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GROWTH AND COST FUNCTION OF THE LIQUEFIED NATURAL GAS CARRIER INDUSTRY

by

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GROWTH AND COST FUNCTION OF THE LIQUEFIED NATURAL GAS CARRIER INDUSTRY

A. Historical Background

The natural gas shortage situation led to the introduction in the early sixties of specialized Tankers capable of transporting natural gas in liquid form.

The first liquefaction plant in the world was built at Arzew, Algeria and the first long-term commercial shipments of liquefied methane were undertaken by Societe Nationale Algerienne de Transport et de Commercialization des Hydrocarbures (SONATRACH) in 1964 to Britain and in 1965 to France. The British ships were the "Methane Princess" and "Methane Progress" built by Vickers and Harland A. Wolff respectively, and the French ship was the "Jules Verne" built by Worms.

B. Growth of the Fleet

Since the first commercial shipments of liquefied natural gas in 1964, the size of Liquefied Natural Gas Carriers in service has been increased from 27,000 m^3 to 131,000 m^3. Designs also exist for Ultra Large Liquefied Natural Gas Carriers of 350,000 m^3 (ULLNGC's) which may be built in the late eighties.

1. Growth of Delivered Fleet

The growth of the delivered fleet in the seventies, classified by size, can be traced in Figure II-1.

Figure II-2 shows the time series of the total capacity over the last decade.

At the end of 1971 the picture was very bright for prospective shipowners, both independents and gas companies. The fact that total capacity delivered by the end of 1971 was only 982,400 m^3 is due to the fact that production processes, and especially shipbuilding, are roundabout, meaning time consuming and capital intensive. As we will show in the next paragraphs, the technology of Liquefied Natural Gas Carriers is complicated and advanced. Hence 3-4 years is a conservative estimate of the lead time from order to delivery. Orders for ships delivered during 1971 should have been placed in 1967 or 1968 at the latest. At that time, however, very few visionary entrepreneurs had calculated, or rather speculated, the growing importance of transporting gas by sea.

We see, therefore, that the fleet grew at the end of 1972 to 623,300 m^3 and at the end of 1973 to 739,900 m^3, because of orders placed around 1970. The end of 1974 was very promising; the fleet exceeded the one million mark (1,165,900 m^3); the Japanese market was open and could absorb as much liquefied natural gas as could be found and the U.S. Maritime Administration had given approval entitling Liquefied Natural Gas Carriers to building subsidies.

End of		Capacity (m³ in 000)						
		2-25	25-50	50-75	75-100	100-125	125-150	Total
1971	No m³(000)	2 9.1	8 280.3	3 193	0 0	0 0	0 0	13 482.4
1972	No m³(000)	0 0	8 280.3	3 193	2 150	0 0	0 0	13 623.3
1973	No m³(000)	0 0	9 309.3	3 193	3 237.6	0 0	0 0	15 739.9
1974	No m³(000)	0 0	11 383	3 193	6 469.9	1 120	0 0	21 1,165.9
1975	No m³(000)	0 0	13 449.5	3 193	9 703	1 120	2 250	28 1,715.5
1976	No m³(000)	0 0	13 449.5	3 193	9 703	2 242	5 625	32 2,212.5
1977	No m³(000)	0 0	13 452.5	3 193	9 705.9	3 364	13 1,637	41 3,352.4
1978	No m³(000)	0 0	13 453.3	3 196.5	9 702.7	3 364	19 2,396.3	47 4,112.8
1979	No m³(000)	0 0	13 453.3	3 196.5	9 702.7	3 364	24 3,030.7	52 4,747.2
1980	No m³(000)	0 0	13 453.3	3 196.5	9 702.7	3 364	26 3,283.3	54 5,000

Figure II-1

(Jacobs 1971-8Q; Oil and Gas Journal 1971-80 ; Lloyds Statistics 1979-80).

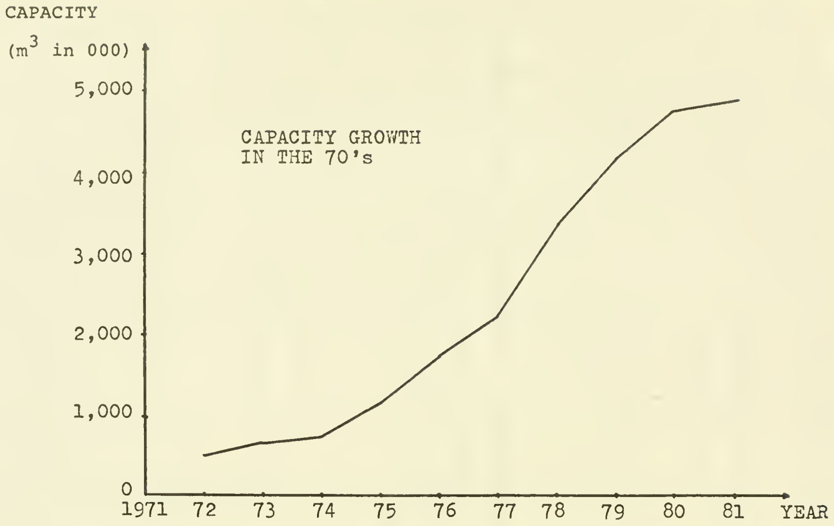
CAPACITY
(m3 in 000)
5,000
4,000
3,000
2,000
1,000
0
CAPACITY GROWTH
IN THE 70's
1971
72
73
74
75
76
77
78
79
80
81
YEAR

Figure II-2

The euphoria of the early seventies is obviously shown in the growth of the fleet in the mid and late seventies. Taking into consideration the normal lead time of 3-4 years from order placement to delivery, as well as financial and regulatory problems that especially in the United States delayed the delivery of some ships, we can explain the growth of the fleet to 1,715,500 m^3 at the end of 1975, to 2,212,500 m^3, at the end of 1976, to 3,352,400 m^3, at the end of 1977 and 4,112,800 m^3 at the end of 1978.

However, the postponement of some liquefied natural gas projects which started in 1974, resulted in embarrassment for those responsible for the tripartite packages, producer-shipper-importer. Although Japan went strongly ahead with the Indonesian project, using ships built in the United States, the Abu Dhabi project to Japan and the Algeria project to the United States ran into difficulties.

The disproportionate influence of environmental groups and the stated policies of the Ford and Carter Administrations towards "energy independence", without having provided the necessary alternatives to imported energy, led to regulatory delays that took a heavy toll on independent shipowners and gas companies. At the end of 1976 five Liquefied Natural Gas Carriers, totaling some 455,000 m^3, or 20% of the delivered fleet, were laid-up for the first time in the short existence of the industry.

Although in 1977 and 1978 Japan kept importing liquefied natural gas at full speed, and so did Europe, the

United States regulatory commissions kept procrastinating, with the result that twelve ships totaling 1,220,000 m^3 were laid up at the end of 1977 and 1978, or 35% and 29% of the delivered fleet respectively.

In 1979 and 1980, the strong position of Japan and Europe seeking additional liquefied natural gas projects, mainly from Indonesia, and the final approval of the United States Californian site at Point Conception for the reception of liquefied natural gas imports, also from Indonesia, brightened the prospects of Liquefied Natural Gas Carriers. At the end of 1979 the fleet totaled 4,742,200 m^3, and at the end of 1980 it reached the 5,000,000 m^3 mark. Only seven ships, totaling 800,000 m^3 or 17% and 16% respectively of the delivered fleet were laid up at the end of 1979 and 1980. However, at the end of 1980 another eight El Paso ships, totaling 1,020,000 m^3 were temporarily idle because of a pricing dispute between El Paso (with United States as arbitrator) and Algeria.

A detailed analysis of the existing fleet of Liquefied Natural Gas Carriers classified by country and year of construction is given in Appendix 1.

2. Rate of Growth of Fleet

In order to understand the growth of the fleet, it is necessary to look at the rate of additions (subtractions) in number and tonnage realized over the previous ten years as shown in Figure II-3.

Figure II-4 shows the time series of the rate of

		Added Capacity (m^3 in 000)						
During		2-25	25-50	50-75	75-100	100-125	125-150	Total
1972	No	(2)	0	0	2	0	0	0
	m^3 (000)	(9.1)	0	0	150	0	0	140.9
1973	No	0	1	0	1	0	0	2
	m^3 (000)	0	29	9	87.6	0	0	116.6
1974	No	0	2	0	3	1	0	6
	m^3 (000)	0	73.7	0	232.3	120	0	426
1975	No	0	2	0	3	0	2	7
	m^3 (000)	0	66.5	0	233.1	0	250	549.6
1976	No	0	0	0	0	1	3	4
	m^3 (000)	0	0	0	0	122	375	497
1977	No	0	0	0	0	1	8	9
	m^3 (000)	0	3	0	2.9	122	1,012	1139.9
1978	No	0	0	0	0	0	6	6
	m^3 (000)	0	0.8	3.5	(3.2)	0	759	760.4
1979	No	0	0	0	0	0	5	5
	m^3 (000)	0	0	0	0	0	634.4	634.4
1980	No	0	0	0	0	0	2	2
	m^3 (000)	0	0	0	0	0	252.6	252.6

Figure II-3.

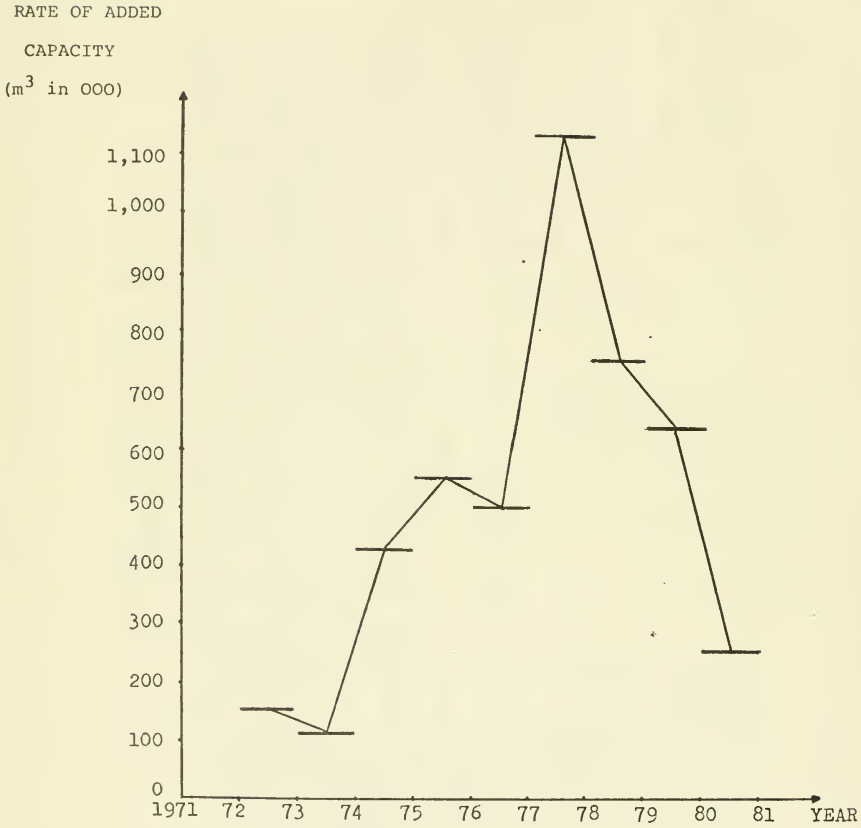
RATE OF ADDED
CAPACITY
(m3 in 000)
1,100
1,000
900
800
700
600
500
400
300
200
100
0
1971
72
73
74
75
76
77
78
79
80
81
YEAR

Figure II-4

added capacity over the last decade.

The cyclical nature of shipbuilding activity has been shown in the Oil Tankers case; (Zannetos, 1965). A similar picture is also clearly shown in the time series of the rate of added capacity for Liquefied Natural Gas Carriers from the end of 1971 to the end of 1980.

The "feast and famine" years, according to Zannetos, are obvious. In the late sixties very few visionary speculators ordered Liquefied Natural Gas Carriers. Hence, taking into account the lead time of 3-4 years from the time an order is placed to the time of delivery, we observe only 140,900 m^3 and 116,600 m^3 of capacity added during 1972 and 1973 respectively.

The bright prospects of the liquefied natural gas projects in the early seventies led to a stampede of orders by both independent shipowners and gas companies. This stampede resulted in new deliveries of 426,000 m^3 in 1974, 549,600 m^3 in 1975, 497,000 m^3 in 1976 and an incredible 1,139,900 m^3 in 1978. This later capacity addition increased the then existing fleet by 50%.

We have already seen in the mid-seventies the reluctance of the United States Government to get more committed to gas imports from OPEC countries, created difficulties for some liquefied natural gas projects with consequent reduction in shipping requirements. This led to cancellations of orders and a declining, although still high, rate of ship added capacity. We observe that 760,400 m^3 were delivered during 1978, 634,400 m^3 during 1979 and 252,600 m^3 during 1980.

A detailed strategic and financial analysis is necessary based on the economics and the technology of the Industry, to shed much more light on the behavior of the participants than these phenomenological conclusions. However, the pattern of confirmed orders outstanding during this decade has also significant explanatory power.

3. Orders Outstanding from 1971 to 1980

The pattern of confirmed orders outstanding in the seventies at the end of each year, classified by expected year of delivery are exhibited in Figure II-5.

