Technical Paper

Journal of the Society of
Naval Architects of Korea
Vol. 21, No. 4, Dec. 1984

# Economic Optimization Study for a 125,000 m$^3$ Class LNG Carrier

by

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## Abstract

This study is concerned with the economic aspects of 125,000 m$^3$ class LNG carriers with different propulsion plant such as conventional steam turbine and slow speed diesel engine with reliquefaction plant. The ship's speed and L/B ratio were optimized with criterion of required freight rate (RFR) by using the PROCAL computer program package.

In order to investigate the effect of fuel oil price, round trip distance and boil-off rate on the RFR and the optimum speed, sensitivity analysis were also performed.

## 1. Introduction

Minimum cost of transport can be no longer obtained through a vessel whose principal dimensions gave minimum building cost as the days of cheap energy. Considerations in compensation for increasing fuel costs upon the design are mainly an optimum choice of speed, hull form and main parameters, and improved overall economics of fuel in the machinery system. The prospective cost of powering a ship must be considered early in the design process and an initial study of the relevant elements will most certainly pay off for both the prospective owner and charterer.

In this study the dimensions, speed and performance of LNG carriers were examined by an economic optimization study. One of the most important features of LNG carriers is the presence of boil-off gas from the cargo tanks. Steam turbine driven ships utilize this gas to supply a portion of the fuel needs of the propulsion and auxiliary machinery plant by burning the gas in conventional marine boilers. Although this practice is a reliable and simple procedure, backed by nearly twenty years experience in practical ship operation, reorientation of the cost of fuel and the value of LNG as a deliverable product in recent years has brought the advancement of the state of the art by the introduction of the concept of shipboard reliquefaction. This concept include the installation of a slow-speed diesel propulsion plant, which takes advantage of the significantly lower fuel rate of this type of machinery as compared to that of the steam turbine plant, with which nearly all earlier LNG carriers were fitted.

Hyundai Heavy Industries Co., LTD. (HHI) has been projecting 125,000 m$^3$ class LNG carriers. For the purpose of an overall optimization of LNG transport cost, the Ship Research Station of Korea Institute of Machinery and Metals (SRS-KIMM) recently carried out an economic evaluation for the two types of projected LNG carriers, one with conventional steam turbine propulsion system, the other with a direct coupled slow speed diesel engine and reliquefaction plant [1].

