RESOURCE MATERIALS

Methane Conversion for Highway Fuel Use (Methanol Plantship Project)

Volume II: Executive Summary

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16. Abstract

In phase I methanol plantship (MPS) work sponsored by the Department of Transportation in fiscal years 1985 and 1986, the contractor identified uncontested methane sufficient to operate 130 MPS's for 20 years, each being of 3,000-short tons per day (2,722-t/d) capacity; demonstrated by analyses and by ship model tank tests that long-term efficient methanol plant operations can be conducted in at-sea environments; and showed that the economics of MPS operations are competitive with land-based plants.

Part I of phase II (report no. FHWA-RD-92-085) assessed the impact of new permitting and environmental legislation on the design and operation of the MPS. The impact of new laws and regulations are measurable. Design and construction costs will increase when design changes are made in order to meet new allowable pollutant release rates; operating costs will increase in order to implement a program that meets new planning, monitoring, and reporting requirements. MPS operability, however, was found to be unaffected by new statutes and changed regulations. New parametric analyses concluded greatest economy of scale at 3,000 short tons per day (2,722 t/d). Research of the MPS design efforts of other similar projects discovered no basis for discontinuance or change of development efforts or plans.

Part II of phase II confirmed that the MPS can address economically, without consequence to production rates, natural gases with impurity levels in excess of 25 percent; a useful methane supply, cost, and composition was confirmed at several sites of interest. MPS design changes to enhance operability and product quality were accomplished; the MPS specification and quotation assembly drawings were detailed to enable refined cost estimation of the MPS to -5 to +15 percent accuracy. Costs were determined for the preparation of an MPS "go to construction" bid package, for detailed design of the MPS, and for construction/installation of the MPS.

This volume is the second in a series of two. The first volume in this series is: FHWA-RD-93-091, Volume I: FINAL REPORT

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FOREWORD

This report presents results of a study undertaken to respond to PL 101-516; that law provided funding for "phase II of the development/design work on a floating methanol production plantship to advance work already completed under phase I of the project, which was authorized by section 152 of the Surface Transportation Act of 1982." Phase I determined the feasibility of producing large volumes of low-cost methanol aboard a plantship. This report consists of two volumes: the final report, FHWA-RD-93-091, and the Executive Summary, FHWA-RD-93-092.

This Executive Summary includes abbreviated presentations of the information in the final report and in an earlier interim report, FHWA-RD-92-085. The study covered: the impact of recent permitting, licensing, and environmental regulations on methanol plantship (MPS) design and operation; analysis of other MPS programs; updating of the process technology, alternative natural gas supplies, MPS design, and economic analysis; and the development of detailed cost estimates for the design and construction of the MPS. An MPS specification and quotation assembly drawings were also prepared.

Charles J. Nemmers, P.E.
Director, Office of Engineering and
Highway Operations Research and Development

NOTICE

METRIC CONVERSION FACTORS

American and British Units			Metric Units
atmosphere		=	101,325 pascals (Pa)
bbl	barrel	=	0.158987 meter^3 (m^3)
Btu	British thermal unit	=	1,055 joules (J)
°	degree (angle)	=	0.01745 radian (rad)
° F	degree, Fahrenheit	=	(°F - 32)/1.8 (°C)
ft	foot	=	0.305 meter (m)
ft^2	square foot	=	0.0929030 square meter (m^2)
ft^3	cubic foot	=	0.0283169 cubic meter (m^3)
ft^3/min	cubic foot/minute	=	0.00047194 cubic meter/second (m^3/s)
g	free fall	=	9.80665 meters/second^2 (m/s^2)
gal	gallon	=	0.00378541 cubic meter (m^3)
hp	horsepower	=	746 watts (W)
in	inch	=	0.0254 meter (m)
in Hg	inch of mercury	=	3,386.38 pascals (Pa)
kn	knot	=	0.5144 meter/second (m/s)
lb	pound	=	0.453592 kilogram (kg)
mi	mile	=	1,609.34 meters (m)
nmi	nautical mile	=	1,852 meters (m)
ton (long)		=	1.016 ton (t)
ton (short)		=	0.907185 ton (t)
yd^3	cubic yard	=	0.764555 cubic meter (m^3)

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CHAPTER 1. INTRODUCTION

While the past decade has seen substantial reductions in the emissions from individual vehicles, the number of vehicles operating has increased substantially. As the Nation's fleet of automobiles continues to grow, so will ambient levels of carbon monoxide, particulate matter, and ozone, unless a technological cleanup solution is implemented. The United States Environmental Protection Agency (EPA) has long appreciated that the automotive industry must begin a transition to a new automotive fuel if any significant progress is to be achieved in the battle to reduce atmospheric emissions. The EPA has studied the wide range of alternative fuels available, and concluded that methanol is the most viable alternative fuel for widespread introduction into the automotive fuel market. Liquid fuels such as methanol have a high energy content per volume and require minimal changes in the existing fuel distribution infrastructure. The molecular structure of methanol is such that it can reduce, by 90 percent, emissions that form ozone, the most serious ground-level pollutant. Methanol has a much lower vapor pressure than gasoline, which reduces evaporation as a pollution source. Also, it is possible to design for high efficiency in dedicated methanol automobiles.

To date, the largest barrier to the implementation of methanol fuel has been its price. The major cost components of methanol are: (1) the cost of feedstock (gas) and (2) the capital investment required for production facilities. Present day land-based construction suffers from the following problem: Construction of production facilities is least expensive in industrialized areas where infrastructure exists and resources are abundant. Gas feedstock has numerous utility applications in industrialized areas that cause it to be expensive. Any attempt to construct a methanol production facility in an underdeveloped area, where feedstock is abundant and inexpensive, results in inflated cost to construct the methanol production facility. Thus, it is not possible to achieve significant methanol price reductions using conventional land-based production technology.

The Methanol Plantship (MPS) is a solution to this problem. Conceptually, it is a methanol plant mounted on a buoyant barge which can be operated offshore. The entire facility can be constructed in a shipyard where equipment, labor force, and quality controls are in place, and costs can be minimized. The facility can then be towed to gas reserves that are so far offshore that there is no conventional use for them and the feedstock cost is therefore quite low. Thus, the MPS concept unites the two major cost components of methanol production at their lowest prices. If this methanol production technology can be demonstrated and commercialized, fuel use of methanol can become a reality.

