5.0 ON-SHORE METHANOL PLANT ECONOMICS

A comparative evaluation was made to assess the economic viability of the methanol plantship concept as compared to a land based methanol facility. The basis for the comparison is a paper presented at the 1987 World Methanol Conference in San Francisco, CA in December, 1987 by Chevron USA, Inc.* The Chevron Engineering Technology Department surveyed 12 sources of information on methanol plant costs; all of the costs were adjusted to a common basis representing an 1,800 MT/day production facility for chemical grade methanol located next to a large oil refinery or petrochemical complex on the U.S. Gulf Coast (such a plant was assumed to produce 200 million gallons per year as compared to the floating plantship output of 308 million gallons per year.

The Chevron survey included plants in Canada, Saudi Arabia, New Zealand, South America, 3 plants in the Gulf Coast and one plant in Delaware. The average adjusted costs of these plants came to $257 million, representing a price of $1.30/annual gallon of capacity. The Yankee Energy floating plantship, with an annual output more than 50% higher, has been estimated at $346.5 million, representing a price of $1.12/annual gallon of capacity or 86% of the average Chevron price.

Since the Chevron estimates were based on off plot requirements representing 44% of a plot investment, a calculation was made to asses that ratio for the plantship. The off plot requirements for the plantship (the barge and mooring) are $121.6 million or 54% of the in plot requirements. When the debt reserve is deducted from the plantship total cost, the ratio becomes 42%, further confirmation of the validity of the plantship cost estimates.

A further evaluation was made comparing plantship economics with fixed plant economics presented by the Chevron study (special situation case). The Chevron methanol price is compared to the plantship estimates in the table below:

	1987 $/US gallon	
	Chevron	Yankee Energy
Feedstock & Fuel Requirements	0.05	0.043
Capital Charge	0.27	0.224
Operating Cost	0.11	0.049
Total	0.43	0.316

The feedstock and fuel requirements values for the plantship are superior; this is readily explained since the floating plantship process design has an overall efficiency of 87,000 BTU/gallon as compared to Chevron's fixed plant design requirement of 102,000 BTU/gallon.

*METHANOL FUEL ECONOMICS; Dixon B. Smith, Chevron, USA Inc., San Francisco, CA; The 1987 World Methanol Conference. December 1-3, 1987.

The capital charge values for the plantship are also superior; this, too, is readily explained since the advanced design of the floating plantship has an estimated unit investment requirement of only 86% of that estimated by Chevron for fixed plants.

The major difference in the foregoing economic comparison appears to be within the operating cost where the plantship value is less than 50% of the Chevron value. However, when the plantship includes U.S. income taxes on the operating side of the ledger, approximately $.04/gallon is added to the cost per gallon of methanol; operating costs are then nearly $.09/gallon versus $.11/gallon in the Chevron case.

The above table shows that a land based plant as estimated by Chevron for the best case would result in a cost per gallon 0.43/0.355 = 1.21 higher than estimated for the plantship. The higher onshore costs can be explained by two major factors; first, the plantship benefits from the economics of scale since it can produce 50% more methanol for a cost increase of only 35% based on a fixed plant U.S. Gulf construction site, or, a cost increase of only 8 percent when compared to the Chevron "special situation" case, investment of $322 million for a fixed plant in Jubail, Saudi Arabia. The second reason is the higher efficiency of the plantship CPOX system compared to the standard reformer cycle plant estimated by Chevron; the plantship as previously stated, requires only 85% of the feedstock and fuel per unit of production compared to the reformer cycle plant.

6.0 PLANTSHIP AND PLANNED OPERATIONS

Paragraphs to follow present a brief description of the project including its operations, also an abbreviated discussion of all critical factors entering into the final design of the project.

6.1 TECHNICAL FEASIBILITY, MANPOWER & RAW MATERIAL RESOURCES

a. Brief description of manufacturing process

The selected methanol manufacturing process is that known throughout the chemicals industry as the I.C.I. (Imperial Chemicals Industry, Ltd.) process. Approximately eighty percent of world methanol production capacity (about 25 million tons/year) uses the I.C.I. process. The I.C.I. process is selected over other methanol production processes because of reliability, efficiency, feedstock adaptability and because economy of scale in single train plants is realized only with the I.C.I. process at the intended 3000 STPD plant size.

In the I.C.I. process, a near stoichiometric mixture of gases, CO, CO2, and H2 is reacted (synthesized) over a copper catalyst to form methanol, CH30H. The synthesis gases for methanol production (CO, CO2, H2) are obtained via the partial oxidation and the catalytic auto-thermal reforming of the feedstock (referred to variously as natural gas or methane, (CH4) and oxygen (O2) and steam (H2O) over a nickel catalyst.

b. Special Requirements

Special Technical Complexities - production of methanol via a floating plantship involves the unique application of each the vessel and the methanol plant. The requirements for the successful exploitation of an offshore natural gas resource by this means are easily stated and are well understood:

First, the feedstock must be deliverable to the plantship, reliably for the desired period. The Poinsettia field meets size requirements; production riser technology by COFLEXIP, Inc. will deliver gas from the ocean floor to the vessel reliably over a twenty year span. For security of supply, four wells are manifolded together on the ocean floor; any three will meet plant requirements for gas. Four separate risers provide reliability via redundancy of delivery paths; for assured continuity of availability, each riser will be replaced twice in the course of system life.

