Commercial-Scale Demonstration of the Liquid Phase Methanol (LPMEOH™) Process

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Disclaimer

Abstract

The Liquid Phase Methanol (LPMEOH™) Demonstration Project at Kingsport, Tennessee, is a \$213.7 million cooperative agreement between the U.S. Department of Energy (DOE) and Air Products Liquid Phase Conversion Company, L.P. (the Partnership). The LPMEOH™ Process Demonstration Unit is being built at a site located at the Eastman Chemical Company (Eastman) complex in Kingsport.

During this quarter, the Cooperative Agreement was modified (Mod A011) on 8 October 1996, authorizing the transition from Budget Period No. 2 (Design and Construction) to the final Budget Period (Commissioning, Start-up, and Operation). A draft Topical Report on Process Economics Studies concludes that methanol coproduction, with integrated gasification combined cycle (IGCC) electric power utilizing the LPMEOH™ process technology, will be competitive in serving local market needs. Planning for a proof-of-concept test run of the liquid phase dimethyl ether (DME) process at the LaPorte Alternative Fuels Development Unit (AFDU) was recommended; and a decision to proceed is pending. Construction (Task 2.2) is 97% complete, as of 31 December 1996. Completion of pipe pressure testing has taken longer than expected. This will delay completion of construction by about three weeks. Commissioning activities (Task 2.3) commenced in mid-October of 1996, and the demonstration unit is scheduled to be mechanically complete on 24 January 1997.

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ACRONYMS AND DEFINITIONS

Acurex	-	Acurex Environmental Corporation
Air Products	-	Air Products and Chemicals, Inc.
AFDU	-	Alternative Fuels Development Unit - The "LaPorte PDU."
Balanced Gas	-	A syngas with a composition of hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2) in stoichiometric balance for the production of methanol
Carbon Monoxide Gas	-	A syngas containing primarily carbon monoxide (CO); also called CO Gas
DME	-	dimethyl ether
DOE	-	United States Department of Energy
DOE-PETC	-	The DOE's Pittsburgh Energy Technology Center (Project Team)
DOE-HQ	-	The DOE's Headquarters - Clean Coal Technology (Project Team)
DTP	-	Demonstration Test Plan - The four year Operating Plan for Phase 3, Task 2 Operation
DVT	-	Design Verification Testing
Eastman	-	Eastman Chemical Company
EIV	-	Environmental Information Volume
EMP	-	Environmental Monitoring Plan
EPRI	-	Electric Power Research Institute
HAPs	-	Hazardous Air Pollutants
Hydrogen Gas	-	A syngas containing an excess of hydrogen (H_2) over the stoichiometric balance for the production of methanol; also called H_2 Gas
IGCC	-	Integrated Gasification Combined Cycle, a type of electric power generation plant
IGCC/OTM	-	An IGCC plant with a "Once-Thru Methanol" plant (the LPMEOH™ Process) added-on.
KSCFH	-	Thousand Standard Cubic Feet per Hour
LaPorte PDU	-	The DOE-owned experimental unit (PDU) located adjacent to Air Product's industrial gas facility at LaPorte, Texas, where the LPMEOH™ process was successfully piloted.
LPDME	-	Liquid Phase DME process, for the production of DME as a mixed coproduct with methanol
LPMEOH™	-	Liquid Phase Methanol (the technology to be demonstrated)
MTBE	-	methyl tertiary butyl ether
NEPA	-	National Environmental Policy Act
OSHA	-	Occupational Safety and Health Administration
Partnership	-	Air Products Liquid Phase Conversion Company, L.P.
PDU	-	Process Development Unit
PFD	-	Process Flow Diagram(s)
ppb	-	parts per billion
Project	-	Production of Methanol/DME Using the LPMEOH™ Process at an Integrated Coal Gasification Facility
psia	-	Pounds per Square Inch (Absolute)
psig	-	Pounds per Square Inch (gauge)
P&ID	-	Piping and Instrumentation Diagram(s)
SCFH	-	Standard Cubic Feet per Hour
Sl/hr-kg	-	Standard Liter(s) per Hour per Kilogram of Catalyst
Syngas	-	Abbreviation for Synthesis Gas
Synthesis Gas	-	A gas containing primarily hydrogen (H_2) and carbon monoxide (CO), or mixtures of H_2 and CO; intended for "synthesis" in a reactor to form methanol and/or other hydrocarbons (synthesis gas may also contain CO_2, water, and other gases)
Tie-in(s)	-	the interconnection(s) between the LPMEOH™ Process Demonstration Facility and the Eastman Facility
TPD	-	Ton(s) per Day
WBS	-	Work Breakdown Structure
wt	-	weight

Executive Summary

The Liquid Phase Methanol (LPMEOH™) Demonstration Project at Kingsport, Tennessee, is a $213.7 million cooperative agreement between the U.S. Department of Energy (DOE) and Air Products Liquid Phase Conversion Company, L.P. (the Partnership). The LPMEOH™ Process Demonstration Unit is being built at a site located at the Eastman Chemical Company (Eastman) complex in Kingsport.

On 4 October 1994, Air Products and Chemicals, Inc. (Air Products) and Eastman Chemical Company (Eastman) signed the agreements that would form the Partnership, secure the demonstration site, and provide the financial commitment and overall project management for the project. These partnership agreements became effective on 15 March 1995, when DOE authorized the commencement of Budget Period No. 2 (Mod. A008 to the Cooperative Agreement). The Partnership has subcontracted with Air Products to provide the overall management of the project, and to act as the primary interface with DOE. As subcontractor to the Partnership, Air Products will also provide the engineering design, procurement, construction, and commissioning of the LPMEOH™ Process Demonstration Unit, and will provide the technical and engineering supervision needed to conduct the operational testing program required as part of the project. As subcontractor to Air Products, Eastman will be responsible for operation of the LPMEOH™ Process Demonstration Unit, and for the interconnection and supply of synthesis gas (syngas), utilities, product storage, and other needed services.