In actuality, the process of designing an operable and efficient MPS is far more complex than simply mounting a methanol plant on a barge. In fact, the both the barge and production plant must be designed specifically and integrated fully. The U.S. Department of Transportation (DOT) began contracting for the development of this concept in 1985. That study, phase I, required the contractor to confirm the availability of abundant subsea feedstock for MPS operation; demonstrate that continuous, long-term methanol plant operations can be efficient in the at-sea environment; and show that the economics of the MPS can be competitive with those of land-based plants.

The phase I findings were very encouraging so that in 1991 the DOT commissioned the present study, phase II, to help push the project to construction. Specifically, the phase II contract was designed to make minor design refinements and develop detailed cost estimates for development of plans and specifications, design, and construction of an MPS.

CHAPTER 2. PART I

This study, phase II, had two distinct objectives. Part I, completed in October 1992, assessed the findings of phase I in light of updated permitting and environmental constraints. Part I was designed to verify the need for executing part II. Discussion of the part I tasks delineated by the contract follows:

TASK A: OTHER METHANOL PLANTSHIP PROGRAMS

Task A examined other plantships that have been proposed, but not constructed, to determine if the obstacles that those projects faced will be obstacles to the current effort. The contract cited 27 articles about ship-mounted methanol production, and required that the contractor analyze them for similarities to, and differences from, this present effort. The Oman Project was most extensively researched and compared to the contractor effort. Other projects examined were: BHP-Australia, Ugland-Indonesia, and the Joint Industry Project Extended Well Test Vessel.

The Oman Project

The Oman Project was to utilize gas from the Bukha field in the Persian Gulf north of the Musandam Peninsula. Being non-contiguous, the Bukha field cannot be pipelined to Oman proper without traversing foreign lands of the United Arab Emirates. The project was initiated in 1988 by Ocean Phoenix, Ltd. Initially conceived as a 2-year project comprising a rehabilitated 500,000-t/yr land-based plant installed aboard a converted very large crude carrier (VLCC), the concept evolved into a 3-year project comprised of a purpose-built barge housing a new plant of 2,500-short tons per day (STPD) (2,268-t/d) capacity. M. W. Kellogg was awarded a turnkey construction contract.

The current contractor met with M. W. Kellogg representatives to discuss the Oman Project. The Oman Project has been on hold since November 1990. It will be resurrected if financing can be found. M. W. Kellogg gave Ocean Phoenix Ltd., a fixed-price turnkey quotation with performance guarantees. Because M. W. Kellogg was assuming all risks, the contingency provided was large, and the contract price was high. M. W. Kellogg believes that the project cost could be significantly reduced by selecting a different contract type that includes risk apportionment.

The cost of the Oman Project was greater than $350 million, of which $120 million was for the construction of the purpose-built barge. The anticipated construction period was 36 months.

BHP-Australia

Broken Hill Properties (BHP) is planning to build a land-based methanol plant using the Imperial Chemicals Industry (ICI) leading concept methanol (LCM) process; they then plan to assess the LCM for plantship use. The capacity of this pilot plant is 300 t/d. Feedstock cost is $2/MMBtu ($1.90/GJ). This plant awaits BHP Petroleum Board approval. The BHP effort is noteworthy because a detailed comparison was made of the costs of large land-based methanol plants vs. floating methanol plants. The BHP study concludes that methanol from the offshore MPS can be sold into U.S. West Coast markets profitably at prices in the range of $0.33 to 0.38/gal ($0.087 to 0.100/L). This is also the finding of the current contractor. The transportation cost of $0.045/gal ($0.012/L) in dedicated 50,000- to 100,000-dwt (50,800- to 101,600-t) tankers also mirrors the estimates in the current contract.

Ugland-Indonesia

The NPC/Ugland project in Sulawesi has been purchased by Akers, a Norwegian company, which also owns Omega, a U.S. marine engineering firm. Omega has reported that the Ugland project was still active as late as July 1991. A project cost of $400 million indicates the use of either a converted tanker or a purpose-built vessel. Ugland has worldwide marketing rights for the NPC-M3 facility, which implies that some aspect of the design must be proprietary and that it evolved at significant cost.

Joint Industry Project (JIP) Extended Well Test (EWT) Vessel

Oceaneering Production Systems in Houston, Texas, is performing design development of a vessel that will enable extended (up to 6 months) flow-testing of oil/gas wells in very deep waters in the Gulf of Mexico (up to 1,525 m of water). The Minerals Management Service (MMS) of the Department of the Interior and seven major oil companies are sponsoring the study. The vessel is required because extended well testing is necessary for delineation and sizing of a subsea field; this testing must be conducted without impact on the environment. Gas produced in association with the oil cannot be flared; also, for test results to be valid, the gas cannot be reinjected. Oceaneering has explored various processes for conversion of gas to useful products — one is methanol. The vessel is being scaled to handle 30,000,000 ft^3/d (850,000 m^3/d) of natural gas — enough to produce 1,000 STPD (907 t/d) of methanol. The plant is reputed to cost in excess of $68 million. The vessel is greater than 80,000 dwt (81,280 t).

Conclusions

Much about the current MPS design was endorsed by the task A analysis of other plantship programs. First, task A research showed many gas resources are uniquely well addressed by methanol plantships. Second, as to technology, the research endorsed the following aspects of the current MPS project:

- Use of a monohull, purpose-built vessel.
- Use of a single-point mooring (SPM).
- Use of nominally 45,000-dwt (45,720-t) off-load tankers at production site to discharge port distances of nominally 2,500 nmi (4,600 km).
- Use of world-scale plants for economy of scale.
- Use of a fully integrated plant and vessel.

Third, the physical parameters of the contractor plant and vessel, and the efficiency of the plant, were corroborated by task A research. Fourth, the cost estimates for construction of a comparable size MPS in other programs closely parallel those derived in the current study — capital cost is in the range of $250 to $300 million; financed construction costs are in the range of $350 to $400 million (1988). Finally, the task A review found nothing that should deter work on the MPS.

TASK B: REGULATIONS IMPACT ASSESSMENT

Task B examined current permitting requirements and environmental regulations, many of which have been written and/or implemented since the completion of the phase I study in 1987, to identify their impact on MPS design, construction, and operation; and to determine if new compliance standards are achievable and cost-effective for the MPS.

Phase I made an assessment of the licenses and permits required for environmental protection by personal interaction with the regulatory authorities and, with them, cooperative examination of their regulatory roles as they impact the MPS. In contrast, this phase II effort used a comprehensive list of potentially relevant statutes as a source from which to develop a pathway to regulatory compliance. Once identified, relevant statutes were researched as to their implementing regulations and permitting requirements.

