of marine power. Fuel cells offer substantially better fuel efficiency and cleaner emissions than diesels or turbines, so they can still be competitive even if certain other costs are higher.

The present report describes the development of a computer cost model capable of comparing the life cycle cost of fuel cell systems to those of conventional marine power sources. Although fuel cell efficiencies can be predicted with some confidence, there are no historical data for fuel cell initial costs, maintenance, manning requirements or disposal. Nonetheless, the model serves as a useful tool for parametric variation of key variables, including future fuel costs. The program also provides comparisons based on best estimates of current costs, and will be used to assess the economic viability of fuel cells for shipboard applications.

1.2 Previous Parametric Studies

Two earlier articles in the Naval Engineers Journal[1] considered the cost of fuel cell systems versus the cost of traditional propulsion systems for marine applications.

In the 1998 article, the authors define the cost of electricity as the combined costs of Operation and Maintenance costs, Capital and Finance Costs and Fuel Cost. The Capital cost for MCFC was stated to be $1500/kW versus a stated cost of $500/kW for medium speed diesels. No data was provided for any of the other costs. A simplified comparison between a 6000 kW fuel cell plant and a 6400 kW diesel plant concluded that there is a $5.8 million difference in Capital costs. Thus savings in fuel and maintenance costs over the life of the vessel has to amount to this difference, plus finance costs to make the systems commercially viable.

The other reference, from 1994, summarized the impact of fuel cell technology on the design, cost and effectiveness of combatants. The cost study was conducted to determine the cost impacts of replacing a traditional ship powering system, Integrated Power System (IPS), with fuel cell systems, specifically PEM fuel cells for ship service. The LCC studies were

---

[1] Allen, S., Ashey, E., Gore, D., Woerner, J., and Cervi, M.. (January 1998). Marine Applications of Fuel Cells - A Multi-Agency Research Program. Naval Engineers Journal. p. 93-106

Goubault, P., Greenberg, M., Heidenreich, T., and Woerner, J.. (May 1994). Fuel Cell Power Plant for Surface Fleet Applications. Naval Engineers Journal. p. 59-76.

conducted with the aid of NAVSEA's Cost Estimating Relationships and General Electric's parameteric cost model PRICE-H. The finding was that LCC of a PEM system was less than 5% higher than LCC of the IPS traditional system for a 30 years life scenario.

1.3 Life Cycle Cost Model

This report documents a LCC computer model that allows comparisons of various types of propulsion and ship service electric plants. The model is applicable to both naval and commercial vessels. The report describes the model's basic assumptions and provides sample outputs. A User's Manual is provided in Appendix A. A sample comparison of four propulsion systems is provided in Appendix B. The computer program itself was provided separately to the United States Coast Guard.

The computation methodology and the assumptions used in the development of this program are outlined in detail in the following sections. In general, the cost data is derived based on the appropriate system weights. The propulsion system weight groups were developed for a low propulsion-power type vessel and for a high power type vessel. Linear interpolation was employed for estimation of Life Cycle Costs at intermediate power levels. The cost-weight relationships are historical for the conventional systems and assumed, with limited justification, for the fuel cell power systems.

2.0 APPROACH

2.1 Propulsion Alternatives

In accordance with the statement of work, the program calculates the life-cycle costs of various propulsion and ship service electrical plants based on plant configuration and prime movers specified by the user. Moreover, the model is sufficiently general that it may be used for sensitivity analysis of the individual elements. The current scope of the model permits comparative cost analyses to be performed for the propulsion plant alternatives listed below. Twin diesel propulsion systems are modeled using the CODAD option.

- Combined Diesel and Diesel (CODAD)
- Combined Diesel or Gas Turbine (CODOG)
- Combined Diesel and Gas turbine (CODAG)
- Combined Gas Turbine and Gas Turbine (COGAG)
- Integrated Diesel Electric (IDE) with Alternating Current (AC) or Direct Current (DC) Motors
- Integrated Gas Turbine Electric (IGTE) with AC or DC Motors
- Proton Exchange Membrane Fuel Cell (PEMFC) with AC or DC Motors
- Molten Carbonate Fuel Cell (MCFC) with AC or DC Motors.

2.2 Methodology

The methodology used in developing the LCC model consisted of the following:

a. Defining the software module structure and top level specification. Various software platforms were evaluated including Microsoft Excel, Price, EDCAS, and ASSET. Due to its inherent advantages in software support costs, user base, and training costs, the program was developed on an Excel platform.

b. Defining each propulsion plant alternative to a rough order of magnitude level of detail. In order to bound the scope of solutions, it was assumed that plant alternatives would be twin screw and would have no more than approximately 42.7 MW (power associated with two General Electric LM 2500 gas turbines) of installed shaft power consistent with upper end expectations for a typical USCG cutter. Propulsor, drive train and shaft characteristics, air intake/exhaust systems, and major auxiliary systems influenced by the propulsion plant were then defined at high (31.4 MW to 42.7 MW depending on the plant alternative) and low (1.0 MW to 2.1 MW depending on the plant alternative) power levels. For these purposes, each high and low level plant alternative was defined by a major machinery equipment list (MEL). These MELs were, for the most part, derived by JJMA using proprietary project databases from past and current clients and are not included in this report. However, samples of MELs for typical propulsion plant alternatives were presented to the USCG separately to confirm that the level of detail was appropriate for purposes of the model. It should be noted that because the LCC program is primarily tuned to USCG vessels or vessels of similar size and function, low speed diesels were determined not to be applicable due to their large space and weight requirements. In addition, the transition between the use of high and medium speed diesel alternatives is not explicit. The transition is performed automatically by the program based on the availability of high speed diesels at the lower power level boundary and prevalent use of medium speed diesels at the high power level boundary.

c. Developing weight estimates for each plant alternative using a traditional Ship Work Breakdown Structure (SWBS) format.

d. Developing algorithms that would estimate the weight of each propulsion plant alternative by SWBS based on user specified shaft power. As discussed above, each propulsion plant has associated high and low power level boundaries that dictate the range of possible solutions for each plant alternative. For power levels specified by the user which fall within these boundaries, propulsion plant weights are linearly interpolated within each SWBS category to estimate the weight of the plant. For user convenience, the range of powering solutions for each plant alternative is clearly marked next to the system title in the pop-up input screen. Selection of an out of range powering level will initiate a “below” or “out of range” warning, and the cost calculation will be suspended.

e. Developing cost estimating relationships (CERs) and algorithms to estimate the initial construction cost of each plant alternative based on the estimated weight of the plant.

f. Developing annual operating and support cost (O&S) algorithms based on the plant operating profile specified by the user. The O&S costs include annual fuel and lube oil consumption, crew and maintenance. For purposes of estimating fuel consumption, it should be noted that the algorithms assume trailed shaft operations only for COGAG propulsion plants at 40% engine loading or less. Therefore, if less than 40% propulsive power is required based on the user specified operating profile, the algorithms assume single gas turbine operation in conjunction with a trailed shaft. The penalty associated with a trailed shaft is assumed to increase the propulsion powering requirement by 20% compared to normal twin screw operation and is reflected in the fuel consumption algorithms as well as any related improvement in specific fuel consumption which may occur due to improved engine loading conditions.

g. Integrating the various software modules into a coherent and comprehensive computer model with appropriate user input and reporting interfaces and formats.

h. Verifying correct functioning of software module through data input and review of derived results.

In addition to propulsion plant alternatives, the LCC model also analyzes life cycle costs associated with ship service generators employing various prime movers including:

- Medium or High Speed Diesel depending upon typical practices in the industry for the rating specified by the user
- Gas Turbine
- MCFC
- PEMFC

The scope of ship service generator solutions was limited to discrete generator ratings of 250, 500, 750 and 1,000 kilowatt electric (kWe). These ratings were selected to cover the full range of expected ship service generators that can reasonably be projected for a typical USCG vessel. Based on these ship service generator ratings, initial construction and O&S cost algorithms were developed in a manner similar to that described previously for the propulsion plant alternatives.

The LCC program permits the user to specify up to six speeds and associated durations within the mission profile with corresponding machinery and power choices. A similar selection is also provided to define the vessel's electric load profile. The comparison of each propulsion and electrical plant alternative includes calculations for acquisition and operational costs for all required auxiliary components (e.g. fuel, lube oil, cooling systems, reformers, fuel cell stacks, power conditioners, reduction gearing, propulsion motors, etc.). The analysis includes:

- Volume
- Weight
- Initial cost
- Crewing Cost
- Annual Fuel and Lube Oil Cost
- Annual and Periodic Maintenance Costs
- Scrap Prices
- Emissions

Default values for the above parameters are calculated automatically, but the user has the option to provide more specific values if desired. The following sections describe the input screens and a full run for a sample system.

3.0 POWERING SYSTEMS SELECTION INPUT/OUTPUT SOFTWARE MODULE

This program module calculates propulsion plant fuel and lube oil rates and annual consumption, given a user selection of propulsion prime mover and ship service generator type and size and input of speed-time operating profile data. The program is valid for installed plant sizes from 1000 to 42,500 shaft kilowatt (skW) and for operating speeds from 0.5 to 28.5 knots.

3.1 Input Sheet

The data input sheet requires the user to select the type of propulsion plant to be considered and the size of plant (in total installed skW). For the mechanical drive propulsion plants, the user also selects the ships service generator types (diesel, gas turbine, or fuel cell) and size (kWe rating, each). For integrated electric propulsion plants (IDE, IGTE, and IFCE), ship service power requirements are combined with propulsion power requirements and specification of ship service generators by the user is not required. The user also inputs the desired annual operating profile by entering speeds and the corresponding operating hours and ship service electric load at each speed. Up to six speed-time data points can be entered. The program treats both underway and non-underway (in port) operating hours. As this worksheet is used as a module within a larger costing model, the input cells are linked to the global input data sheet. The drop-down menu screens for main propulsion and electrical power generation system type and size are depicted in Figures 1 and 2.

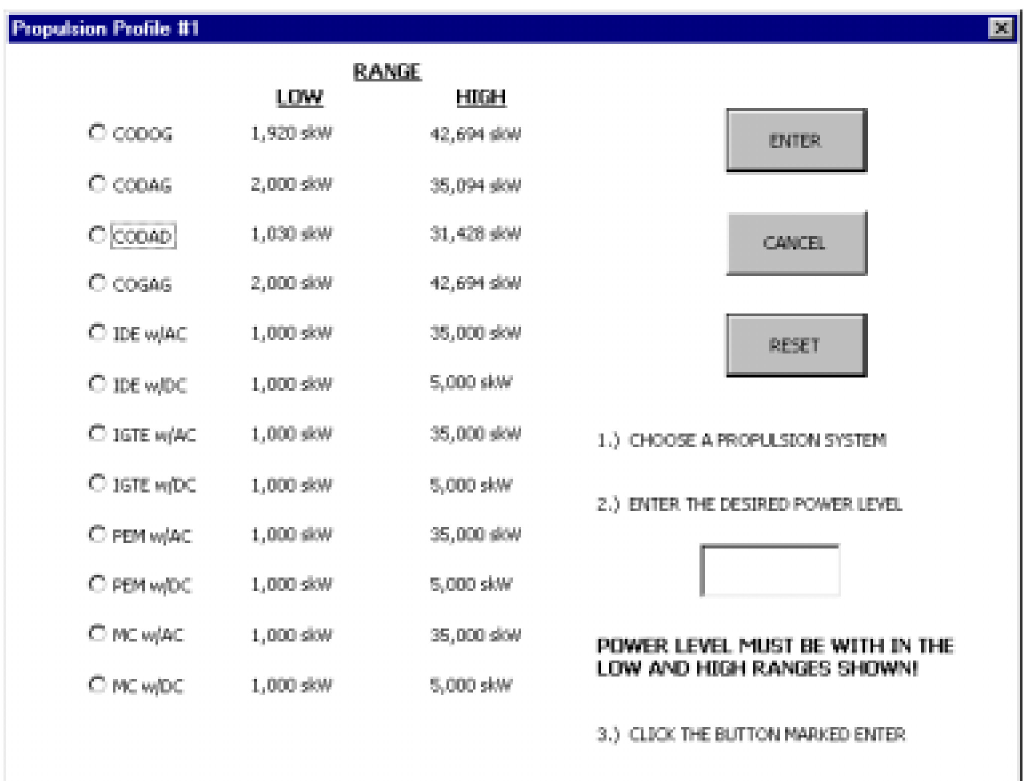

Figure 1. Drop-down menu screen for propulsion.

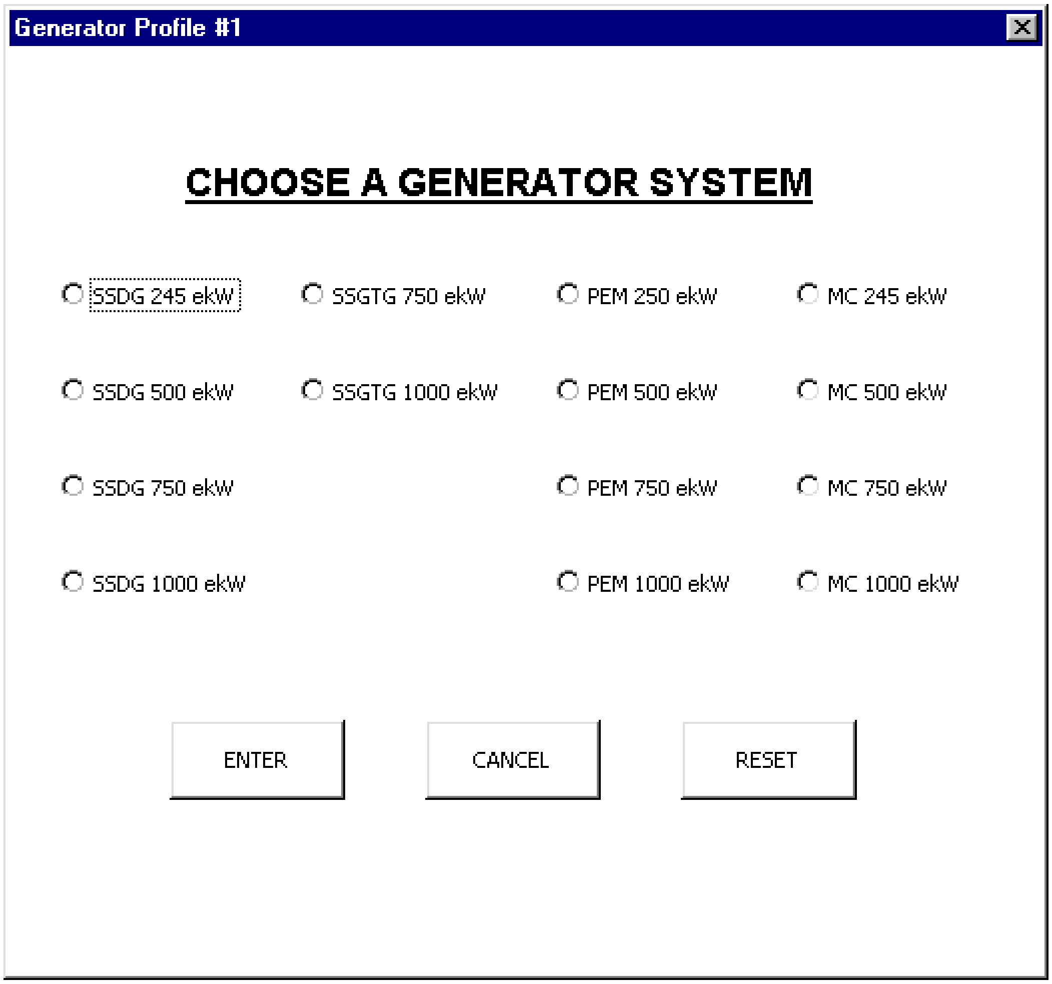

Figure 2. Drop-down menu screen for generators.

3.2 Calculation Sheets

These are the internal sheets that perform all of the calculations in this program. They are protected to prevent inadvertent modifications. There is no password for protection; to unprotect the sheet, click the “Tools,” menu, then “Protection,” and “Unprotect sheet.”

3.3 Output Sheets

The output sheets provide tabular results of the calculations based on the input data. Again, since this program is used as a module, these results are linked back to the costing calculation program.

4.0 INITIAL CONSTRUCTION COST SOFTWARE MODULE

This cost estimating module employs cost estimating relationships (CERs) based on the use of relationships between weights of equipment to be installed and the cost of the equipment and the installation activity. The program module contains a CER screen (Figure 3) that shows the cost relationship for a propulsion system by SWBS. The screen shows the SWBS number, description of the SWBS category, weight of equipment, labor hours, material required (cost), labor rate, and total procurement cost for the SWBS category.

INITIAL COST: ***PROPULSION SYSTEM***						**CODAD**
			CER			**5,475 skW**
SWBS	**DESCRIPTION**	**WEIGHT (TONNES)**	**LABOR**	**MATERIAL**	**LABOR RATE $/hr**	**Enter Ship Profile #1**
120	**TRUNKS AND ENCLOSURES**					**$ 44,596**
	SHIP PROFILE #1	3.50	230	$ 2,300	$ 18.18	2.35
	SHIP PROFILE #2	2.63	230	$ 2,300	$ 18.18	2.67
180	**FOUNDATIONS**					**$ 478,543**
	SHIP PROFILE #1	10.96	910	$ 2,300	$ 18.18	5.28
	SHIP PROFILE #2	27.92	910	$ 2,300	$ 18.18	11.72
230	**PROPULSION UNITS**					**$ 7,257,341**
	SHIP PROFILE #1	29.63	360	$ 228,610	$ 18.18	10.43
	SHIP PROFILE #2	36.80	360	$ 228,610	$ 18.18	16.27
240	**TRANSMISSION, PROP. SYS.**					**$ 1,945,157**
	SHIP PROFILE #1	34.30	130	$ 50,800	$ 18.18	15.05
	SHIP PROFILE #2	18.88	130	$ 50,800	$ 18.18	7.59
250	**SUPPORT SYSTEMS**					**$ 898,222**
	SHIP PROFILE #1	4.52	1020	$ 152,410	$ 18.18	3.07
	SHIP PROFILE #2	3.35	1020	$ 152,410	$ 18.18	3.64
260	**PROP. SUPP'T SYS. - FUEL, LUBE**					**$ 201,411**

Figure 3. CER screen.