In Figure II-6 we show confirmed orders outstanding on top of the existing fleet, at the end of each year, from 1971 to 1980.

In Figure II-7 we show confirmed orders outstanding at the end of each year along with the deliveries (rate of added capacity) during each year, from 1971 to 1980.

The time series of the confirmed orders outstanding compared with existing capacity at the end of each year and with deliveries during each year corroborates the conclusions we drew in the previous paragraph.

At the beginning of the decade of the seventies, the opportunity of transporting gas by sea was realized and at the end of 1971 and 1972 we observe confirmed outstanding orders of 1,958,200 m^3 and 2,346,200 m^3 respectively. The bright prospects of the liquefied natural gas projects in

Year of Expected Delivery		Orders Outstanding at the end of									
		1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1972	No m^3(000)	1 75	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
1973	"	5 307	5 192	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
1974	"	7 542	8 582	7 467	0 0	0 0	0 0	0 0	0 0	0 0	0 0
1975	"	6 550	8 713	9 875	9 793	0 0	0 0	0 0	0 0	0 0	0 0
1976	"	3 365	4 490	10 1,245	8 995	6 745	0 0	0 0	0 0	0 0	0 0
1977	"	1 120	3 370	16 2015	19 2400	14 1764	12 1505	0 0	0 0	0 0	0 0
1978	"	0 0	0 0	6 755	4 509	11 1399	12 1518	12 1518	0 0	0 0	0 0
1979	"	0 0	0 0	0 0	3 385	5 635	10 1276	9 1146	13 1651	0 0	0 0
1980	"	0 0	0 0	0 0	2 260	2 260	3 390	4 510	5 638	7 893	0 0

1981	No m^3(000)	0 0	0 0	0 0	1 130	1 130	1 130	3 388	2 260	6 768	6 768
1982	"	0 0	0 0	0 0	0 0	0 0	0 0	2 260	3 388	2 253	3 378
1983	"	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 260	4 510
Total	"	23 1959	26 2346	38 3738	46 5473	39 4936	38 4820	30 3822	23 2938	17 2174	13 1656

Figure II-5

(Jacobs 1971-1980;Oil and Gas Journal 1971-1980; Lloyd's Statistics 1979-1980)

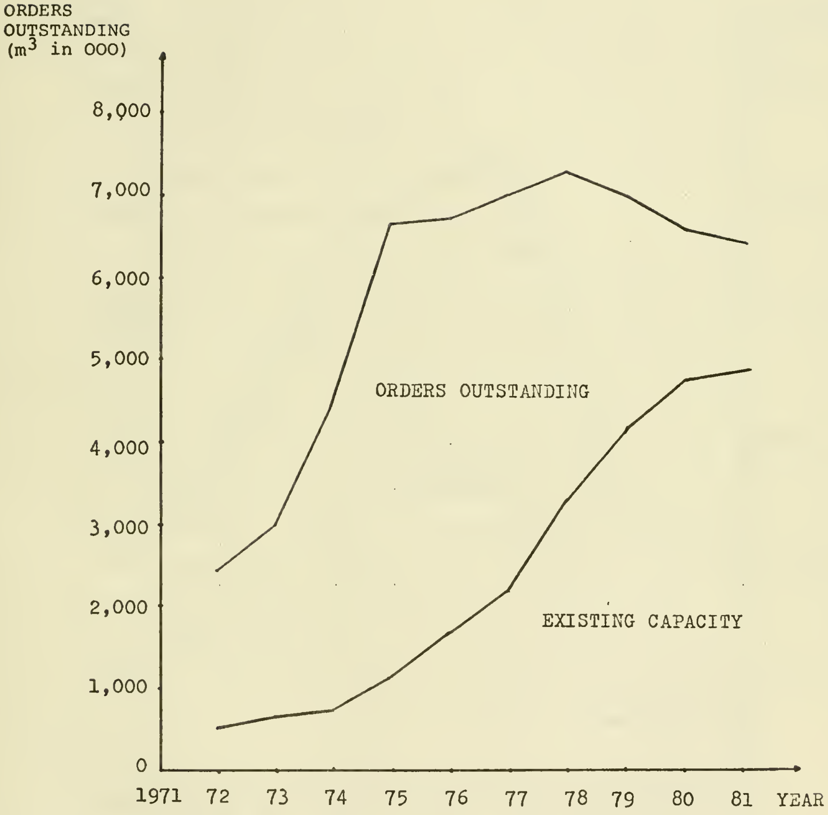
ORDERS OUTSTANDING (m³ in 000)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1971
72
73
74
75
76
77
78
79
80
81
YEAR
ORDERS OUTSTANDING
EXISTING CAPACITY

Figure II-6

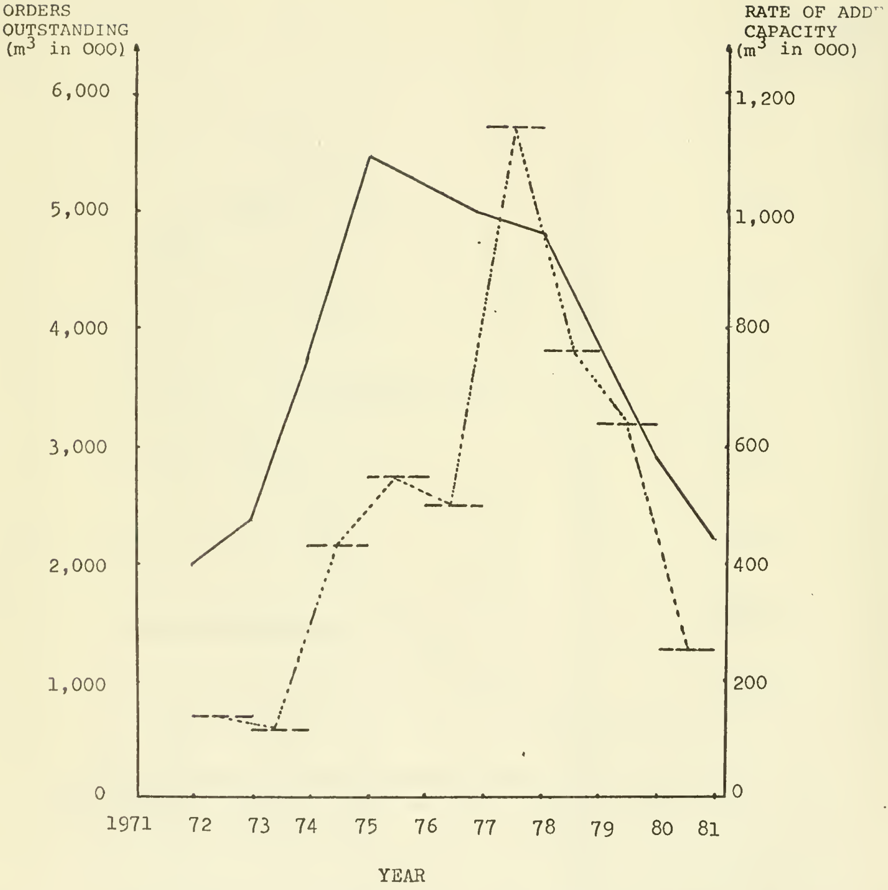
ORDERS
OUTSTANDING
(m^3 in 000)
6,000
5,000
4,000
3,000
2,000
1,000
0
RATE OF ADD
CAPACITY
(m^3 in 000)
1,200
1,000
800
600
400
200
0
1971
72
73
74
75
76
77
78
79
80
81
YEAR

Figure II-7

the early seventies enticed experienced independent shipowners and gas company project managers to place so many orders that created a backlog for shipbuilders all over the world until 1981. At the end of 1973, there were 3,738,500 m^3 in confirmed orders outstanding; at the end of 1974 there were 5,473,100 m^3 confirmed orders outstanding or 500% of the existing fleet (!) and at the end of 1975 there were 4,936,500 m^3 confirmed orders outstanding.

The difficulties that some liquefied natural gas projects ran into, especially in the United States, caused a decline in confirmed orders outstanding in the second half of the seventies. Hence, at the end of 1976, there were 4,820,400 m^3; at the end of 1977 there were 3,822,800 m^3; at the end of 1978, there were 2,938,200 m^3, at the end of 1979 there were 2,174,600 m^3 and at the end of 1980, there were only 1,656,600 m^3 confirmed orders outstanding.

The impact of technological constraints as well as of capital intensity and availability of appropriate shipbuilding facilities on deliveries are conspicuously shown in the confirmed orders outstanding vs. deliveries time series. We observe that, confirmed orders outstanding time series lead deliveries time series by 3-4 years; the orders' cycle looks like the deliveries cycle transposed by a period of 3-4 years. These cycles cover ten years, as opposed to oil tanker cycles that cover three to five years and Stock Market cycles, that cover a few days or months. The reason for the roundaboutedness of the cycle in the case of the Liquefied Natural Carriers is the innovative technology and capital intensity involved, as well as the fact that the relevant market was very new and not adequately organized (information impactedness).

The confirmed orders outstanding and the deliveries per year have traced a full cycle in the seventies. However, we cannot but observe that the participants of the Liquefied Natural Gas Carrier Market exhibited a certain behavior. When the market was bullish in the early seventies, confirmed orders for ships were placed galore, whereas when the market was bearish in the late seventies confirmed orders outstanding fell precipitously. It seems paradoxical that sophisticated independent shipowners and gas company managers did not realize in 1974 that ordering 500% of the then existing fleet would depress the market, at least in the short run.

Out strategic and financial analysis will address this question in depth. We expect that our findings will show: first, a different pattern of behavior among independent shipowners and gas companies because they face different information and opportunity sets and also have different strategic flexibility alternatives; second, the causality of high orders-deliveries may be reversed, namely, that high expected deliveries by opponents in the future in a bullish environment may create price-elastic dynamic expectations that lead to increased orders in the present. Vice versa low expected deliveries in the future, in a bearish environment, may create price-elastic dynamic expectations that lead to decreased orders in the present. All these mean of course that the market is efficient in a dynamic sense only; (Zannetos, 1965 for Oil Tankers; Hsieh, 1981 for Exchange Rates).

C. Cost Function of the Industry

As it has been proven in many instances the cost function approach is probably one of the most useful tools in dealing with production processes. The cost function guarantees minimum cost and incorporates all the economically relevant aspects of the existing technology given a level of desired output and input and output prices. Under the assumptions of economic theory regarding production processes in the case of the Liquefied Natural Carrier Industry, output can be defined as the outcome of the ocean transportation process that results in carrying a quantity of liquefied natural gas from the locus of production and liquefaction to the locus of regasification and consumption. Similar definitions have been given for grain, Benford, 1967 ; for oil, Zannetos 1965 ; and for containers, Caracostas 1979.

The total quantity of liquefied natural gas transported annually by a certain Liquefied Natural Gas Carrier is given by

$$C = \nabla \frac{\left[(F-B) - \frac{F.G.D.}{24\ V} \right] (365-T_0)}{\left(\frac{Di}{12\ V} + T_H \right)}$$

where

C = quantity of liquefied natural gas transported annually (m^3)

$\bar{V}$ = cargo capacity of this Carrier (m^3)

T_o = time spent off-hire because of repairs, major engine overhauls, etc. (days)

F = tank filling coefficient as a percentage of cargo capacity (%)

B = percentage of cargo capacity used in ballast condition (%)

G = boil-off rate as a percentage of cargo capacity per day (% / day)

D_i = one way distance between ports (nautical miles)

V = Carrier speed (knots = nautical miles/hr)

T_H = time spent in harbor

A rigorous proof of this formula is given in Appendix 2, along with empirical values for certain parameters.

1. Capital Costs

The strong shipbuilding movement of the seventies created the fleet that is shown in Appendix 1. In Appendix 3 we have summarized the major design characteristics of the fleet such as main dimensions, power plant, speed and fuel requirements; we classified our data again in terms of country and year of construction. In Appendix 4 we present a statistical summary of the main dimensions and capacities of existing Liquefied Natural Gas Carriers.

a) Tank Design Technology

The hull of any Liquefied Natural Gas Carrier is similar to any other tanker, although Oil Tankers have a less slender configuration because they have lower service speeds. A number of designs and advanced technologies have been applied, however, in the construction of the insulated tanks that contain the liquefied natural gas. Containment systems have been classified by the Intergovernmental Maritime Consultative Organization in Independent Tanks (Types A,B,C), Membrane Tanks, Semi-Membrane Tanks and Integral Tanks; (IMCO, 1976).

i) Independent Tanks

"Independent tanks are self-supporting: they do not form part of the ship's hull and are not essential to the hull strength; they may be:

"Type A - designed primarily using...classical ship-structural analysis procedures."

Containment systems in this class are: Conch; Hitachi (Prismatic); Esso.

"Type B - designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatique life and crack propagation characteristics."

Containment systems in this class are: Moss; Sener; Hitachi (Sphere); Verolme

"Type C - designed using pressure vessel criteria."

Containment systems in this class are: Zellentank Linde; Ocean Phoenix.

ii) Membrane Tanks

"Membrane tanks are non-self-supporting tanks which consist of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane." Containment systems in this class are: Gaz Transport and GT/MDC; Technigaz.

iii) Semi-Membrane Tanks

"Semi-membrane tanks are non-self-supporting tanks in the loaded condition and consist of a layer, parts of which are supported through insulation by the adjacent bull structure, whereas the rounded parts of this layer connecting the above-mentioned parts are designed also to accomodate the thermal and other expansion or contraction."