Numerous statutes were identified by the study team as potentially relevant to MPS design, construction, and operation. Those statutes subjected to analysis and specific relevance determination were:

- Clean Air Act.
- Clean Water Act.
- Oil Pollution Act.
- Comprehensive Environmental Response, Compensation, and Liability Act.
- Superfund Amendments and Reauthorization Act.
- Occupational Safety and Health Act.
- Toxic Substance Control Act.
- Resource Conservation and Recovery Act.
- Federal Insecticide, Fungicide, and Rodenticide Act.
- Safe Drinking Water Act.
- National Environmental Policy Act.
- Hazardous Materials Transportation Act.
- Ports and Waterways Safety Act.
- Rivers and Harbors Act of 1899.
- Marine Protection, Research, and Sanctuaries Act.
- Outer Continental Shelf-Lands Act.
- Coastal Zone Management Act.

The three primary Federal agencies that promulgate regulations and govern the issuance of permits for offshore oil- and gas-related operations, and hence the MPS, are the Environmental Protection Agency (EPA), the Minerals Management Service (MMS), and the

United States Coast Guard (USCG). The EPA role is to ensure air and water quality. MMS regulates environmental protection of the Outer Continental Shelf (OCS). The U.S. Coast Guard regulates vessel design, operations safety, and prevention of pollution from ships.

In accordance with the regulations promulgated by these agencies, the MPS will have to:

- Apply for an air permit in accordance with New Source Performance Standards.
- Apply for a water permit in accordance with National Pollution Discharge Elimination System (NPDES) requirements.
- Establish a spill prevention, control, and countermeasure plan.
- Establish a solid waste management plan will meet environmental requirements.

Conclusions

A tabular summation of the impact of the statutes via related regulations and permitting requirements is given in table 1.

Table 1. Summation of statutes/regulations impact.
(Based on MPS operation on the OCS)

	Consequence to MPS			
Legislation	Design	Operating	Cost	None
Clean Air Act				
Geographic Non-Attainment Areas				X
Emissions from Moving Sources			X	
Toxic Air Pollutants				
Overview	X	X		
New Source Performance Standards			X	
Permits			X	
Clean Water Act				
Overview	X	X	X	
EPA National Pollution Discharge Elimination System Regulations				
Technology-Based Effluent Guidelines	X		X	
Water Quality-Based Effluent Guidelines	X	X		

Table 1. Summation of statutes/regulations impact (continued).				
	Consequences to MPS			
Legislation	Design	Operating	Cost	None
NPDES Permitting Process			X	
New Source Performance Standards	X	X	X	
Oil Pollution Act of 1990 and Section 311 of the Clean Water Act			X	
Comprehensive Environmental Response, Compensation, and Liability Act			X	
Superfund Amendments and Reauthorization Act			X	
Occupational Safety and Health Act	X		X	
Toxic Substance Control Act				X
Resource Conservation and Recovery Act			X	
Federal Insecticide, Fungicide, and Rodenticide Act				X
Safe Drinking Water Act	X	X	X	
National Environmental Policy Act				X
Hazardous Materials Transportation Act				X
Marine Protection, Research, and Sanctuaries Act				X
Outer Continental Shelf-Lands Act				X
Coastal Zone Management Act				X

Overall, the impact of licensing and permitting requirements that have come into existence since the phase I study have had a minimal impact on the MPS design and cost. Most technology vendors anticipate and design for safety and environmental regulations. Thus, compliance solutions for methanol plant operations and ship construction can be purchased more or less "off the shelf". To the extent that methanol production at sea is a unique application of typical methanol production technology, task B research showed that:

- Methanol is a much less hazardous substance than many of the products, such as oil, which are typically produced and handled at sea. Thus, no extraordinary compliance measures are necessary.

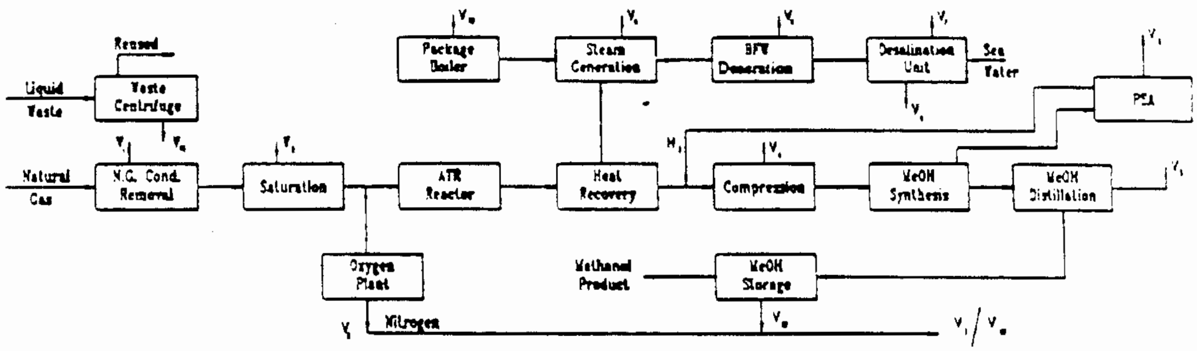
- Emissions control regulations tend to be less stringent at sea than on land, thus no adjustment of land-based methanol plant operation to reduce plant effluents offshore is necessary.

TASK C: USAGES AND YIELDS, WASTE STREAMS, AND FLOWS AND EMISSIONS

Task C examined the chemical process technology for the MPS, which has changed since completion of the phase I study. Process flow parameters were examined in light of new regulatory constraints and with respect to potential application in various size MPS facilities.

The methanol production process can be broken down into three phases. After the feedstock gas is separated: (1) the methane component is converted to synthesis gas; (2) the synthesis gas is then converted to methanol; and (3) the methanol is distilled to grade (AA, A, or Fuel) specification.

A general flow schematic for a 3,000-STPD (2,722-t/d) methanol plant is presented in figure 1.



Vent Streams

V_1*	=	Natural Gas to Flare on Startup — Non-continuous
V_2*	=	Flue Gas from Startup Heater — Non-continuous
V_3	=	Excess Nitrogen — Continuous
V_4*	=	Reformed Gas to Flare — Non-continuous (occurs on compressor trip)
V_5	=	PSA Purge Gas and Distillation Column Vent Gas to Boiler — Continuous
V_6	=	Concentrated Sea Water to Sea — Continuous
V_7	=	Steam/Air to Atmosphere from Ejector — Continuous
V_8	=	Vent Steam from Deaerator — Continuous
V_9	=	Vent Steam from LP/Ejectors — Continuous
V_{10}	=	Stack Gas from Package Boiler — Continuous
V_{11}	=	Separated Water from Waste Streams — Continuous
V_{12}	=	Vent Gas from Methanol Storage — Continuous

* V_1, V_2, V_4 — Only vent to the flare system during startup and emergencies.