The weight estimates of the equipment and systems to be installed are calculated by the model for each of the different plant configurations selected by the user using linear interpolation between the low and high power level boundaries of each propulsion plant alternative.

For the cost of the equipment and the cost to install these systems, JJMA has used in-house values developed for various ship acquisition programs over the last 10 years. These values reflect our knowledge of the complexity, integration, labor required and material procurement efforts required for installation of propulsion systems onboard marine vessels. JJMA has gathered and calculated these values through research and investigation of the costs for marine construction. Where possible, these values have been compared against actual costs charged by shipyards or values used in their detailed estimates. Separate values are used for the equipment procurement costs and the labor to install costs. This separation is used to accurately identify the differences in procurement cost versus labor to install. Each SWBS shown in the program uses different values to reflect the costs associated with the equipment and labor for that specific SWBS.

The program calculates the initial procurement costs used in the model by using the estimated weight (in tonnes) of the equipment, labor hours, material cost, and labor rate. Required labor hours per tonne, material costs per tonne, and labor rates are pre-determined, SWBS-dependent values. The labor rate shown on the CER screen is an unburdened labor rate. The program automatically calculates an estimated burdened labor rate of 2.5 times the unburdened labor rate and uses the burdened labor rate to calculate the total procurement cost. The program multiplies the weight estimate (in tonnes) times the labor hours per tonne times the burdened labor rate to obtain the total labor cost. The program also multiplies the weight estimate (in tonnes) times the material cost per tonne to obtain the total material cost. Labor and material costs are then added together and charged to the appropriate SWBS weight group. The sum of all the SWBS costs then gives the total initial procurement cost of the entire plant, including all supporting systems.

When fuel cells are used to produce power, the method of calculation was modified to reflect some actual unit costs. Based on recent (November 1999) discussions with Fuel Cell Energy, Inc. (FCE), formerly Energy Research Corporation (ERC), the cost for the fuel stack is realistically $300-320/kW. The fuel stack weight is approximately 30-40% of the module weight. Thus for initial cost estimating purposes, the expense is based on a weighted average taking into account both the module total weight and the actual fuel stack weight ratio and unit cost.

5.0 OPERATING AND SUPPORT COSTS SOFTWARE MODULE

The LCC model automatically calculates the Operating and Support (O&S) costs for the selected propulsion and electric plant operating profile and desired power level (Figure 1). The program calculates an "OPERATING /SUPPORT / MISC." cost (O&S Cost) by totaling the following outputs into a single sum, which is presented in the Life Cycle Cost Analysis at the end of the program.

- Annual Fuel Cost (Propulsion)
- Annual Lube Oil Cost (Propulsion)
- Annual Fuel Cost (Generators)
- Annual Lube Oil Cost (Generators)
- Crew Cost/Year
- Preventative Maintenance Cost, and
- Annualized Fuel Stack Replacement (5 Year Replacement Period)

5.1 Fuel and Lube Oil Calculations

5.1.1 Background

The fuel and lube oil calculation spreadsheet was developed for use as a module within the larger cost model developed for the USCG Fuel Cell LCC Task to provide data for comparing conventional and fuel cell propulsion and electrical plants.

5.1.2 Approach

These calculations were developed through investigation of fuel rates and annual consumption for plants at the extreme ends of the size spectrum. Data for large conventional plants were taken from previous studies and parametric curves were developed for each type of plant over the range of expected operating speeds. Data for the small conventional plants were specifically developed for use in this program. Again, curves were developed for each plant over the range of operating speeds. The equations of these curves are used in the calculation sheet as described above to calculate parametrically the fuel rates for the type of plant under consideration at the extreme ends of the size range (large and small plants). The fuel rates and resulting annual fuel consumption for the plant under consideration are calculated by linear interpolation based on the size of the plant. This calculation can be reviewed in the calculation work sheets. For mechanical drive plants, the ship service generator fuel rates are calculated separately from propulsion rates. For integrated electric plants, fuel rates are based on the total power required for propulsion and ship service loads. Lube oil rates are calculated based on a percentage of the fuel rate at each speed. Lube oil replacements (sump refills) are based on an average operating hour basis. Use of steam propulsion and auxiliary systems is not treated in this program.

5.1.3 Propulsion Plant Assumptions

To reduce the amount of user input data required, certain assumptions were made regarding the plant operating environment, operating philosophy, and existing technology, as described below. These assumptions are based on previous design experience with both USCG and other projects. While these assumptions may differ from the specific design under investigation, they represent a valid design condition from which relative comparison between the plants under consideration may be drawn. The following assumptions were made in developing the parametric equations:

a. Ambient Conditions

- Air temperature = 38 degrees C for outside ambient
- Air temperature = 45 degrees C for machinery space ambient
- Seawater temperature = 32 degrees C

b. Duct Losses for Gas Turbines

- 150 mm water gauge (w.g.) intake loss
- 200 mm w.g. exhaust loss

c. Speed-Power Curve

1. For speeds above 8 knots, power is assumed proportional to speed cubed, with the constant of proportionality derived from the maximum speed and power data. The data is based on the speed at plant MCR (with no margins) and the installed skW. Powering below 8 knots is based on linear interpolation between the 8-knot power and a plant idle condition (0 knots)as shown below:
    - Diesel engine power = 5% of MCR for operating engines at 25% of engine rpm
    - Gas turbine power = 5% of MCR for operating engines at 20% of engine rpm
    - Fuel cell power = 10% of MCR for operating cells.
2. At speeds below 8 knots, the above interpolation yields a better estimate of power than the cubic curve estimate accounting for the increased power required to overcome waves, current, and wind along with the requisite power required for propulsion auxiliaries and for a marginal engine operating condition.

d. Plant Operating Modes. All plants are twin shafts. It was assumed that both shafts would be operating throughout the range of speeds, with the exception of the large COGAG plant. Integrated plants were operated with gensets loaded up to 80 - 85% maximum, to allow for inclusion of ship service electric load.

e. Margins

- Hull Fouling and Sea State = 10% on skW
- Trail Shaft = 20% on skW (used for large COGAG plant only)
- Engine Manufacturer's Tolerance on specific fuel consumption (SFC):
  = 5% (diesels and gas turbines)
  = 10% (fuel cells)

f. Component Efficiencies

- Stern tube bearing efficiency = 0.99
- Reduction gear efficiency = 0.97 (CODAD, large plant with 4 engines operating)
  = 0.98 (CODAD, large plant with 2 engines operating and small plant)
  = 0.965 (CODOG, COGAG, large plant, average of port and starboard gears with and without idler)
  = 0.955 (CODOG, COGAG, small plant, average of port and starboard gears with and without idler)
  = 0.958 (CODAG, large plant)
  = 0.948 (CODAG, small plant)
- AC Electric Motor = 0.975
- DC Electric Motor = 0.96
- Electric Drive = 0.97 (0.99 each for drive, converter, transformer).
- Part load (operating load / installed skW) efficiency losses are calculated per SNAME T&R Bulletin 3-28, Figure 1.

g. Fuel

- Fuel Specification - ASTM D975, 2-D
- LHV = 42,700 kJ/kg

h. Lube Oil and Maintenance

- Lube oil density = 838 kg/m^3
- Diesel engine lube oil consumption rate = 0.5% of fuel rate
- Gas turbine lube oil consumption rate = negligible
- Propulsion engine lube oil replacement interval = 4000 operating hours
- Ship service generator lube oil replacement interval = 1000 operating hours

5.2 Specific Fuel Consumption Maps

Fuel consumption for the various propulsion prime movers and for the ship service generators is calculated by multiplying the Specific Fuel Rates (SFR) by the power consumed at the corresponding speed specified and by the hours of operation at the specified speed. These specific fuel rates are based on typical SFR curves which were established based on manufacturers' data using representative prime movers at high and low installed power ranges. Figures 4 and 5 depict the specific fuel consumption (SFC) of fuel cells in comparison with diesel generator sets and propulsion gas turbines, respectively, that represent a significant presence in the marine industry, with the exception of the ICR gas turbine[2]. Given the significant competition in this market, the SFC of prime movers from other manufacturers with similar power, rotational speed, and features are expected to be similar. Figures 6 and 7 depict SFR as function of load speed in either a small plant configuration (Figure 6) or a large plant configuration (Figure 7), respectively. The method for deriving the power at each speed and the associated fuel rate is discussed in sections 5.3 and 5.4.

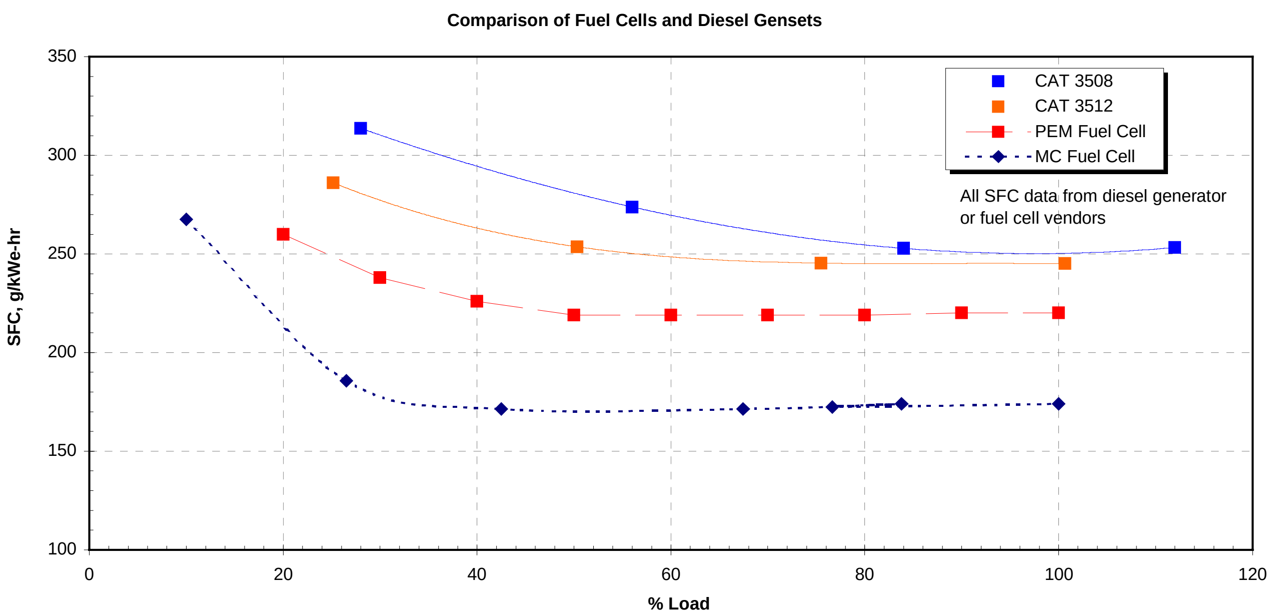

Figure 4. Comparison of fuel cells and diesel gensets specific fuel consumption.

---

[2] Specific Fuel Consumption (SFC) data presented in Figure 4 was developed from the following references:

- Cat 3508/3512 per Caterpillar Marine Power Systems Manual, 1998
- PEM Fuel Cell per MTI email, 11 Aug 1999
- MC Fuel Cell per ERC letter, 17 Aug 1999
- GE LM2500 per GE email, 11 Dec 1997
- WR-21 per Northrop Grumman FAX, 3 Dec 1997

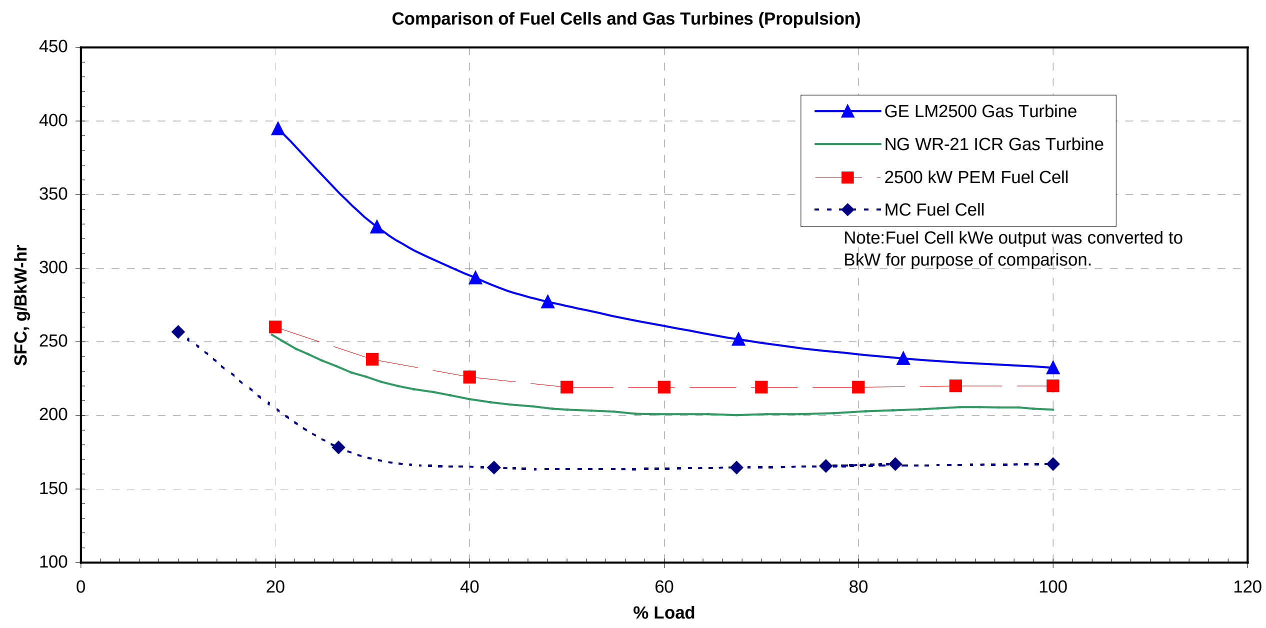

Figure 5. Comparison of fuel cells and gas turbines propulsion specific fuel consumption.

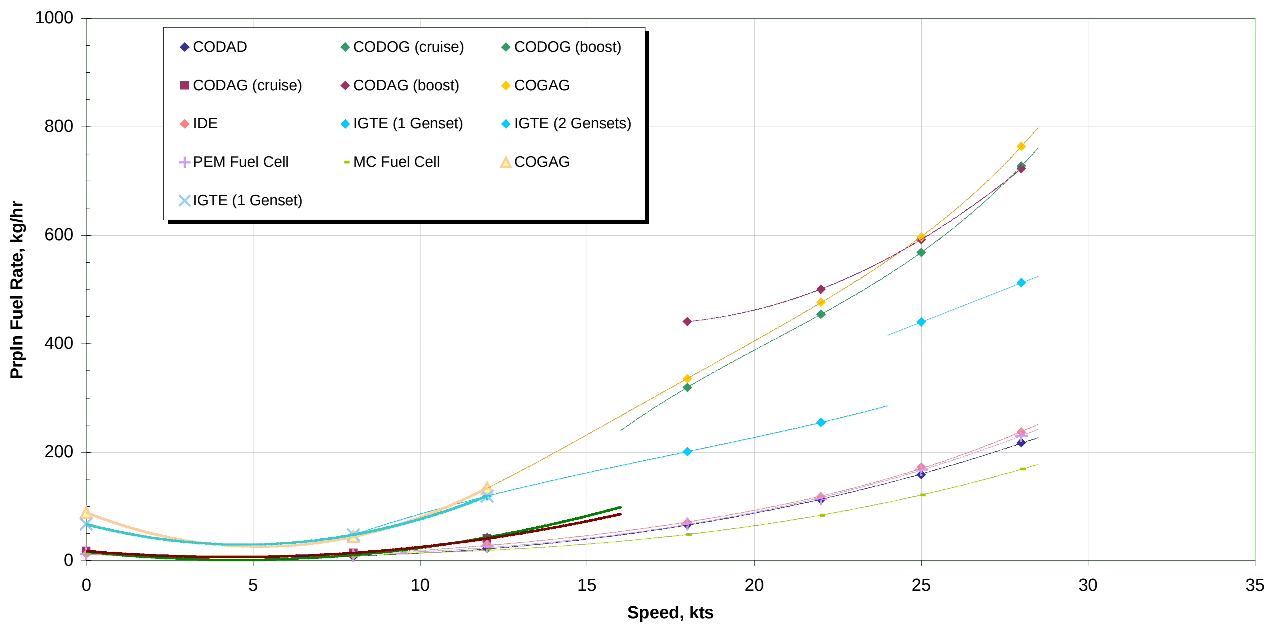

Figure 6. Small plant fuel rates versus speed.