The aims of the optimization study in this paper

Manuscript received: Nov. 21, 1984
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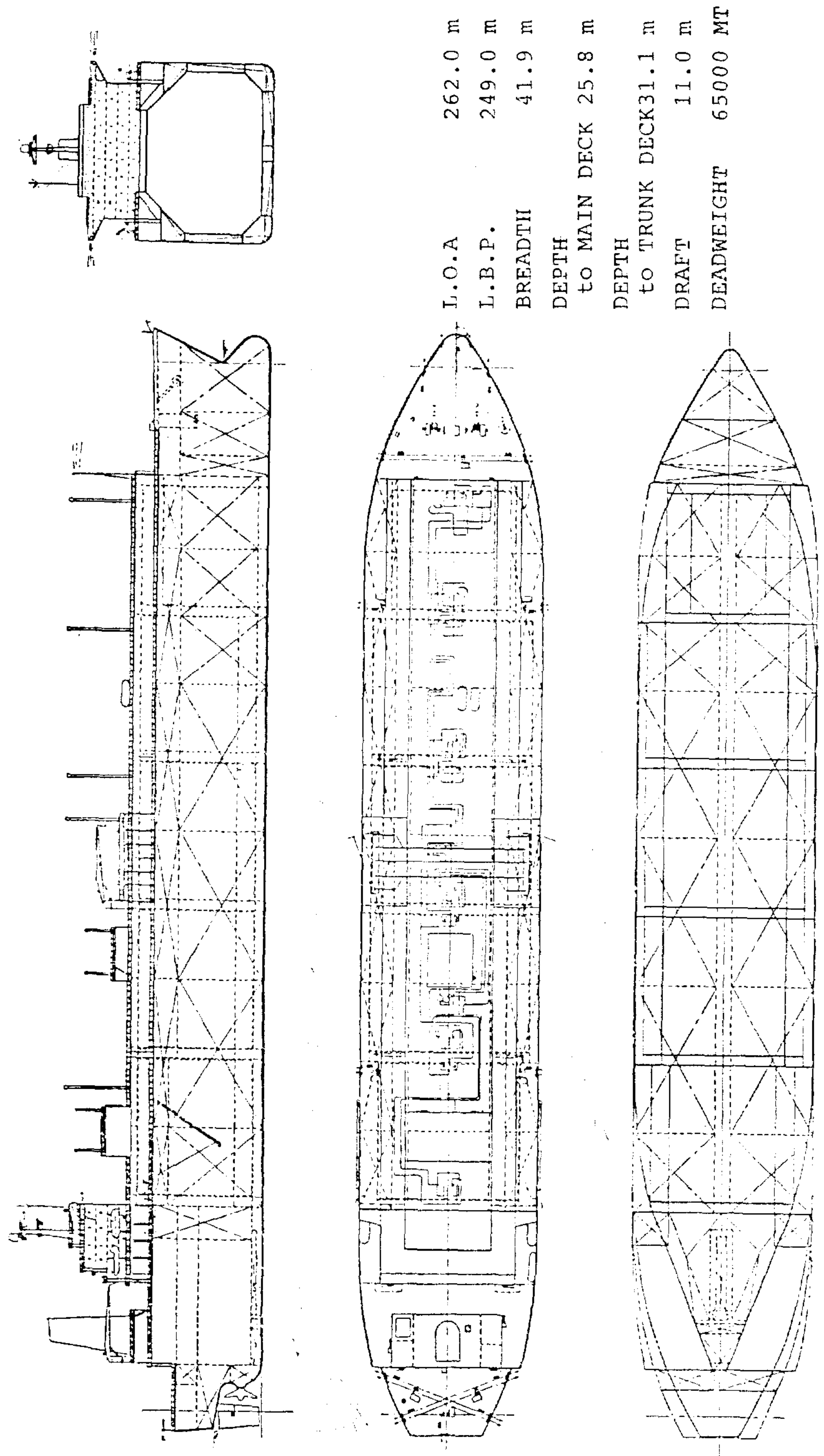


**Fig. 1** LNG Carrier-general arrangement

are:

—to compare the economic aspect of steam turbine with the one of diesel engine

—to determine optimum speed and principal dimensions

for the proposed Hyundai 125,000 m³ class LNG carriers. Simplified general arrangement for the projected vessel is shown in Figure 1.

## 2. Economic Criterion

Economic comparison of two LNG carriers having disparate cargo handling and containment system characteristics, such as the diesel driven ship and the steam driven ship, may be made on the basis of the cost of delivery per unit volume, i.e. required freight rate (RFR).

The optimum ship will have the least required freight rate expressed as:

$$RFR=\frac{\text{Capital cost}+\text{Annual operating cost}}{\text{Annual delivered LNG quantity}}$$

Capital cost=Building cost×Capital recovery factor.

The operating costs include following items:

*Time constant operating costs:*

Crew costs

Insurance costs

Maintenance and repair costs

Nitrogen costs

Miscellaneous costs

Port costs

*Voyage expences:*

Heavy fuel oil costs

Diesel oil costs

Lubrication oil costs

Boil-off vapour costs as fuel

The economic data used in this paper is shown in Appendix.

## 3. Program System

The PROCAL program system which generates technical and economic results for one specific ship at a time and gives detailed output for this ship was used for the economic evaluation [2,3]. This system