Containment systems in this class are: - I.H.I. (Ishikawajima Shipyard); BS/Sasebo (Bridgestone/Sasebo Shipyard).

iv) Integral Tanks

"Integral tanks form a structural part of the ship's hull and are influenced in the same manner and by the same loads which stress the adjacent hull structure."

Containment systems in this category are: - Perm-Bar II (Owens-Corning); MDC-3D (McDonnell Douglas); also Shell and others still under development.

A summary of the major characteristics of all existing tank designs, in service, on order or as viable alternatives, is given in Appendix 5. Experience has shown that independent spherical Moss tanks (Type B) and membrane Technique tanks are the most successful designs.

b) Shipbuilding Prices

"Because the contract price is considered confidential information, it has been impossible to put together a reliable and continuous time-series index of the cost of shipbuilding in order to quantify monthly changes;" (Zannetos, 1965, p. 76).

The situation has not changed significantly since these lines were written and especially in the case of technologically innovative and sophisticated Liquefied Natural Gas Carriers. Extreme secrecy covers data relevant to construction costs. There are quite a few reasons behind such a corporate policy. First and most important, although shipbuilding is an internationally competitive industry, in terms of structure, national policies with respect to employment, defense requirements and sheer pride have created a network of construction subsidies that greatly distort the pricing schemes from true economic cost. Second, each contract is subject to intense negotiations that lead to different terms because of different number of vessels ordered, different degree of intervention during construction, options of cancellation and even different existing and expected market conditions each year. Third, construction statistics usually appear some time after contracts have been signed, which is especially true for Liquefied Natural Gas Carriers with all regulatory delays involved.

For our purposes, we used data from a number of sources; published public data from Dart 1970 , Ropers 1972 , Bousba 1973 , Faridany 1974 , Zellner 1977 , Kavanagh 1977 , Fortune 1980 , Oil and Gas Journal 1970-1980 ; published confidential data from Fairplay International Records and Statistics 1970-1980 , United States Maritime Administration 1981 ; private communication with General Dynamics 1979, 1981 , Distrigas 1980, 1981 . Prices quoted in various currencies were translated in U.S. dollars using the time series of currency fluctuations during the seventies.

Data were cross-checked for validity with respect to quotation sources. In the late sixties-early seventies French shipyards had some kind of monopoly power because they were the first to move into the new field based on the new designs developed by various Naval Architects and the cryogenic technology developed by N.A.S.A. In the mid-and late seventies, however, shipbuilders from the United States, Sweden, Norway, and recently Japan gave to the Liquefied Natural Gas Carrier shipbuilding industry the international,competitive character which is inherent to most shipping operations. From a U.S. investor's point of view, whether an independent shipowner or a gas company, it does not matter if the prices of the early seventies reflected only economic cost or economic cost plus some rent, because the structure of the industry was such that rents should be incorporated in the cost function of the industry.

Similarly, from the point of view of the U.S. investor again, subsidies given by the Maritime Administration should be included in the cost function of the industry and lower the capital costs to the level of the world competitive fringe. Actually in order for a subsidy program to be approved under Title XI of the Maritime Administration, the applicant must file the lowest price obtained in a competitive bid outside the United States. Hence we have not adjusted for market power, but we have adjusted for Construction Differential Subsidies (CDS). Our data are shown in Figure II-8 in nominal dollars. Note that we did not adjust for different tank designs because from experience it has been shown that although membrane designs generally cost less in terms of construction materials, they are more labor intensive and more prone to cracks; hence, all designs have almost identical total cost.

Economies of scale realized in shipbuilding costs are manifested in Figure II-9.

Our data amplify the impact that competitive structure in the shipbuilding industry and approval of the Construction Differential Subsidies program had on Liquefied Natural Carrier construction prices decline in the mid-seventies.

c) Financing

The question of financing will be left open and discussed in later research due to its very important nature. Generally 50-80% of the ship value is available

	Shipbuilding cost (million $)										
Capacity (000m3)	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	30	32	35	42	43	30	34	37	42	45	51
50	43	47	52	61	62	43	49	54	61	69	72
75	60	65	72	84	86	60	68	75	85	96	100
125	75	82	90	115	90	76	85	94	106	120	125

Figure II-8

Capacity (000m³)	Average Shipbuilding Cost ($/m³)										
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	857	914	1,000	1,200	1,228	857	971	1,057	1,200	1,285	1,957
50	860	940	1,040	1,220	1,240	860	980	1,080	1,220	1,380	1,440
75	800	866	960	1,120	1,146	300	907	1,000	1,133	1,280	1,333
125	600	656	720	920	720	608	680	752	848	960	1,000

Figure II-9

through bank loans at around 12% in the early seventies and 14% in the late seventies, for 10-16 years; (Zannetos, Papageorgiou and Cambouris 1981). Furthermore, a number of loan structures will be employed.

d) Scrap Value

Because of the relatively short life of the Liquefied Natural Gas Carrier Industry, scrap values simply do not exist. However, we will apply an abandonment value algorithm in our analysis and assume after 20 years scrap values of 10%-30% depending on market conditions.

2. Operating Costs

Operating costs for Liquefied Natural Gas Carriers are approximately equal to Oil Tankers' costs registered under high cost American or Norwegian flags. It means that Liquefied Natural Gas Carriers lie on the right hand tail of the cost distribution of the Tanker industry because regulatory bodies require well trained crews and frequent inspections due to increased concern about safe operations.

The first five - wages and salaries, subsistence and supplies, insurance, maintenance and repair, miscellaneous - of the eight components of operating cost, are usually referred to as "out-of-pocket" costs, because the owner, independent or gas company, assumes them on a cash flow basis, whereas fuel costs and port charges are paid by the charterer, producer's government or gas company, and taxes are a legal liability to the country of the owner's domicile. Only in the case of a "bareboat" charter, the charterer assumes all of the operating costs.

From the point of view of a United States investor operating costs have a different influence on his decision-making as far as cash flow and taxes are concerned. A qualified U.S. owner can file under Title VI of the Maritime Administration for an Operating Differential Subsidy based on the differential between United States operating costs and foreign competitors' operating costs. Hence, operating costs on a cash flow basis should be considered as given in the following paragraphs. For tax calculations, however, we should take into account regulations that will be discussed in the following paragraph about taxes.

a) Wages and Salaries

This component of operating costs differs significantly according to flag of registry. In our case we used data from various sources, published public data from Jacobs 1970-1980 , Drewry 1970-1980 , Arripol 1975 , Polemis 1976 , Zellner 1977 , Serghiou and Zannetos 1978 , Marcus 1980 , Zannetos, Papageorgiou and Cambouris 1981 ; unpublished data from United States Maritime Administration 1975, 1980 , Distrigas 1980, 1981 , Exxon 1981 . Wages and salaries were quoted in nominal dollars.

In Figure II-10 we present our wages and salaries data representing the true economic cost to an American registered vessel. We have adjusted for subsidies and therefore it also represents the high end of the wages and salaries distribution under Norwegian and Japanese registries.

Capacity (000 m^3)	Wages and Salaries (000 $) during 1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	656	682	710	750	793	819	878	1,028	1,164	1,355	1,584
50	656	682	710	750	793	819	878	1,028	1,164	1,355	1,584
75	682	704	738	780	825	860	916	1,098	1,230	1,522	1,870
125	798	830	864	913	965	1,020	1,078	1,288	1,418	1,677	1,980

Figure II-10

However, in our strategic and financial analysis we will also use scenaria, where 50% and 75% of the American wages and salaries given in Figure III-10 will be considered representative of some foreign competitor's wages and salaries costs, e.g., under Liberian flags of registry.

Economies of scale realized in the wages and salaries component of operating costs are manifested in Figure II-11.

The rapid inflation of the wages and salaries component of operating costs in the seventies is shown clearly in Figure II-10. We observe that wages and salaries increased almost 250% from 1970 until 1980, or at an approximately 10% constant rate compounded annually. This real wage rigidity, and even wage increase rigidity since the nominal wage increase in some years exceeded the increase in Consumers' Price Index, is one of the characteristic phenomena of the previous decade that led to the general inflation of those years. As a first approximation, this phenomenon can be attributed to three factors. First, productivity increases in the transportation of liquefied natural gas industry led to higher compensation for people who participated in this industry. Second, increased union power of seamen led to higher compensation for the members of the union because productivity increased and/or because the general level of prices increased. Third, inflationary expectations crept into contract negotiations. The latter is obvious if we look at the structure of wage increase

	Average Wages and Salaries (\$/m^3)										
Capacity (000^{3}m)	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	18.7	19.5	20.3	21.4	22.7	23.4	25.1	29.4	33.3	38.7	45.3
50	13.1	13.6	14.2	15.0	15.9	16.4	17.6	20.6	23.3	27.1	31.7
75	9.1	9.4	9.8	10.4	11.0	11.5	12.2	14.6	16.4	20.3	24.9
125	6.4	6.6	6.9	7.3	7.7	8.2	8.6	10.3	11.3	13.4	15.8

Figure II-11

rates; in 1970-71 the increase was 4%, whereas in 1979-80 it was 18%.

b) Subsistence and Supplies

This component of operating costs does not differ significantly across flags of registry, except for the subsidized U.S. costs. We used published public data from Faridany 1974 , Drewry 1975, 1980 , Arripol 1975 , Polemis 1970 , Zellner 1977 , Serghiou and Zannetos 1978 , Marcus 1980 , Zannetos, Papageorgiou and Cambouris 1981 ; unpublished data from United States Maritime Administration 1975, 1980 , Distrigas 1980, 1981 , Exxon 1981 . All subsistence and supplies data are quoted in nominal dollars.

In Figure II-12 we present our subsistence and supplies data representing the true economic cost to an American registered vessel. We have adjusted for subsidies and therefore these data also represent the high end of the subsistence and supplies distribution for Oil Tankers under most world registries.

Economies of scale realized in the subsistence and supplies component of operating costs are manifested in Figure II-13.

The inflation of subsistence and supplies costs was moderate for small sizes and significant for large sizes. For the 125,000 size, costs increased 218% from 1970 until 1980, or an approximate 8% constant rate compounded annually. Subsistence and supplies costs had no economic justification to inflate very rapidly in the past decade and Figure II-11

Capacity (OOO m^3)	Subsistence and Supplies (OOO$) during										
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	59.6	62.2	65	68.8	72.8	77	81.4	86	90.8	95.8	101
50	59.6	62.2	65	68.8	72.8	77	81.4	86	90.8	95.8	101
75	62.3	66	70	74.3	78.8	83.7	88.9	94.4	100.2	106.3	112.9
125	80	81.2	82.9	85.1	87.8	91	94.7	98.9	103.6	108.8	114.5

Figure II-12

Capacity (000 m^3)	Average Subsistence and Supplies ($\$/m^3$)										
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	1.70	1.78	1.86	1.97	2.08	2.20	2.33	2.46	2.59	2.74	2.89
50	1.19	1.24	1.30	1.38	1.46	1.54	1.63	1.72	1.82	1.92	2.02
75	0.83	0.88	0.93	0.99	1.05	1.12	1.19	1.26	1.34	1.42	1.51
125	0.64	0.65	0.66	0.68	0.70	0.73	0.76	0.79	0.83	0.87	0.92

Figure II-13

corroborates this hypothesis. We expect that our strategic and financial analysis will prove the relatively minor importance of the subsistence and supplies component of operating costs in managerial decision-making.

c) Insurance

This component of operating costs does not differ significantly according to flag of registry. Insurance rates are competitively determined in the London or New York marine insurance markets. Insurance brokers have also considered Liquefied Natural Gas Carriers as high risk ventures and have therefore established uniform insurance rates and policies. There is, however, a significant confusion and disagreement about insurance costs among various data sources. We used unpublished data from the London insurance market (West of England Club), Aegis 1980 , Cayzer Steel Bowater International 1980 and from the New York insurance market, United Brands 1981 . All insurance data were quoted in nominal dollars.

Hence in Figure II-14 we present our insurance data representing the true economic cost to an American registered Liquefied Natural Gas Carrier. We have adjusted for subsidies and therefore these data are also representative of Norwegian and Japanese registries. We will not use scenaria for reduced insurance costs by operators other than above, because U.S. operators may try to insure higher capital values but they have lower premia due to their higher credibility. Hence in the well-informed, competitive marine

		Approximate Capacity (000 m^3)							
		35		50		75		125	
		H+M	P+I	H+M	P+I	H+M	P+I	H+M	P+I
Insurance Costs (000$) during	1970	180	37	284	44.5	402	53	517.5	69
	1971	192	37.5	310	45	435.5	53.5	566	69
	1972	210	38	343	45.5	482.5	54	621	70
	1973	252	38	402.5	46	563	55	793.5	70.5
	1974	258	38.5	409	46	576	55	621	71
	1975	180	39	284	46.5	402	56	524.5	72
	1976	210	39.5	323.5	47	455.5	56.5	586.5	73
	1977	222	39.5	356.5	47.5	502.5	57	648.5	73.5
	1978	252	40	402.5	48	569.5	57.5	731.5	74
	1979	270	40.5	455.5	48.5	643	58	828	75
	1980	306	41	475	49	670	58.5	862.5	75.5

Note: An estimated 35% Back Call on P+I at end of insurance period (1 year).