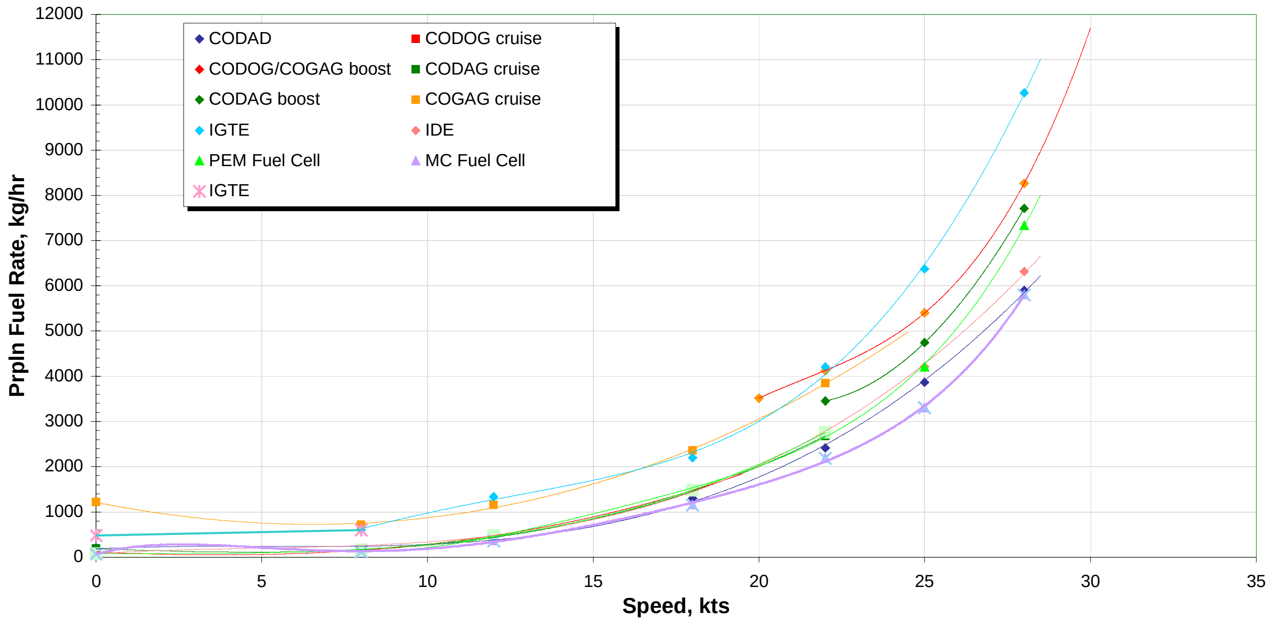

Figure 7. Large plant fuel rates versus speed.

5.3 Speed Power Curves

Speed power curves were developed for small power (1000 skW) and large power (maximum of 42,500 skW) plants. The curves were developed for "generic" ships that produce 0-28.5 kts. Power requirements are calculated based on traditional naval architecture cubic relationships as follows:

$$\text{POWER} = \text{MAXIMUM POWER} \times \left(\frac{\text{SPEED}}{\text{MAXIMUM SPEED}} \right)^3$$

Other assumptions regarding speed, plant MCR assumptions, and power determination were discussed previously.

5.4 Fuel Consumption Determination Process

The LCC program does not have a set of explicit equations from which fuel rates for a propulsion plant are calculated, since specific hull form development and development of related propulsive powering estimates are beyond the scope of the LCC Model. Instead the program determines the fuel rate for a specified propulsion plant by interpolating between fuel rate curves for small and large power plants at varying speeds. The fuel rate curves, shown in Figures 6 and 7, were developed from historic data from various ship design studies and analyses performed previously for other programs. However in the case of fuel cells, Figures 4 and 5 are the SFC curves that were used to develop the SFR curves for small and large plants. The curves shown in Figures 6 and 7 were derived by first developing Speed-Power curves for a large and a small propulsion plant, as described earlier. The power (coordinate) derived from this calculation was converted to a fuel rate (coordinate) using the SFC curves obtained from historical data or data derived specifically for this purpose, as in the case of fuel cells. Thus large power plant and small power plant curves for fuel rate versus speed were developed.

For a specific installed power plant (i.e., type and rated skW) and defined speed (i.e., from the Propulsion Profiles in the Speed-Time Profiles), the program iterates between the fuel rate versus speed curves shown in Figures 6 and 7 to determine the fuel consumption rate. This is done by the program by determining the fuel rate for the specified speed from both the small plants and large plants. Then the program uses linear interpolation between the minimum fuel rate (i.e., small plant) and maximum fuel rate (i.e., large plant) to determine the resultant fuel rate corresponding to the power for the plant specified by the user. (E.g., at 20 kts find the fuel rates for both a small plant and a large plant and then iterate, for example for a 5700 kW plant, between 1000 kW and 42,500 kW.)

5.5 Fuel and Lube Oil Costs

The fuel and lubricant oil costs are determined by the selected propulsor system (Figure 1) and selected generator system (Figure 2) and operator determined speed-time propulsion profiles and ship service (generator) load-time profiles. The default fuel cost is $272/MT. This is comparable to current USCG fuel costs, which are approximately $0.80 - $0.90/gal or about $271.62/MT. The lube oil default cost has been set at $1,533/MT, which is the approximate cost of SAE30 lube oil. If actual fuel and/or lube oil costs differ from the program default amounts, corrected values for fuel and lube oil can be entered by the operator. The operator adjusted fuel costs and lube oil costs must be made in two locations, the speed-time propulsion profiles page and the ship service (generator) load-time profiles page (lines 105, 116, 177, and 188 in the User Worksheet page). Note, if the operator saves the LLC program with the operator adjusted values for fuel and lube oil costs in place, then the new values will become the program default values.

5.6 Maintenance and Manning Costs

During initial development of the program, the maintenance cost used was the "Preventive" figure. The program was enhanced to enable selection between this figure or the "Contractor Supplied" maintenance figure. The maintenance cost is assumed to be proportional to the acquisition cost of the propulsion system. For Fuel Cells the maintenance cost is established by adding the (averaged yearly) replacement cost for the fuel stacks to other costs proportional to the acquisition costs. These assumptions require revisiting for future program improvements.

Manning costs are composed of a manning requirement and an average cost per man-year. The default value for the average yearly cost per man-year is set to $38,000 and can be changed by the user. This default value represents neither a specific average base pay level nor a "loaded" cost value including benefits, insurance, retirement, etc. The value was selected to provide the user a start in determining crew costs and represents a possible average cost. The crew number can be machinery oriented or the total vessel crew. In naval applications where the crew is not dedicated to a single job, it is recommended that the total vessel crew number be used.

6.0 LIFE CYCLE COST (LCC) PROGRAM

6.1 General

LCC Program users will only interact with the USER Worksheet. All other sheets perform calculations and results are copied back to the User Worksheet. Calculations are performed on the various support sheets behind the user worksheet. Fuel calculations are for plant sizes from 1000 to 42,500 skW and for operating speeds from 0 to 28.5 knots.

User input is permitted in green shaded cells only. If the operator saves the LLC program with the operator adjusted values in the green shaded cells for fuel oil and lube oil costs and fuel cell stack replacement period, then the new values will become the program default values. The tan cells contain formulas that may be linked to other sheets. User input in these cells will most likely cause errors in calculations. Every effort has been made to assist the user in the use of this model. Conditional statements are used throughout the model to prevent user input that is beyond the scope of the model. Cost estimating relationships are contained in the model. Macros have been written, based on weight, to calculate the acquisition cost of the equipment. These relationships are based on JJMA experience and data collected over years. These relationships are based on the estimated weight for each power plant type by rated power. A "PRINT" button is available with a drop-down menu (Figure 8) to enable the printout of output screens. The program also allows simultaneous comparison of two system types.

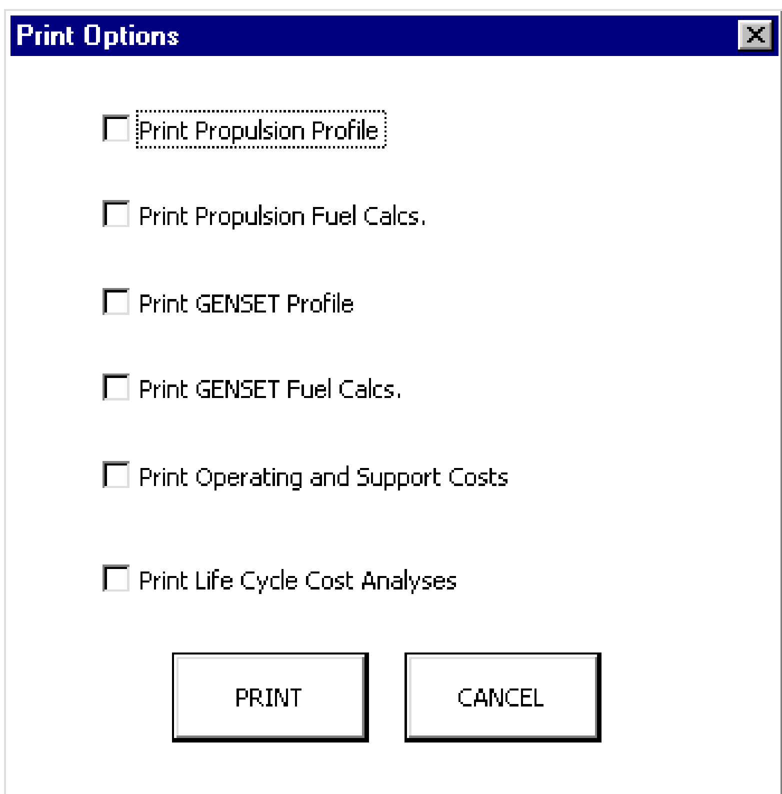

Figure 8. Print drop-down menu.

6.2 Macros

Inside Excel, under the Tools menu choice, is the Macro area. The LCC Model contains Excel macros for the following propulsion systems:

- CODAD
- CODOG
- CODAG
- COGAG
- IDE
- IGTE
- PEMFC
- MCFC

These macros are named as such followed by a 1 or 2 depending on which ship propulsion system type is desired. There are also two macros named *Clearheading1* and *Clearheading2* that clear the data inserted by these macros and return the column headings to Ship Profile #1 or #2.

6.3 Ship Service Generators Section

The SHIP SERVICE GENERATORS section of the program is activated upon selecting a ship's service generator (Figure 2) and selecting enter on the SHIP SERVICE GENERATORS screen. The TOTAL INITIAL COSTS (1) SHIP SERVICE GENERATOR cell will display the sum of the values from the SWBS 120, 180, 310, 320, 340, and 550 cost cells.

6.4 Ships Crew Required

Ships Crew Required depends on USER input. The USER must input the number of ships crew to be considered by the LCC Model. The cost of a crewman for a year defaults to $38,000. This cost can be changed by the USER if desired. A value (equal to the number of ship's crew times the crewman yearly cost) will be displayed in the tan cell to the right in column j or l.

6.5 Fuel Calculations

Operational scenarios for fuel calculations are USER defined. Up to six speed-time and electric load profiles can be entered. The program calculates an average fuel rate given in kg/hr as well as a total annual fuel rate in MT/yr.

6.6 Preventive Maintenance

Preventive Maintenance is calculated at 3.5% of the total initial cost of the system. A second row is available for user definition of maintenance cost. The program selects the proper value based on the USER's choice. When fuel cells are considered, a fuel stack replacement cell becomes active and the annualized stack replacement cost is added to the annual preventive maintenance costs to obtain a total annual preventive maintenance cost. User's input is required to set the length of period between stack replacement. The input cell, in the Annual Operating & Support Costs program sheet-Support section, identifies the rate of replacement, e.g., a ten-year replacement cycle will show a "10" in the cell to the left of "*YEARS FOR FUEL STACK REPLACEMENTS*" (Figure 9). The amount shown by the program for Fuel Stack Replacement Costs is the annual cost to reach the total replacement cost during the replacement cycle. Based on recent (November 1999) discussions with FCE, the replacement cost for the fuel stack is realistically $300-320/kW, and the replacement period is expected to be 5 years. The fuel stack weight is approximately 30-40% of the module weight. Thus for maintenance cost estimating purposes, the expense is based on both the module initial cost and the actual fuel stack weight ratio and unit cost. The replacement cost is added to 30% of the initial cost based maintenance to form the total expense estimate. It should be noted that there is no experience to back up maintenance costs for fuel cells. The input cell is a user modifiable cell, however if the user changes the value in the cell from the default to another value and saves the LCC Program with the modification in place, then the modified value will become the new default value.

Figure 9. Fuel stack replacement cost line.

6.7 Life Cycle Cost Analysis Section

In the section "Life Cycle Cost Analysis," there is a summary of the Initial Cost. The Period of Analysis, Interest Rate, etc., are simply amortization calculations based on Initial Cost, the Period of Analyses (assumes the life of the equipment unless the number of replacements is greater than 1), and the number of replacements. Separate inflation rates can be assigned for the overall period of analysis, fuel costs and for operating/support/miscellaneous costs. Figure 10 shows the positioning of the inflation rate input cells within the Life Cycle Cost Analysis program sheet.

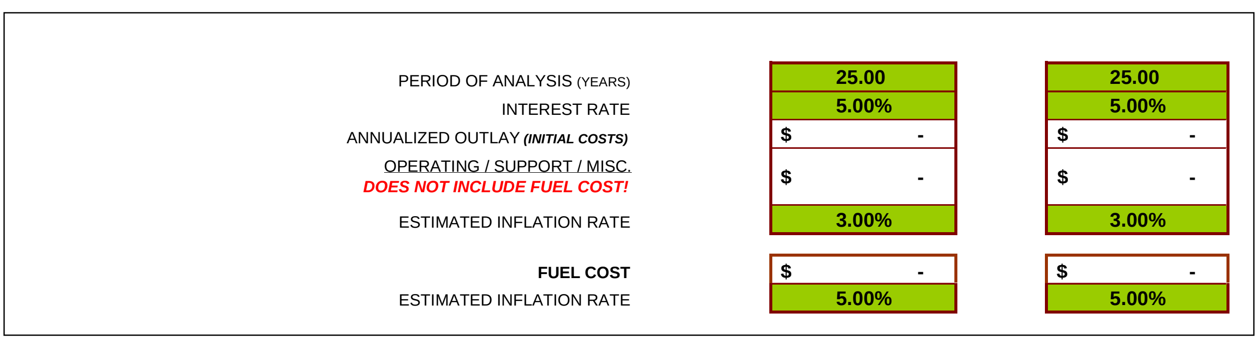

Figure 10. Interest rate input cells.

6.8 Net Present Value

Net Present Value (NPV) is defined as the discounting of future cash flows (in this case expenses) for a specified period of time back to current dollars. For the LCC program this calculation includes total initial propulsion system costs, total initial ship's service generator costs, operating/support/miscellaneous costs, and fuel oil and lube oil costs. The LCC program calculates the value in the NPV cell as a summary of three individual NPV calculations. The first NPV calculation is computed on the summary of the Initial Outlay Propulsion System plus the Initial Outlay Generator System discounted at the rate shown in the Interest Rate cell. The second calculation is the summary of the Operating/Support/Misc. cost forecasted for the time period shown in the Period of Analysis cell and then these values are discounted at the rate shown in the Estimated Inflation Rate cell. The final value used is the summary of the Fuel costs forecasted for the time period shown in the Period of Analysis cell then discounted at the rate shown in the separate Estimated Inflation Rate cell shown next to the Fuel Cost cell.

6.9 Emission Credits

The sheet dedicated to Emission Calculation is titled "emission credits." All data available to date is integrated into the program. The summation of annual dollar credits is exported to the last cells on the USER SHEET. The value is not added to any other costs since neither credits nor penalties are yet enforceable. A negative entry in the "*TOTAL EMISSIONS CREDIT ($/YEAR)*" cell signifies a yearly monetary penalty.

In 1994 the California Federal Implementation Plan[3] (CFIP) was signed by the EPA. The basic penalty of $10,000 per ton on NOx emitted would have applied to all commercial shipping. The CFIP was suppressed by the California State Implementation Plan (CSIP) that removed the monetary penalties.

IMO limits for NOx are effective after January 1, 2000. No limits were set for HC, CO, or PM. NOx limit for engines running at less than 130 rpm was set to 17.0 g/kW-hr. This limit drops to 9.8 g/kW-hr for engines running more than 2000 rpm. The program assumes a $2000/ton NOx penalty derived from current rates and several land based emission credit trading auctions. The spreadsheet is arranged to accept formulas for other exhaust gas's calculations for "Emissions Credit." Once these formulas are available it should be fairly straightforward to incorporate them into the program.

---

[3] As owner and operator of many ships and boats propelled by diesel, gasoline, gas turbine, and steam plants, the U.S. Navy has developed a policy for procuring engines compliant with marine engine exhaust emission requirements. The international rules are promulgated by the International Maritime Organization (IMO) in an Annex to MARPOL. The rules are now going through ratification by member states. The national rules are being promulgated by the U.S Environmental Protection Agency (EPA). Only rules for spark ignition marine (gasoline) engines were finalized and proposed rules for marine diesels of less than 37 kW were proposed. The exhaust gases are largely comprised of nitrogen, oxygen, carbon dioxide and water vapor with smaller quantities of CO, SOx, NOx, and partially reacted HC and particulate matter (PM).

7.0 PROGRAM SCREENS

A sample of program screens is shown in Figures 11 through 16. These screens are blank LCC Program screens and provide an illustration of the individual program screens before ship and generator profiles are entered. The types of propulsion systems, power requirements, generator requirements, propulsion speed and time profiles, ship service generator requirements, fuel and lube oil costs, and crew size were selected to provide a sampling of output by the program, not to compare the types of systems. Occasionally the Annual Operating and Support Costs screen will have one or more of the initial cost cells blanked out on the computer screen. This condition is related to the capacity of the Excel column cell to display the computed data and is not an indication that the data is not being properly calculated or is not available for further calculations. By selecting the individual cell showing this blanked out condition, the operator will read the cell contents at the top of the Excel page or the user can widen the Excel column to view the data.