Figure 1. Flow schematic and emission sources: 3,000-STPD (2,722-t/d) methanol plant, phase II.

The phase I process plant used Davy McKee/Engelhard synthesis gas technology and ICI methanol synthesis technology. In the period between phase I and phase II, the Davy McKee technology, which was an advanced, combustionless, auto-thermal reactor (ATR), was developed substantially. Promise was so great that rights to some of the technology were purchased by ICI. Most importantly, however, development had not progressed at the time of phase II to the point of readiness for commercial application. Therefore, Haldor Topsoe, Inc.'s combustion-type, CATPOX ATR synthesis gas technology (which is available commercially) was selected for phase II evaluation.

When operating, the plant produces 3,000 STPD (2,722 t/d) of methanol. The preliminarily determined daily usages (24-h basis) for raw materials and yield of methanol are listed in table 2 below:

Table 2. Daily usages at 3,000-STPD (2,722-t/d) methanol yield.

Description	Units	Quantity
Process Natural Gas	MMft³ MMBtu/ST (HHV) methanol	75.30 26.60
Package Boiler and Feed Pre-Heater Fuel	MMft³ MMBtu/ST (HHV) methanol	3.40 1.20
Gas Turbine Electric Generators	MMft³ MMBtu/ST (HHV) methanol	7.10 2.51
Total Natural Gas	MMft³ MMBtu/ST (HHV) methanol	5.80 30.31
Oxygen	ST	1,873.00
Sea Water	gpm	170,776.00

Note: Small amounts of treatment chemicals for raw water, cooling water, boiler feedwater, boiler water, and distillation column pH control will also be required.

Nomenclature, with metric conversion as necessary:

MMft³ - Million cubic feet (60 °F, 14.7 psia) = 28,330 m³ (16 °C, 101 MPa)
MMBtu/ST - Million Btu's per short ton = 1.163 GJ/t
ST - Short ton (1 ST = 2,000 lb) = 0.907 t
Process natural gas higher heating value (HHV) = 1,059.9 Btu/ft³
Btu/ft³ - Btu per cubic foot (60 °F, 14.7 psia) = 37.24 kJ/m³ (16 °C, 101 MPa)

Exported quantities of waste streams as currently estimated follow in table 3:

Table 3. Waste streams.

Description	Units[1]	Quantity
Distillation (Column Vent)	lb/h Btu/ft^3 (LHV)	24,650 473
Deaerator Vent	lb/h	6,700
Package Boiler Flue Gas[2]	lb/h	928,000
Clean Water (Treated Blowdown)	gal/h	2,210
Saline Blowdown	gal/h	120,000
Sea Water (Thermal)	gal/h	10,250,000

[1] 1 lb = 0.454 kg; 1 Btu/ft^3 = 37.24 kJ/m^3; 1 gal = 0.0037 m^3.

[2] Will contain less than 0.07 lb of NO_x per MMBtu of fuel gases combusted (the upper limit allowed under the Clean Air Act).

Daily consumption/flows are currently estimated as follows in table 4:

Table 4. Daily consumption/flows.

Description	Units[1]	Quantity
Oxygen	ST	1,873
Steam, Saturated	lb	14,525,000
Desalinized Water	gal	140,000
Recycle Steam Condensate	lb	3,720,000
Process Condensate Recycle (to Saturator)	lb	2,486,000
Recycle Column Bottoms (to Saturator)	lb	849,600
Closed-Loop Cooling Water	gal	180,900,000
Electric Power (Operating)	MW	19.7

[1] 1 ST = short ton = 0.907 t; 1 lb = 0.454 kg; 1 gal = 0.0037 m^3

Conclusions

The effluents identified in task C are tolerable. No changes in the present MPS design utilizing Haldor Topsoe, Inc. synthesis gas technology are necessary.

TASK D: SEA STATE UPDATE

Task D determined whether the MPS, as designed in phase I, could be placed at selected global sites and still operate within the motion parameters established in phase I. After identifying three new sites and their respective environments (raw wind, wave, and current), a theoretical motion study was conducted.

A numerical model of the MPS was built for input into the Interactive System for Applied Aquatic Computations (ISAAC), a program commonly used by naval architects to assess motion. The proposed design of the MPS has a unique hull form characterized by large upper and lower sponsons. The sponsons cause the MPS to have the improved motion damping properties of a reduced waterplant vessel while retaining large load-carrying capacity. The following MPS characteristics were represented:

Table 5. Principal dimensions.

Length	780 ft
Breadth	200 ft
Depth	96 ft
Draft (Operating)	55 ft
Displacement (Operating)	179,595 LT
Methanol Storage	68,356 LT
Ballast Capacity	88,706 LT
Draft (Lightship)	22 ft
Displacement (Lightship)	67,332 LT

1 ft = 0.305 m; 1 LT = 1.016 t

The motion study was conducted by varying the environment to which the MPS would be exposed in the Caribbean Sea, the Arabian Sea, and the Bight of Biafra, and comparing the responses to the acceptable responses from phase I. Conclusions were then drawn regarding the operability and durability of the MPS. Operating and storm conditions are shown in Table 6.

Table 6. Environmental matrix operating condition (10-year storm)				
Location	Wave Height[1] ft[2]	Wave Period s	Wind Speed kn	Current Speed kn
Caribbean Sea	10	8.9	24.5	1.65
Arabian Sea	14	6.5	16.0	0.6
Bight of Biafra	8.5	10.0	16.5	0.7
and survival condition (100-year storm).				
Caribbean Sea	28	13.25	80.8	3.0
Arabian Sea	31	13.89	57.5	1.1
Bight of Biafra	23	18.00	82.0	2.4

[1] Wave height = significant wave height = average height of the highest 33-1/3 percent of waves passing a stationary location in a period of 20 minutes.

[2] 1 ft = 0.305 m; 1 kn = 1 nautical mile/h = 1.85 km/h

Effects on Operability

On the basis of the comparability of results (phase I to phase II and site to site), the MPS design is capable of maintaining less than 1 degree of pitch and roll in the worst operating conditions. The maximum MPS response noted was 2.59 degrees of roll and 5.85 degrees of pitch in the worst storm conditions. The motion responses identified in this task show that the present MPS design is operable and will endure storm conditions easily.