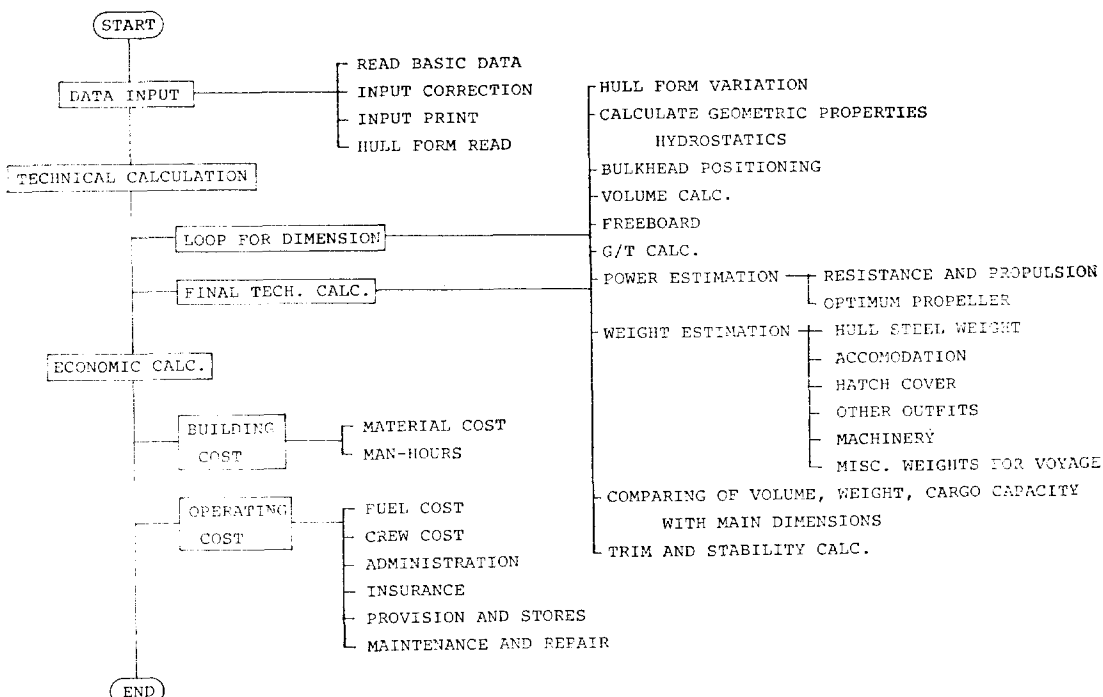


**Fig. 2** Flow diagram of PROCAL

provides fast and reliable design and cost estimates at preliminary stage in the transport analysis and ship design process.

The PROCAL may be used for:

- preliminary ship design
- comparison of alternative ships
- speed and fuel cost analysis
- tendering

for the following four ship types:

- bulk carriers
- general cargo vessels including Ro/Ro
- container ships
- tankers

For LNG carrier, the type of bulk carriers was modified. Figure 2 shows flow diagram of PROCAL.

For the purpose of optimization, we made use of PROCAL to get technical and economic result for a series of ships by systematically varying the ship's main dimensions and speeds ('parametric study'). It is worth noting that the program is not designed for the automatic search of the optimum ship, and presents the results of every ship to the user in the form of tables to allow a fuller interpretation.

At conceptual design stage where volume of calculation could be tremendous if the field of investigation is fairly wide, one may use a sophisticated search strategy which, usually, tests several hundred combinations of design variables (principal dimensions, speed) until that particular combination of design variables has been found which results in the optimum objective function value and observes all given constraints [4, 5].

## 4. Results

### 4.1 Economic Evaluation for Different Machinery Systems

Table 1 shows the main characteristics of the LNG carriers evaluated in this study. In the process of comparing different machinery configurations, the vessels were assumed to have an optimum service speed of about 18.5 knots. The assumed optimum speed will be examined in the subsequent optimization study. Service speed is calculated at 90% of maximum continuous rating of propelling plant with 15% sea margin.

**Table 1** Principal Particulars of LNG Carriers

| Ship | Conv. steam | Diesel |
|---|---|---|
| Capacity($m^3$) | 125,000 | 125,000 |
| L.O.A.(m) | 262.00 | 262.00 |
| L.P.P.(m) | 249.00 | 249.00 |
| Breadth mld(m) | 41.90 | 41.90 |
| Depth to main deck(m) | 25.80 | 25.80 |
| Depth to trunk deck(m) | 31.10 | 31.10 |
| Design draught(m) | 11.0 | 11.0 |
| Deadweight at 11.0m draught | 65,000MT | 65,000MT |
| Class | BV | BV |
| Power, MCR(SHP) | 29,560 | 29,560 |
| Power, NCR(SHP) | 26,600 | 26,600 |
| Service speed(Knots) | 18.5 | 18.5 |
| Cargo tanks(Technigaz Mark III Membrane system) | 5 | 5 |
| Complement(persons) | 38 | 38 |
| Boil-off burning | Yes | No |
| Reliquefaction | No | Yes |
| Boil-off rate, guaranteed (percent per day) | 0.18 | 0.18 |
| Boil-off rate, loaded (percent per day) | 0.166 | 0.166 |
| Boil-off rate, ballasted (percent per day) | 0.04 | 0.04 |