PRINT | **LCC MODEL for:** | **SHIP'S PROPULSION SYSTEMS** | **SHIP'S SERVICE GENERATORS** | Go To Prop. Profile | Go To Prop. Fuel Calcs | Go To Gen. Profile | Go To Gen. Fuel Calcs

INITIAL COST: ***PROPULSION SYSTEM***

			CER			SHIP PROFILE #1	SHIP PROFILE #2
SWBS	DESCRIPTION	WEIGHT (TONNES)	LABOR	MATERIAL	LABOR RATE $/hr	Enter Ship Profile #1	Enter Ship Profile #2
120	TRUNKS AND ENCLOSURES					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
180	FOUNDATIONS					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
230	PROPULSION UNITS					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
240	TRANSMISSION, PROP. SYS.					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
250	SUPPORT SYSTEMS					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
260	PROP. SUPP'T SYS. - FUEL, LUBE					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
310	ELECTRIC POWER GENERATION					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
320	SWITCHGEAR & PANELS					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
340	DIESEL SUPPORT SYSTEMS					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
510	CLIMATE CONTROL					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
540	FUEL / LUBE, HAND'G & STORAGE					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
550	AIR, GAS, MISC. SYSTEMS					$ -	$ -
	SHIP PROFILE #1						
	SHIP PROFILE #2						
	TOTAL INITIAL PROPULSION SYSTEM COSTS					$ -	$ -

Figure 11. LCC program sheet – Propulsion system costs.

Figure 12. LCC program sheet – Lube oil and fuel costs.

INITIAL COST: ***SHIP SERVICE GENERATORS***			***CER***			**Gen. Profile #1**	**Gen. Profile #2**
SWBS	**DESCRIPTION**	**WEIGHT (TONNES)**	**LABOR**	**MATERIAL**	**LABOR RATE $/hr**	Enter Gen. Profile #1	Enter Gen. Profile #2
120	TRUNKS AND ENCLOSURES					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
180	FOUNDATIONS					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
310	ELECTRIC POWER GENERATION					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
320	SWITCHGEAR & PANELS					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
340	DIESEL SUPPORT SYSTEMS					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
550	AIR, GAS, MISC. SYSTEMS					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
	TOTAL INITIAL COST (1) SHIP'S SERVICE GENERATOR					$ -	$ -

Figure 13. LCC program sheet – CER for ship's service generator costs.

FUEL:	**SHIP SERVICE LOAD / TIME PROFILES**	**SHIP SERVICE LOAD**	**ANNUAL HOURS**	**SHIP SERVICE LOAD**	**ANNUAL HOURS**		**Min. # of GenSets Required**	
	SERVICE LOAD PROFILE 1							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 2							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 3							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 4							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 5							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 6							
			NUMBER OF GENSETS REQUIRED			--		--
	AVERAGE FUEL RATE							
	ANNUAL TOTALS							
	ANNUAL FUEL COST @ $$$$/MT		$ 272		$ 272	$ -		$ -
			TOTAL LUBE OIL CONSUMPTION		DIESEL			
					GT			
			LUBE OIL REPLACEMENTS		DIESEL			
					GT			
			TOTAL LUBE OIL		DIESEL			
					GT			
	ANNUAL LUBE OIL COST @ $$$$/MT		$ 1,533		$ 1,533	$ -		$ -
	TOTAL INITIAL COST, SHIP'S SERVICE GENERATORS					$ -		$ -
	*TOTAL COST, (1) SHIP'S SERVICE GENERATOR) * (MIN. # GENSETS REQUIRED)*							

Figure 14. LCC program sheet – Total initial cost ship's service generator costs.

ANNUAL OPERATING & SUPPORT COSTS: (CURRENT YEAR DOLLARS)

OPERATING:

	SHIP PROFILE #1		**SHIP PROFILE #2**			
	NUMBER	*CER*	*NUMBER*	*CER*		
SHIP'S CREW REQUIRED						
CREW COST/YEAR ($38,000/yr)		$ 38,000		$ 38,000	$ -	$ -

SUPPORT:

		SHIP PROFILE #1		**SHIP PROFILE #2**			
PLACE AN "X" IN THE GREEN BOX BELOW TO INDICATE HOW MAINTENANCE IS PERFORMED **CHOOSE ONE ONLY!**		INITIAL COST	CER	INITIAL COST	CER		
x	PREVENTIVE	$ -	3.5%	$ -	3.5%		
	CONTRACTOR SUPPLIED	$ -	5.0%	$ -	5.0%		
		10	***YEARS FOR FUEL STACK REPLACEMENT***			$ -	$ -

MISCELLANEOUS:

	SHIP PROFILE #1		**SHIP PROFILE #2**			
	INITIAL COST	CER	INITIAL COST	CER		
DISPOSAL	$ -	2.0%	$ -	2.0%	$ -	$ -

Figure 15. LCC program sheet – Annual operating and support costs summary.

LIFE CYCLE COST ANALYSIS:

INITIAL OUTLAY PROPULSION SYSTEM			
	LABOR	$ -	$ -
	OVERHEAD	$ -	$ -
	MATERIAL	$ -	$ -
	TOTAL	$ -	$ -
INITIAL OUTLAY GENERATOR SYSTEM			
	LABOR	$ -	$ -
	OVERHEAD	$ -	$ -
	MATERIAL	$ -	$ -
	TOTAL	$ -	$ -
	PERIOD OF ANALYSIS (YEARS)	25.00	25.00
	INTEREST RATE	5.00%	5.00%
	ANNUALIZED OUTLAY ***(INITIAL COSTS)***	$ -	$ -
	OPERATING / SUPPORT / MISC. ***DOES NOT INCLUDE FUEL COST!***	$ -	$ -
	ESTIMATED INFLATION RATE	3.00%	3.00%
	FUEL COST	$ -	$ -
	ESTIMATED INFLATION RATE	5.00%	5.00%
	ANNUAL EXPENSE (CURRENT YEAR)	$ -	$ -
	TOTAL OWNERSHIP COST FOR PERIOD OF ANALYSIS	$ -	$ -
	NET PRESENT VALUE (NPV)	$ -	$ -
	TOTAL EMISSIONS CREDIT ($/Year) ***(Negative Value = Penalty)***	#VALUE!	#VALUE!

Figure 16. LCC program sheet –Life cycle cost analysis summary.

8.0 VERIFICATION AND COMPARISON

8.1 Verification

In order to verify the operation of the LCC Program, multiple runs of the program were conducted using a sampling of all major propulsion types. To ensure consistency between the runs, a common set of assumptions was used during all the runs. Thus during the verification process the only variable was the type of propulsion system selected.

Assumptions used during the verification test which were based on data typical of a USCG 270-ft WMEC are as follows:

- Propulsion Power required (skW): 5475
- Speed – Time Profiles:

Speed (kts)	Time (hrs)
17.0	385
14.5	980
11.0	1,540
8.0	595

- Generator required: SSDG 750 ekW
- Ship Service Load – Time Profile: 330 ekW for 3,500 hrs
- Crew: 100

Consumable costs, period of analysis, and interest/inflation rates are assumptions that are not specific to any one type of application. Consumable costs, i.e., the fuel oil and lube oil costs, were determined on current market costs of these products. The period of analysis, interest rate, and inflation rate were selected based on current financial market interest rates, current inflation rate, and typical service life for a sea going vessel. These costs and rates are as follows:

- Fuel Cost: $271.62/MT
- Lube Oil Cost: $1,533.00/MT
- Period of Analysis: 20 and 25 years
- Interest Rate: 5.00%
- Estimated Inflation Rate: 3.00%

Other propulsion power settings were used to check the trends exhibited by the program on both sides of the typical USCG 270-ft WMEC power requirement of 5475 skW. These power settings are as follows:

- 2500 skW,
- 4000 skW, and
- 7000 skW

Numerical results of the runs were not used for comparison purposes, but rather to determine if the program is functioning as designed. During the verification test, the tester looked for trends such as increasing initial costs as the power required increases and decreasing the annualized cost when the life cycle is increased while at the same time the total cost of ownership increases.

All costs, except for initial cost of the generator (which did not vary in size), increase as the propulsion power required increases. Further, the annualized costs for a 20-year life cycle are more than the annualized costs for a 25-year life cycle. The total 25-year life cycle costs are greater than the 20-year life cycle costs. These trends were repeated on all verification runs on all propulsion systems, thus verifying that the program functions as it was expected to function.

8.2 Comparison – Fuel Cells and Conventional Marine Power Systems

The same conditions and assumptions used in the verification runs were used in comparison runs for four marine propulsion systems: CODAD, IDE, PEMFC and MCFC. In these comparisons each propulsion system was rated at 5,475 skW with a 500 ekW ships service generator. Initially, a conventional Diesel only system (CODAD) was compared to an Integrated Diesel Electric system (IDE). The second computer runs added the new powering systems, i.e., the MC and the PEM fuel cell systems. The computer output pages and post analysis charts are provided in Appendix B. Table 1 provides a summary of the significant cost figures for the four types of powering systems in this comparison scenario.

It must be admitted that certain parts of the LCC program require further verification before they can be used with confidence. In particular, all of the fuel cell costs, except fuel consumption and pollution reduction credits, lack service experience. It would also be useful to benchmark some of the diesel costs against installations, which were not in the original database. Lacking definitive costs for maintenance (including fuel cell stack replacement), manning, and disposal, these will tentatively be considered similar for the fuel cell and diesel electric powering systems discussed below. The maintenance costs for fuel cell systems were modified to include the latest estimate of actual fuel stack replacement costs for replacement intervals of five years. In addition no credit is taken for savings in manning costs that are expected to be realized with the operation of fuel cells. Manning costs are one of the more significant expenses in the operation of vessels.

A fuel cell propulsion system is identical to an integrated diesel system except the prime movers, where the diesel generators are replaced by fuel cell and electrical conversion systems. It is thus reasonable to compare life cycle costs of a fuel cells system to an IDE system while a direct diesel drive has in common with either the IDE or the fuel cell systems just the tail end, i.e. shafts and propellers.

Table 1. Propulsion system cost comparison.

TYPE COST	SYSTEM			
	CODAD ($)	IDE ($)	MCFC ($)	PEMFC ($)
Propulsion Initial Cost	11,305,313	24,825,269	36,118,681	37,067,092
Cost Per kW	2,065	4,534	6,597	6,770
Annual Fuel Cost	446,783	502,465	371,640	479,976
Annual Oil Cost	12,841	14,249	0	0
Generators Initial Cost	3,224,697	1,612,349	1,900,733	2,220,049
Annual Fuel Cost (Generators)	83,376	83,332	69,013	82,230
Annual Oil Cost (Generators)	2,747	3,142	0	0
Annual Total Fuel Costs	530,159	585,797	440,653	562,206
Annual Total Fuel & Oil Costs	545,747	603,188	440,653	562,206
Maintenance (% of Cost)	508,550	925,317	443,560	458,350
Maintenance (Stack Replacement)	0	0	350,400	350,400
Maintenance (Total)	508,550	925,317	793,960	808,750
Annual Operating/Support/ Miscellaneous Costs	524,138	942,708	793,960	808,750
Total Annualized Expenses	2,085,237	3,404,319	3,932,184	4,158,475
Total Ownership Costs	82,290,568	131,248,369	149,090,146	158,735,519
NPV	39,182,745	62,007,487	65,971,588	70,432,029
Annual Emission Credit	-48,729	-48,719	0	0

The initial cost of the entire 5475 kW diesel-electric system (including propulsion motors and installation) is $24,825,269 (details are shown in Appendix B) (or $4534/kW). This compares to an initial cost of $36,118,681, or $6597/kW for a MCFC propulsion system. The annual operating costs of the MCFC system are lower than those of the IDE system. For the operational scenario studied, the annual fuel cost savings with the MCFC system amount to $162,000 ($441,000 vs. $603,000) and $131,000 for maintenance ($794,000 vs. $925,000). This savings of almost $300,000 in operational costs is not sufficient to compensate for the difference in the initial costs. It is quite clear however that a change in fuel costs could make the fuel cell system to be economically feasible. To demonstrate the effect of fuel cost on the economical viability of the fuel cell marine propulsion system the diesel fuel cost was increased by a 2.14 factor to approximately $582/tonne. This is roughly $1.93/gallon, which is less than the cost of the diesel oil sold at gas stations in Europe. The increase from $272 to $582 per tonne equalizes the NPV of systems in the 25 years which is the period of analysis.

The combined total NPV of its life cycle for a fuel cell system is $66 million as compared to the combined NPV of $62 million for an integrated diesel electric system, not including manning costs. Raising the fuel cost by 2.14 times the current United States cost equalizes the NPV of both propulsion systems at about $80 million for the 25 years.

Emission penalties, once enacted and enforced, could add another $50,000 to the annual operating costs of a 5475 kW propulsion system. This, by itself, may not be sufficient to equalize annualized costs but added scrubbing requirements to the diesel electric system and increase in fuel costs can do it. If fuel cell actually received NOx credits of $2000/tonne, a fuel price increase to $544/tonne (twice the current price) was sufficient to equalize the NPV of both propulsion systems.

A CODAD system is less costly than an IDE propulsion system and, as found in numerous feasibility studies, can become economically advantageous when the operational profile requires a significant partial power operation. The requirements for quiet operation, range and endurance, and flexibility of arrangements are apparently sufficient to make a large number of new propulsion system selections for both commercial and future navy vessels Integrated Diesel Electric. The same argument is valid for the fuel cell systems, although the higher initial costs of the fuel cell systems may require other incentives until the initial fuel cell costs decrease.

The comparison results presented above are preliminary, and subject to numerous assumptions, but give some idea of the comparative economics of a diesel electric system relative to a fuel cell electric system.

9.0 RECOMMENDATIONS FOR FUTURE PROGRAM DEVELOPMENT

The Life Cycle Cost (LCC) program is fully functional and the correct operation of all the major modules was verified. The large number of permutations resulting from the large range of powers and operational scenarios that may be specified by the user does not allow for the verification of all these scenarios due to limited time and budget. Further, model validation involving the comparison of resulting values to actual data was not performed. Currently, acquisition or operational cost data for fuel cell systems is very scarce and does not reflect actual service conditions relative to conventional propulsion or power generation systems employing diesel or gas turbine prime movers.

The following is a list of issues that need to be addressed and incorporated into later versions of the model. These issues have been compiled by JJMA based on internal experience and from USCG comments:

a. Add a page of data that is generated that can be of interest to a user, either as a point validation or for any consequential use. Such data should include Specific Fuel Consumption at the speed of interest.

b. Add an intermediate power level design point. At this time the program interpolates, linearly, between a small and a large power design points. This may lead to significant errors, in particular because of the discrete nature of power plants availability.

c. Add user-defined operation of a single shaft (trailing shaft).

d. Improve the archiving process to allow easier comparison of systems.

e. Allow user definition of the diesel speed category, i.e., low, medium and high-speed diesels.

f. Allow for added emergency generators or redundant generators to comply with regulatory requirements.

g. Add “out of range” warnings to additional items (speed, etc.)

h. Add a “What If” calculation that will allow the analysis to iterate in order to reach a requested final result.

i. Improve estimation of maintenance costs in particular for the fuel cell alternatives.

j. Improve estimation of acquisition costs in particular for the fuel cell alternatives.

k. Validation – Compare the results obtained by the model to in service life cycle costs tracked by the USCG and to PEM life cycle costs (MTI Report of 21 June 1999).

l. Prepare two output screens, one for “Detail” information and one for “Summary” data. The present user input screen would become the “Detail” screen and a shorter, “Summary” screen prepared for quick review of the model’s results.

The items in the list should be considered and prioritized for the enhancement of the program. Many more improvements will undoubtedly be requested following a period of program usage.

10.0 CONCLUSIONS

This report describes the development of an economic model for comparing various types of marine power plants, including fuel cells operating on diesel fuel. While historical data on fuel cell systems are lacking, the report presents best available estimates of key variables, and can be used for parametric studies, or revised comparisons as better data become available.

The report compares four basic types of propulsion and generator systems: conventional diesel (CODAD), diesel electric (IDE), and two fuel cell-electric systems (MCFC and PEM). Numerical results of these comparisons are shown in Table 1. Compared to the CODAD system, initial costs for all three electric options are substantially higher, with the PEM-electric option being highest. Fuel and maintenance costs for the IDE are substantially higher than for the CODAD. Both fuel cell systems show lower maintenance costs than the CODAD, and the MCFC fuel system also has significantly lower fuel consumption. Both fuel systems offer improved emissions over the diesels. The net result is that the NPV of the MCFC system is only slightly higher (6%) than that of the IDE alternative.

Future increases in fuel and emission costs, and/or lower fuel cell system acquisition costs, can make MCFC systems fully competitive with IDE systems.

APPENDIX A.
LCC MODEL USER'S MANUAL

A1. BACKGROUND

The following paragraphs provide guidance on running the Life Cycle Cost program, entering data, editing, and printing and saving the results. The rationale for many of the following instructions was laid down in the report on the LCC Model. Excel spreadsheets were used to develop the program. This is a well-known product, thus most of the instruction should be very easy to implement. The delivered product features "command buttons" to make it easier for the user to interact with the model. Conditional statements are used throughout the model to prevent user input that is beyond the scope of the model. Direct user input is permitted in the green shaded cells only. If the operator saves the LLC program with the operator adjusted values in the green shaded cells for fuel oil and lube oil costs, fuel cell stack replacement period, and crew cost/year, then the new values will become the program default values. The tan cells contain formulas that may be linked to other sheets. User input in these cells will most likely cause errors in calculations in the program. Cost estimating relationships are contained in the model using macros that are based on weight to calculate the acquisition cost of the equipment.