Respecting the vessel, it must remain on station over the gas field in worst-case weather. No hurricane has visited the planned operating site in more than one hundred years. Nevertheless, tank tests of a vessel model have been conducted to derive mooring loads in the one-hundred year storm and the mooring is designed to meet this experimentally determined load.

Also respecting the vessel, it must meet regulatory requirements as these pertain to safety of property and life at sea, also, as to environmental impacts. Plant/vessel design has evolved consistent with domestic and international requirements in these regards; each Lloyds' Register of Ships and the United States Coast Guard have reviewed this or like projects and found them capable of meeting imposed criteria. Similarly, for the most favorable economics of application to derive, the vessel should remain on station for at least ten years without recourse to drydocking for inspection. Again, each the Coast Guard and Lloyds expect that appropriate vessel design and a proper maintenance and repair regimen will result in approval of a 10-year drydocking interval.

As to the methanol plant, design for the dynamic environment of the vessel is of legitimate concern in two ways - can distillation columns operate at expected accelerations and angles of motion - also, can the plant be designed for expected ship flexures? The plant designer has determined that the answer to each question is "Yes." Vessel motions determined via tank testing revealed that even conventional "tray-type" distillation columns would prove acceptable, however, the more conservative approach of using "packed-bed" distillation columns has been elected; these are tolerant of motions beyond those anticipated. Respecting vessel flexure, the process plant designer, Davy McKee Corporation (process engineer for more than sixty percent of world methanol capacity), has met more stringent flexure/acceleration criteria in two 2500 STPD methanol plants completed in New Zealand in 1986; the criteria in this instance derived from potential earthquake loadings. Waller Marine, Inc., naval architects and marine engineers for the vessel, have incorporated in the structure stiffness such that foundations for plant modules will not experience excessive relative movement under loads to be encountered either in the plantship tow to site or in plantship operation.

<u>Needs for Know-how</u> - both marine and chemical plant operators are required; normal manning complement is 65 (provision is made aboard for 80 additional persons who will be required in 2-week periods of annual or bi-annual plant shut-down for scheduled routine maintenance, catalyst replacement, etc.). Know-how requirements are not unique; they are those peculiar to marine operations of the offshore oil and gas industry, also, those peculiar to a methanol plant. One aspect does set this project apart from others, the requirement for self-sufficiency. Important repair and maintenance functions must necessarily be met by the on-board crew, specifically, the degree of self-sufficiency which will characterize this offshore plantship will far exceed its onshore counterpart. Operations will be entrusted to commercial firms which contract such services, e.g., Operators, Inc. (a Tenneco company) or Davy Corporation, Ltd.

<u>Special Skills</u> - as noted, required skills are not unique to the planned project; they are those appropriate to a moored vessel routinely off-loading product, e.g., as does the Exxon "Hondo" project converted tanker moored off the California coast, and those appropriate to a methanol plant. Specific skills required are those listed in Table 1.

Table 1. Manning and Accommodation List
(Page 1 of 2)

PERSONNEL: Description	Number	ACCOMMODATION: 1-Man w/ bath	1-Man split bath	2-Man w/ bath	REMARKS
Plant Operating Crew:					• Two 12-hour shifts to provide 24-hour coverage.
Processing Foreman	2	2			
Operator	4	4			
Outside Man	4		4		
Lab Technician	2		2		
Water Quality Tech.	2		2		
Mechanical Tech.	2		2		
Instrument Tech.	2		2		
Electrical Tech.	2		2		
Subtotal	20	6	14	—	
Marine Operating Crew:					
Bargemaster	1	1			• With dayroom.
Tankerman	2		2		
Barge Engineer	1		1		
Asst. Barge Engineer	1		1		
A/B Seaman	4			2	
Subtotal	9	1	4	2	
Administration:					
Superintendent	1	1			• With dayroom.
Purser/Stores Mgr.	1	1			• With attached office and slop chest. (Purser also acts as medic.)
Clerk	1		1		
Security	3		3		
Subtotal	6	2	4	—	
Natural Gas Production:					
Production Foreman	1	1			• With dayroom.
Well / Subsea Tech.	4		4		
Subtotal	5	1	4	—	

Table 1 . Manning and Accommodation List
(Continued -- Page 2 of 2)

PERSONNEL Description	Number	ACCOMMODATION 1-Man w/ bath	1-Man split bath	2-Man w/ bath	REMARKS
Plant Maintenance:					
Maint. Foreman	1	1			• Two qualified as crane operators.
Mechanic	6		6		
Utility	6			3	
Subtotal	13	1	6	3	
Steward's Dept.:					
Steward	1	1			• With attached office.
Cook	2		2		
Baker	1	1			
Galley / Utility	8			4	
Subtotal	12	2	2	4	
Spares:					
Company & Owner	2	2			• With attached office.
Shut-down Crew	41	5	4	16	
Subtotal	43	7	4	16	