TASK E: REVISE/UPDATE ECONOMICS

Task E made an economic analysis of 1,000-, 2,000-, and 3,000-STPD (907-, 1,814-, and 2,722-t/d) plants to determine optimal sizing. Capital costs, efficiency characteristics, and operating expenses were compared. In making these comparisons it was assumed that the three plants are nearly identical, and differ only by the physical size of the plant equipment. Implicit in this assignment was the assumption that a determination as to general project economic viability would be made. The execution of part II was contingent upon a favorable economic determination in task E.

Capital Costs, Efficiency, and Operating Expenses

MPS capital costs are summarized in table 7.

Table 7. MPS capitalization and financing comparison.

Item/MPS	3,000-STPD (2,722-t/d)	2,000-STPD (1,814-t/d)	1,000-STPD (907-t/d)
Startup	7/1/97	4/1/97	1/1/97
Overnight Vessel Expense	$127,950	$ 97,297	$ 59,941
Overnight Plant Expense	136,795	108,297	72,749
Overnight Inventory Expense	24,887	18,873	11,847
Overnight Eng./Tech Support	29,286	23,790	16,441
Overnight Owner Expense	22,126	21,382	20,638
Overnight Deploy/Mooring	28,229	21,467	13,225
Cum. Overnight Capital	$369,273	$291,106	$194,841
Construction Insurance	15,043	11,126	6,837
Construction Loan Interest	68,033	50,318	30,919
Initialization Fees	7,731	6,031	3,992
Construction Contingency	24,300	18,881	12,194
Working Capital Reserve	9,086	7,506	6,024
Debt Reserve	21,932	17,110	11,325
Project Capitalization	$515,398	$402,078	$266,132
Project Equity	128,850	100,520	66,533
Project Long-Term Debt	386,548	301,558	199,599

MPS efficiency characteristics are summarized in table 8.

Table 8. Plant capacity profile and catalyst efficiency impact.

Plant Year		3,000-STPD (2,722-t/d) Capacity (Full Days)	2,000-STPD (1,814-t/d) Capacity (Full Days)	1,000-STPD (907-t/d) Capacity (Full Days)	Catalyst Efficiency (Impact Days)
1997	1	255	254	253	3
1998	2	350	349	348	0
1999	3	350	349	348	0
2000	4	340	339	338	3
2001	5	350	349	348	0
2002	6	350	349	348	0
2003	7	340	339	338	3
2004	8	350	349	348	0
2005	9	350	349	348	0
2006	10	340	339	338	3
2007	11	350	349	348	0
2008	12	350	349	348	0
2009	13	340	339	338	3
2010	14	350	349	348	0
2011	15	350	349	348	0
2012	16	183[1]	184[1]	185[1]	3
2013	17	350	349	348	0
2014	18	350	349	348	0
2015	19	340	339	338	3
2016	20	350	349	348	0

[1] Reflects less production time due to scheduled overhaul.

MPS administrative, operating, and maintenance costs are summarized in table 9.

Table 9. First full year operating expenses.[1]

Startup MPS Capacity	7/1/97 3,000 STPD (2,722 t/d)	4/1/97 2,000 STPD (1,814 t/d)	1/1/97 1,000 STPD (907 t/d)
Home Office			
Management	$ 1,296,000	$ 1,285,000	$ 1,275,000
Administrative	833,000	826,000	829,000
Insurance	9,142,000	6,829,000	4,347,000
Subtotal	11,270,000	8,939,000	6,441,000
Feedstock[2]			
Base Cost	16,741,000	11,171,000	7,070,000
Adjustments	0	0	0
Subtotal	16,741,000	11,171,000	7,070,000
Site Expense			
MPS Operator	7,608,000	7,314,000	7,025,000
Incentive Fee	0	0	0
Workboat/Tug	401,000	397,000	394,000
Replenishment	2,398,000	1,741,000	1,051,000
Inspections	337,000	335,000	332,000
Subtotal	11,744,000	9,787,000	8,802,000
Accruals			
Catalyst	2,089,000	1,381,000	685,000
Waste Disposal	-28,000	-19,000	-9,000
Drydock/Overhaul	4,449,000	3,352,000	2,238,000
Turn-Around Repair	892,000	892,000	892,000
Subtotal	7,402,000	5,706,000	3,824,000
Delivery Expense[3]			
Shuttle/Port Costs	12,272,000	10,723,000	9,268,000
Tariffs	0	0	0
Storage	0	0	0
Subtotal	12,272,000	10,723,000	9,268,000
Operating Expense	$58,429,000	$46,326,000	$35,406,000

[1] Assumes production capacity for 1998.

[2] Based on $0.50/MMBtu ($0.47/GJ) and 34.05, 34.18, and 34.39 MMBtu/t (35.92, 36.06, and 36.28 GJ/t) for different size MPS's.

[3] Based on $12.88/t, $16.93/t, and $29.35/t for 3,000-, 2,000-, and 1,000-STPD (2,722-, 1,814-, and 907-t/d) MPS's, respectively.

Conclusions

Table 10 and figure 2 illuminate relative economic viability conclusions made about the three different size MPS's. Clearly, the 3,000-STPD (2,722-t/d) MPS is more economically viable than the 2,000-STPD (1,814-t/d) and 1,000-STPD (907-t/d) versions.

Table 10. Economic viability comparison: three MPS's [$0.25/MMBtu ($0.24/GJ) feedstock].

MPS Capacity (STPD)[1]	Second Year Methanol Breakeven Price ($/gal)[2]	Equity Payback, Year (Methanol Price $0.41/gal)	Equity Payback, Year (Methanol Price $0.56/gal)
1,000	$0.511	Never	7 (2003)
2,000	0.355	6 (2002)	3 (1999)
3,000	0.295	4 (2000)	2 (1998)

[1] 1 STPD = 0.907 t/d; 1 gal = 3.79 L

[2] Full revenue potential is reached in the second operating year.