For a given ship size and speed, a vessel equipped with reliquefaction will be capable of delivering more LNG per unit of time than a conventional carrier. Assuming zero loss in the vapor handling systems, the quantity of LNG discharged will be equal to the quantity loaded. The steam driven ship, in which boil-off vapor is burned as fuel, will, of course deliver less LNG per voyage, because of the loss of cargo on both the loaded and ballasted legs of the voyage.

A material balance has been prepared to show the difference between the annual delivery capabilities of the diesel driven ship and the steam driven LNG carrier. The material balance and the transport costs are shown in Table 2.

From the results of Table 2, we could derive definite economical advantage of diesel driven ship.

The economical performance of diesel driven ship is about 8% higher (i.e. 8% lower RFR) than that of steam driven ship.

**Table 2** Required freight rate for different propulsion system of 125,000 cubic meter class LNG carriers at 18.5 kts, boil-off vapor gas price $6/mm BTU

| | Item | Unit | Steam turbine | Diesel engine with reli. plant |
|---|---|---|---|---|
| 1. Material Balance | Power(MCR) | BHP | 29,560 | 29,560 |
| | Power(NCR) | BHP | 26,600 | 26,600 |
| | Distance(round) | N.M | 7,000 | 7,000 |
| | Sailing(load) | day/R.T | 7.9 | 7.9 |
| | Sailing(ballast) | day/R.T | 7.9 | 7.9 |
| | Load/Disch. | day/R.T | 1.0 | 1.0 |
| | Manouv.(harb) | day/R.T | 2.0 | 2.0 |
| | Boil-off period | day/R.T | 8.9 | 8.9 |
| | Voyage/year | no./year | 18.35 | 18.35 |
| | Ship capacity | cub. | 125,000 | 125,000 |
| | Load factor | cargo load/cap. | 0.98 | 0.98 |
| | B.O.R.(loaded) | %/day | 0.166 | 0.166 |
| | B.O.R.(ballast) | %/day | 0.04 | 0.04 |
| | Residual | cub. | 400 | 400 |
| | Boil-off, loaded | cub. | 1,810 | 0 |
| | Boil-off, ballasted | cub. | 436 | 0 |
| | Ann. boil-off quant. | cub. | 41,214 | 0 |
| | Cargo disch. per year | cub. | 2,202,861 | 2,244,198 |
| 2. Transport Cost | Ship price | '000USD | 141,370 | 147,540 |
| | Capital cost | '000USD | 17,530 | 18,295 |
| | Time constant op. cost | '000USD | 7,807 | 7,834 |
| | Voyage cost | '000USD | 9,198 | 6,203 |
| | Annual total cost | '000USD | 34,534 | 32,382 |
| 3. Required Freight Rate | R.F.R | USD/cub. | 15.677 | 14.429 |
| | R.F.R | cents/mmBTU* | 65.320 | 60.122 |

* $1m^3 = 24$ mmBTU

### 4.2 Optimum Speed

Operating at the optimum speed is the easiest way to save money (provided the vessel can command an acceptable freight rate). However, with present day fuel costs the optimum speed for most cargo vessels is generally below the design value.

For each design alternative, the ship's service speed is varied within the 14-21 knots range to determine the optimum speed. Building cost has been evaluated in increments depending on ship speed, as the size of the propulsion plant varies.

For a ship with steam propulsion plant, it is found that the most economic speed seems to be about 17.5 ~18.5 knots as shown in Figure 3. The cost of boil-off vapor used as fuel was assumed to be $6.0/mmBTU.