Normal Operating Crew: 65

Maximum Crew: 108

	1-Man w/ bath	1-Man split bath	2-Man w/ bath
Stateroom Allocation:	20	38	25

c. Probable sources of equipment supply

Representative listings of methanol plantship equipment suppliers are given in Appendix D. The plantship hull and associated bulks (piping, foundations, etc.) are expected to be of non-domestic origin. Vessel subsystems, e.g., diesel electric generators, cargo pumps, desalination plant, will be of domestic origin as will a large portion of the gas field production/delivery equipments. Process plant components are expected to be of 80 to 85 percent domestic origin.

d. Availability of manpower and infrastructure facilities

Manpower - Davy McKee Corporation offers to clients for whom it is methanol plant engineer/constructor the opportunity to contract with Davy for continuing operation of the plant post start-up and acceptance. Operators, Inc., a Tenneco company, provides like services to plant owners. Importantly, Tenneco has been an owner-operator of methanol plants and remains the largest domestic marketer of methanol. It is planned that plant operation be contracted with Davy, Tenneco or an equally qualified plant operator. Experienced personnel will comprise initial manning; they will be retained in the pre-operational period at times appropriate to their attaining full familiarity with the plant and ship prior to "tow-to-site" and "start-up." A training program will be established to assure a continuing supply of qualified personnel, preferrably of Trinidad-Tobago citizenship.

Infrastructure Facilities - arrangements as to infrastructure facilities are:

(1) water - requirements for process make-up and for potable use are met by a desalination plant aboard the ship; backup is provided by fresh water ballast in tanks of the dedicated methanol off-take tanker. Process cooling needs are met via saltwater/process fluid heat exchangers.

(2) electric power - the plantship is self-sufficient; three 5 megawatt diesel generators (natural gas fueled; two operating, one in back-up service) will meet the 9 megawatt domestic and process plant load.

(3) crew rotation/consumables resupply - emergency needs are met by precontracted standby helicopter service; routine requirements are met via long term chartered supply boat service. Spares not stored aboard ship yet considered to be too vital for their delivery to await vendor re-supply, will be stored in a local onshore plantship support complex (administrative office/training facility/warehouse/secure lay-down yard).

(4) communications - principal support will be provided administratively from the local onshore complex; the dominant communications link will be radio-telephone. Commercial communications means will couple local, regional and corporate offices.

(5) transportation - note has already been made of retained helicopter and chartered supply boat services. Non-domestic crew rotation to Europe, the States and elsewhere will be via commercial airlines. Methanol transfer from the ship to the buyer will be via dedicated long-term chartered tanker(s) of nominally 50,000 dwt.

e. Sources, costs and quality of raw material supply; relations with support industries

Raw Material Source/Supply - raw materials required in manufacture of the methanol are natural gas, oxygen and steam. Oxygen and steam are produced on board without recourse to imports; the natural gas is lifted from the sea floor by risers tied to wells in the Poinsettia Field. Tenneco estimates, based on sound engineering practices, that the Poinsettia Field contains sufficient recoverable natural gas to meet the needs of the plantship for a twenty year period of operation. Gas quality for production of methanol is excellent; 99.6 percent methane (CH4), 0.2 percent N2 0.2 percent C2 to C, less than 1 ppm sulfur, 86 lbs of water per million cubic feet of gas. Specific gravity is 0.556 and the high heating value (HHV) is 1011.8 BTU/SCF; molecular weight is 16.105. The gas cost basis has been derived (capital required for field development and gas delivery; annual costs for gas delivery and for field/delivery system maintenance) and a "delivered-cost" gas contract, including the royalty rate to be paid the Government of Trinidad-Tobago (GOTT), developed. It is the subject of Paragraph 4.2.

Relations with Support Industries - principal Yankee Energy interfaces to the gas, marine and chemicals industries are, respectively, Tenneco, Waller Marine, Inc., and Davy McKee Corporation; each enjoys a long and beneficial relationship with suppliers in its field of operations.

f. Import Restrictions

In the planned plantship project import restrictions are appropriately addressed with respect to four categories of materials—the natural gas feedstock; materials imported to Trinidad; materials imported to the United States for plantship construction; and, plantship product methanol imported to the United States — each is addressed below:

Natural Gas Feedstock - this will be produced by Tenneco from leased property of the GOTT. It will be converted to methanol prior to export from Trinidad to the United States. The question is moot, therefore, respecting natural gas as a material subject to either U.S. or Trinidian import restrictions.

Materials Imported to Trinidad-Tobago - materials, including the plantship, are imported to Trinidad-Tobago for project development; materials include those for gas field development and maintenance, also, plantship mooring components, etc. (pipe, gauges, valves, chemicals, chains, et al). An agreement between the GOTT and Yankee Energy will cover the terms under which the plantship will be permitted to operate in Trinidadian waters. An application for Import Duty Concessions (under Section 49A of Customs Ordinance Chapter 32, No.2) will be filed with the GOTT to enable the desired project to proceed unencumbered by GOTT import restrictions (duties).