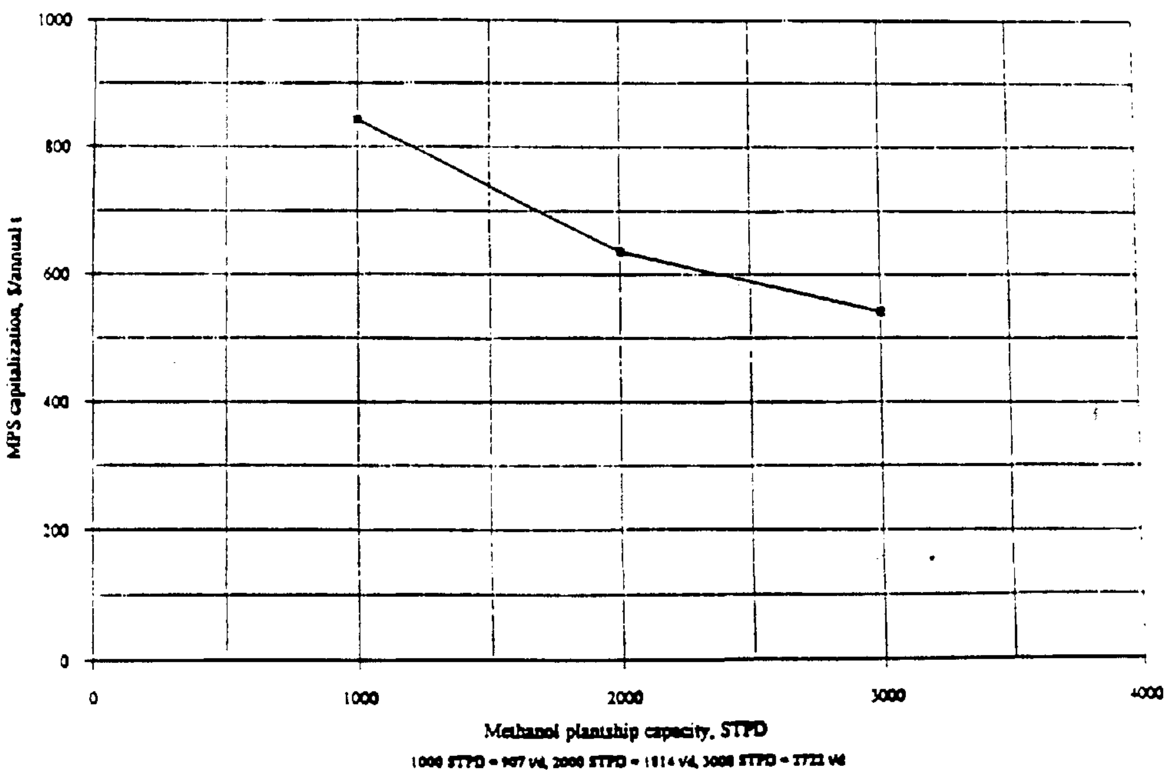


Figure 2. MPS capitalization vs. MPS capacity.

Recognizing that it is easier to market small quantities of methanol than it is to market large quantities of methanol, the objective of this task was to determine the smallest capacity plant design that is commercially viable. Present day contract methanol prices f.o.b. U.S. Gulf Coast have been in the range of $0.40/gal ($0.11/L). Clearly, the 1,000-STPD (2,722-t/d) MPS is not economically viable with a breakeven methanol price of $0.51/gal ($0.13/L). The 2,000-STPD (1,814-t/d) MPS could be profitable, but with a profit margin of only $0.05/gal ($0.013/L), it would be difficult to raise equity for project financing. Furthermore, the present day methanol market tends to fluctuate, and prices are quite likely to fall below $0.35/gal ($0.09/L) at some point during the MPS operating life. In this case, the 2,000-STPD (1,814-t/d) MPS would operate at a loss. The 3,000-STPD (2,722-t/d) MPS, which has a breakeven methanol price of $0.29/gal ($0.08/L), could achieve a profit margin of approximately $0.10/gal ($0.03/L). This is profitable enough to entice equity investors and weather any temporary drop in the market price of methanol. Thus, the 3,000-STPD (2,722-t/d) MPS is the optimal design.

CHAPTER 3. PART II

Part II of phase II, completed in May 1993, developed detailed cost estimates for design of the MPS in light of part I findings; development of plans and specifications for the MPS; and construction of an MPS of cost-effective size and structure.

TASK F: UPDATE GAS SUPPLY

Task F refined understanding of the gas supply by performing an analysis of the effect on MPS design of various methane impurity scenarios; it also updated gas supply assessments at six candidate sites.

Task F made two determinations. First, it was postulated that methane feedstock would vary in purity. Thus, methane impurity scenarios (0 to 25 percent) were analyzed for effect on plant production rates. Second, addressing a broad set of project-related criteria for feedstock selection, an assessment was made of the relative attractiveness of feedstocks available from Angola, Cameroon, Equatorial Guinea, Nigeria, Trinidad, and Venezuela.

Feedstock Impurity Effect on Plant Production Rate

Three feedstocks of varying purity were identified. They represent a range of purities typically encountered in the field. The feedstock analyses are from actual sites at Trinidad, Equatorial Guinea, and Venezuela, respectively. Their respective purities were 99.69, 84.48, and 73.20 percent by volume.

Typically, feedstock impurities are sulfur, chlorides, heavy metals, arsenic, ammonia, and/or oils. Table 11 presents approximate analyses for each candidate feedstock. To illustrate the impact of impurities on production, it was determined how each of three 3,000-STPD (2,722-t/d) methanol plants would perform when designed for a specific candidate feedstock.

Table 12 presents plant productivity measures (estimated plant consumptions as a function of methane purity) for the three feedstocks.

Reassessment of Methane Supply

Because all of the potential feedstock sites for the MPS project are remote, all of the countries in ownership of the production rights are relatively new to the management of their hydrocarbons. This managerial immaturity often results in unpredictable behavior that poses a far greater threat to the MPS project than any feedstock impurity scenario. In order to complete this assessment of gas supply sites, the contractor rated the various gas supply candidates in each of the following categories:

Table 11. Candidate feedstock analyses (mole percent).			
Component	Feedstock 1	Feedstock 2	Feedstock 3
CO_2	0.06	7.14	0.75
N_2	0.10	0.14	0.30
CH_4	99.69	84.48	73.20
C_2	0.11	4.31	8.66
C_3	0.03	2.15	5.05
C_4	0.01	0.99	2.06
C_5	----	0.35	2.40
C_6	----	0.17	7.58
C_7	----	0.16	----
C_8+	----	0.11	----

Table 12. Plant consumptions at 3,000-STPD (2,722-t/d) methanol.			
	Feedstock		
	1	2	3
Feedstock Purity, Percent Methane	99.69	84.48	73.20
H_2:C Ratio, Process Gas	1.99	1.85	1.82
Process Gas, MMft^3/d	80.00	76.00	71.00
Btu/ft^3 (HHV)	1,009.80	1,059.90	1,136.80
Feedstock, MMft^3/d	89.30	94.00	89.00
Btu/ft^3 (HHV)	1,009.80	1,049.60	1,543.50
O_2 Required, STPD	1,850.00	1,873.00	1,860.00

1 MMft^3 = 28.33 x 10^3 m^3; 1 Btu/ft^3 = 37.24 kJ/m^3; 1 STPD = 0.907 t/d

- Production right status/configuration (i.e., American major/national producer joint venture, foreign major/national producer joint venture, independent producer, or national producer).