For a diesel driven ship with reliquefaction plant, the optimum speed seems to be 17.0~18.5 knots (Fig. 3).

Frequently, the ship owner has been allowed to burn boil-off vapor at a rate corresponding to the guaranteed maximum boil-off for the ship. For this case, the optimum speed seems to be about 17.5~18.0 knots (Fig. 3).

In this analysis, the interest cost of the cargo was not taken into consideration. However, cargo is "tied up" during transport at sea, meaning that the owner's realization of a profit is delayed by the length of

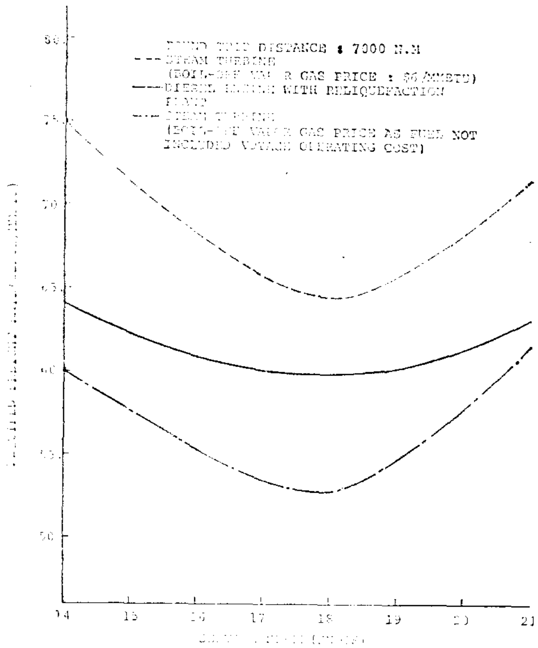


**Fig.** 3 Optimum service speed for different propulsion system of 125,000 cubic meter class LNG carriers

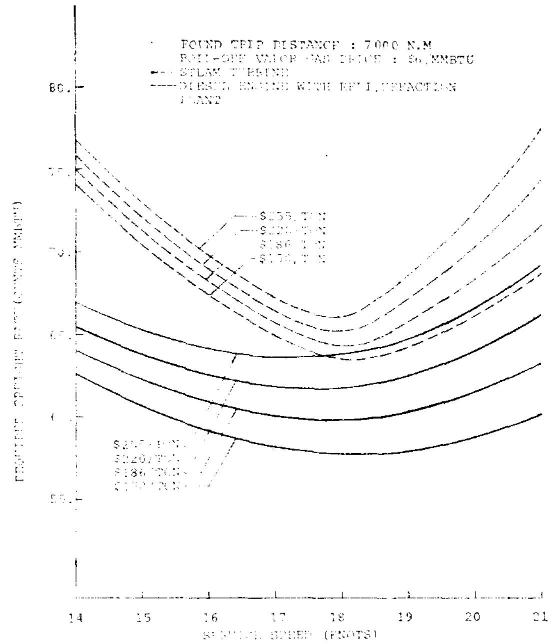


**Fig.** 4 Optimum service speed for different fuel oil price of 125,000 cubic meter class LNG carrier

the voyage. This fact may influence the freight rate in the sense that the owner of a faster ship may obtain a higher freight rate or charter rate or has better chances to find cargo or charters at all. Such considerations may result in an economic speed that might differ from the speed estimated without considering the cargo value [6, 7].

**4.3 Sensitivity of Results of Various Changes**

In order to examine the sensitivity of the economic measure (RFR) to the various parameters, some of these were changed individually.

Effects of change of fuel oil price, round trip distance and boil-off rate on the RFR and optimum speed are shown in Figures 4, 5, 6 respectively.