Figure II-14

		Capacity (000 m^3)							
		35		50		75		125	
		H+M	P+I	H+M	P+I	H+M	P+I	H+M	P+I
Average Insurance Costs ($/m^3)	1970	5.14	1.06	5.68	0.89	5.36	0.71	4.14	0.55
	1971	5.49	1.07	6.20	0.90	5.81	0.71	4.53	0.55
	1972	6.00	1.09	6.86	0.91	6.43	0.72	4.97	0.56
	1973	7.20	1.09	8.05	0.92	7.51	0.73	5.79	0.56
	1974	7.37	1.10	8.18	0.92	7.68	0.73	5.92	0.57
	1975	5.14	1.11	5.68	0.93	5.36	0.75	4.20	0.58
	1976	6.00	1.13	6.47	0.94	6.07	0.75	4.69	0.58
	1977	6.34	1.13	7.12	0.95	6.70	0.76	5.19	0.59
	1978	7.20	1.14	8.05	0.96	7.59	0.77	5.85	0.59
	1979	7.71	1.16	9.11	0.97	8.57	0.77	6.62	0.60
	1980	8.74	1.17	9.50	0.98	8.93	0.78	6.90	0.60

Figure II-15

insurance market, premia are equalized across operators.

For purposes of comparison in terms of relative importance we chose to present separately the Hull and Machinery (H+M), Protection and Indemnity (P+I) and Cargo (C) components of insurance cost.

Economies of scale realized in the insurance cost component of operating costs are manifested in Figure II-15.

The cargo rate component of the insurance costs was quoted to be 0.25% plus 0.0375% for war, strikes, etc. or 0.2875% of the FOB value of the liquefied natural gas aboard. We will include this item in our algorithm for each vessel. The FOB prices of liquefied natural gas were calculated for our on-going research.

The inflation of insurance costs has been minimal and in real terms declined. From Figure II-14 we observe that the H+M component of insurance costs in the seventies closely tracked the market construction value of Liquefied Natural Gas Carriers, whereas the P+I component remained almost constant. The competitive nature of the insurance market explains this behavior of insurance costs.

d) Maintenance and Repairs

This component of operating costs does not differ significantly across flags of registry, except for the subsidized U.S. costs. It differs significantly across operators and actually is one of the most difficult aspects of shipping management; however, it is equalized across registries. We used published public data from Faridany 1974 , Polemis 1976 , Zellner 1977 , Serghiou and Zannetos 1978 , Marcus 1980 , Zannetos, Papageorgiou and Cambouris 1981 ; unpublished data from United States Maritime Administration 1975, 1980 , Distrigas 1980, 1981 , Exxon 1981 , United Brands 1981 . All maintenance and repairs data are quoted in nominal dollars.

In Figure II-16 we present our maintenance and repairs data, representing the true economic cost to an American registered Liquefied Natural Gas Carrier. We have adjusted for subsidies and therefore these data also represent the high end of maintenance and repairs distribution for Oil Tankers under most registries.

Economies of scale realized in the maintenance and repairs component of operating costs are manifested in Figure II-17.

The inflation of maintenance and repairs costs in the seventies was quite severe. The major reasons are the rapid inflation of input materials, inflation of workers' wages in repair shipyards and the reluctance of seamen unions to allow their members to perform maintenance and repairs while at sea. The relative importance of the maintenance and repairs component of operating costs will be further assessed by our strategic and financial analysis.

e) Miscellaneous

This component of operating costs covers costs not included in the previous four categories and does not differ at all across flags of registry, except for the subsidized

Capacity (000 m^3)	Maintenance and Repairs (000$) during										
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	180	198	218	240	263	290	310.5	363	412	479	560
50	180	198	218	240	263	290	310.5	363	412	479	560
75	188	207	228	251	276	304	324	388.5	435	538	661
125	214	235	259	285	313	345	366	435	482.5	580	695

Figure II-16

Capacity (000 m^3)	Average Maintenance and Repairs ($/$m^3$)										
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	5.14	5.66	6.23	6.86	7.51	8.29	8.87	10.37	11.77	13.69	16.00
50	3.60	3.96	4.36	4.80	5.26	5.80	6.21	7.26	8.24	9.58	11.20
75	2.51	2.76	3.04	3.35	3.68	4.05	4.32	5.18	5.80	7.17	8.81
125	1.71	1.88	2.07	2.28	2.50	2.76	2.93	3.48	3.86	4.64	5.56

Figure II-17

U.S. costs. We used published public data from Polemis 1976 , Serghiou and Zannetos 1978 , Zannetos, Papageorgiou and Cambouris 1981 ; unpublished data from United States Maritime Administration 1975, 1980 . All miscellaneous costs data are quoted in nominal dollars.

In Figure II-18 we present our miscellaneous costs data representing the true economic cost to an American registered Liquefied Natural Gas Carrier. We have adjusted for subsidies and therefore these data also represent the high end of the miscellaneous costs distrubtion for Oil Tankers under most registries.

Economies of scale realized in the miscellaneous component of operating costs are manifested in Figure II-19.

The inflation of miscellaneous costs in the seventies was minimal; actually in real terms these costs declined. The reason may be that increased managerial efficiency through operational learning eliminated unexpected costs; (Findlater and Prew 1977).

f) Fuel Costs

The majority of Liquefied Natural Gas Carriers built in the seventies was equipped with steam turbines as our data show in Appendix 3. This type of power plant offered the advantages of high horsepower concentration, as far as the size of the engine room is concerned, and of being able to use the cargo boil-off directly into the boiler. Diesel engine manufacturers started offering the same features only in the late seventies.

Capacity (000 m^3)	Miscellaneous Costs (000 $) during										
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	30	30.5	31	32	32.5	33	33.5	34	35	35.5	36
50	30	30.5	31	32	32.5	33	33.5	34	35	35.5	36
75	30	30.5	31	32	32.5	33	33.5	34	35	35.5	36
125	33.5	34	34.5	35	36	36.5	37	38	38.5	39	40

Figure II - 18

	Average Miscellaneous Costs ($/m^3)										
Capacity (000 m^3)	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
35	0.86	0.87	0.89	0.91	0.93	0.94	0.96	0.97	1.00	1.01	1.03
50	0.60	0.61	0.62	0.65	0.06	0.06	0.67	0.68	0.70	0.71	0.72
75	0.40	0.41	0.41	0.43	0.43	0.49	0.45	0.45	0.47	0.47	0.48
125	0.27	0.27	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.31	0.32

Figure II-19

The fuel consumption for each Liquefied Natural Gas Carrier is given in Appendix 6 and the time series of the price of Bunker C, Heavy Viscosity Fuel (HVF) and Diesel Oil, (Parra, Ramos and Parra 1980 , Drewry 1980) is given in Appendix 6.

The rapid inflation of fuel prices took a heavy toll on fuel costs. However, burning boil-off gas in the boiler reduced these costs significantly, although we have to consider the opportunity cost of boil-off gas. As a matter of fact, Classification Societies allow the use of boil-off gas at sea with a fuel pilot of 10%, but forbid it in port.

We have proved in Appendix 7 that if the boil-off gas is sufficient to provide the Liquefied Natural Gas Carrier with enough fuel during the loaded part of the trip, but only with part of the required fuel (since boil-off rate is halved) during the ballast part of the ship, then the required fuel at sea is approximately 32.5% of the total fuel that would be required if no boil-off took place. Obviously, if the boil-off gas is sufficient to provide the Liquefied Natural Gas Carrier with enough fuel during the ballast part of the trip, then the required fuel at sea is 10% (fuel pilot) of the total fuel that would be required if no boil-off took place.

Fuel consumption at port data are scarce. We used Oil Tanker data equipped with steam turbines with similar horsepowers, (Arripol 1975 , Polemis 1976 , Zannetos, Papageorgiou and Cambouris 1981 , Exxon 1981) in Figure II-20.

	Approximate Capacity (000 m^3)			
	35	50	75	125
Tons in Port (Loading and Discharging)	40	40	50	70

Figure II-20

g) Port Charges

This component of operating costs is defined by the various Port Authorities all over the world. We used published data from Arripol 1975, Platou 1976 and unpublished data from Distrigas 1980, Exxon 1981. Port charges are quoted in nominal dollars.

In Figure II-21 we present our port charges data. It is characteristic that the trades Algeria - U.S. and Indonesia-Japan have approximately similar port charges irrespective of the size of the Liquefied Natural Gas Carriers involved. This means that the management practice of Port Authorities was to establish a uniform policy for handling liquefied natural gas until they learn about the operational difficulties that might arise.

We observe a rapid inflation of port charges that has very little economic justification. It should be noted that this step function from 1974 to 1975 can also be observed in Oil Tanker port charges and in fuel price increases. From 1974 to 1980 we observe a 800% increase in port charges, or an approximately 41% constant rate compounded annually. Although longshoremen union power may be an explanation, the sympathetic movement with fuel prices remains unexplained.

h) Taxes

Shipping operations are by nature international. Hence, the effective tax brackets for income tax purposes vary, as much as the countries of domicile of shipping corporations vary, Price-Waterhouse 1973-1979.

	Port Charges Per Trip (000 $) during									
	1970	1971	1972	1973	1974	1975	1976	1978	1979	1980
All sizes	10	10	10	10	10	47	52	58	72	80

Figure III-21

From a United States corporation point of view, the marginal tax bracket is assumed to be 46%, if accounting profits are positive. Depreciation, interest payments and lease payments are deductible from operating income. Subsidies are not allowed to be included in tax calculations, but since, along with guarantees from the U.S. Government, they result in lowering the market borrowing rate of shipping corporations, the value of subsidized loans will be included in our analysis. Loss carry forwards are restricted to five years only, with the option to use more than one year's losses during a profitable year.

The same institutional environment is used for Norwegian and Japanese corporations. We will use scenaria with reduced costs for Liberian and other corporations, but in that case the marginal tax rate is assumed to be 10% (or 0%), with minimal (or zero) value of resulting tax shields.

D. Long-Run Supply Curve of the Industry

We can use the cost structure of the industry that we have analyzed in order to derive the long run supply curve of the Liquefied Natural Gas Carrier Industry. Since an organized spot market has not developed for Liquefied Natural Gas Carriers in the seventies, and probably will not develop in the eighties, the most relevant concept for long range strategic planning is the long run supply curve. The dynamic long run supply curve must allow for the appropriate risk adjustment of the time value of tax shields, for industry risk adjustment and strategic considerations whereas the static short term supply curve is a function of the out of pocket costs minus lay-up costs for the asset/stock owner, whether it is a gas/oil company or an independent.

These complex issues are explicitly addressed by our further research; however, for expository purposes we present here the quasi-dynamic supply curve of the industry, unadjusted for industry risks and strategic considerations, although tax shields have been discounted at a uniform cost of equity. We therefore present our results based on a present value type of analysis according to the Zannetos, Papageorgiou, Cambouris 1981 exposition for the calculation of the "certainty equivalent" break-even time charter rate.

We used a set of assumptions which our further research qualifies by employing extensive sensitivity analysis. We examined the Algeria (Skikda) - U.S. (Everett) route, whereas we assume a 20% cost of equity, a 12.5% average lending rate, a 13 year loan repayment period and a 32% tax rate. In Figures II-22, II-23 and II-24 we present our dynamic long run supply curve for 1980 in dollars per cubic meter of carrying capacity and in dollars per million BTU for actual vessels with size class characteristics derived from Appendices 1 and 3.

The superiority of larger sizes is apparent. However, the consideration of various components and dimensions of risk is necessary before we draw conclusions for strategic planning and conduct.

Long-Run Supply Curve for 1980

Capacity (000m^3)		Type of Tanks Spherical	Membrane	Prismatic
25.5	\$/m^3			55.338
	\$/MMBTU			2.449
50	\$/m^3		40.443	
	\$/MMBTU		1.790	
75	\$/m^3		30.172	
	\$/MMBTU		1.335	
87.6	\$/m^3	26.460	26.865	
	\$/MMBTU	1.171	1.189	
122	\$/m^3	20.924	20.605	
	\$/MMBTU	0.898	0.912	
125	\$/m^3	19.294	20.302	
	\$/MMBTU	0.884	0.894	

Figure II-22

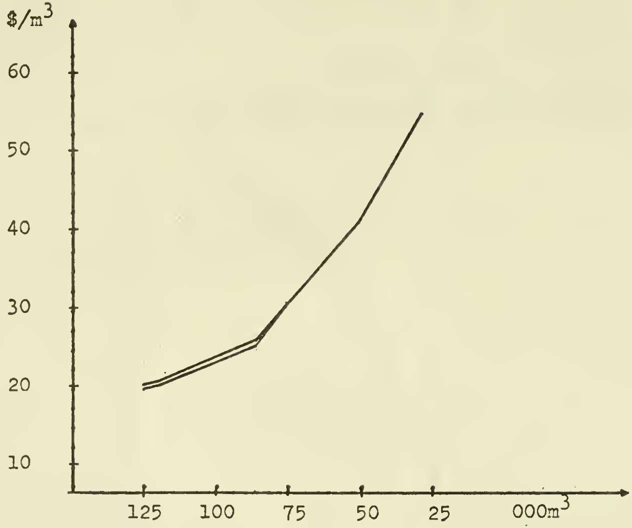

Figure II-23

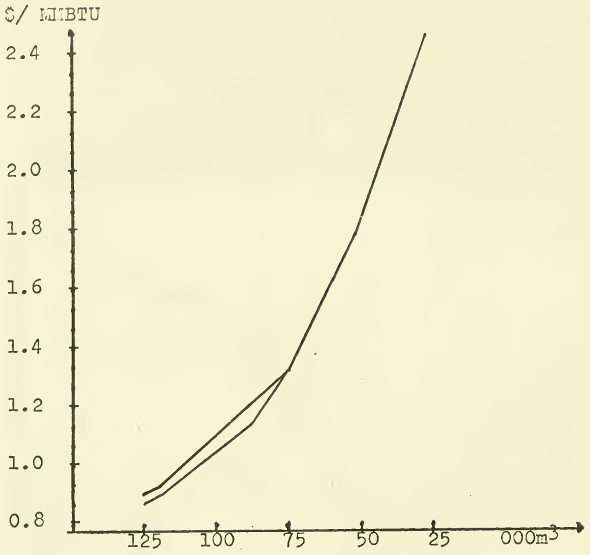

Figure II-24

E. Conclusions

The inception and early development of the Liquefied Natural Gas Carrier industry was the outcome of the derived demand for gas transportation created by the perceived, and realized, natural gas shortages in the United States and in Western Europe. Hence, the concept of a "floating pipeline" was born in order to provide natural gas to the United States, where production to reserve ratios had been falling through the sixties, and to Western Europe, where indigenous production had always been insufficient to satisfy demand.