The only spreadsheet to be employed by the user is the USER WORKSHEET. Use the USER WORKSHEET to provide all input data and to evaluate the resultant outputs. The program will open either directly with this sheet or with the last sheet opened when saved at the previous run. All the workbook sheets can be hidden allowing only the CREDITS worksheet and the USER WORKSHEET to be visible to the user. To hide a worksheet, use the normal Excel Hide/Unhide command function. On the bottom of the Excel screen, select the sheet you wish to hide (i.e., Sheet 1, Sheet 2, etc.). After selecting the sheet to hide, select *Format* at the top of the screen to display the *Format* pull down menu. From this menu, select *Sheet*, then select *Hide* from the Sheet pull down menu. If there is a need to view any of the hidden worksheets, they can be opened through the same selection steps as hiding a worksheet. Select *Format* to view the pull down menu. To view a hidden worksheet, select *Unhide* to view the *Unhide* pull down menu. This menu lists all hidden sheets. Select the sheets desired for viewing and press *OK*.

A2. GETTING STARTED

When opening the LCC Program for the first time, the program will open to the CREDIT WORKSHEET shown in Figure A-1. Press the ENTER button on the CREDIT worksheet to enter the program.

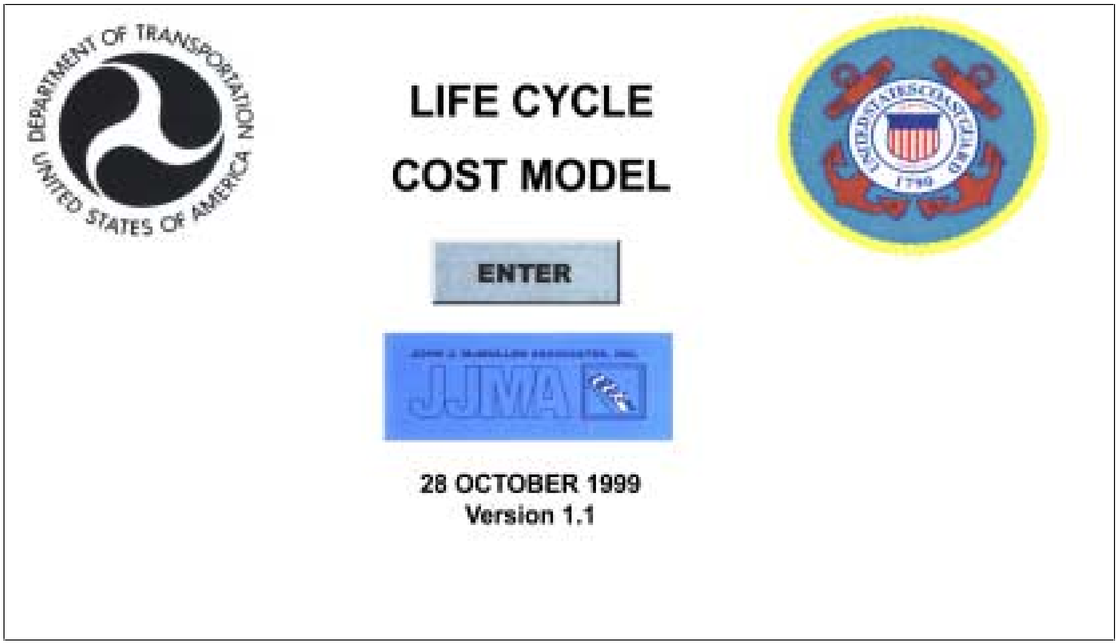

Figure A-1. CREDIT worksheet.

A3. PROGRAM STEPS

Program steps are divided into two parts:

- Data Input
- Output Data or Results

A3.1 Data Input

a. Step 1 – Select Ship Profile
b. Step 2 – Enter Propulsion Speed – Time Profiles
c. Step 3 – Select Generator Profile
d. Step 4 – Enter Ship Service Load/Time Profiles
e. Step 5 – Enter Crew Size
f. Step 6 – Select Support Cost Category
g. Step 7 – Enter Period of Analysis

A3.2 Output Data – Results

Step 8 – Review Results

A4. STEP 1 – SELECT A SHIP PROFILE

a. Select a Ship Propulsion System. Two different powering profiles are allowed at the same time. A dropdown menu facilitates the selection (Figure A-2). Select both the prime mover and enter the propulsion power requirement in kW. Note the power range for which your selection is valid. If an out of range power level is entered, the program will alarm you by a notice of OUT OF RANGE.

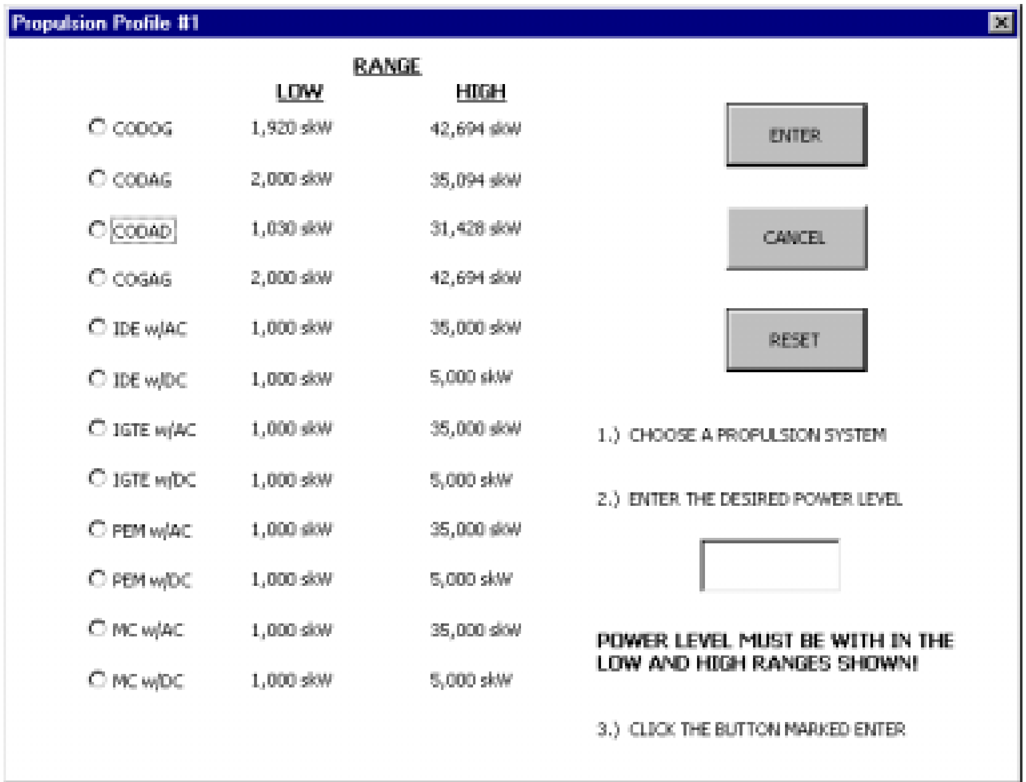

Figure A-2. Propulsion profile drop-down menu.

b. If the RESET button is pressed, the existing data in the spreadsheet, for the prime mover, is cleared.

c. After selecting the prime mover and entering the power press ENTER. This will bring the user back to the USER WORKSHEET.

A5. STEP 2 – ENTER PROPULSION SPEED – TIME PROFILES

a. Enter the ship’s propulsion speed-time scenario data. This can be done by scrolling down to the required data cells (Figure A-3), or by pressing a short-cut button, “Go To Prop. Fuel Calcs” (Figure A-4), on the shortcut bar at the top of the USER’s WORKSHEET.

Figure A-3. Propulsion system speed – time profiles.

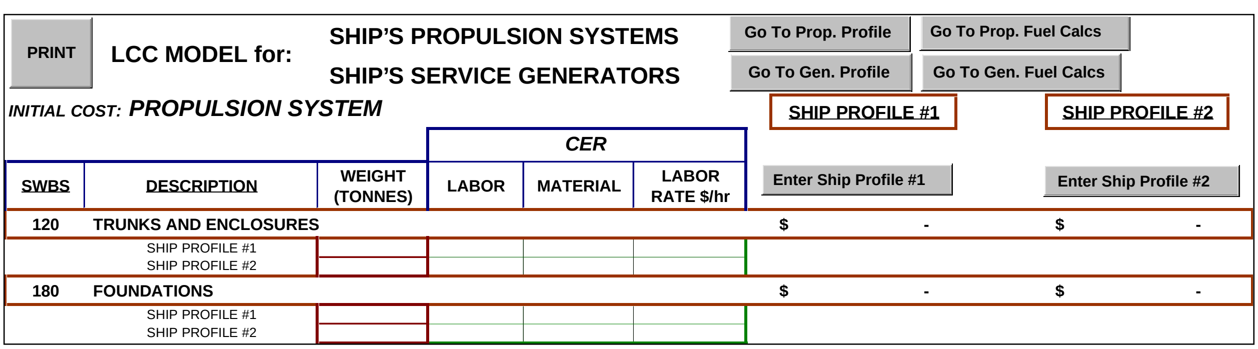

Figure A-4. Shortcut buttons at top of user worksheet.

b. Enter up to six speed power points. As you enter the data, the program fuel consumption cells are immediately calculated. Lubrication consumption is calculated concurrently and displayed for relevant machinery types.

c. The default fuel cost is $272/MT. This is comparable to USCG fuel costs of approximately $0.80 - $0.90/gal or about $271.62/MT. The lube oil default cost has been set at $1,533/MT, which is the approximate cost of SAE30 lube oil. If actual fuel and/or lube oil costs differ from the program default amounts, corrected values for fuel and lube oil can be entered by the user. The user adjusted fuel costs and lube oil costs must be made in the speed-time propulsion profiles page (lines 105 and 116 User Worksheet page). Note, if the user saves the LLC program with the user adjusted values for fuel and lube oil costs in place, then the new values will become the program default values.

A6. STEP 3 – SELECT GENERATOR PROFILE

a. Select a ship generator. Again, this can be done by scrolling down to the required data cells to the SHIP SERVICE GENERATORS worksheet (Figure A-5), or by pressing a short-cut button, “Go To Gen. Profile” (Figure A-4), at the top of the USER’s WORKSHEET. To select the desired generator system, select the button, “Enter Generator Profile” on Figure A-5, and the pull-down menu for generators (Figure A-6) will appear. Note, if the propulsion system is an integrated electric system (Diesel, Gas Turbine, or Fuel Cells), the user still needs to select a ship service generator. It can be the same machine type as the main prime mover, or a different type. If an additional generator needs to be installed, the user can introduce a larger ship service power load, for a short period of operation (e.g., one hour) that would force the addition of a generator unit. This is done when entering the ship service load/time profiles in Step 4.

INITIAL COST: ***SHIP SERVICE GENERATORS***						Gen. Profile #1	Gen. Profile #2
			CER				
SWBS	**DESCRIPTION**	**WEIGHT (TONNES)**	**LABOR**	**MATERIAL**	**LABOR RATE $/hr**	Enter Gen. Profile #1	Enter Gen. Profile #2
120	**TRUNKS AND ENCLOSURES**					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
180	**FOUNDATIONS**					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
310	**ELECTRIC POWER GENERATION**					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
320	**SWITCHGEAR & PANELS**					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
340	**DIESEL SUPPORT SYSTEMS**					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
550	**AIR, GAS, MISC. SYSTEMS**					$ -	$ -
	GEN. PROFILE #1						
	GEN. PROFILE #2						
	TOTAL INITIAL COST (1) SHIP’S SERVICE GENERATOR					$ -	$ -

Figure A-5. Ship’s service generators worksheet.

b. If the RESET button is pressed, the existing data in the spreadsheet, for the generator system, is cleared.

c. After selecting the generator system and required power level, press ENTER. This will bring the user back to the USER WORKSHEET.

d. The default fuel cost for generators is $272/MT. This is comparable to USCG fuel costs of approximately $0.80 - $0.90/gal or about $271.62/MT. The lube oil default cost has been set at $1,533/MT, which is the approximate cost of SAE30 lube oil. If actual fuel and/or lube oil costs differ from the program default amounts, corrected values for fuel and lube oil can be entered by the user. The operator adjusted fuel costs and lube oil costs for the generator must be made in the ship service (generator) load-time profiles page (lines 177, and 188 in the User Worksheet page). Note, if the user saves the LLC program with the user adjusted values for fuel and lube oil costs in place, then the new values will become the program default values.

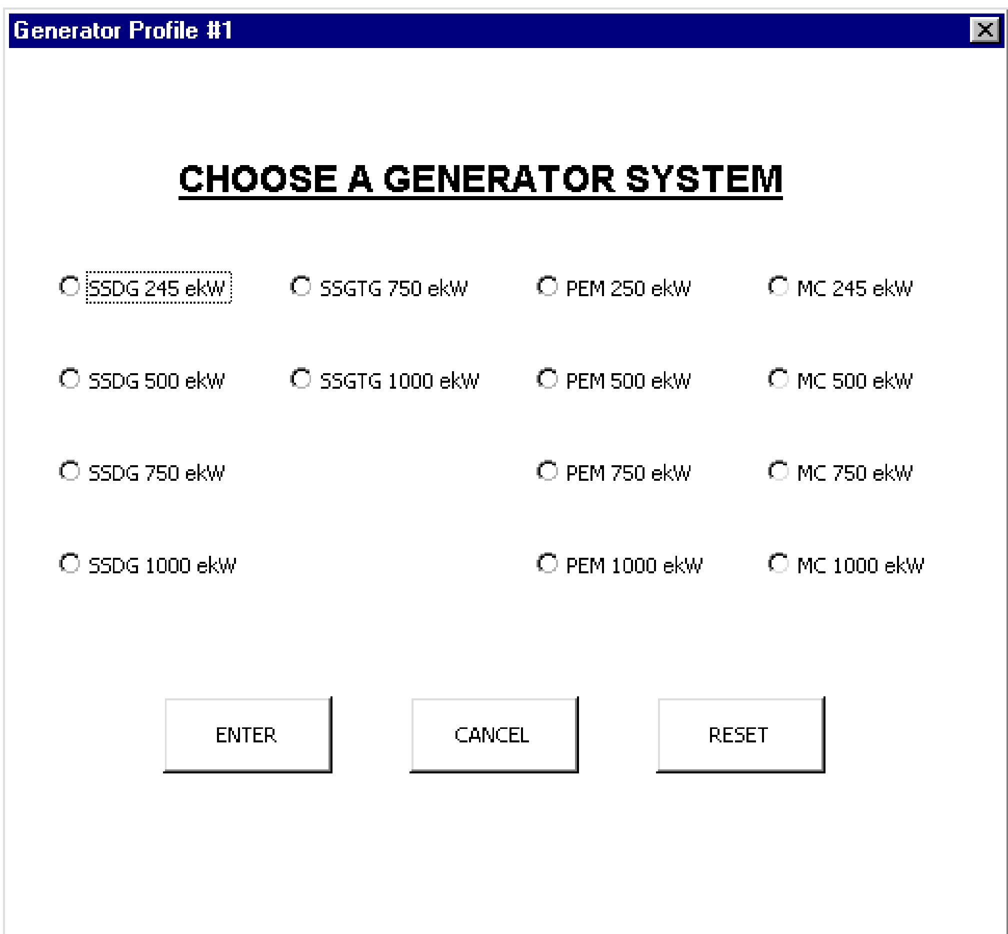

Figure A-6. Generators pull-down menu.

A7. Step 4 – ENTER SHIP SERVICE LOAD/TIME PROFILES

a. After selecting the generator profile, enter the ships service load/time profiles. To do this, scroll down to the required data cells (Figure A-7) or press a short-cut button, "Go To Gen. Fuel Calcs" (Figure A-3) at the top of the USER's WORKSHEET.

b. Enter up to six service load-time profiles. As you enter the data, the program fuel consumption cells are immediately calculated. Lubrication consumption is calculated concurrently and displayed for relevant machinery types.

c. The program will automatically calculate the number of generators required based on the power selected for the generator system and the service load required for a specific service load profile. If an additional generator is needed, the user can introduce a large service load for a short period of time, i.e. one or two hours, and that will force the program to add a generator to the "NUMBER OF GENSETS REQUIRED" field.

FUEL:	SHIP SERVICE LOAD / TIME PROFILES	SHIP SERVICE LOAD	ANNUAL HOURS	SHIP SERVICE LOAD	ANNUAL HOURS		Min. # of GenSets Required	
	SERVICE LOAD PROFILE 1							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 2							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 3							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 4							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 5							
			NUMBER OF GENSETS REQUIRED			--		--
	SERVICE LOAD PROFILE 6							
			NUMBER OF GENSETS REQUIRED			--		--
	AVERAGE FUEL RATE							
	ANNUAL TOTALS							
	ANNUAL FUEL COST @ $$$$/MT		$ 272		$ 272	$ -		$ -
		TOTAL LUBE OIL CONSUMPTION			DIESEL			
					GT			
		LUBE OIL REPLACEMENTS			DIESEL			
					GT			
		TOTAL LUBE OIL			DIESEL			
					GT			
	ANNUAL LUBE OIL COST @ $$$$/MT		$ 1,533		$ 1,533	$ -		$ -
	TOTAL INITIAL COST, SHIP'S SERVICE GENERATORS					$ -		$ -
	*TOTAL COST, (1) SHIP'S SERVICE GENERATOR) * (MIN. # GENSETS REQUIRED)*							

Figure A-7. Ship service load/time profiles.

A8. <u>STEP 5</u> – ENTER CREW SIZE

a. Scroll down to "ANNUAL OPERATING & SUPPORT COSTS: (CURRENT YEAR DOLLARS)" worksheet to enter crew size (Figure A-8).

b. Enter the number of crew. The program will automatically determine the crew cost. The number of crew can be either the machinery crew or the entire vessel crew. The average cost per crewman can be modified by the user.