Materials Imported to the United States - the plantship hull will be imported to the United States for installation of the methanol plant (which itself will be substantially but not totally comprised by materials/components of domestic origin). It is not believed that any materials of the foregoing description are subject to import restrictions. If later detailed investigation proves otherwise, accommodation will be made to the imposed restriction(s).

Methanol Imported to the United States - methanol imported to the United States is subject to restrictions (duties) in specific instances. Specifically, methanol imported for use as a chemical feedstock is dutiable at 18.8% ad valorem when imported from non-Caribbean and non-qualifying non-LDC nations. Methanol for use as a fuel or as a fuel additive is not subject to import duties irrespective of country of origin. The foregoing means that the methanol to be produced by this project will not be subject to import restrictions, either because it is from the Caribbean, or, because it is intended for fuel use (John Hurley, Tariff Classification of U.S. Custom Service; 6/3/88).

g. Proposed Plant Location (in relation to):

Suppliers - the plantship is moored at the site of required feedstock; critical spares are stored aboard while less critical spares and required foodstuffs will be replenished from ashore.

Markets - methanol off-take agreements are the subject of Paragraph 4.3. In the course of system life markets are expected to be on each the East and the Gulf Coasts, 4000 and 4500 miles roundtrip, respectively, from the plantship. Transportation costs (long-term charter) to these markets are 3.2 and 3.5 cents/gallon of methanol moved, provided transport is in nominally 50,000 dwt tankers and two roundtrips are completed each month.

Infrastructure - power and water needs are met on site; foodstuffs are obtained locally and are transported by chartered supply boat. Hotel and non-critical medical services are provided aboard ship; emergency medical care is provided via precontracted helicopter service to Port-of-Spain, Trinidad. Non-Trinidadian operating personnel are provided commercial air travel to and from their home at the end and start of each on-board duty cycle.

Manpower - at start-up of plant operations it is anticipated that only about ten percent of the on-board crew will be Trinidadian. It is an objective that through operation of an intensive and comprehensive formal and apprentice-type training program, that within 5 to 10 years all operating personnel, ashore in Trinidad and aboard the plantship, will be Trinidadian.

h. Proposed Plant Size

Plant design is single train and plant design capacity is 3000 STPD; Davy McKee is the intended engineer/constructor. The four largest single train plants priorly designed and constructed are two at 2500 STPD in New Zealand (1986) and two 2750 STPD plants in the USSR (1983); Davy McKee was also engineer/constructor on each of these.

The present maximum physical capability of single train I.C.I. process methanol plants is approximately 3450 STPD. This size plant offers the optimum economy-of-scale. At any greater production capacity it becomes necessary that certain plant components/subsystems be duplicated and operated in parallel, a weight, plan area and cost penalty when these are stated on a per unit of production basis. Name plate capacity is what is warranted by the engineer/constructor; planned for name plate plantship production capacity is 3000 STPD through the minimum 3-yr -life of process catalysts. Beginning of catalyst-life plant capability will be name plate capacity plus 10 to 15 percent, i.e., in the range of 3300 to 3450 STPD.

7.0 TECHNICAL SPECIFICATIONS, METHANOL PLANTSHIP PROJECT

This section presents the particulars of work performed respecting plantship design and operation. These are the basis upon which findings of commercial and financial feasibility are made in Section 4. Key system features are these: plantship product is methanol; the plantship design is purpose built to manufacture chemical grade methanol from natural gas of the quality available at the intended operating site (61° 30" west longitude, 11° 12" north latitude, nominally 30 miles off the northwest coast of Trinidad).

At initiation of this feasibility study, it was considered that commercial viability might be dependent upon, or enhanced by, the manufacture of two products, methanol and ammonia. This possibility was raised by the availability from the methanol plant of essentially zero cost by-product hydrogen, a feedstock (along with natural gas) in ammonia manufacture. Market analysis and technical considerations, however, were found to argue for a single product system (Appendix E). Ammonia prices were projected to remain soft in the mid to long term due in large part to abundant production capacity at land-based sites of low cost gas. Technically, plantship design was found to be made more complex by incorporation of two processing plants on a single vessel, and, of equal importance, system operations were found to be greatly complicated by the necessity to off-load products of distinctly different handling requirements, methanol storage and handling at sea being accomplished safely with significantly greater ease and less expense than is safe ammonia storage and handling. The decision was made to predicate system design on the manufacture of methanol, exclusively.

Also at the outset of the feasibility study, it was believed that commercial viability could be dependent upon, or favored by, reduced first costs which might associate with conversion of a very large crude carrier (VLCC) to a methanol plant platform, as compared to construction of a new, purpose-built, barge platform. A thorough survey, Appendix F, was made of the world inventory of VLCCs; size, number, age and probable acquisition/conversion cost at date of need were considered determinant parameters. The study revealed that acquisition costs for used VLCCs had doubled in the 18 months ending in August 1987; interestingly, acquisition/conversion costs were found not to differ too significantly from design/construction of a purpose-built hull. More importantly, it was determined that in the post-1990 period relatively few VLCCs with a remaining useful life of 20 years would be available for conversion. Moreover, conversion engineering and re-construction, which will be unique to each application in the likely absence of available duplicate like-model VLCCs, would cause the loss of the replication advantage of purpose-built systems, and, finally, the potential for remaining on site for ten to twenty years without recourse to yard availability for major maintenance, an attribute of a purpose-built design, will be lost in VLCC conversions. This means that "conversions" must incur the added operating costs attendant to the more frequent extended plant downtime which associate with leaving the operating site to undergo hull overhaul/maintenance in a ship repair yard. The decision was reached to proceed with a plantship feasibility study premised on a barge-type platform which is purpose-built to house and operate a methanol process plant.