Demand for imported liquefied gas created the derived demand for vessels capable of carrying gas in liquid form. Supply responded to this demand with a high technology and capital intensive product, the Liquefied Natural Gas Carrier. The relevant technology had been developed in the United States by N.A.S.A. and had been commercially applied by various firms for air liquefaction, transportation and storage. British and French engineers, however, pioneered the implementation of this innovative technology for natural gas ocean transportation in the mid-sixties.

The growth of the fleet of Liquefied Natural Gas Carriers, since feasibility was proven in 1964-65, has been impressive resulting in a total capacity of 5,000,000 m^3 at the end of 1980. We have discussed the roundaboutedness and consequent lumpiness in investment that the advanced and complicated technology of Liquefied Natural Gas Carriers requires. Given that in this case supply was driven by demand, we have shown that the bright prospects of liquefied natural gas projects in the early seventies led to an impressive level of total capacity in the late seventies. However, the technical, regulatory and political problems of liquefied natural gas projects in the late seventies created unemployment for one sixth to one fifth of the then existing fleet.

The expectations of the participants in the Liquefied Natural Gas Carrier Industry are clearly manifested in the time series of the rate of added capacity that we have presented. From a managerial point of view, it is interesting to notice that the rate of added capacity to the industry has completed a full cycle in the seventies. It started at approximately 100,000 m^3 in the early seventies, it increased to 1,100,000 m^3 in 1977-1978, and precipitously fell to approximately 200,000 m^3 in the late seventies.

Capital expansion in an industry reflects management assessment about existing or growing demand and insufficient supply. We have chosen orders outstanding as a surrogate for managerial decision making as far as capital expenditures are concerned. Our results proved that in the early seventies a stampede took place in placing orders which led to record level of added capacity rate. Our results corroborated our hypothesis that due to the roundaboutedness of the relevant technology, orders outstanding would have completed in the seventies a full cycle transposed by a period of 3-4 years from the full cycle of the rate of added capacity.

This pattern for capacity ordering and capacity addition in the industry has been explained by a demand pull argument that also incorporates expectations. Since the demand from existing or confirmed liquefied natural gas projects was lower than the response of supply in the early seventies, we cannot but argue that expectations of some kind inflated the projections of managers on the supply side. Some researchers have hypothesized in the case of Oil Tankers that strategic considerations on the part of oil companies, namely to create overcapacity and secure their supply in the long run, has created this stampede phenomenon. Zannetos, 1966 has explained this complicated phenomenon and convincingly argued for the existence of price-elastic expectations. We can argue that in the Liquefied Natural Gas Carrier Industry gas/oil companies never flooded the market with long-term contracts, but proceeded to order vessels on the basis of confirmed and mainly expected liquefied natural gas projects, which supports the hypothesis of expectations.

The derivation of capital and operating costs for the Liquefied Natural Gas Carrier Industry has been a continuous and diligent research effort. Researchers have always been faced with difficulties in their attempts to compile meaningful data on capital expenditures of firms, and the complex regulatory environment concerning Construction/Operating Differential Subsidies in the United States did not facilitate our task. Combining data from published sources and private communications with industry sources we have developed a time series of capital and operating costs classified by size for the decade 1970-1980.

Our shipbuilding cost time series is a textbook example of the effect that low barriers to entry can have on the pricing policies of an industry. French shipyards which pioneered the high technology application of transporting by sea liquefied gas enjoyed considerable monopolistic power and high prices in the early seventies. Entry barriers, however, through proprietary technology and/or patents were not significant. Our shipbuilding cost data show a drop in prices in 1974 caused by the entry in the market of shipbuilders from the United States, Sweden, Norway and from Japan. A very important aspect determining the future size composition of the fleet is the extensive economies of scale in shipbuilding costs realized by larger sizes.

The major components of operating costs have been wages and salaries, maintenance and repairs and fuel costs. Wages and salaries inflated during the seventies in the same manner as in most industries. Maintenance and repairs costs inflated severely in the seventies and reflected the fact that shipyards could pass their increased costs on to shipping operations. Fuel costs inflated severely in the seventies and reflected the steep increases in the price of heavy viscosity fuel and bunkers. The future size composition of the fleet was determined by the extensive economies of scale in operating costs realized by larger sizes.

Based on this cost structure we derived the long run supply curve of the Liquefied Natural Gas Carrier Industry

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APPENDIX 1

BELGIUM

			Methania		
Service			Bethioua, Algeria to Zeebrugge, Belgium		
Owner			Methania S.A.		
Manager			Belgische Zeevart Maatschappis C.M.B.		
Builder/Country			Chantiers Navals N.V. Boelwerf S.A. Tamse, Belgium		
Year Completed			1978		
Flag of Registry			Belgian		
Cargo Capacity	Liquid	m^3	131,000		
		bbl	823,833		
	Gas	$ft^3 (10^6)$	2,895		

FRANCE

			Jules Verne	Euclides	Descartes
Service			Arzew, Algeria to Le Havre, France	Ethylene/Methane	Charter, Algeria to Everett, Mass.
Owner			Gaz Marine	"Carbocoke" Societa di Navigazone S.p.A.	Gazocean-Armement
Manager			Gazocean	"Carbocoke" Societa di Navigazone S.p.A.	Gazocean-Armement
Builder/Country			Ateliers et Chantiers de la Seine Maritime, Le Trait, France	Ateliers et Chantiers du Havre, Le Havre, France	Chantiers de l'Atlantique St. Nazaire, France
Year Completed			1965	1971	1971
Flag of Registry			French	Italian	French
Cargo Capacity	Liquid	m^3	25,500	4,000	50,000
		bb l	160,364	25,155	314,440
	Gas	$ft^3 (10^6)$	564	88	1105

			Hassi R'Mel	Gadinia	Gadila
Service			Skikda, Algeria to Fos, France	Brunei to Japan	same
Owner			Compagnie Nationale Algerienne de Navigation (CNAN)	Shell Tankers (U.K.) Ltd.	same
Manager			Compagnie Nationale Algerienne de Navigation (CNAN)	Shell Tankers (U.K.)	same
Builder/Country			Constr. Nav. et Ind. de La Mediterranee, La Seyne, France	Chantiers de l'Atlantique St. Nazaire, France	same
Year Completed			1971	1972	1973
Flag of Registry			Algerian	British	same
Cargo Capacity	Liquid	m^3	40,109	75,000	same
		bbl	252,237	471,660	same
	Gas	$ft^3 (10^6)$	886	1,657	same

			Gari	Charles Tellier	Gastrana
Service			Brunei to Japan	Algeria to France	Brunei to Japan
Owner			Shell Tankers (U.K.) Ltd.	Compagnie des Messageries Maritimes	Shell Tankers (U.K.) Ltd.
Manager			Shell Tankers (U.K.)	Compagnie des Messageries Maritimes	Shell Tankers (U.K.)
Builder/Country			Chantiers de l'Atlantique, St. Nazaire, France	Chantiers Naval de La Ciotat, La Ciotat, France	Chantiers de l'Atlantique, St. Nazaire, France
Year Completed			1973	1973	1974
Flag of Registry			British	French	British
Cargo Capacity	Liquid	m^3	75,000	40,081	75,000
		bbl	471,660	252,061	471,660
	Gas	$ft^3 (10^6)$	1,657	886	1,657

			El Paso Paul Kayser	Ben Franklin	Gouldia
Service			Bethioua, Algeria to Cove Point, Md., and Savannah, Ga.	El Paso I. Charter (Arun, Indonesia to California)	Brunei to Japan
Owner			El Paso Paul Kayser Tanker Co.	Gazocean	Shell Tankers (U.K.) Ltd.
Manager			El Paso Marine Co.	Gazocean Armement	Shell Tankers (U.K.)
Builder/Country			Ateliers et Chantiers de Dunkerque et Bordeaux (France-Gironde), Dunkirk, France	Chantiers Naval de La Ciotat, La Ciotat, France	Chantiers Naval de La Ciotat, La Ciotat, France
Year Completed			1975	1975	1975
Flag of Registry			Liberian	French	British
Cargo Capacity	Liquid	m^3	125,000	120,000	75,000
		bb 1	786,100	754,656	471,660
	Gas	$ft^3 (10^6)$	2,762	2,651	1,657

			Isabella	Geomitra	Genota
Service			Spot Market	Brunei to Japan	same
Owner			Middleburgh Shipping Co.	Shell Tankers (U.K.) Ltd.	same
Manager			Middleburgh Shipping Co.	Shell Tankers (U.K.)	same
Builder/Country			Constr. Nav. et Ind. la Mediterranee, La Seyne, France	same	same
Year Completed			1975	1975	1975
Flag of Registry			Liberian	British	British
Cargo Capacity	Liquid	m^3	35,500	77,731	77,731
		bbl	223,252	488,835	488,835
	Gas	$ft^3 (10^6)$	784	1,718	1,718

			1402 ex. Montana	El Paso SONATRACH	Gastor
Service			In Lay up at Shipyard	Bethioua, Algeria to Cove Point, Md., and Savannah, GA.	Spot Market (Arun, Indonesia to Calif.)
Owner			CNIM	El Paso SONATRACH Tanker Co.	Zodiac Shipping N.V.
Manager				El Paso Marine Co.	Gastransco Ltd.
Builder/Country			Constr. Nav. et Ind. la Mediterranee, La Seyne, France	Ateliers et Chantiers de Dunkerque et Bordeaux (France-Gironde) Dunkirk, France	Chantiers de l'Atlantique, France
Year Completed			1975	1976	1976
Flag of Registry			French	Liberian	Panama
Cargo Capacity	Liquid	m^3	35,500	125,000	122,000
		bbl	223,252	786,100	767,234
	Gas	$ft^3(10^6)$	784	2,762	2,696

			Mostefa Ben Boulaid	El Paso Consolidated	Edouard L.D.
Service			El Paso I Charter (Skikda, Algeria to Everett, Ma.)	Bethioua, Algeria to Cove Point, Md., and Savannah, Ga.	same
Owner			Compagnie Nationale Algerienne de Navigation (CNAN)	El Paso Consolidated Tanker Co.	S.A. Louis Dreyfus et Cie.
Manager			Compagnie Nationale Algerienne de Navigation (CNAN)	El Paso Marine Co.	S.A. Louis Dreyfus et Cie.
Builder/Country			Chantiers Naval de La Ciotat, La Ciotat, France	Ateliers et Chantiers de Dunkerque et Bordeaux (France-Gironde), Dunkirk, France	Ateliers et Chantiers de Dunkerque et Bordeaux Dunkirk, France
Year Completed			1976	1977	1977
Flag of Registry			Algerian	Liberian	French
Cargo Capacity	Liquid	m^3	125,260	125,000	129,440
		bbl	787,735	786,100	814,022
	Gas	$ft^3 (10^6)$	2,768	2,762	2,860

			Nestor	Larbi Ben M'Hidi	Tenagu Satu
Service			Spot Market	El Paso I Charter (Skikda, Algeria to Lake Charles, La.)	Sarawak/Japan
Owner			Odyssey Trading Co.	Compagnie Nationale Algerienne de Navigation (CNAN)	Malaysian International Shipping Corp.
Manager			Gastransco Ltd.	Compagnie Nationale Algerienne de Navigation (CNAN)	Malaysian International Shipping Corp.
Builder/Country			Chantiers de l'Atlantique, St. Nazaire, France	Constr. Nav. et Ind. la Mediterranee, La Seyne, France	Ateliers et Chantiers de Dunkerque et Bordeaux Dunkirk, France
Year Completed			1977	1977	1979
Flag of Registry			British	Algerian	Malaysian
Cargo Capacity	**Liquid**	m^3	122,000	129,500	130,000
		bbl	757,234	814,400	817,544
	Gas	$ft^3 (10^6)$	2,696	2,861	2,973