- Supply quantity.

- Cost and availability.

- Gas association (i.e., dry, condensate associated, or oil-associated).

The gas supply candidates were rated on an escalating scale (0 is best) in each category. Composite scores were used to rate gas supplies overall (lowest score is best). Table 13 presents the host country candidates and their resultant specific composite ratings.

Candidate number 5 is the most desirable gas supply candidate largely because of the ownership participation of an American major oil company that can facilitate negotiation. Furthermore, the gas project is relatively well developed. Much of the gas delivery system is already installed. It is interesting to note that candidates 4 and 6 are also relatively appealing gas sources. However, both are located in countries that suffer from political instability. In the event of political change, or mineral rights acquisition by a major oil company, candidates 4 and 6 would become attractive gas supply options.

Brief consideration was given to domestic feedstock reserves. These are abundant; the Minerals Management Service, Department of Interior, estimates the deep Gulf of Mexico holds 32 trillion ft^3 (0.9 trillion m^3), sufficient to operate more than 53 MPS's of 3,000-STPD (2,722-t/d) capacity for 20 years. However, because of the price that natural gas itself can bring in the U.S. — more than $2.00/million Btu ($1.90/GJ) — the gas is not an immediately attractive MPS feedstock candidate. In fact, at the May 1993 Offshore Technology Conference in Houston, Texas, a consortium of major domestic oil companies disclosed engineering development plans to step off from existing subsea Gulf infrastructure in 1,000 ft (300 m) of water to address gas/oil resources that lay in progressively deeper waters, to and beyond 5,000 ft (1,500 m).

TASK G: UPDATE DESIGN

Task G updated the design of the MPS in light of the information learned in tasks A through F. The point of departure for MPS design update and refinement was the 3,000-STPD (2,722-t/d) MPS design developed in phase I. Much of the work done in tasks A through F served to reinforce design decisions made in phase I. The only major design changes made in phase II were: (1) a new methanol process technology supplier was selected; (2) the product (methanol) quality was upgraded; (3) the plantship operating site was changed; and (4) an improved, less costly, MPS mooring/riser system was defined. The vessel and superstructure were altered only as required by plant, site, and mooring changes.

Table 13. Parameter analyses of methane supply.

Candidate	Country	Ownership Production Rights	Supply Reserve Amount	Cost/Availability					Gas Association	Composite Score
				C	D	P/G	GT	DEL		
1	Trinidad	4	0	1	1	3	0	0	0	9
2	Eq. Guinea	3	2	0	0.5	0	1	0	0.5	7
3	Venezuela	4	1	0	0.5	2	2	0	0.7	10.2
4	Angola	2	1	0	1	0	2	0	0.5	6.5
5	Nigeria	1	1	1	0	0	0	1	0	4
6	Cameroon	2	3	0	0	1	1	1	1	9

<u>Legend</u>

C = Composition
D = Development Cost
P/G = Producing/Gathering Cost
GT = Gas Treatment Cost
DEL = Costs for Delivery of Gas

The Methanol Process Technology

As discussed earlier in chapter 2, the methanol process technology was changed from a combination of Englehard/Davy McKee Corporation Catalytic Partial Oxidation (CATPOX) Syngas and ICI Low Pressure Methanol processes to Haldor Topsoe, Inc.'s Auto-Thermal Reformer (ATR) Syngas and Low Pressure Methanol processes because the phase I syngas process was not sufficiently proven for commercial operation. The new technologies integrated into the MPS with little variation from the original design.

Product quality was upgraded by the addition of a second distillation column. Manufacture of "Chemical" grade methanol rather than "Fuel" grade will permit servicing of all traditional methanol markets in addition to the rapidly expanding fuel oxygenate (MTBE) and "neat" fuel methanol markets. It is impossible to predict which end uses will demand the most methanol product over the scheduled 20-year operational period. Thus, product flexibility will enhance the financial security of the project.

The Operating Site

Based on the results of task F, the assumed operating site was changed from Trinidad to a generic West African offshore site. West African feedstocks contain greater impurities (heavy hydrocarbons) not present in the Trinidad feedstock, so a feedstock pre-treatment section was added to the process train aboard the MPS.

The Mooring

In phase I, a bow-mounted turret mooring was selected. In phase II, the MPS is configured for connection to a mooring structure (floating or bottom-fixed) by either a rigid arm or a soft-yoke. This mooring means reduced mooring loads are imposed on the MPS, and therefore reduces mooring and MPS structure costs. If the MPS operates in shallow water, the rotating table and swivels of the mooring will be on a bottom-piled platform. If it operates in deep water, a Catenary Anchor Leg Mooring (CALM) will be used.

The Vessel

The MPS task G effort resulted in the following changes to the hull and superstructure of the MPS:

- The shape of the MPS forebody was redesigned to result in less surge and pitch, and to accommodate the new mooring system.
- The MPS tank plan was redesigned to simplify the cargo transfer and ballast system; this redesign also reduces the amount of steel in the MPS, and hence reduces the cost.
- The accommodations were redesigned to allow for longer crew rotations, thus reducing operating expenses of transporting crew from a West African location. Accordingly, recreational facilities were added and storage capacity was increased.

- The capability of the workshop and the capacity of the spares storage areas were increased in anticipation of operating in a less-developed region of the world.

- The phase I azimuthing thrusters were replaced with tunnel thrusters, an economy measure.

- As a consequence of phase II design changes, there has been a 40-LT (40.7-t) reduction in the lightship weight. The new lightship weight is 67,310 LT (68,410 t).

TASK H: DRAWINGS

Task H required that the phase I quotation assembly drawings used to estimate the cost to construct the methanol plantship be updated and refined to achieve a refined cost estimate -5 to +15 percent accuracy, and that the continuing accuracy of phase I specifications be assessed.

Requisite quotation assembly drawings, process flow diagrams, and the ship and process equipment listings were developed in conjunction with task G design updating.