ANNUAL OPERATING & SUPPORT COSTS: (CURRENT YEAR DOLLARS)

OPERATING:

	SHIP PROFILE #1		SHIP PROFILE #2			
	NUMBER	*CER*	*NUMBER*	*CER*		
SHIP'S CREW REQUIRED						
CREW COST/YEAR ($38,000/yr)		$ 38,000		$ 38,000	$ -	$ -

SUPPORT:

PLACE AN "X" IN THE GREEN BOX BELOW TO INDICATE HOW MAINTENANCE IS PERFORMED
CHOOSE ONE ONLY!

		SHIP PROFILE #1		SHIP PROFILE #2			
		INITIAL COST	CER	INITIAL COST	CER		
x	PREVENTIVE	$ -	3.5%	$ -	3.5%		
	CONTRACTOR SUPPLIED	$ -	5.0%	$ -	5.0%		
		10	*YEARS FOR FUEL STACK REPLACEMENT*			$ -	$ -

MISCELLANEOUS:

	SHIP PROFILE #1		SHIP PROFILE #2			
	INITIAL COST	CER	INITIAL COST	CER		
DISPOSAL	$ -	2.0%	$ -	2.0%	$ -	$ -

Figure A-8. Annual operating and support costs worksheet.

A9. <u>STEP 6</u> – SELECT SUPPORT COST CATEGORY

a. Scroll down to support costs in "ANNUAL OPERATING & SUPPORT COSTS: (CURRENT YEAR DOLLARS)" worksheet (Figure A-8). Select how the maintenance is to be performed on the selected propulsion system. The program will automatically calculate maintenance support costs. This will be included in the "OPERATING / SUPPORT / MISC." field in the "LIFE CYCLE COST ANALYSIS" worksheet (see Step 7).

b. If fuel cells are selected, the fuel stack replacement cell turns active. The cell is defaulted to a ten-year replacement cycle and shows a "10" in the cell to the left of "YEARS FOR FUEL STACK REPLACEMENT"(Figure A-9). Note, a recent change in the estimate of fuel cell stack life suggests a life expectancy of five years. The amount shown in the cell(s) for Fuel Stack Replacement Cost is the annual fuel stack replacement cost (Total Replacement Cost ÷ Replacement Period). The user can modify this cost, once better data is available. The total cost of maintenance, in this case, is the summation of the preventive maintenance costs and the fuel cell stack replacement costs. If the user changes the value for the replacement cycle and then saves the LLC program with the adjusted value in place, then the new value will become the program default amount.

10	YEARS FOR FUEL STACK REPLACEMENT	$ -	$ -

Figure A-9. Fuel stack replacement cost line.

A10. Step 7 – ENTER PERIOD OF ANALYSIS

a. Scroll down the "LIFE CYCLE COST ANALYSIS" worksheet to enter the period of analysis (Figure A-10). Note, the period of analysis is in years.

b. Scroll down to review rates for inflation figures (general and fuel cost specific). These estimated inflation rates can be modified by the user to reflect current or expected inflation rates.

c. Upon entering the period of analysis, the program automatically calculates the annual expense, total ownership cost, net present value, and emissions credit.

LIFE CYCLE COST ANALYSIS:

INITIAL OUTLAY PROPULSION SYSTEM		
LABOR	$ -	$ -
OVERHEAD	$ -	$ -
MATERIAL	$ -	$ -
TOTAL	$ -	$ -
INITIAL OUTLAY GENERATOR SYSTEM		
LABOR	$ -	$ -
OVERHEAD	$ -	$ -
MATERIAL	$ -	$ -
TOTAL	$ -	$ -
PERIOD OF ANALYSIS (YEARS)	25.00	25.00
INTEREST RATE	5.00%	5.00%
ANNUALIZED OUTLAY ***(INITIAL COSTS)***	$ -	$ -
OPERATING / SUPPORT / MISC. ***DOES NOT INCLUDE FUEL COST!***	$ -	$ -
ESTIMATED INFLATION RATE	3.00%	3.00%
FUEL COST	$ -	$ -
ESTIMATED INFLATION RATE	5.00%	5.00%
ANNUAL EXPENSE (CURRENT YEAR)	$ -	$ -
TOTAL OWNERSHIP COST FOR PERIOD OF ANALYSIS	$ -	$ -
NET PRESENT VALUE (NPV)	$ -	$ -
TOTAL EMISSIONS CREDIT ($/Year) ***(Negative Value = Penalty)***	#VALUE!	#VALUE!

Figure A-10. Life cycle cost analysis worksheet/summary.

A11. STEP 8 – REVIEW RESULTS

a. OUTPUT DATA - PRINTING RESULTS

To print any of the six program output screens, first select the "PRINT" button in the shortcut bar at the top of any of the program screens as shown in Figure A-11. Selecting the "PRINT" button enables the Print Options drop-down menu (Figure A-12). Select the desired program screen and select the "ENTER" button to start printing. To cancel the Print Options menu and return to the LCC Program screen, select the "CANCEL" button.

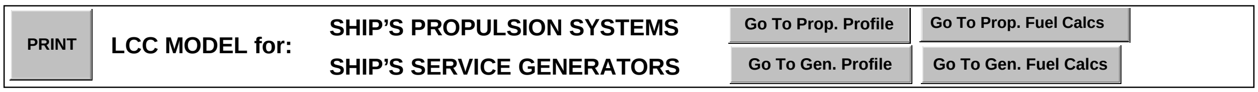

Figure A-11. LCC program shortcut bar.

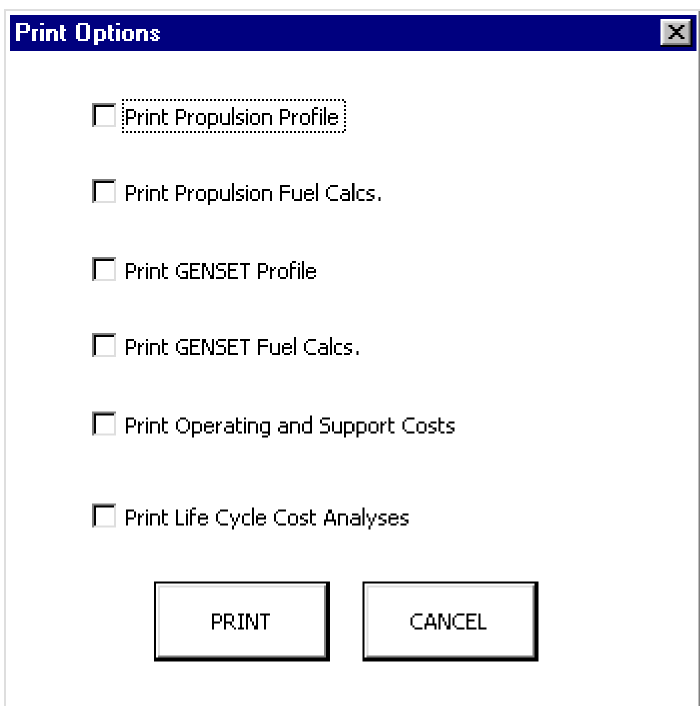

Figure A-12. LCC program print options menu.

b. OUTPUT DATA - CALCULATED RESULTS REVIEW

1) Review the results. Intermediate data is presented in the spreadsheets adjacent to input data. Summary data, in particular Life Cycle Cost summaries are presented at the end of the USER WORKSHEET.

2) Modify any of the green input data cells. This will allow the user to check sensitivity to a single parameter (such as fuel cost per tonne), or to correct

erroneous data. Note, if the user saves the LLC program with the adjusted green input data cell values for fuel and lube oil costs and fuel cell stack replacement period in place, then the new values will become the program default values.

3) The user can generate customized calculations and charts such as comparison of two profiles, by using data from the program Excel cells.

4) Emission credits are calculated and presented (stand alone) in the last cell of the program.

5) “What if?” calculations can be done by iterating inputs, such as fuel costs, interest rates, etc.

[This page intentionally left blank.]

APPENDIX B.
SAMPLE COMPARISON – DIESEL VS. FUEL CELL

B1. BACKGROUND

A comparison of the life cycle cost for four ship powering plants is displayed in the following sections and figures. The operating scenario duplicates the USCG assumed operational scenario for a typical vessel such as the 270-ft medium endurance cutter. The comparison work can be considered as a higher level validation test of the program and as an initial economic feasibility study for the current prevailing marine propulsion systems and potential future marine powering systems.

B2. SAMPLE COMPARISON LCC MODEL RUNS

The same conditions and assumption used in the verification runs were used in comparison runs for four marine propulsion systems: CODAD, IDE, PEMFC and MCFC. In the first run, a conventional Diesel only system (CODAD) was compared to an Integrated Diesel Electric system (IDE). The second computer run added the new powering systems, i.e., the MC and the PEM fuel cell systems. A comparison of these propulsion systems is provided in Table B-1.

Table B-1. Propulsion system cost comparison.

TYPE COST	SYSTEM			
	CODAD ($)	IDE ($)	MCFC ($)	PEMFC ($)
Propulsion Initial Cost	11,305,313	24,825,269	36,118,681	37,067,092
Cost Per kW	2,065	4,534	6,597	6,770
Annual Fuel Cost	446,783	502,465	371,640	479,976
Annual Oil Cost	12,841	14,249	0	0
Generators Initial Cost	3,224,697	1,612,349	1,900,733	2,220,049
Annual Fuel Cost (Generators)	83,376	83,332	69,013	82,230
Annual Oil Cost (Generators)	2,747	3,142	0	0
Annual Total Fuel Costs	530,159	585,797	440,653	562,206
Annual Total Fuel & Oil Costs	545,747	603,188	440,653	562,206
Maintenance (% of Cost)	508,550	925,317	443,560	458,350
Maintenance (Stack Replacement)	0	0	350,400	350,400
Maintenance (Total)	508,550	925,317	793,960	808,750
Annual Operating/Support/ Miscellaneous Costs	524,138	942,708	793,960	808,750
Total Annualized Expenses	2,085,237	3,404,319	3,932,184	4,158,475
Total Ownership Costs	82,290,568	131,248,369	149,090,146	158,735,519
NPV	39,182,745	62,007,487	65,971,588	70,432,029
Emission Credit	-48,729	-48,719	0	0

Comparison of the data generated from Life Cycle Cost (LCC) program runs comparing the ship powering plants are shown in Figures B-1 through B-3. The LCC model run print outs for the four ship powering plants are duplicated in paragraphs B2.5 and B2.6. Paragraph B2.5 shows the LCC model run using a CODAD propulsion system and an IDE w/AC propulsion system. Paragraph B2.6 shows the LCC model run using an MCFC w/AC propulsion system and a PEM w/AC propulsion system.

B2.1 Initial Costs – Equipment and Installation

The initial costs shown in Figure B-1 include the acquisition costs of the equipment and the installation costs. The cost per kW installed is $2065 for the diesel (CODAD) system, $4534 for the integrated electric (IDE) system, $6597 for the MCFC, and $6770 for the PEMFC. This corresponds to a ratio of 2.2 for the diesel electric system versus the diesel direct system and 3.2 to 3.3 ratio for the fuel cell installation to diesel installation. Note that the price per kW prime mover can be extracted directly from the corresponding ship work breakdown system (SWBS) category, primarily SWBS 230 and 310, for propulsion and is smaller than the total initial costs. As there is no experience to validate fuel cell installation costs, these numbers should be treated cautiously.

B2.2 Annual Costs

The annual costs shown in Figure B-2 are extracted from the spreadsheets in paragraphs B2.5 and B2.6. The fuel consumption figures developed by the model are accurate for the selected operational scenario. The maintenance costs should be treated cautiously. For the fuel cell propulsion systems (MCFC and PEMFC), the maintenance figures combine preventative maintenance with a five-year cycle of fuel stack replacement annualized cost. Both the IDE and diesel systems consume more fuel and oil than the fuel cell systems. Comparing the IDE system with fuel cell systems is meaningful. The IDE system is more expensive in fuel/lube oil consumption and maintenance than the fuel cell systems.

B2.3 Total Ownership Costs

The total ownership costs shown in Figure B-3 are extracted from the spreadsheets shown in paragraphs B2.5 and B2.6. Manning expenses were omitted from this comparison (i.e., the crew manning requirement was set to zero for these comparisons). If the prediction of reduced manning requirements for operating fuel cell systems is realized, then ownership cost will shift in favor of fuel cell systems. Comparing the integrated electric systems, i.e. IDE systems, with fuel cell systems is a valid comparison of similar systems. In general CODAD systems are less expensive.

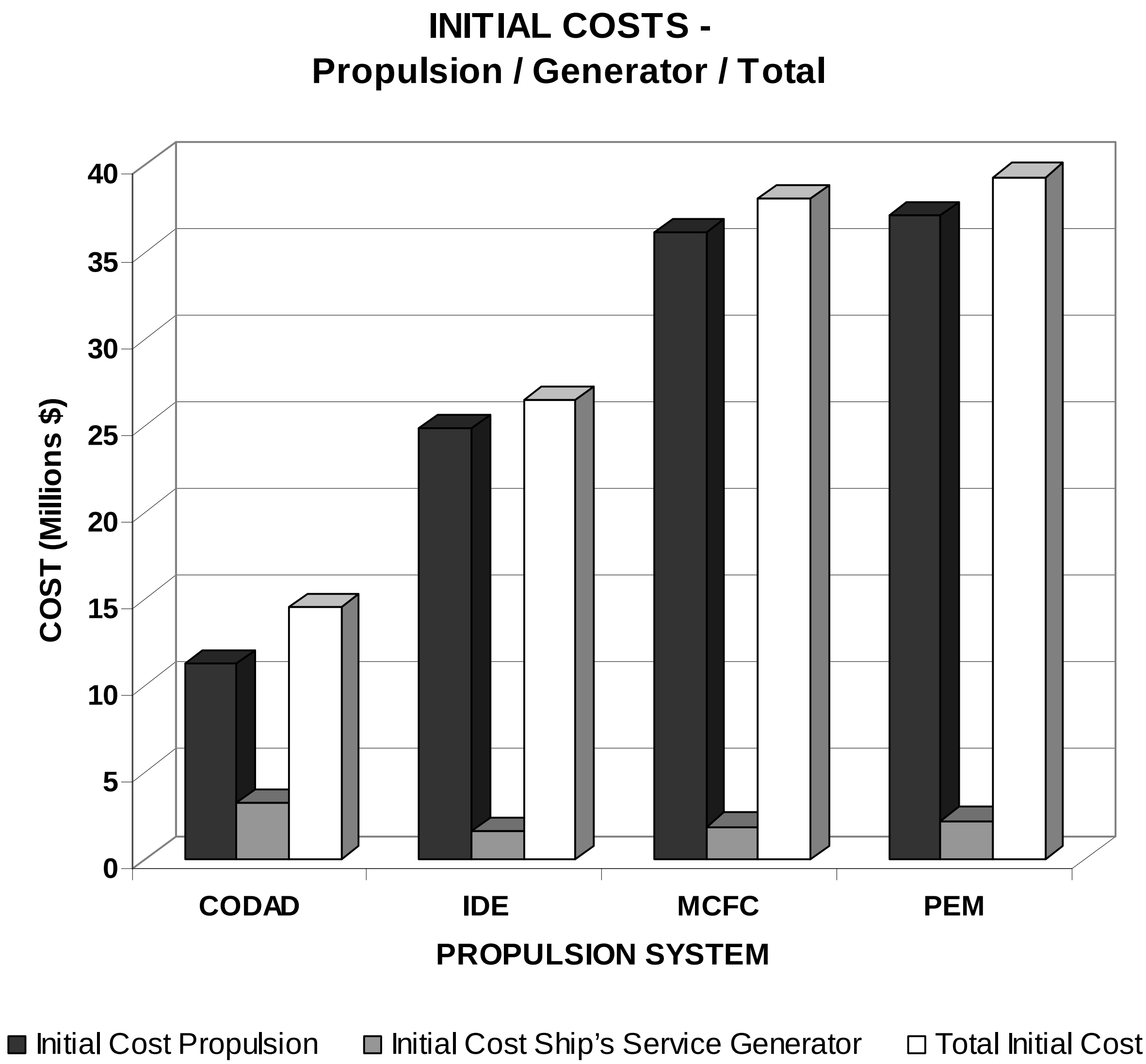

Figure B-1. Propulsion system initial costs.