			Bechir Chihani	Tenaga Dua	Mourad Didouche
Service			El Paso I Charter Skikda, Algeria to Lake Charles, La	Sarawak/Japan	Skikda, Algeria to Lake Charles, La
Owner			Compagnie Nationale Algerienne de Navigation (CNAN)	Malaysian International Shipping Corp.	Compagnie Nationale Algerienne de Navigation (CNAN)
Manager			Compagnie Nationale Algerienne de Navigation (CNAN)	Malaysian International Shipping Corp.	Compagnie Nationale Algerienne de Navigation (CNAN)
Builder/Country			Constr. Nav. et Ind. la Mediterranee, La Seyne, France	Ateliers et Chantiers de Dunkerque et Bordeaux Dunkirk, France	Chantiers de l'Atlantique, St. Nazaire, France
Year Completed			1979	1980	1980
Flag of Registry			Algerian	Malaysian	Algerian
Cargo Capacity	Liquid	m^3	130,000	130,000	125,000
		bbl	817,544	817,544	786,100
	Gas	$ft^3 (10^6)$	2,873	2,973	2,762

			Ramdane Abane		
Service			Bethioua, Algeria to Zeebrugge, Belgium		
Owner			Compagnie Nationale Algerienne de Navigation (CNAN)		
Manager			Compagnie Nationale Algerienne de Navigation (CNAN)		
Builder/Country			Chantiers de l'Atlantique St. Nazaire, France		
Year Completed			1980		
Flag of Registry			Algerian		
Cargo Capacity	Liquid	m^3	125,000		
		bbl	786,100		
	Gas	$ft^3 (10^6)$	2,762		

FEDERAL REPUBLIC OF GERMANY

			Melrose	Heriot	Anna Schulte
Service			Ethylene/Methane	same	Methane/Ethylene
Owner			Gibson Gas Tankers Ltd.	same	Bernard Schulte
Manager			Geo. Gibson, Co., Ltd.	Geo. Gibson & Co., Ltd.	
Builder/Country			Heinrich Brand K.G., Oldenburg, Germany	same	same
Year Completed			1971	1972	1973
Flag of Registry			British	British	Germany
Cargo Capacity	Liquid	m^3	2,725	2,469	2,420
		bb 1	17,137	15,527	15,219
	Gas	$ft^3 (10^6)$	60	55	53

			Sophie Schulte	Sophie Schulte	Elisabeth
Service			Ethylene/Methane	same	same
Owner			Bernard Schulte	same	same
Manager					
Builder/Country			Heinrich Brand K.G., Oldenburg, Germany	same	same
Year Completed			1974	same	same
Flag of Registry			German	same	same
Cargo Capacity	Liquid	m^3	2,420	same	same
		bb l	15,219	same	same
	Gas	$ft^3(10^6)$	53	same	same

			Golar Freeze	Hoegh Gandria	
Service			El Paso I Charter	Spot Market	
Owner			Gotaas Larsen	Leif Hoegh & Co.	
Manager					
Builder/Country			Howaldswerke-Deutche Werft Aktiengesellschaft Kiel, Germany	same	
Year Completed			1977	same	
Flag of Registry			Liberian	Norwegian	
Cargo Capacity	Liquid	m^3	125,858	125,820	
		bbl	791,496	791,307	
	Gas	$ft^3 (10^6)$	2,781	2,781	

ITALY

			Esso Brega	Esso Portovenere	Esso Liguria
Service			Marsa el Brega, Libya to La Spezia, Italy	same	same
Owner			Prora Transporti S.p.A.	same	same
Manager			Esso Transport Co., Inc.	same	same
Builder/Country			Italcantieri S.p.A., Genoa, Italy	same	same
Year Completed			1969	1970	1970
Flag of Registry			Italian	same	same
Cargo Capacity	Liquid	m^3	41,000	same	same
		bbl	257,841	same	same
	Gas	$ft^3 (10^6)$	966	906	906

			Sankyo Ethlyene Maru		
Service			Ethylene/ Methane		
Owner			Akashi Kisen K.K.		
Manager			Kyown Sangyo Kaiun K.K.		
Builder/Country			Tagumu Shipyard of Naikai Shipyard & Engineering Co., Ltd., Japan		
Year Completed			1974		
Flag of Registry			Japan		
Cargo Capacity	Liquid	m^3	1,100		
		bb l	6,918		
	Gas	$ft^3 (10^6)$	24		

NORWAY

			Venator	Norman Lady	Lucian
Service			Abu Dhabi to Japan	Abu Dhabi to Japan	Spot Market
Owner			Peder Smedvig	Buries Markes Ltd.	Hilmar Rekstén
Manager					
Builder/Country			Moss-Rosenberg Verft A/S, Moss, Norway	same	same
Year Completed			1973	1973	1974
Flag of Registry			Norwegian	British	Norwegian
Cargo Capacity	Liquid	m^3	29,388	87,600	29,570
		bbl	184,815	550,899	186,086
	Gas	$ft^3 (10^6)$	649	1,936	654

			LNG Pollenger	Hilli	Gimi
Service			Charter, Algeria to Everett, Ma.	Abu Dhabi to Japan	same
Owner			LNG Carriers, Ltd.	Gotaas-Larsen, Inc.	same
Manager			P&O Bulk Shipping Div.		
Builder/Country			Moss-Rosenberg Verft A/S, Stavanger, Norway	same	same
Year Completed			1974	1975	1976
Flag of Registry			British	Liberian	Liberian
Cargo Capacity	Liquid	m^3	87,600	126,277	126,277
		bbl	550,899	793,816	793,816
	Gas	$ft^3 (10^6)$	1,936	2,789	2,789

			Khanuur		
Service			Abu Dhabi to Japan		
Owner			Gotaas-Larsen Inc.		
Manager					
Builder/Country			Moss-Rosenberg Verft A/S, Stavanger, Norway		
Year Completed			1977		
Flag of Registry			Liberian		
Cargo Capacity	Liquid	m^3	126,360		
		bbl	794,653		
	Gas	$ft^3 (10^6)$	2,792		

SPAIN

			Laieta	Saint Jordi	
Service			Marsa el Brega Libya to Barcelona, Spain	Ethylene/Methane	
Owner			Nav. do Productos	same	
Manager			Esso International Services		
Builder/Country			Ast. y Tall del Norooste El Perrol, Spain	Tomas Ruiz de Velasco S.A. Bilbao, Spain	
Year Completed			1970	1977	
Flag of Registry			Spanish	Spanish	
Cargo Capacity	Liquid	m^3	40,000	5,000	
		bb l	251,352	31,444	
	Gas	$ft^3(10^6)$	884	110	

SWEDEN

			Arctic Tokyo	Polar Alaska	559
Service			Kenai, Alaska to Negishi, Japan	Kenai, Alaska, to Negishi, Japan	
Owner			Arctic LNG Transportation Co.	Polar L.N.G. Shipping Corp.	Roderi AB Molmoil
Manager			Arctic LNG Transportation Co.	Polar L.N.G. Shipping Corp.	Roderi AB Molmoil
Builder/Country			Kockums M/V A/B, Malmo, Sweden	same	same
Year Completed			1969	same	1979
Flag of Registry			Liberian	same	Swedish
Cargo Capacity	Liquid	m^3	71,500	same	133,000
		bbl	449,649	same	836,410
	Gas	$ft^3 (10^6)$	1,580	same	2,939

			564		
Service					
Owner			Roderi AB Molmoil		
Manager			Roderi AB Molmoil		
Builder/Country			Kockums M/V A/B, Malmo, Sweden		
Year Completed			1979		
Flag of Registry			Swedish		
Cargo Capacity	Liquid	m^3	133,000		
		bbl	836,410		
	Gas	$ft^3 (10^6)$	2,939		

UNITED KINGDOM

			Methane Progress	Methane Princess	
Service			Arzew, Algeria to Canvey, U.K.	same	
Owner			Methane Tanker Finance Ltd.	Conch Methane Tankers Ltd.	
Manager			Shell Tankers (U.K.) Ltd.	same	
Builder/Country			Harland & Wolff, Ltd. Belfast, U.K.	Vickers-Armstrong (S.Bs.) Ltd., Barrow, U.K.	
Year Completed			1964	1964	
Flag of Registry			British	British	
Cargo Capacity	Liquid	m^3	27,400	27,400	
		bbl	172,313	172,313	
	Gas	$ft^3 (10^6)$	605	605	

UNITED STATES OF AMERICA

			Massachusetts (Barge)	LNG Aquarius	LNG Aries
Service			Spot Market	Indonesia to Japan	Indonesia/Japan
Owner			Coastal Cryogenics Tankship Corp.	Wilmington Trust Co.	same
Manager			Paul Johnson Associates, Inc.	Energy Transportation Co.	same
Builder/Country			Todd Shipyards Corp., U.S.A.	General Dynamics Corp., Quincy Mass., U.S.A.	same
Year Completed			1973	1977	same
Flag of Registry			American	same	same
Cargo Capacity	Liquid	m^3	5,088	125,000	same
		bbl	31,997	786,110	same
	Gas	$ft^3 (10^6)$	112	2,762	same

			LNG Capricorn	LNG Gemini	LNG Leo
Service			Indonesia/Japan	same	same
Owner			Wilmington Trust Co.	Patriot I Shipping Corp.	Partiot II Shipping Corp.
Manager			Energy Transportation Co.	same	same
Builder/Country			General Dynamics Corp., Quincy, Mass., U.S.A.	same	same
Year Completed			1978	same	same
Flag of Registry			American	same	same
Cargo Capacity	Liquid	m^3	125,000	same	same
		bb l	786,110	same	same
	Gas	$ft^3 (10^6)$	2,762	same	same

			El Paso Southern	LNG Taurus	LNG Virgo
Service			Algeria to Cove Point, Md. and Savannah, Ga.	Indonesia/Japan	same
Owner			El Paso Arzew Tanker Co.	Patriot III Shipping Corp.	Patriot IV Shipping Corp.
Manager			El Paso Marine Co.	Energy Transportation Co.	same
Builder/Country			Newport News Shipbuilding & Dry Dock Co., Virginia, U.S.A.	General Dynamics Corp., Quincy, Mass., U.S.A.	same
Year Completed			1978	1979	same
Flag of Registry			American	same	same
Cargo Capacity	Liquid	m^3	126,540	125,000	same
		bbl	795,785	786,100	same
	Gas	$ft^3 (10^6)$	2,796	2,762	same

			LNG Libra	LNG Libra	El Paso Howard Boyd
Service			Indonesia/Japan	Indoensia/Japan	Algeria to Cove Point, Md. and Savannah, Ga.
Owner			Patriot V Shipping Corp.	Patriot VI Shipping Corp.	El Paso Arzew Tanker Co.
Manager			Energy Transportation Co.	Energy Transportation Co.	El Paso Marine Co.
Builder/Country			General Dynamics Corp., Quincy, Mass., U.S.A.	General Dynamics Corp., Quincy, Mass., U.S.A.	Newport News Shipbuilding & Dry Dock Co., Virginia, U.S.A.
Year Completed			1979	same	same
Flag of Registry			American	same	same
Cargo Capacity	Liquid	m^3	125,000	same	126,020
		bbl	786,100	same	792,515
	Gas	$ft^3 (10^6)$	2,762	same	2,785

			El Paso Columbia	El Paso Savannah	El Paso Cove Point
Service			Algeria to Cove Point, Md. and Savannah, Ga.	same	same
Owner			El Paso Columbia Tanker	El Paso Savannah Tanker Co.	El Paso Cove Point Tanker Co.
Manager			El Paso Marine Co.	same	same
Builder/Country			Avondale Shipyards, Inc., New Orleans, LA., U.S.A.	same	same
Year Completed			1980	same	same
Flag of Registry			American	same	same
Cargo Capacity	Liquid	m^3	127,800	same	same
		bbl	803,709	same	same
	Gas	$ft^3(10^6)$	2,824	same	same

			Lake Charles	Louisiana
Service			Skikda, Agleria to Lake Charles, Ga.	same
Owner			Lachmar	same
Manager			Energy Transportation Co.	same
Builder/Country			General Dynamics Corp., Quincy, Mass., U.S.A.	same
Year Completed			1980	same
Flag of Registry			same	same
Cargo Capacity	Liquid	m^3	125,000	same
		bbl	786,100	same
	Gas	$ft^3(10^6)$	2,762	same

(Institute of Gas Technology [1970-80]; Oil and Gas Journal [1970-80]; Ropers [1972]; Farridany [1974]; American Gas Association [1977]; Lloyd's Statistics [1979-80])

APPENDIX 2

Let us have, TV = volume of liquefied natural gas per trip loaded on the Carrier at the liquefaction plant (m^3).

TG = total volume of boil-off gas (m^3).

N = number of round trips per year

C, ∇, To, F,B,G,Di, V, T_H = as defined in the text.

The total volume of the boil-off gas per trip is given by the relation

$$TG = G \cdot F \cdot \nabla \cdot \frac{Di}{24\ V}$$

The number of round trips per year is given by the relation

$$N = \frac{365 - To}{2 \cdot \frac{Di}{V \cdot 24} + T_H}$$

The volume of liquefied natural gas delivered per trip is the difference between the volume loaded and the volumes of boiloff and ballast. Hence, the total volume of LNG delivered per year is given by the relation

$$C = (TV - \text{ballast} - \text{boil-off}) \cdot N$$

or $$C = (F\ \nabla - B \cdot \nabla - G \cdot F \cdot \nabla \cdot \frac{Di}{24\ V})\ N$$

or $$C = [(F-B) - GF\ \frac{Di}{24\ V}] \cdot \nabla \cdot \frac{365 - To}{\frac{Di}{12V} + T_H}$$

$$C = \nabla \cdot \frac{(365-To)\ \ [(F-B) - \frac{FG\ Di}{24V}]}{(\frac{Di}{12V} + T_H)}$$

Using detailed trading performance data for each ship for 1974, 1975, 1978, 1979,(Drewry 1976; 1980) we estimated off-hire time and time spent in harbor. Our calculations showed insensitivity of the data with respect to year and size of the Liquefied Natural Gas Carrier used in the particular trade route.