7.1 VESSEL NARRATIVE/PARTICULARS

The point-of-departure for definition of a vessel for this site specific system feasibility study was the methanol plantship design accomplished by Yankee Energy Corporation under Contract No. DTFH61-85-C-00076 to the U.S. Department of Transportation (DOT Final Report copy delivered herewith for reference). Decisions which were determinant of major features of the DOT plantship system, and which were critical in design of this site specific plant-support vessel, were re-visited in this feasibility study in the detail necessary to sustain technical feasibility determinations.

7.2 DESIGN CONSIDERATIONS

The DOT plantship design aspects which were re-evaluated because they are critical to definition of the site specific plant vessel were:

Production Capacity - The DOT system produced 3000 short tons of methanol per day in a single stream plant. The rationale for this figure and production means was: a market exists for at least this added amount of product; single stream plants enjoy a production unit cost advantage as compared to plants employing parallel processing streams; in single stream plants using the largest of available reliable equipment/components, optimum ecomony-of-scale is reached at 3000 STPD rated name plate capacity. These facts remain operative in the instance of the specific site under consideration, therefore, the vessel is designed to support a 3000 STPD process plant.

Storage Capacity - The DOT system provided on-board storage for 24 days production of product, approximately 66,000 long tons of methanol (22 days storage at a 110 percent production rate; 3300 STPD delivered into 72,600 short tons of storage capacity, a reasonable expectation based on historical production records for methanol plants engineered by planned subcontractor Davy McKee Corporation and using the intended I.C.I. syngas to methanol conversion process). Assuming that the methanol transfer tanker will operate at 14 knots in service to Houston from Trinidad (2292 n.m) and assuming one day turnaround at each terminus, round trip is 18 days and tanker capacity must be at least 54,000 short tons. A six day excess of on-board storage is thus made available (if DOT system storage capacity is retained) to account for unscheduled tanker delays, or bad weather which might act to prevent transfer interfacing of tanker and production facility. No basis for increase or decrease of the DOT system on-board storage capacity was discovered in the course of study, therefore, the plantship continues to provide 24 day storage capacity at the rated methanol production rate.

Crew/Crew Accommodations - No basis for change of the DOT operating crew was discovered; accommodations remain for 65 in the normal crew. Though crew size has not been changed, consideration is being given extending the period between crew rotations, for either all or a part of the crew. This would not influence ship design but it would have a salutary effect on operating costs. During the period of turnaround, a plant maintenance spantime of 10 to 14 days which occurs at nominally annual intervals, accommodations are now provided for an additional 80 temporary workmen aboard the plantship. This is an increase from 40 temporaries on the DOT vessel and represents both the remoteness from U.S. facilities and a re-thinking of requirements to sustain the 10 year availability interval.

Process Plant Type/Arrangement - The plant vessel design is strongly influenced by the process plant type selected and its arrangement onboard the ship. Details of process plant considerations are reported in Paragraph 8; plant type is unchanged from that of the DOT system but further engineering study resulted in redesign of certain subsystems to improve safety, cost and reliability/maintainability. Plant type remains synthesis gas production via catalytic auto-thermal reforming of methane in the presence of oxygen; an I.C.I. process loop converts syngas to methanol. Process plant subsystems redesign netted a plant weight reduction to 16,500 long tons and a reduction of plant plan area requirement to 25,000 sq. ft.; these are reductions of 25% and 17%, respectively, respecting the DOT system. Reduced concentrated loads also meant less vessel structure required to distribute loads. These savings largely result from a decision to drive oxygen plant compressors via steam turbines rather than via very large, very high voltage (13,800 V) electric motors. This makes possible a simplified and safer shipboard electrical system (maximum voltage 4160 V); it permitted replacement of a very expensive, long-lead procurement, 37.5 megawatt gas turbine generator by a relatively inexpensive, readily available, packaged steam boiler and by addition to the ship electrical service of a third 5 megawatt diesel generator. Other plant rearrangements were detailed to improve interfacing of the plant to the vessel. The substance of all changes was a material improvement in plantship cost (Appendices A and B), also, in system susceptability to modularization, a construction attribute. Changes did not materially impact plantship physical charateristics which remain nominally those of the DOT system; length overall, 780 ft; beam (average), 200 ft; draft, 55 ft; displacement, 180,000 long tons. Existing ships systems drawings were revised to reflect re-engineering; approximately three dozen supplementary drawings were generated to facilitate accurate cost estimating of ship construction by Hyundai, Verolme and by McDermott.