**4.4 Optimization of Principal Dimensions**

In Figure 7 the required freight rate for a diesel driven 125,000m$^3$ LNG carrier is shown as a function of systematic variations in length, breadth and speed. For all alternatives the block coefficient was adjusted by the program. Depth and draught were kept constant. The optimum ship given these restrictions turned out to have a length of 249 m and a breadth of

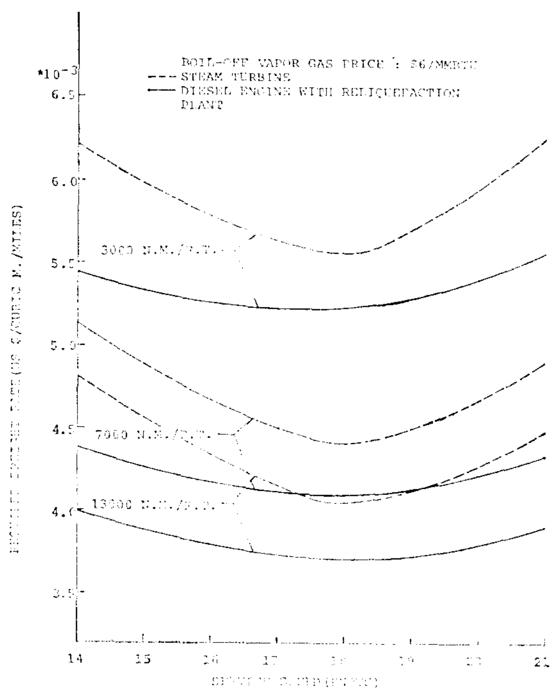


**Fig.** 5 Optimum service speed for different round trip distance of 125,000 cubic meter class LNG carrier

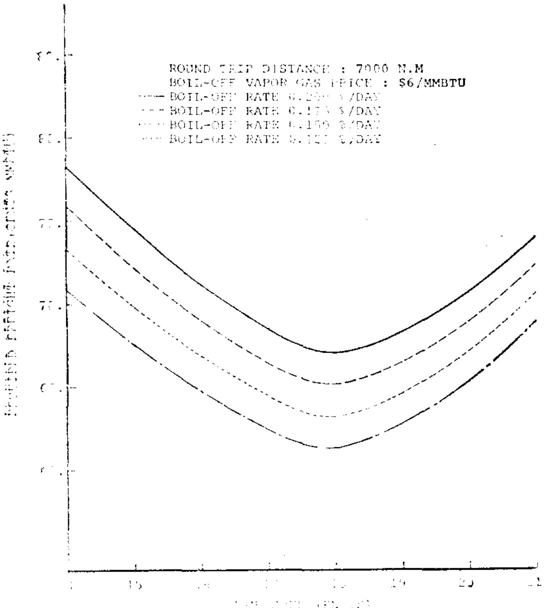


**Fig. 6** Optimum service speed for different boil-off rate of 125,000 cubic meter class LNG carrier with steam turbine propulsion system

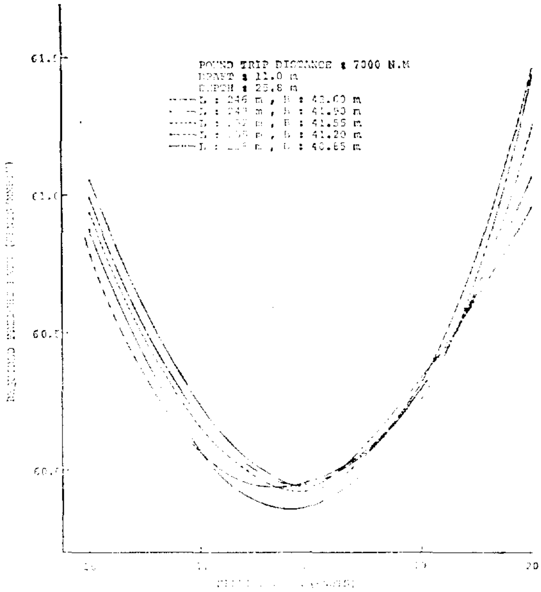

**Fig. 7** Economic evaluation for different L/B ratio of 125,000 cubic meter class LNG carrier with diesel engine and reliquefaction plant

41.90 m in the service speed range of 17~19 knots.

## 5. Conclusion

From the economic evaluation for 125,000m³ LNG carriers it was found that

1) Unless boil-off vapor is to be charged at zero cost, it appears that the LNG carrier of slow speed diesel engine propulsion system with reliquefaction plant will be economically superior to the ship of steam turbine propulsion system.

2) For a ship with steam driven propulsion plant the economic speed seems to be about 17.5~18.5 knots.