Hence we have over the years:

Average time spend off-hire, To = 34 days with a standard deviation of 17.4 days.

Average time spent in port, T_H = 4.80 days with a standard deviation of 1.05 days.

The Inter-Governmental Maritime Consultative Organization Code of 1975 defines the following filling coefficients based on the tank designs discussed in the text, Inter-Governmental Maritime Consultative Organization 1975 .

For spherical tanks, Fs = 99.5%

For membrane tanks, Fm = 98%

For prismatic, self supporting tanks, Fp = 97%

The United States Coast Guard also defines the ballast requirement, because part of the cargo has to remain in the ship in order to keep tanks at a low temperature;(United States Coast Guard 1980).

For all tank designs, B = 5%

The boil-off rate is a very important parameter in Liquefied Natural Gas Carrier design because of the use of natural gas in the propulsion system. Data are confidential and the various designs are protected with patents. We determined the boil-off rates to be as follows;(Ropers 1972 , Faridany 1974).

For spherical and membrane tanks, $G = 0.25 \cdot \left(\frac{\nabla}{120,000} \right)^{-1/3}$ (%/day)

For prismatic, self-supporting tanks, $G = 0.14 \cdot \left(\frac{\nabla}{125,000} \right)^{-1/3}$ (%/day)

(with longer cool-down and warm-up times).

In the ballast condition the boil-off rate is assumed to be half of the above loaded condition.

The distances between major ports used in liquefied natural gas transportation are given below.

TRADE	EXPORT TERMINAL	IMPORT TERMINAL	ROUTE DISTANCE (Nautical Miles) (One Way)
ALGERIA - UK	Arzew	Canvey Island	1,570
-FRANCE	Arzew	Le Havre	1,410
-FRANCE	Skikda	Fos	400
-FRANCE	Arzew	Montoire	1,200
-U.S.	Skikda	Everett	3,680
-U.S.	Arzew	Cove Point/ Savannah	3,720/ 3,920
-U.S.	Skikda	Lake Charles	5,340
-SPAIN	Skikda	Barcelona	400
-WEST GERMANY	Arzew	Wilhelmshaven	1,850
-HOLLAND	Arzew	Elmshaven	1,600

TRADE	EXPORT TERMINAL	IMPORT TERMINAL	ROUTE DISTANCE (Nautical Miles) (One Way)
LIBYA-ITALY	Marsa el Brega	La Spezia	1,000
-SPAIN	Marsa el Brega	Barcelona	1,060
BRUNEI-JAPAN	Lumut	Negishi/ Sodegaura/Semboku	2,200
ALASKA-JAPAN	Kensi	Negishi	3,300
-U.S.	Nikisi	Point Conception	2,200
ABU DHABI -JAPAN	Das Island	Tokyo	6,500
INDONESIA -JAPAN	Arun Bontang	Osaka	3,220/ 2,600
-U.S.	Arun	Point Conception	8,000
MALAYSIA -JAPAN	Bintulu (Sarawak)	Negishi	2,480

APPENDIX 3

BELGIUM

		Methania				
Year Delivered		1978				
Length (ft)		918' 6"				
Breadth (ft)		136' 6"				
Draft (ft)		36' 9"				
Tanks	No	5				
	Type	Gaz Transport Membrane				
Propulsion	Type	Steam Turbine Stal Laval				
	HP	45,000				
Speed (knots)		19				
Fuel (tons/day)		20 HVF				

FRANCE

		Jules Verne	Euclide	Descartes	Hassi R'Mel	Gadinia
Year Delivered		1965	1971	1971	1971	1972
Length (ft)		659' 6"	351' 1"	721' 10"	656'	852' 2"
Breadth (ft)		81' 6"	47' 1"	104' 6"	96' 2"	114' 9"
Draft (ft)		24' 8"	20'	27' 7"	27' 11"	37' 9"
Tanks	No	7	4	6	6	5
	Type	Cylind., Vert., Insulated, nickel steel	Spherical, 9% Nickel Steel	Technigaz Membrane	Gaz Transport Membrane	Technigaz Membrane
Propulsion	Type	2 Steam Turbines, Parsons	2 S.A. 6-Cylinder Sulzer	Steam Turbine, Stal Laval	Steam Turbine	Steam Turbine, Stal Laval
	HP	11,500	5,500	17,700	16,250	20,800
Speed (knots)		17.5	15.5	17	17.6	18.2
Fuel (tons/day)		85 Fuel Gas	19 HV Fuel	105		107 HV Fuel

		Gadila	Gari	Charles Tellier	Gastrana	El Paso Paul Kayser
Year Delivered		1973	same	same	1974	1975
Length (ft)		852' 2"	same	646'	852' 2"	920' 8"
Breadth (ft)		114'	same	95' 11"	114'	136' 6"
Draft (ft)		37' 9"	same	26' 9"	37' 9"	36' 1"
Tanks	No	5	same	same	same	same
	Type	Technigaz Membrane	same	same	same	Gaz Transport Membrane
Propulsion	Type	Steam Turbine, Stal Laval	same	same	same	same
	HP	20,800	same	16,800	20,800	45,000
Speed (knots)		18.2	same	17.5	18.2	18.5
Fuel (tons/day)		107 HV Fuel	same	30	107 HV Fuel	210

		Ben Franklin	Gouldia	Isabella	Geomitra	Genota
Year Delivered		1975	same	same	same	same
Length (ft)		895'	844' 2"	651' 3"	830' 1"	852' 2"
Breadth (ft)		134' 8"	114' 2"	87'	114' 2"	114'
Draft (ft)		36' 4"	37' 9"	14' 3"	31'	same
Tanks	No	6	5	same	same	same
	Type	Technigaz Membrane	same	Gaz Transport Membrane	same	same
Propulsion	Type	Steam Turbine, Stal Laval	same	Steam Turbine, Blehm & Voss	Steam Turbine, Stal Laval	same
	HP	33,650	20,800	23,000	20,800	same
Speed (knots)		18.5	18.2	20.2	18.2	same
Fuel (tons/day)		180	110 HV Fuel		HV Fuel	same

		1402 ex. Montana	El Paso Sonatrach	Gastor	Mostefa Ben Boulaid	Bachir Chihani
Year Delivered		1976	1976	same	same	1977
Length (ft)		651' 3"	920' 8"	900' 4"	895' 1"	924' 3"
Breadth (ft)		87'	136' 6"	137' 10"	134' 6"	136' 6"
Draft (ft)		34' 3"	36' 1"	37' 1"	40'	35' 7"
Tanks	No	5	5	6	6	5
	Type	Gaz Transport Membrane	Gaz Transport	Gaz Transport Membrane	Technigaz Membrane	Gaz Transport Membrane
Propulsion	Type	Steam Turbine, Blohm & Voss	Steam Turbine, Stal Laval	same	same	Steam Turbine, General Elec.
	HP	23,000	45,000	34,000	32,400	36,000
Speed (knots)		20.2	18.5	19	19.8	19.4
Fuel (tons/day)			185	180		

		El Paso Consolidated	Edouard L.D.	Nestor	Larbi Ben M'Hidi	Tenagu Satu
Year Delivered		1977	same	same	same	1979
Length (ft)		920' 8"	same	900' 4"	924' 3"	924' 3"
Breadth (ft)		136' 6"	same	137' 10"	136' 6"	136' 6"
Draft (ft)		36' 1"	same	37' 1"	35' 7"	36' 1"
Tanks	No	5	5	6	5	5
	Type	Gaz Transport Membrane	same	same	same	same
Propulsion	Type	Steam Turbine, Stal Laval	same	same	Steam Turbine, General Elec.	Steam Turbine, Stal Laval
	HP	45,000	same	34,000	36,000	45,000
Speed (knots)		18	20	19	19.4	20.7
Fuel (tons/day)		185	210	180		

		Tenaga Dua	Mourad Didouche	Ramdane Abane		
Year Delivered		1980	same	same		
Length (ft)		924' 3"	902' 3"	902' 3"		
Breadth (ft)		136' 6"	137'	same		
Draft (ft)		36' 1"	36' 9"	36' 11"		
Tanks	No	5	6	6		
	Type	Gaz Transport Membrane	same	same		
Propulsion	Type	Steam Turbine, Stal Laval	Steam Turbine	same		
	HP	45,000	34,000	same		
Speed (knots)		20.7	20	same		
Fuel (tons/day)						

W. GERMANY (FEDERAL REPUBLIC)

		Melrose	Heriot	Anna Schulte	Sophie Schulte	Elisabeth
Year Delivered		1971	1972	1973	1974	1974
Length (ft)		285' 3"	257' 7"	256' 2"	same	same
Breadth (ft)		42' 8"	41' 8"	41' 9"	same	same
Draft (ft)		18'	17'	20' 4"	same	same
Tanks	No	3	2	same	same	same
	Type	Semi- refrigerated LGA Zellentank	same	same	same	same
Propulsion	Type	4 S.A., 8 Cylinder MWM	same	same	same	same
	HP	2,500	2,400	same	same	same
Speed (knots)		13.5	14.5	13.5	same	same
Fuel (tons/day)		9 Gas-Oil	9 Diesel Oil			

		Golar Freeze	Hoegh Gandria			
Year Delivered		1977	same			
Length (ft)		942' 11"	943' 5"			
Breadth (ft)		142' 8"	142' 5"			
Draft (ft)		37' 10"	37' 9"			
Tanks	No	5	same			
	Type	Insulated, Spherical Aluminum	same			
Propulsion	Type	Steam Turbine, General Electric	same			
	HP	40,000	same			
Speed (knots)		20	same			
Fuel (tons/day)			160			

ITALY

		Esso Brega	Esso Portovenere	Esso Liguria		
Year Delivered		1969	1970	1970		
Length (ft)		682'	same	same		
Breadth (ft)		96'	same	same		
Draft (ft)		28' 6"	same	same		
Tanks	No	4	same	same		
	Type	Rectangular, Insulated, Aluminum	same	same		
Propulsion	Type	Steam Turbine, De Laval	same	same		
	HP	15,000	same	same		
Speed (knots)		18	same	same		
Fuel (tons/day)		90	same	same		

JAPAN

		Sankyo Ethylene Maru				
Year Delivered		1974				
Length (ft)		213' 3"				
Breadth (ft)		42' 8"				
Draft (ft)		13' 5"				
Tanks	No	1				
	Type	Spherical Aluminum 9% Nickel Steel, Rectangular				
Propulsion	Type	4 S.A., 6 Cylinder Daihatsu				
	HP	1,300				
Speed (knots)		10				
Fuel (tons/day)		5.7				

NORWAY

		Venator	Norman Lady	Lucian	LNG Pollenger	Hilli
Year Delivered		1973	1973	1974	1974	1975
Length (ft)		595' 8"	818' 7"	595' 6"	858' 1"	963' 9"
Breadth (ft)		95' 2"	131' 3"	95' 2"	131' 3"	136' 6"
Draft (ft)		29'	34' 5"	29'	34' 5"	37' 9"
Tanks	No	4	5	4	5	6
	Type	Insulated, Spherical Aluminum	Insulated, Spherical Nickel Steel	Insulated, Spherical Aluminum	Spherical, Insulated Nickel Steel	Spherical, Insulated, Aluminum
Propulsion	Type	Z.S.A. 7-Cylinder Sulzer	Steam Turbine, General Electric	Gas Turbine General Electric	Steam Turbine, General Electric	same
	HP	20,000	30,000	20,000	30,000	40,000
Speed (knots)		19.5	19.5	19.0	19.5	19.7
Fuel (tons/day)		72 HV Fuel	164	83 Fuel Oil	164	

		Gimi	Khannur			
Year Delivered		1976	1977			
Length (ft)		963' 9"	same			
Breadth (ft)		136' 6"	same			
Draft (ft)		37' 9"	same			
Tanks	No	6	same			
	Type	Spherical, Insulated, Aluminum	same			
Propulsion	Type	Steam Turbine, General Electric	same			
	HP	40,000	same			
Speed (knots)		19.7	same			
Fuel (tons/day)						

SPAIN

		Laieta	Saint Jordi			
Year Delivered		1970	1977			
Length (ft)		682'	359' 11"			
Breadth (ft)		96'	60' 10"			
Draft (ft)		28' 6"	20' 6"			
Tanks	No	4				
	Type	Rectangular, Insulated, Aluminum	Spherical, Insulated, 9% Nickel Steel			
Propulsion	Type	Steam Turbine, De Laval	B & W			
	HP	15,000	15,000 Brake hp			
Speed (knots)		18	14.5			
Fuel (tons/day)			16 Diesel Oil			