Mooring and Natural Gas Supply System Interfaces - these are discussed concurrently because each system comes aboard the ship at a rotary turret near the bow. The mooring and the gas supply system interface has been redesigned from the DOT system because of the changed design parameters of the specific operating site. Mooring will now occur in 530 ft. of water whereas the previous design was for 325 ft. of water depth; the gas pressure knock-down system must now address 4300 psi whereas the prior design was for 2000 psi. Respecting the knock-down system, bigger heat exchangers are required to prevent freeze-up of hydrocarbon liquids condensed out of the methane when pressure is reduced to 500 psi from 4300 psi; the rotary turret is increased in diameter to accommodate the increased size of equipment required on the gas field side of the sliding rotary seal. As to the mooring redesign, chain size, length, and cost increase; chain number goes from 6 to 8. Concurrently, internal ship structure was redesigned to distribute the increased mooring loads. Design/cost proposals were sought from IMODCO and from SOFEC. Each submitted designs and estimates and assurances of technical feasiblity; topics addressed were design, model test, procurements, fabrication, installation on the ship, deployments on and in the seabed, and hook-up to the plantship. The mooring development schedule is as follows (lapse times to be integrated to ship construction/deployment schedule):

ACTIVITY	LAPSE TIME (months) AFTER START
Design and testing	6
Procurement/fabrication	11
Installation on plantship	13
Deploy, install, commission	14.5 (total span time)

Product Transfer - The means of methanol transfer to the transporting tanker is unchanged from the DOT system design.. The means and cost of product transportation are addressed in Paragraph 6.

Essential Support Systems - These systems, e.g., fire, ventilation, potable water, emergency power, including necessary redundancy, are unchanged from the DOT system.

Regulatory - The selected operating site, Trinidadian waters, is not under jurisdiction of the U.S. Coast Guard in accordance with whose safety standards the DOT system was designed. However, safety of crew and plant/vessel remain paramount concerns. Therefore, no relief of system design requirements is assumed to derive from operation at a foreign site. In follow-up of this determination, work throughout this feasiblity study period was conducted in concert with Thomas Sear/Price Forbes, USA of the Sedwick Group, London (marine specialists and the third largest insurance broker in the world) to assure that mooring, towing, and inspection in the course of construction/assembly is in accord with sound underwriting principles. Finally, system drawings will be submitted to Lloyds' Register of Shipping (which has already concurred in the generic feasiblity of this approach to methanol production) for review/approval of the design as being in compliance with Class rules and with appropriate international standards/conventions.

Self-Sufficiency - The DOT system placed heavy reliance on on-board accommodation of spares and maintenance/repair capability. This design philosophy is retained in the site specific system. It is planned that a shore-side facility/office be maintained in Trindad for administration, house-keeping, and training activities. The capabilities of the indigenous industrial/commercial infrastructure is also assumed to become dominant in plantship support as the competence of this infrastructure is demonstrated over time.

7.3 PLANT VESSEL COST

All aspects of developed platform costs, including "off-site" systems, e.g. evaporators for boiler feed and for potable water, electric power, hotel services, etc., are backed by one or more quotations. This applies as well to such cost elements as mooring service, towing service, and methanol transportation costs in cents/gallon. All are reflected in Appendicies A and B, the development of Capital Requirements and Operating Expenses, respectively.

8.0 PROCESS PLANT NARRATIVE/DESCRIPTORS

Among the three major project parts, plant vessel, process plant and gas collection/delivery system, only the process plant is changed by this TDP study in any consequential way from the methanol plantship system developed for the Department of Transportation.

8.1 PROCESS PLANT DESIGN CHANGES FROM DOT PLANTSHIP

The "generic" DOT plantship design was premised on an operating site in the western U.S. Gulf of Mexico. Feedstock gas analysis, water depths and vertical temperature profile differed from the Trinidad site; proximity to the U.S. industrial infrastructure placed systems design for repair and maintenance in an entirely different context than does plantship operation nominally 2250 n.m. from U.S. support facilities. System changes derived largely from these factors are itemized below:

1) **Electric Power Generation** - housekeeping and emergency power needs were previously met by two five (5) megawatt dual-fuel (natural gas and/or diesel oil) diesel generator sets; process plant electrical power requirements, 32 MW, were supplied by a 37.5 megawatt General Electric Frame 6 gas turbine generator unit. A major part of the 32 MW load was motor drives for the oxygen plant compressors (process air, 21 MW, and nitrogen, 7 MW) and for the sea water coolant pumps, 2 MW. With the gas turbine system aboard, it was necessary that operating personnel be expert in maintenance of steam, diesel and gas turbine equipments. Consideration was given, and the decision was made, to substitute a packaged boiler (500,000 lb/hr) and an additional 5 MW diesel generator for the gas turbine system; steam turbine drives would replace the aforementioned compressor drives and certain other motor drives, e.g., the syngas circulator drive. Not only was remote site operability enhanced but these ancillary benefits were derived:

a) the highest voltage system aboard ship is reduced from the 13,800 volts of the gas turbine generator output to the 4160 volts generated by the diesel generator sets; this is a safety consideration.

b) a net capital saving of at least $4 million is realized; the gas turbine cost was $9 million, that of the package boiler and diesel generator are $2.3 and $2.5 millions, respectively (assumes a cost wash on steam versus electric motor drives).

c) plan area required for installation of the process plant, and process plant weight are each reduced significantly (the cumulative effect of this and other changes to be described in subsequent paragraphs is a 25 percent reduction in plant weight, from 20,600 to 16,500 ST, and a 17 percent reduction in required plant area, from 29,000 to 25,000 sq. ft.

d) improved availability of power for start-up/re-start of process plant on site.