**ANNUAL COSTS -
Propulsion and Generator Fuel/Oil and Maintenance**

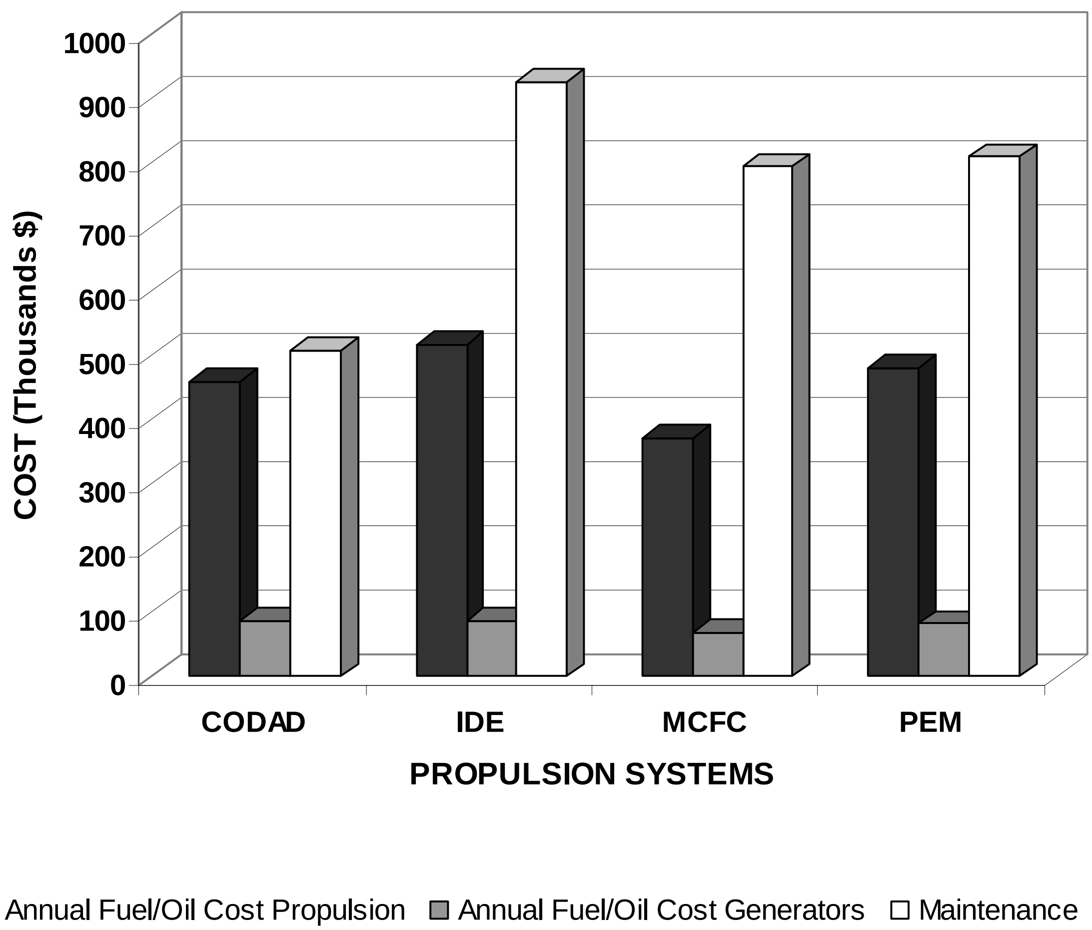

Figure B-2. Propulsion system annual costs.

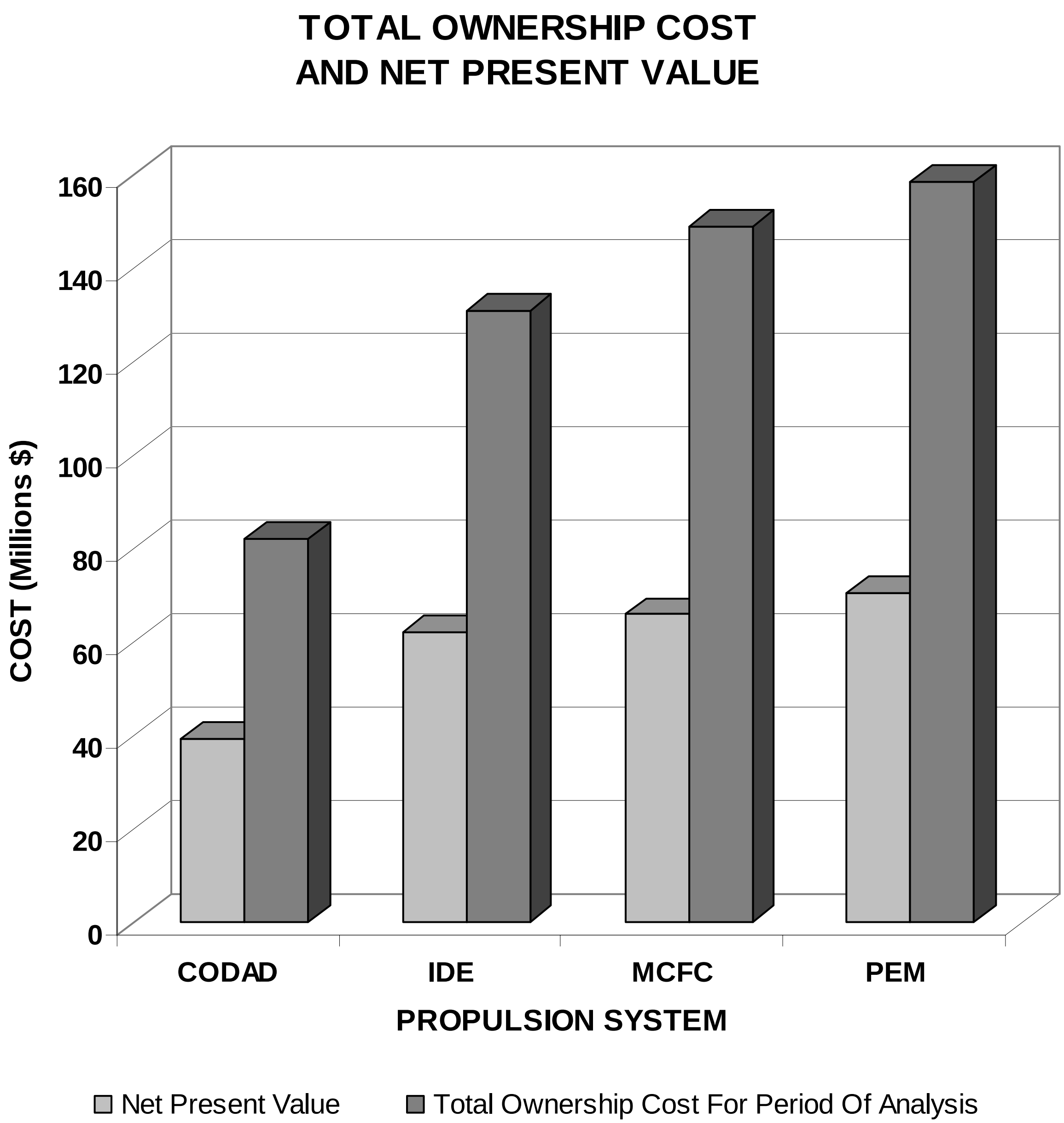

Figure B-3. Propulsion system total ownership costs.

B2.4 <u>Fuel Cell and Conventional Marine Power Systems Preliminary Economic Feasibility</u>

It must be admitted that certain parts of the LCC program require further verification before they can be used with confidence. In particular, all of the fuel cell costs, except fuel consumption and pollution reduction credits, lack service experience. It would also be useful to benchmark some of the diesel costs against installations, which were not in the original database. Lacking definitive costs for maintenance (including fuel cell stack replacement), manning, and scrapping, these will tentatively be considered similar for the fuel cell and diesel electric propulsion systems in the discussion below. Thus, no credit is taken for saving in manning costs that are expected to be realized with the operation of fuel cells. Manning costs are one of the more significant expenses in the operation of vessels.

A fuel cell propulsion system is identical to an integrated diesel system except the prime movers, where the diesel generators are replaced by fuel cell and electrical conversion systems. It is thus reasonable to compare life cycle costs of a fuel cells system to an IDE system while a direct diesel drive has in common with either the IDE or the fuel cell systems just the tail end, i.e. shafts and propellers.

The initial cost of the entire 5475 kW diesel-electric system (including propulsion motors and installation) is $24,825,269 (Figure B-1), or $4534/kW. This compares to an initial cost of $36,118,681, or $6597/kW, for a MCFC propulsion system. However, the annual operating costs of the MCFC system are lower than those of the IDE system. For the operational scenario studied, the annual fuel cost savings with the MCFC system amount to $162,000 ($441,000 vs. $603,000) and $131,000 savings in maintenance ($794,000 vs. $925,000). This savings of almost $300,000 ($113,000 fuel savings plus $131,000 maintenance savings) in operational costs is not sufficient to compensate for the difference in the initial costs. It is quite clear that an increase in operational costs, for example a change in fuel costs, could make the fuel cell system economically feasible.

To demonstrate the effect of fuel cost on the economical viability of the fuel cell marine propulsion system, the diesel fuel cost was increased by a factor of 2.14 to $582/tonne. This equates to roughly $1.93/gallon, a cost that is less than the cost of the diesel oil sold at gas stations in Europe. The increase from $272 to $582 per tonne equalizes the NPV of systems in the 25-year period of analysis. Further, an increase of fuel costs to $1115/tonne equalizes the annualized expenses (including acquisition, installation and operation) of the two systems at $5.5 million per year, while offering a significant reduced NPV for the fuel cell system over 25 years ($104 million vs. $113 million).

When using the original fuel costs of $272 per tonne, the total NPV for the life cycle of a fuel cell system is $66 million. This compares to the combined NPV of $62 million for an integrated diesel electric system. In both cases manning costs were not included. Raising the fuel cost by 2.14 times the current United States cost equalizes the NPV of both propulsion systems at about $80 million over the 25-year period.

Emission penalties, once enacted and enforced, could add another $50,000 to the operating costs of a 5475 kW diesel propulsion system. This, by itself, may not be sufficient to equalize annualized costs between a diesel-electric (IDE) system and a MCFC system. However the adding of scrubbing requirements to the diesel electric system and an increase in fuel costs will equalize the annualized costs between the systems. If fuel cell systems actually received NOx credits of $2000/tonne, then a fuel price increase to $544/tonne (twice the current price) is sufficient to equalize the NPV of both propulsion systems.

A CODAD system is less costly than an IDE propulsion system and, as found in numerous feasibility studies, can become economically advantageous when the operational profile requires a significant partial power operation. The requirements for quiet operation, range and endurance, and flexibility of arrangements are apparently sufficient to make a large number of new propulsion system selections for both commercial and future navy vessels Integrated Diesel Electric. The same argument is valid for the fuel cell systems, although the higher initial costs of the fuel cell systems may require other incentives until the initial fuel cell costs decrease.

The comparison results presented above are preliminary, and subject to numerous assumptions, but give some idea of the comparative economics of a diesel electric system relative to a fuel cell electric system.

B2.5 CODAD Propulsion System vs. IDE w/AC Propulsion System LCC Model Printout

INITIAL COST: ***PROPULSION SYSTEM***

SWBS	DESCRIPTION	WEIGHT (TONNES)	CER LABOR	CER MATERIAL	CER LABOR RATE $/hr	CODAD 5,475 skW (Enter Ship Profile #1)	IDE w/AC 5,475 skW (Enter Ship Profile #2)
120	**TRUNKS AND ENCLOSURES**					$ 44,596	$ 35,087
	SHIP PROFILE #1	3.50	230	$ 2,300	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	2.75	230	$ 2,300	$ 18.18	[illegible]	[illegible]
180	**FOUNDATIONS**					$ 478,543	$ 966,966
	SHIP PROFILE #1	10.96	910	$ 2,300	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	22.15	910	$ 2,300	$ 18.18	[illegible]	[illegible]
230	**PROPULSION UNITS**					$ 7,257,341	$ 9,014,873
	SHIP PROFILE #1	29.63	360	$ 228,610	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	36.80	360	$ 228,610	$ 18.18	[illegible]	[illegible]
240	**TRANSMISSION, PROP. SYS.**					$ 1,945,157	$ 1,070,894
	SHIP PROFILE #1	34.30	130	$ 50,800	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	18.88	130	$ 50,800	$ 18.18	[illegible]	[illegible]
250	**SUPPORT SYSTEMS**					$ 898,222	$ 595,520
	SHIP PROFILE #1	4.52	1020	$ 152,410	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	3.00	1020	$ 152,410	$ 18.18	[illegible]	[illegible]
260	**PROP. SUPP'T SYS. - FUEL, LUBE**					$ 201,411	$ -
	SHIP PROFILE #1	1.68	1520	$ 50,800	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2		1520	$ 50,800	$ 18.18		
310	**ELECTRIC POWER GENERATION**					$ -	$ 12,049,991
	SHIP PROFILE #1		410	$ 137,170	$ 18.18		
	SHIP PROFILE #2	77.34	410	$ 137,170	$ 18.18	[illegible]	[illegible]
320	**SWITCHGEAR & PANELS**					$ -	$ 524,678
	SHIP PROFILE #1		810	$ 39,630	$ 18.18		
	SHIP PROFILE #2	6.86	810	$ 39,630	$ 18.18	[illegible]	[illegible]
340	**DIESEL SUPPORT SYSTEMS**					$ -	$ 55,082
	SHIP PROFILE #1		100	$ 16,760	$ 18.18		
	SHIP PROFILE #2	2.59	100	$ 16,760	$ 18.18	[illegible]	[illegible]
510	**CLIMATE CONTROL**					$ 165,850	$ 149,532
	SHIP PROFILE #1	1.71	1520	$ 27,690	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	1.55	1520	$ 27,690	$ 18.18	[illegible]	[illegible]
540	**FUEL / LUBE, HAND'G & STORAGE**					$ 96,790	$ 106,184
	SHIP PROFILE #1	0.82	1520	$ 48,260	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	0.90	1520	$ 48,260	$ 18.18	[illegible]	[illegible]
550	**AIR, GAS, MISC. SYSTEMS**					$ 217,404	$ 256,460
	SHIP PROFILE #1	1.89	1270	$ 57,150	$ 18.18	[illegible]	[illegible]
	SHIP PROFILE #2	2.23	1270	$ 57,150	$ 18.18	[illegible]	[illegible]
	TOTAL INITIAL PROPULSION SYSTEM COSTS					$ 11,305,313	$ 24,825,269

FUEL: SPEED - TIME PROFILES	SPEED	ANNUAL HOURS	SPEED	ANNUAL HOURS		
PROPULSION PROFILE 1	17.0 kts.	385 hrs.	17.0 kts.	385 hrs.	**1,022.1 kg / hr.**	**1,110.8 kg / hr.**
					393.5 MT / yr.	**427.6 MT / yr.**
			TOTAL L.O. CONSUMPTION		**2.0 MT / yr.**	**2.1 MT / yr.**
PROPULSION PROFILE 2	14.5 kts.	980 hrs.	14.5 kts.	980 hrs.	**629.1 kg / hr.**	**713.7 kg / hr.**
					616.5 MT / yr.	**699.5 MT / yr.**
			TOTAL L.O. CONSUMPTION		**3.1 MT / yr.**	**3.5 MT / yr.**
PROPULSION PROFILE 3	11.0 kts.	770 hrs.	11.0 kts.	770 hrs.	**324.0 kg / hr.**	**377.5 kg / hr.**
					249.5 MT / yr.	**290.7 MT / yr.**
			TOTAL L.O. CONSUMPTION		**1.2 MT / yr.**	**1.5 MT / yr.**
PROPULSION PROFILE 4	11.0 kts.	770 hrs.	11.0 kts.	770 hrs.	**324.0 kg / hr.**	**377.5 kg / hr.**
					249.5 MT / yr.	**290.7 MT / yr.**
			TOTAL L.O. CONSUMPTION		**1.2 MT / yr.**	**1.5 MT / yr.**
PROPULSION PROFILE 5	8.0 kts.	595 hrs.	8.0 kts.	595 hrs.	**224.5 kg / hr.**	**233.3 kg / hr.**
					133.6 MT / yr.	**138.8 MT / yr.**
			TOTAL L.O. CONSUMPTION		**0.7 MT / yr.**	**0.7 MT / yr.**
PROPULSION PROFILE 6					--	--
					--	--
			TOTAL L.O. CONSUMPTION			
AVERAGE FUEL RATE					**469.3 kg / hr.**	**527.8 kg / hr.**
ANNUAL TOTALS		**3,500 hrs.**		**3,500 hrs.**	**1,642.6 MT / yr.**	**1,847.3 MT / yr.**
ANNUAL FUEL COST @ $$$$/MT		$ 272		$ 272	**$ 446,783**	**$ 502,465**
	TOTAL LUBE OIL CONSUMPTION			**DIESEL**	**8.21 MT / yr.**	**9.24 MT / yr.**
				GT		
	LUBE OIL REPLACEMENTS			**DIESEL**	**0.16 MT / yr.**	**0.06 MT / yr.**
				GT		
	TOTAL LUBE OIL			**DIESEL**	**8.38 MT / yr.**	**9.29 MT / yr.**
				GT		
ANNUAL LUBE OIL COST @ $$$$/MT		$ 1,533		$ 1,533	**$ 12,841**	**$ 14,249**

INITIAL COST: SHIP SERVICE GENERATORS

SWBS	DESCRIPTION	WEIGHT (TONNES)	CER LABOR	CER MATERIAL	CER LABOR RATE $/hr	SSDG 500 ekW — Enter Gen. Profile #1	SSDG 500 ekW — Enter Gen. Profile #2
120	TRUNKS AND ENCLOSURES					$ 16,835	$ 16,835
	GEN. PROFILE #1	1.32	230	$ 2,300	$ 18.18		
	GEN. PROFILE #2	1.32	230	$ 2,300	$ 18.18		
180	FOUNDATIONS					$ 74,221	$ 74,221
	GEN. PROFILE #1	1.70	810	$ 2,300	$ 18.18		
	GEN. PROFILE #2	1.70	810	$ 2,300	$ 18.18		
310	ELECTRIC POWER GENERATION					$ 1,210,601	$ 1,210,601
	GEN. PROFILE #1	7.77	410	$ 137,170	$ 18.18		
	GEN. PROFILE #2	7.77	410	$ 137,170	$ 18.18		
320	SWITCHGEAR & PANELS					$ 225,511	$ 225,511
	GEN. PROFILE #1	2.95	810	$ 39,630	$ 18.18		
	GEN. PROFILE #2	2.95	810	$ 39,630	$ 18.18		
340	DIESEL SUPPORT SYSTEMS					$ 3,622	$ 3,622
	GEN. PROFILE #1	0.17	100	$ 16,760	$ 18.18		
	GEN. PROFILE #2	0.17	100	$ 16,760	$ 18.18		
550	AIR, GAS, MISC. SYSTEMS					$ 81,559	$ 81,559
	GEN. PROFILE #1	0.71	1270	$ 57,150	$ 18.18		
	GEN. PROFILE #2	0.71	1270	$ 57,150	$ 18.18		
	TOTAL INITIAL COST (1) SHIP'S SERVICE GENERATOR					**$ 1,612,349**	**$ 1,612,349**