SWEDEN

		Arctic Tokyo	Polar Alaska	559	564	
Year Delivered		1969	same	1979	same	
Length (ft)		798' 4"	799'	941' 1"	same	
Breadth (ft)		111' 6"	same	137' 1"	same	
Draft (ft)		32' 11"	32' 9"	35' 1"	same	
Tanks	No	6	same	5	same	
	Type	Gaz Transport Membrane	same	same	same	
Propulsion	Type	Steam Turbine	same	same	Kockums s tal Laval	
	HP	20,000	same	40,800	same	
Speed (knots)		18.25	17	20.1	same	
Fuel (tons/day)		Fuel Oil as a Complement to Evaporated Gas	same	202	same	

UNITED KINGDOM

		Methane Progress	Methane Princess			
Year Delivered		1964	same			
Length (ft)		621'	same			
Breadth (ft)		81'	same			
Draft (ft)		26'	same			
Tanks	No	9	same			
	Type	Rectangular, Insulated, Aluminum	same			
Propulsion	Type	2 Steam Turbines	same			
	HP	12,500	same			
Speed (knots)		17.25	same			
Fuel (tons/day)		75 Fuel Oil	same			

UNITED STATES OF AMERICA

		Massachusetts (Barge)	LNG Aquarius	LNG Aries	LNG Capricorn	LNG Gemini
Year Delivered		1973	1977	1977	1978	1978
Length (ft)		297'	936'	same	same	same
Breadth (ft)		60'	143' 10"	same	same	same
Draft (ft)		15' 6"	36"	same	same	same
Tanks	No	4	5	same	same	same
	Type	Cylindrical, Insulated, Aluminum	Spherical, Insulated, Nickel Steel	same	same	Insulated Spherical Aluminum
Propulsion	Type	Non Self-Propelled	Steam Turbine, General Electric	same	same	same
	HP		43,000	same	same	same
Speed (knots)			20	same	same	same
Fuel (tons/day)						

		LNG Leo	El Paso Southern	LNG Taurus	LNG Virgo	LNG Libra
Year Delivered		1978	same	1979	same	same
Length (ft)		936'	948' 5"	936'	same	same
Breadth (ft)		143' 10"	135'	143' 10"	same	same
Draft (ft)		36'	same	same	same	same
Tanks	No	5	same	same	same	same
	Type	Insulated, Spherical Aluminum	Prismatic, Insulated, Stainless Steel	Insulated Spherical Aluminum	same	same
Propulsion	Type	Turbine General Electric	Steam Turbine De Laval	Steam Turbine, General Electric	same	same
	HP	43,000	40,560	43,000	same	same
Speed (knots)		20	18.5	20	same	20.4
Fuel (tons/day)		Fuel Oil Natural Gas	190 Fuel Oil	Fuel Oil Natural Gas	same	same

		El Paso Arzew	El Paso Howard Boyd	Lake Charles	Louisiana	El Paso Columbia
Year Delivered		1979	same	1980	same	same
Length (ft)		948' 6"	same	936 '	same	931' 5"
Breadth (ft)		135'	same	143' 10"	same	140' 5"
Draft (ft)		36'	same	same	same	same
Tanks	No	5	same	5	same	same
	Type	Prismatic, Insulated, Stainless Steel	same	Insulated Spherical Aluminum	same	Rectangular, Insulated, Aluminum
Propulsion	Type	Steam Turbine, De Laval	same	Steam Turbine, General Electric	same	Steam Turbine
	HP	40,560	same	43,000	same	41,570
Speed (knots)		18.5	same	20	same	18.5
Fuel (tons/day)		190 Fuel Oil	same			200 Fuel Oil

		El Paso Savannah	El Paso Cove Point			
Year Delivered		1980	same			
Length (ft)		931' 5"	same			
Breadth (ft)		140' 5"	same			
Draft (ft)		36'	same			
Tanks	No	5	same			
	Type	Rectangular Insulated, Aluminum	same			
Propulsion	Type	Steam Turbine	same			
	HP	41,570	same			
Speed (knots)		18.5	21			
Fuel (tons/day)		210 Fuel Oil	200 Fuel Oil			

(Institute of Gas Technology [1970-80]; Ropers [1972]; Faridany [1974]; Lloyd's Statistics [1979-80]; Drewry [1976-80])

APPENDIX 4

We present the dimensional characteristics of Liquified Natural Gas Carriers with insulated tanks. We define

GRT = Gross Registered Tonnage ($100\ ft^3$)

NRT = Net Registered Tonnage ($100\ ft^3$)

∇ = capacity (m^3)

L = length (ft)

B = beam (ft)

T = draft (ft)

The statistical relationships, along with their R^2 adjusted for degrees of freedom are:

1) $GRT = 3.0121 \times \nabla^{.8679}$

$R^2 = 97.4\%$ adjusted for d.o.f.

2) $GRT = NRT / (-1.5738 \times 10^{-7} \times NRT + .60311)$

$R^2 = 99.5\%$ adjusted for d.o.f.

3) $NRT = \nabla / (8.0648 \times 10^{-6} \times \nabla + 1.8079)$

$R^2 = 96.4\%$ adjusted for d.o.f.

4) $\nabla = 1.237 \times 10^{-5}\ L^{3.363}$

$R^2 = 97.9\%$ adjusted for d.o.f.

5) $\nabla = .0146029 \times B^{3.2435}$

$R^2 = 96.7\%$ adjusted for d.o.f.

6) $\nabla = 3{,}633{,}326 / EXP\ (129.546/T)$

$R^2 = 87.6\%$ adjusted for d.o.f.

(National Ports Council 1979)

APPENDIX 5

Designs in service or on order:

Conch (Independent). Aluminum tanks of trapezoidal shape, subdivided at the center line. Secondary barrier/ insulation-a combination of balsa panels, sprayed-on polyurethane foam, and glass fiber.

The current design results from cautious and continuous development of the first prototype LNG carrier (1959), combined with experience gained from the first two commercial carriers, which have been in day-to-day LNG service since 1964. This is the only design with true subdivision of tanks.

Moss (Independent - Type B). Spherical tanks of aluminum or 9% Ni steel supported on a cylindrical skirt at their equator. The very limited secondary barrier comprises a 'drip pan' to collect possible small leaks.

This is a relatively recent, but very popular, design relying on modern, sophisticated, design techniques and carefully controlled construction procedures.

Others. The Esso (independent double wall, aluminum tank design, although successfully operating since about 1970, is no longer being marketd; likewise the Gas Marine (independent) vertical cylindrical, 9% Ni steel, design which has twelve years successful service. Neither is suitable for large ship sizes now required.

Gaz Transport (Membrane). Invar (0.7 mm, 36% Ni steel) primary barrier, supported by two layers of perlite-filled insulating boxes, with an Invar secondary barrier (0.7 mm) between them.

The current design is very similar to the original system, which was incorporated in the two 71,500 m^3 ships, employed on the Alaska/Japan LNG service since 1969/70; however, the most recent development combines the GT Invar membrane primary barrier, with the MDC-3D system used as the insulation/secondary barrier. (See also below under MDC-3D).

Technigaz (Membrane). The stainless steel (1.2 mm) 'corrugated' primary barrier is supported by balsa/PVC or PUF panels faced with plywood (or, later, reinforced aluminum foil), which acts as a secondary barrier.

The current design is the result of continuous development and service experience since 1964.

Other designs, approved by Regulatory Bodies, which are viable alternatives to existing ones:

Hitachi (Independent - Type A). Aluminum trapezoid tanks, similar to the Conch design, fitted on raised supports giving easy access to the underside of the tanks.

Sener (Independent - Type B). Spherical tanks of aluminum alloy. The principal difference between this and the Moss design lies in the supports, which are of 'double-wall' design, the top edge being 'cantilevered' to join the equator in a tee-joint; at this point, like Moss, it supports the sphere. The design claims to reduce substantially the stresses in the critical equatorial zone.

The Crinavis shipyard in Spain has been designed to build this system exclusively in series production.

Hitachi/ CBI (Independent - Type B. Spherical tanks of aluminum alloy. The difference between this and previously mentioned spherical designs lies in the support technique; this is a development of an earlier CB&I design and comprises a double ring girder with 32 projecting 'spurs', fitted in keyways built into the hull structure. The spheres are located, and free to expand and contract, without deformation to themselves or the supporting structures.

Verolme (Independent - Type B). Multi-vertical, cylindrical, Aluminum alloy. Partial secondary barrier still under review.

All the above designs utilize cylinders to contain the LNG cargo, a considerable number being used per ship; this automatically presents problems of support and interconnection of containers, but at the same time, offers multicompartmentation as a safety factor. The Verolme design combines multi-cylinder containment with a very large ship size.

Zellentank LGA (Independent - Type C). Multi-horizontal, cylindrical. Nine percent Ni steel or aluminum alloy. No secondary barrier.

Linde (Independent - Type C). Multi-vertical, cylindrical, Aluminum alloy. No secondary barrier.

Ocean Phoenix (Independent - Type C). Multilobe trapezoidal. Nine percent Ni steel or aluminum alloy. Not yet fully approved in concept by the Regulatory Bodies. The system is primarily designed to carry gas under pressure but can also ship it in atmospheric form. The tanks are semi-compartmented.

Bridgestone/Sasebo (BS/SSK) (Semi-Membrane). Trapezoidal, unstiffened, tanks of 6 mm 9% Ni steel with PUF insulation/support and 3 mm stainless steel secondary barrier.

IHI (Semi-Membrane). Trapezoidal tanks of 15-35 mm aluminum alloy, designed and developed by the Ishikawajima shipyard.

Dytam (Integral Tanks Installed in a Prestressed Concrete Hull). An unconventional approach to LNG shipping which combines a new Naval Architecture approach to the ship's hull, with a new integral containment system (typically Owens Corning - Perm Bar II). The concrete hull itself provides the secondary barrier requirement.

Owens Corning - Perm Bar II (Integral). A modular system of factory made, foam filled panels interconnected in such a manner as to provide all the gas detection, testing and secondary barrier requirements demanded of this design category.

McDonnell Douglas - MDC-3D (Integral). A modular system of factory made, foam filled, three dimensionally reinforced panels. Although this system has been accepted, in association with a Gaz Transport primary barrier, for a two ship contract by Sun Shipbuilding (see under Gas Transport above), it has been primarily developed as an Integral containment system.

([Ropers 1972 ; Bousba 1973 ; Ffooks 1977, 1980)

APPENDIX 6

Average Bunker "C", Heavy Viscosity Fuel and Diesel Oil prices for 1970-1980.

Year	Bunker "C" and HVF ($/Ton)	Diesel Oil ($/Ton)
1970	10.02	18.91
1971	13.55	22.00
1972	16.95	31.02
1973	25.45	46.02
1974	75.89	120.85
1975	79.73	120.56
1976	84.25	125.86
1977	94.08	134.44
1978	95.75	136.45
1979	142.17	272.51
1980	175.00	329.00

APPENDIX 7

Let

P = horsepower of the Liquefied Natural Gas Carrier (HP)

η = efficiency of power plant (%)

D_i = distance between ports (nautical-miles)

N = vessel speed (knots)

W = total fuel required at sea if no boil-off took place (tons)

w' = total fuel required at sea with boil-off (tons)

S = specific engine consumption (tons/HP·hr)

H = fuel heating value (BTU/ton)

L = liquefied natural gas heating value (BTU/ton)

$G1$ = boil-off rate during loaded part of trip (%/day)

$G2$ = boil-off rate during ballast part of trip (%/day)

A. In the case where boil-off does not take place:

$$P \cdot S \cdot \frac{2D_i}{V} = W$$

or

$$W = \frac{2P \cdot S \cdot D_i}{V}$$

B. In the case where the boil-off rate is sufficient to provide the Liquefied Natural Gas Carrier with enough fuel during the loaded part of the trip only:

$$P\cdot S \cdot \frac{D_i}{V}(1 - .10) = G_1\cdot\nabla\cdot\frac{D_i}{V}\cdot\frac{L}{H}\cdot d$$

or

$$G_1 = \frac{0.9\cdot P\cdot S\cdot H}{\nabla\cdot L\cdot d}$$

We know that

$$G_2 = 0.5\ G_1 = \frac{0\cdot 45\cdot P\cdot S\cdot H}{\nabla\cdot L\cdot d}$$

The quantity of fuel required for the fuel pilot during the loaded part of the trip, and for supplementing the boil-off gas during the ballast part of the trip is given by:

$$w' = \frac{0\cdot 10\cdot P\cdot S\cdot Di}{V} + \frac{P\cdot S\cdot Di}{V} - G_2\cdot d\cdot\nabla\cdot\frac{Di}{V}\cdot\frac{L}{H}$$

or $$w' = \frac{1.10\cdot P\cdot S\cdot Di}{V} - d\ \frac{0.45\cdot P\cdot S\cdot H}{\eta\cdot\nabla\cdot\ L\cdot d}\cdot\nabla\cdot\ \frac{Di}{V}\cdot\ \frac{L}{H}$$

or $$w' = \frac{0.65\cdot P\cdot S\cdot Di}{V}$$

Hence

$$\frac{w'}{w} = \frac{\dfrac{0.65\cdot P\cdot S\cdot Di}{V}}{2\ \dfrac{P\cdot S\cdot Di}{V}} = 32.5\%$$

C. In the case where the boil-off rate is sufficient to provide the Liquefied Natural Gas Carrier with enough fuel during the ballast part of the trip

$$\frac{w'}{w} = 10\%$$

D. Every intermediate case for the boil-off rate is a linear combination of the above extreme cases.