TASK I: FINAL COST ESTIMATES

Task I determined the cost of designing, developing plans and specifications for, and constructing the MPS. Project economics were assessed continuously as new cost/impact effects were determined. Task I required the contractor to do three things: (1) prepare a pre-bid package enumerating costs for the preparation of a final bid package for use to "go to construction;" (2) prepare a cost estimate for designing the MPS; and (3) prepare a cost estimate for constructing the MPS.

Cost for "Go to Construction" Bid Package

To determine the cost of preparing an MPS bid package, a definitive work statement was prepared. Preparation of the MPS "go to construction" bid package will require approximately 7.5 months. The costs developed against the work statement are categorized as: process plant cost, plant vessel cost, and owner's expense. Table 14 presents these costs.

Table 14. "Go to construction" final bid package cost.

Element	Estimated Cost
Owner's Expense (7-1/2 month period)	$1,860,000
Process Plant Package	1,500,000
Plant Vessel Package	508,500
Total	$3,868,500

Cost for MPS Design

Design of the MPS will require approximately 20 months; this includes the time devoted to preparation of the "go to construction" bid package. In addition to owner, process engineer, and construction contractor costs, costs will be incurred for technology licensing and facility classification. Table 15 presents the costs for MPS design.

Table 15. Cost for MPS design.

Owner's Expense in MPS Design Period	$ 6,332,800
Process Engineer's Engineering Cost	6,680,224
Licensor's Engineering Cost	500,000
MPS Contractor's Engineering Cost	4,068,000
Classification/Permit/Certification Costs	489,550
Total	$18,070,574

Cost for MPS Construction

The cost to construct the plantship is presented in table 16. From start of work on the "go to construction" bid package to installation onsite, lapsed time will be 42 to 48 months.

Table 16. Cost for MPS construction.

Owner's Expense	$ 57,747,550
Process Plant	156,725,855
Plant Vessel	171,373,680
Total	$385,847,085

It should be noted that the cost to construct the MPS (presented in table 16) is inclusive of the cost to design, which, in turn, is inclusive of cost to prepare the final bid package.

CHAPTER 4. METHANOL MARKET DISCUSSION

The following discussion of methanol market trends is provided as a context for the anticipated development of the MPS, and for the potential for replication of the first-of-a-kind project described herein.

Traditionally, methanol has been utilized in the production of dimethyl terephtalate (DMT), acetic acid, methyl methacrylate, and solvents. More recently, methanol has been used as feedstock for methyl tertiary butyl ether (MTBE) and tertiary amyl methyl ether (TAME), which are oxygenated fuel additives for gasoline blends, and, in its purest form, as fuel. While the traditional chemical markets for methanol are predicted to exhibit steady, moderate growth, these more recent applications, especially MTBE, promise dramatic growth throughout the foreseeable future.

The use of MTBE is the most viable option for compliance with Clean Air Act air quality regulations in non-attainment regions. These regions of the U.S. consume 50 percent of the domestic gasoline consumption, approximately 150 x 10^6 t/yr. It will require the output of eight world-scale methanol plants to produce enough MTBE to bring these non-attainment regions into compliance by the mid-1990's. (This calculation assumes that no MTBE is distributed to regions that are not designated as non-attainment areas. Practically, this is not possible because distribution techniques tend to lack precision.) It takes 3 to 5 years to build a methanol plant, and only two world-scale methanol plants are presently under construction. Thus, it is reasonable to anticipate a methanol supply shortage at the end of this decade. Figure 3 reflects current demand for methanol and projects the demand for methanol through 1995.

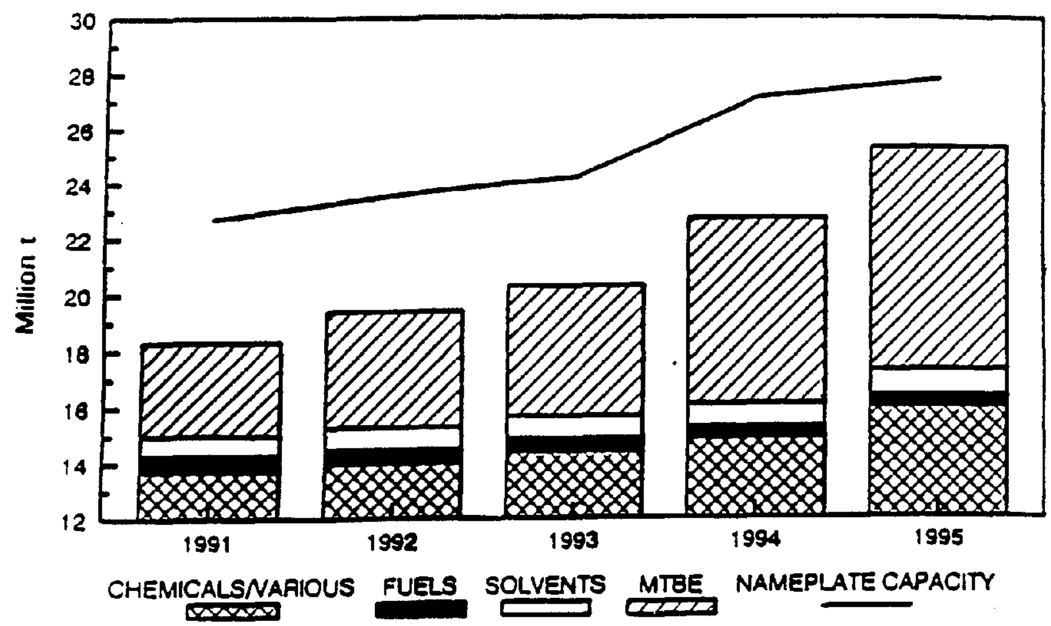


Figure 3. Forecasted world methanol demand by product group.

These demand projections are constrained by the relatively high cost of traditional, land-based methanol production. If the cost of methanol can be reduced by the development of new technologies such as the MPS, the demand for methanol may well increase faster than presently forecasted. The potential market for clean-burning, fuel-grade methanol is huge, and yet, difficult to predict. Many powerplants in non-attainment areas are facing the alternatives of shutting down or finding an economically acceptable technical solution to emissions control. Inexpensive methanol fuel use would be an option preferable to purchasing expensive selective catalytic reduction (SCR) technology or scrubbers.

In addition, there is the perception among many experts that methanol will be the transportation fuel of preference in the 21st century. Flexible fuel vehicles currently are being manufactured by a number of automobile manufacturers. If the cost of methanol production can be reduced, these vehicles should provide the impetus for widespread vehicular use of methanol fuel, which should in turn produce a dramatic increase in global demand for methanol.