FUEL:	SHIP SERVICE LOAD / TIME PROFILES	SHIP SERVICE LOAD	ANNUAL HOURS	SHIP SERVICE LOAD	ANNUAL HOURS		2 GenSets	Min. # of GenSets Required	1 GenSets
	SERVICE LOAD PROFILE 1	330 ekW	3,500 hrs	330 ekW	3,500 hrs		87.5 kg / hr.		87.5 kg / hr.
							306.4 MT / yr.		306.4 MT / yr.
			NUMBER OF GENSETS REQUIRED				1		1
	SERVICE LOAD PROFILE 2	600 ekW	1 hrs				161.2 kg / hr.		
							0.2 MT / yr.		–
			NUMBER OF GENSETS REQUIRED				2		
	SERVICE LOAD PROFILE 3								
							–		–
			NUMBER OF GENSETS REQUIRED						
	SERVICE LOAD PROFILE 4								
							–		–
			NUMBER OF GENSETS REQUIRED						
	SERVICE LOAD PROFILE 5								
							–		–
			NUMBER OF GENSETS REQUIRED						
	SERVICE LOAD PROFILE 6								
							–		–
			NUMBER OF GENSETS REQUIRED						
	AVERAGE FUEL RATE						87.6 kg / hr.		87.5 kg / hr.
	ANNUAL TOTALS		3,501 hrs.		3,500 hrs.		306.5 MT / yr.		306.4 MT / yr.
	ANNUAL FUEL COST @ $$$$/MT		$ 272		$ 272		$ 83,376		$ 83,332
			TOTAL LUBE OIL CONSUMPTION			DIESEL	1.53 MT / yr.		1.53 MT / yr.
						GT			
			LUBE OIL REPLACEMENTS			DIESEL	0.26 MT / yr.		0.52 MT / yr.
						GT			
			TOTAL LUBE OIL			DIESEL	1.79 MT / yr.		2.05 MT / yr.
						GT			
	ANNUAL LUBE OIL COST @ $$$$/MT		$ 1,533		$ 1,533		$ 2,747		$ 3,142
	TOTAL INITIAL COST, SHIP'S SERVICE GENERATORS						$ 3,224,697		$ 1,612,349

TOTAL COST, (1) SHIP'S SERVICE GENERATOR) * (MIN. # GENSETS REQUIRED)

ANNUAL OPERATING & SUPPORT COSTS: (CURRENT YEAR DOLLARS)

OPERATING:

	SHIP PROFILE #1 NUMBER	SHIP PROFILE #1 CER	SHIP PROFILE #2 NUMBER	SHIP PROFILE #2 CER		
SHIP'S CREW REQUIRED						
CREW COST/YEAR ($38,000/yr)		$ 38,000		$ 38,000	$ -	$ -

SUPPORT:

PLACE AN "X" IN THE GREEN BOX BELOW TO INDICATE HOW ***MAINTENANCE IS PERFORMED***

CHOOSE ONE ONLY!

		SHIP PROFILE #1 INITIAL COST	SHIP PROFILE #1 CER	SHIP PROFILE #2 INITIAL COST	SHIP PROFILE #2 CER
X	PREVENTIVE	$ 14,530,011	3.5%	$ 26,437,617	3.5%
	CONTRACTOR SUPPLIED	$ 14,530,011	6.0%	$ 26,437,617	6.0%

5	YEARS FOR FUEL STACK REPLACEMENT	$ -	$ -

MISCELLANEOUS:

	SHIP PROFILE #1 INITIAL COST	SHIP PROFILE #1 CER	SHIP PROFILE #2 INITIAL COST	SHIP PROFILE #2 CER		
DISPOSAL	$ 14,530,011	2.0%	$ 26,437,617	2.0%	$ 290,600	$ 528,752

LIFE CYCLE COST ANALYSIS:

INITIAL OUTLAY PROPULSION SYSTEM		
LABOR	$ 714,984	$ 1,520,451
OVERHEAD	$ 1,072,476	$ 2,280,677
MATERIAL	$ 9,517,854	$ 21,024,140
TOTAL	$ 11,305,313	$ 24,825,269
INITIAL OUTLAY GENERATOR SYSTEM		
LABOR	$ 303,406	$ 151,703
OVERHEAD	$ 455,109	$ 227,555
MATERIAL	$ 2,466,182	$ 1,233,091
TOTAL	$ 3,224,697	$ 1,612,349
PERIOD OF ANALYSIS (YEARS)	25.00	25.00
INTEREST RATE	5.00%	5.00%
ANNUALIZED OUTLAY *(INITIAL COSTS)*	$ 1,030,940	$ 1,875,814
OPERATING / SUPPORT / MISC. *DOES NOT INCLUDE FUEL COST!*	$ 15,588	$ 17,391
ESTIMATED INFLATION RATE	3.00%	3.00%
FUEL COST	$ 530,159	$ 585,797
ESTIMATED INFLATION RATE	5.00%	5.00%
ANNUAL EXPENSE (CURRENT YEAR)	$ 1,576,687	$ 2,479,002
TOTAL OWNERSHIP COST FOR PERIOD OF ANALYSIS	$ 63,749,195	$ 97,512,006
NET PRESENT VALUE (NPV)	$ 26,839,290	$ 39,548,346
TOTAL EMISSIONS CREDIT ($/Year) *(Negative Value = Penalty)*	$ (48,729)	$ (48,719)

B2.6 MCFC w/AC Propulsion System vs. PEM w/AC Propulsion System LCC Model Printout

INITIAL COST: PROPULSION SYSTEM

SWBS	DESCRIPTION	WEIGHT (TONNES)	CER LABOR	CER MATERIAL	CER LABOR RATE $/hr	MCFC w/AC 5,475 skW (Enter Ship Profile #1)	PEM w/AC 5,475 skW (Enter Ship Profile #2)
120	TRUNKS AND ENCLOSURES					$ 33,516	$ 39,219
	SHIP PROFILE #1	2.83	230	$ 2,300	$ 18.18		
	SHIP PROFILE #2	3.08	230	$ 2,300	$ 18.18		
180	FOUNDATIONS					$ 1,219,016	$ 1,694,232
	SHIP PROFILE #1	27.92	910	$ 2,300	$ 18.18		
	SHIP PROFILE #2	38.81	910	$ 2,300	$ 18.18		
230	PROPULSION UNITS					$ 9,014,873	$ 9,014,873
	SHIP PROFILE #1	36.80	360	$ 228,610	$ 18.18		
	SHIP PROFILE #2	36.80	360	$ 228,610	$ 18.18		
240	TRANSMISSION, PROP. SYS.					$ 1,070,894	$ 1,070,894
	SHIP PROFILE #1	18.88	130	$ 50,800	$ 18.18		
	SHIP PROFILE #2	18.88	130	$ 50,800	$ 18.18		
250	SUPPORT SYSTEMS					$ 665,955	$ 852,168
	SHIP PROFILE #1	3.35	1020	$ 152,410	$ 18.18		
	SHIP PROFILE #2	4.29	1020	$ 152,410	$ 18.18		
260	PROP. SUPP'T SYS. - FUEL, LUBE					$ -	$ -
	SHIP PROFILE #1		1520	$ 50,800	$ 18.18		
	SHIP PROFILE #2		1520	$ 50,800	$ 18.18		
310	ELECTRIC POWER GENERATION					$ 23,171,506	$ 23,514,804
	SHIP PROFILE #1	186.82	410	$ 137,170	$ 18.18		
	SHIP PROFILE #2	189.81	410	$ 137,170	$ 18.18		
320	SWITCHGEAR & PANELS					$ 524,678	$ 524,678
	SHIP PROFILE #1	6.86	810	$ 39,630	$ 18.18		
	SHIP PROFILE #2	6.86	810	$ 39,630	$ 18.18		
340	DIESEL SUPPORT SYSTEMS					$ -	$ -
	SHIP PROFILE #1		100	$ 16,760	$ 18.18		
	SHIP PROFILE #2		100	$ 16,760	$ 18.18		
510	CLIMATE CONTROL					$ 149,532	$ 149,532
	SHIP PROFILE #1	1.55	1520	$ 27,690	$ 18.18		
	SHIP PROFILE #2	1.55	1520	$ 27,690	$ 18.18		
540	FUEL / LUBE, HAND'G & STORAGE					$ 75,667	$ 75,667
	SHIP PROFILE #1	0.64	1520	$ 48,260	$ 18.18		
	SHIP PROFILE #2	0.64	1520	$ 48,260	$ 18.18		
550	AIR, GAS, MISC. SYSTEMS					$ 193,044	$ 131,025
	SHIP PROFILE #1	1.88	1270	$ 57,150	$ 18.18		
	SHIP PROFILE #2	1.14	1270	$ 57,150	$ 18.18		
	TOTAL INITIAL PROPULSION SYSTEM COSTS					$ 36,118,681	$ 37,067,092

FUEL: SPEED - TIME PROFILES	SPEED	ANNUAL HOURS	SPEED	ANNUAL HOURS		
PROPULSION PROFILE 1	17.0 kts.	385 hrs.	17.0 kts.	385 hrs.	896.3 kg / hr.	1,158.2 kg / hr.
					345.1 MT / yr.	445.9 MT / yr.
			TOTAL L.O. CONSUMPTION			
PROPULSION PROFILE 2	14.5 kts.	980 hrs.	14.5 kts.	980 hrs.	567.9 kg / hr.	737.0 kg / hr.
					556.5 MT / yr.	722.2 MT / yr.
			TOTAL L.O. CONSUMPTION			
PROPULSION PROFILE 3	11.0 kts.	770 hrs.	11.0 kts.	770 hrs.	246.4 kg / hr.	320.5 kg / hr.
					189.8 MT / yr.	246.8 MT / yr.
			TOTAL L.O. CONSUMPTION			
PROPULSION PROFILE 4	11.0 kts.	770 hrs.	11.0 kts.	770 hrs.	246.4 kg / hr.	320.5 kg / hr.
					189.8 MT / yr.	246.8 MT / yr.
			TOTAL L.O. CONSUMPTION			
PROPULSION PROFILE 5	8.0 kts.	595 hrs.	8.0 kts.	595 hrs.	143.2 kg / hr.	172.9 kg / hr.
					85.2 MT / yr.	102.9 MT / yr.
			TOTAL L.O. CONSUMPTION			
PROPULSION PROFILE 6					--	--
					--	--
			TOTAL L.O. CONSUMPTION			
AVERAGE FUEL RATE					390.4 kg / hr.	504.2 kg / hr.
ANNUAL TOTALS		3,500 hrs.		3,500 hrs.	1,366.3 MT / yr.	1,764.6 MT / yr.
ANNUAL FUEL COST @ $$$$/MT		$ 272		$ 272	$ 371,640	$ 479,976
	TOTAL LUBE OIL CONSUMPTION		DIESEL			
			GT			
	LUBE OIL REPLACEMENTS		DIESEL			
			GT			
	TOTAL LUBE OIL		DIESEL			
			GT			
ANNUAL LUBE OIL COST @ $$$$/MT		$ 1,833		$ 1,833	$ -	$ -

INITIAL COST: SHIP SERVICE GENERATORS

SWBS	DESCRIPTION	WEIGHT (TONNES)	CER LABOR	CER MATERIAL	CER LABOR RATE $/hr	MC 500 ekW (Enter Gen. Profile #1)	PEM 500 ekW (Enter Gen. Profile #2)
120	TRUNKS AND ENCLOSURES					$ 10,075	$ 11,988
	GEN. PROFILE #1	0.79	230	$ 2,300	$ 18.18		
	GEN. PROFILE #2	0.94	230	$ 2,300	$ 18.18		
180	FOUNDATIONS					$ 73,785	$ 102,163
	GEN. PROFILE #1	1.69	810	$ 2,300	$ 18.18		
	GEN. PROFILE #2	2.34	810	$ 2,300	$ 18.18		
310	ELECTRIC POWER GENERATION					$ 1,579,858	$ 1,866,538
	GEN. PROFILE #1	10.14	410	$ 137,170	$ 18.18		
	GEN. PROFILE #2	11.98	410	$ 137,170	$ 18.18		
320	SWITCHGEAR & PANELS					$ 225,511	$ 225,511
	GEN. PROFILE #1	2.95	810	$ 39,630	$ 18.18		
	GEN. PROFILE #2	2.95	810	$ 39,630	$ 18.18		
340	DIESEL SUPPORT SYSTEMS					$ 11,505	$ 13,848
	GEN. PROFILE #1	0.54	100	$ 16,760	$ 18.18		
	GEN. PROFILE #2	0.65	100	$ 16,760	$ 18.18		
550	AIR, GAS, MISC. SYSTEMS					$ -	$ -
	GEN. PROFILE #1		1270	$ 57,150	$ 18.18		
	GEN. PROFILE #2		1270	$ 57,150	$ 18.18		
	TOTAL INITIAL COST (1) SHIP'S SERVICE GENERATOR					$ 1,900,733	$ 2,220,049

FUEL:	SHIP SERVICE LOAD / TIME PROFILES	SHIP SERVICE LOAD	ANNUAL HOURS	SHIP SERVICE LOAD	ANNUAL HOURS	1 GenSets	Min. # of GenSets Required	1 GenSets
	SERVICE LOAD PROFILE 1	330 ekW	3,500 hrs.	330 ekW	3,500 hrs.	72.5 kg / hr.		86.4 kg / hr.
						253.7 MT / yr.		302.3 MT / yr.
	NUMBER OF GENSETS REQUIRED					1		1
	SERVICE LOAD PROFILE 2							
						--		--
	NUMBER OF GENSETS REQUIRED							
	SERVICE LOAD PROFILE 3							
						--		--
	NUMBER OF GENSETS REQUIRED							
	SERVICE LOAD PROFILE 4							
						--		--
	NUMBER OF GENSETS REQUIRED							
	SERVICE LOAD PROFILE 5							
						--		--
	NUMBER OF GENSETS REQUIRED							
	SERVICE LOAD PROFILE 6							
						--		--
	NUMBER OF GENSETS REQUIRED							
	AVERAGE FUEL RATE					72.5 kg / hr.		86.4 kg / hr.
	ANNUAL TOTALS		3,500 hrs.		3,500 hrs.	253.7 MT / yr.		302.3 MT / yr.
	ANNUAL FUEL COST @ $$$$/MT		$ 272		$ 272	$ 69,013		$ 82,230
	TOTAL LUBE OIL CONSUMPTION				DIESEL			
					GT			
	LUBE OIL REPLACEMENTS				DIESEL			
					GT			
	TOTAL LUBE OIL				DIESEL			
					GT			
	ANNUAL LUBE OIL COST @ $$$$/MT		$ 1,535		$ 1,533	$ -		$ -
	TOTAL INITIAL COST, SHIP'S SERVICE GENERATORS					$ 1,900,733		$ 2,220,049
	TOTAL COST, (1) SHIP'S SERVICE GENERATOR) * (MIN. # GENSETS REQUIRED)							

ANNUAL OPERATING & SUPPORT COSTS: (CURRENT YEAR DOLLARS)

OPERATING:

	SHIP PROFILE #1		SHIP PROFILE #2			
	NUMBER	*CER*	*NUMBER*	*CER*		
SHIP'S CREW REQUIRED						
CREW COST/YEAR ($38,000/yr)		$ 38,000		$ 38,000	$ -	$ -

SUPPORT:

PLACE AN "X" IN THE GREEN BOX BELOW TO INDICATE HOW MAINTENANCE IS PERFORMED
CHOOSE ONE ONLY!

		SHIP PROFILE #1		SHIP PROFILE #2			
		INITIAL COST	CER	INITIAL COST	CER		
X	PREVENTIVE	$ 38,019,415	3.5%	$ 39,287,141	3.5%		
	CONTRACTOR SUPPLIED	$ 38,019,415	6.0%	$ 39,287,141	6.0%		
		5	YEARS FOR FUEL STACK REPLACEMENT			$ 350,400	$ 350,400

MISCELLANEOUS:

	SHIP PROFILE #1		SHIP PROFILE #2			
	INITIAL COST	CER	INITIAL COST	CER		
DISPOSAL	$ 38,019,415	2.0%	$ 39,287,141	2.0%	$ 760,388	$ 785,743

LIFE CYCLE COST ANALYSIS:

INITIAL OUTLAY PROPULSION SYSTEM		
LABOR	$ 2,413,417	$ 2,622,585
OVERHEAD	$ 3,620,126	$ 3,933,877
MATERIAL	$ 30,085,138	$ 30,510,630
TOTAL	$ 36,118,681	$ 37,067,092
INITIAL OUTLAY GENERATOR SYSTEM		
LABOR	$ 151,267	$ 176,562
OVERHEAD	$ 226,900	$ 264,844
MATERIAL	$ 1,522,567	$ 1,778,643
TOTAL	$ 1,900,733	$ 2,220,049
PERIOD OF ANALYSIS (YEARS)	25.00	25.00
INTEREST RATE	5.00%	5.00%
ANNUALIZED OUTLAY ***(INITIAL COSTS)***	$ 2,697,571	$ 2,787,519
OPERATING / SUPPORT / MISC. ***DOES NOT INCLUDE FUEL COST!***	$ 350,400	$ 350,400
ESTIMATED INFLATION RATE	3.00%	3.00%
FUEL COST	$ 440,654	$ 562,206
ESTIMATED INFLATION RATE	5.00%	5.00%
ANNUAL EXPENSE (CURRENT YEAR)	$ 3,488,624	$ 3,700,125
TOTAL OWNERSHIP COST FOR PERIOD OF ANALYSIS	$ 132,918,281	$ 142,024,416
NET PRESENT VALUE (NPV)	$ 55,205,572	$ 59,307,029
TOTAL EMISSIONS CREDIT ($/Year) ***(Negative Value = Penalty)***	$ -	$ -