2) Methanol Converter

The DOT process plant used a conventional I.C.I. quench-type methanol converter. Change has been made to an I.C.I. tube cooled converter (TCC), a simple, low differential pressure, gas-to-gas type reactor/heat exchanger; it has these advantages:

a) single reactor capacity is extended beyond 3000 STPD to accommodate the beginning-of-catalyst-life methanol production capabilities of the process plant (1.1 to 1.15 times nameplate).

b) improved mechanical soundness; minimum differential pressures to avoid tube sheet problems.

c) improved ease of catalyst loading/unloading.

d) minimum control; eliminates use of either quench or steam generation control.

e) improved, simple, heat recovery.

f) reduced rate of gas recycle; reduced power consumption in gas circulation

g) reduced catalyst volume.

3) Pressure Swing Absorber

The DOT process plant incorporated a PSA because of assumptions respecting gas quality, also, because I.C.I. had very tight requirements on the quality of syngas permitted to be in contact with the catalyst of the methanol reactor. The PSA is removed from the TDP process plant. Two factors permit this, the quality of Poinsettia field gas and the issuance by I.C.I. of relaxed specifications on the syngas purity required at syngas contact with the TCC catalyst.

4) Other

A five degree increase, from 75°F to 80°F, in the coolant water temperature available at the Trinidad operating site required both increased circulation rates and the re-sizing of heat exchangers and plumbing used to transfer process waste heat to the ocean environment. Also, the TDP process plant substitutes an inexpensive zinc oxide sulfur guard for the more expensive natural gas desulfurization system used in the DOT process plant; this was possible because the Poinsettia gas is virtually sulfur free. In fact, gas quality is so good respecting sulfur that consideration was even given to elimination of the sulfur guard. Prudence, however, prevailed; it was included in the system on the off-chance sulfur contaminations would increase beyond the tolerable 0.25 ppm limit as gas reserves are drawn-down over the 20 year life of the plantship.

These additional changes are incorporated:

a) fuel gas compressor deleted; this was required to treat waste gas from the methanol reactor for the gas turbine but is not required by the firebox of the package boiler.

b) syngas compressor and circulator share a common steam turbine drive, condenser and condensate pump.

c) desalination plant capacity is increased to assure adequate supplies of feedwater for the packaged boiler.

d) it was decided to adapt exhaust gas waste heat recovery systems to the diesel generators; these will raise 60 psig steam for the desalination system evaporators, also, steam to heat to 155°F the natural gas flowing from the risers to the pressure knock-down system (to avoid hydrate formation due to cooling occasioned by the drop in gas pressure from 3000 to 500 psi). Steam raised by the waste heat recovery system reduces demand on the package boiler and allows a smaller package boiler to be used.

e) accommodations for temporary workmen required during annual plant turn-around were modified; provisions are now made for 80 temporaries rather than 40.

f) a falling film-type saturator replaces the tower-type saturator of the DOT process plant; studies revealed the film-type to be less costly and more appropriate to the plantship.

g) the tray-type distillation column of the DOT process plant has been replaced by a packed bed type distillation column; the latter, though possibly less efficient, is, because of its tolerance for non-vertical operation, more appropriate to operation on a plantship.

The net cost effect of the foregoing changes to process plant design (and also due to the now improved definition of required engineering, procurement and supervision services) is a $15.2 million decrement respecting the cost of the DOT process plant; the site specific process plant capital cost estimate is $126.22 million. Detail of the cost estimate appears in Appendices A and B; a listing of domestic vendors for process plant equipment appears in Appendix D.

8.2. HEAT REJECTION DESIGN BASIS

The National Oceanographic Data Center of the National Geophysical Data Center was the source of the water temperature data at the operating site. More than 800 vertical temperature profiles within 40 miles of the operating site were analyzed; they covered all months of the year and were obtained in 29 of the past 35 years. Data recorded at 30 and 90 meters was studied;

temperature average at 30M is 77.9°F and at 90M is 69.2°F, an 8.7°F difference. Average monthly high and low temperatures at 30M were also studied; these values were 81.1°F and 73.1°F. Extrapolation of data to the design draft of the vessel, 18M, the coolant water draw depth, raised all temperatures 1.3°F on average. On this basis it was decided the system design would be predicated on a heat exchange cold-sink temperature of 80°F.