3) For a diesel driven ship with reliquefaction plant, the optimum speed seems to be 17.0~18.5 knots.

4) The economic speed is well defined, but rather insensitive to variations of important parameters, even if distinct trends can be observed.

5) The principal characteristics of the projected 125,000m³ LNG carrier seems to be best choice in the service speed range of 17~19 knots.

## References

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## Appendix: Economic Data

The following assumptions are made as basis for the economic evaluation.

*Operating days:* 345 days per year

*Time in ports:* 3 days per voyage

*Round trip distance:* 7,000 nautical miles

*Boil-off rate*

Guaranteed boil-off rate is 0.18 percent of the cargo per 24 hours at 32°C sea temperature and 45°C air temperature.

Adjusting the boil-off rate for average conditions during a complete voyage, the following boil-off figures are assumed:

Loaded condition: 0.166%/day

Ballast condition: 0.04%/day

*Building cost*

The building cost of the steam driven LNG carrier is assumed to be $141.4 million.

For the diesel driven LNG carrier, the additional cost for the reliquefaction plant is assumed to be $6.14 million. For both cases, machinery plant costs are based on the powering of 29,560 HP. An increase in service speed will lead to a higher building cost due to an more expensive propulsion plant.

*Capital cost*

The capital cost is calculated with building cost and capital recovery factor of 12.43 percent based on the ship life of 15 years and the interest rate of 9% per year.

*Crew cost*

Crew cost is assumed to be $2.35 million per year.

*Cost basis of boil-off vapor as fuel*

The pricing of boil-off vapor used as fuel on the steam ships is a subject that cannot be treated objectively. It is a factor of operating cost that is most easily determined as part of contractual negotiations.

The operating costs for the steam driven ship are estimated in two ways:

1) The cost of boil-off vapor used as fuel assumed to be zero.

2) The cost of boil-off vapor used as fuel assumed to be $6.00 per million BTUs.

In the calculation of the cost of boil-off vapor and its use as fuel, it is assumed that all boil-off vapor is paid for at the price shown in 1) or 2) above, but utilization of the vapor is assumed to be 95 percent of the total boil-off, the remaining 5 percent being unusable by reason of venting.

The cost of boil-off vapor does not enter into the operating costs of the diesel driven ship.

*Fuel prices*

| | |
|---|---|
| Heavy Fuel Oil | $186/ton |
| Marine Diesel Oil | $255/ton |
| System Oil | $1,236/ton |
| Cylinder Oil | $1,483/ton |

*Specific fuel consumption*

a) Ship of slow speed diesel engine propulsion system with reliquefaction plant.

Heavy fuel oil at sea: 127.2 g/HP.h

Heavy fuel oil at port: 2.2 ton/h

Marine diesel oil consumption at sea: 0.6 ton/h

System oil: 0.01 ton/h

Cylinder oil: 0.02 ton/h

b) Steam turbine propulsion system

Boil-off gas: 160 mmBTU/h and

Heavy fuel oil: 83 g/HP.h

based on the propulsion power of 26,600HP.

$1m^3 = 24$ mmBTU.

The increase or decrease of propulsion power will lead to higher or lower heavy fuel oil consumption respectively.

*Cost of nitrogen and other consumables:* $350,000 per year.

Liquid nitrogen is required on LNG carriers to provide a medium for control and cargo measurement instrumentation and to permit the routine purging of ship cargo piping before connection and after disconnection of ship's piping and loading arms.

Other consumables include deck, engine and steward's stores, and spare parts for conventional and cargo-related portions of the ship.

*Insurance costs*

P & I insurance estimates are based upon past practice; Hull insurance is based upon a premium of 1.25 percent of vessel cost per year.

*Maintenance and repair costs*

Maintenance and repair costs are projected in accordance with experience-based standard methods. Estimates are made separately for hull and machinery maintenance, and for cargo system maintenance.

*Port costs*

The cost of port charges are assumed to be $130,000 per round trip.

*Miscellaneous costs:*

Miscellaneous costs, which include fleet management and ship classification fees are other unidentified costs.

These minor cost components are estimated in accordance with standard estimating practices.