An analysis of water temperatures at 90M was conducted to learn if significant advantage to plant design would result from extension of a cold water suction pipe to 90 meters to obtain the benefits of a lowered heat exchange cold-sink temperature; on average the temperature here is 11°F lower than at 18 M. The benefits were judged not sufficient to warrant the cost and difficulty of stabilizing the cold water pipe over this distance, nor accepting the current drag on it and its support structure, nor accepting the risk of pipe interference with mooring chains and gas delivery system risers.

8.3 MODULARIZATION

Process plant design has proceeded on the premise that major subsystems and equipments will be modularized for installation aboard the plantship; cost estimating was premised on the lift of 15 modules of 200 to 1200 tons. Waller Marine identified each McDermott and Teledyne as capable at Morgan City, LA using crane barges of 600 T and 800 T lift capacities; day costs are $36,000 and $60,000 respectively. The cranes would be used in tandem to make the larger lifts.

To further narrow the range of uncertainty respecting the cost of the modularization approach, and to eliminate design feasibility questions, Waller Marine developed design criteria for use by Davy McKee in performance of preliminary module structural designs and for preparation of bid specifications. The module design basis prepared by Waller from experimental tank motion studies at Offshore Technology Corporation is:

Maximum Weight	Approximately 1100 T
Limiting Dimensions	As per hull drawings
Sagging/Hogging Deflection	1 inch over 100 feet length
Torsional Deflection	1 inch over 100 feet diagonal
Maximum Wind Loading	112 MPH sustained 135 MPH gusting
Max G Force (100 ft above deck)	0.5 g horizontal 0.3 g vertical

Deck Support Steelwork

Major Longitudinal Steel	10 ft pitching between bulkheads
Major Transverse Steel	12 ft 6 in from centerline to first steel, then 10 ft pitching
Secondary Transverse Steel	2 ft 6 in pitching

Davy McKee modularized two sections of the process plant to better understand requirements, to improve scheduling and to develop improved cost estimates; the process plant areas involved were the methanol synthesis section and the methanol distillation section, excepting the methanol reactor and the distillation column, respectively.

8.4 OXYGEN PLANT

Selection of the catalytic auto-thermal partial oxidation process for manufacture of the syngas feedstock for the methanol synthesis loop means that the plantship will house an oxygen plant; a 3000 STPD methanol plant requires a 2000 STPD oxygen plant. In the DOT study, size and cost data were approximated from limited input by oxygen plant vendors; most significantly, the U.S. Coast Guard in the course of the DOT study gave as its explicit opinion the judgement that manufacture and storage of methanol can occur safely in the presence of oxygen manufacture aboard ship.

To confirm a readiness on the part of oxygen plant vendors to design and supply oxygen plants of the prescribed size for at sea operation, Davy McKee forwarded the following questions to Union Carbide/Linde Division; Air Products; Airco; Lotepro; and L'air Liquide:

a) are you prepared to work with Davy McKee in developing an integrated methanol plant/oxygen plant design?

b) are you prepared to bid competitively for a 2,000 STPD shipmounted oxygen plant for a specific project?

c) can you provide "typical" information for an equivalent land-based plant, including cost, overall sizes and weights and utility requirements, assuming major machines are driven by medium pressure steam turbines?

d) are you prepared at this stage to send a technical representative to Davy McKee to discuss possible developments in this area?

Significantly, all answered in the affirmative to all four questions; none expressed reservations respecting an at-sea integrated methanol plant/oxygen plant system.

8.5 PRE-CONTRACT ENGINEERING

The process plant cost estimate presented in Appendix A is $126.2 million and is considered accurate in the range -6.3 % to + 19.1 % (- $8 million to + $24 million, i.e., process plant cost is estimated to lay in the interval from $118 million to $150 million). A pre-contract engineering phase will initiate the plantship development program. In this period a 'definitive' cost estimate, one accurate to +/- 10%, will be prepared; respecting the process plant this will entail the following:

Definitive Cost Estimate

This will require six months to complete and cost $300,000 (see notes 1 and 2); the work will cover these activities:

- Confirmation of Process Data - PFD and 4-line specifications
- Preliminary P&ID - major instrumentation, materials and line sizing will be setforth
- Engineering Inquiry Requisitions will be processed for equipment
- Check prices for bulk materials will be obtained
- Plant layout drawings and studies to determine overall layout and grouping of equipment into modules
- Preliminary structural design of modules
- Material Take-offs for all bulk materials
- Interface with oxygen plant vendor
- Interface with ship designer
- Issue and review of inquiries for fabrication and installation of modules on ship
- Preparation and review of estimate

NOTE: 1. This sum does not cover monies required by the Oxygen Plant vendor or module fabricator to produce definitive designs to +/-10% accuracy for this application. To produce the necessary degree of accuracy in this design, definitive information is needed in both of these areas. Indications are that these vendors will not produce information on which they are prepared to take a commitment without being paid to do some preliminary engineering. It is estimated that each vendor will require approximately $30,000.

NOTE 2. It is assumed that the design of the ship and the construction decisions are sufficiently advanced to make the necessary judgements on the plant layout, plant/ship interface, pricing details, and on installation of modules and major equipment on the ship and on completion of on-board coupling of modules to each other and to the ship. It is considered by Yankee that this work will be undertaken concurrent with pre-contract engineering on the plant vessel.