The project involves the construction of an 80,000 gallons per day (260 tons per day (TPD)) methanol unit utilizing coal-derived syngas from Eastman's integrated coal gasification facility. The new equipment consists of syngas feed preparation and compression facilities, the liquid phase reactor and auxiliaries, product distillation facilities, and utilities.

The technology to be demonstrated is the product of a cooperative development effort by Air Products and DOE in a program that started in 1981. Developed to enhance electric power generation using integrated gasification combined cycle (IGCC) technology, the LPMEOH™ process is ideally suited for directly processing gases produced by modern-day coal gasifiers. Originally tested at a small, DOE-owned experimental unit in LaPorte, Texas, the technology provides several improvements essential for the economic coproduction of methanol and electricity directly from gasified coal. This liquid phase process suspends fine catalyst particles in an inert liquid, forming a slurry. The slurry dissipates the heat of the chemical reaction away from the catalyst surface, protecting the catalyst and allowing the methanol synthesis reaction to proceed at higher rates.

At the Eastman complex, the technology is being integrated with existing coal-gasifiers. A carefully developed test plan will allow operations at Eastman to simulate electricity demand load-following in coal-based IGCC facilities. The operations will also demonstrate the enhanced stability and heat dissipation of the conversion process, its reliable on/off operation, and its ability to produce methanol as a clean liquid fuel without additional upgrading. An off-site product testing program will be conducted to demonstrate the suitability of the methanol product as a transportation fuel and as a fuel for stationary applications for small modular electric power generators for distributed power.

The four-year operating test phase will demonstrate the commercial application of the LPMEOH™ process, to allow utilities to manufacture and sell two products: electricity and methanol. A typical commercial-scale IGCC coproduction facility, for example, could be expected to generate 200 to 350 MW of electricity, and to also manufacture 45,000 to 300,000 gallons per day of methanol (150 to 1000 TPD). A successful demonstration at Kingsport will show the ability of a local resource (coal) to be converted in a reliable (storable) and environmentally preferable way to provide the clean energy needs of local communities for electric power and transportation.

This project may also demonstrate the production of dimethyl ether (DME) as a mixed coproduct with methanol if laboratory and pilot-scale research and market verification studies show promising results. If implemented, the DME would be produced during the last six months of the four-year demonstration period. DME has several commercial uses. In a storable blend with methanol, the mixture can be used as a peaking fuel in gasification-based electric power generating facilities, or as a diesel engine fuel. Blends of methanol and DME can be used as chemical feedstocks for synthesizing chemicals, including new oxygenated fuel additives.

The project was reinitiated in October of 1993, when DOE approved a site change to the Kingsport location. DOE conditionally approved the Continuation Application to Budget Period No. 2 (Design and Construction) in March of 1995 and formally approved it on 1 June 1995 (Mod M009). After approval, the project initiated Design - Phase 1 - activities; and initiated Construction - Phase 2 - activities in October of 1995. The project required review under the National Environmental Policy Act (NEPA) to move to the construction phase. DOE prepared an Environmental Assessment (DOE/EA-1029), and subsequently a Finding of No Significant Impact (FONSI) was issued on 30 June 1995. The demonstration unit is scheduled to be mechanically complete in January of 1997.

During this quarter, the Cooperative Agreement was modified (Mod A011) on 8 October 1996, authorizing the transition from Budget Period No. 2 (Design and Construction) to the final Budget Period (Commissioning, Start up, and Operation). This modification provides the full $213,700,000 of authorized funding, with 56.7% participant cost share and 43.3% DOE cost share.

A draft Topical Report on Process Economics Studies was issued for review. The study concludes that methanol coproduction, with IGCC electric power utilizing the LPMEOH™ process technology, will be competitive in serving local market needs. The study results are also being incorporated into a paper "Fuel and Power Coproduction", which will be presented in January at the DOE's 5th Annual Clean Coal Technology Conference.

A recommendation to continue with DME design verification testing was made. DME design verification testing studies show the liquid phase DME (LPDME) process will have a significant economic advantage for the coproduction of DME for local markets. The market applications for DME are large. An LPDME catalyst system with reasonable long-term activity and stability is beening developed. Planning for a proof-of-concept test run at the LaPorte Alternative Fuels Development Unit (AFDU) was recommended; and a decision to proceed is pending.

The off-site product-use test plan is to be updated by May of 1997. During this quarter, Air Products and Acurex initiated contacting prospective Federal, State, and University product-use test participants who are involved in fuel cell, transportation, and stationary power plant developments.

A project review meeting was held in Kingsport in early December. The equipment is installed, and installation of the demonstration unit showed tremendous progress since the project review meeting in September. Programming of the instrument control system was completed during this quarter, and design engineering is now completed. The construction and operation permits have been obtained. Operator training was completed during this quarter, and final plans for startup and initial operation have been made.

Construction (Task 2.2) is 97% complete, as of the end of December 1996. Completion of pipe pressure testing has taken longer than expected. This has impacted completion of insulation and will delay completion of construction by about three weeks. Commissioning activities (Task 2.3) commenced in mid-October of 1996, and will be completed late in January of 1997. Startup, of the utility systems, is also scheduled to begin late in January.

The demonstration unit is scheduled to be mechanically complete on 24 January 1997. Ninety-one percent (91%) of the $38 million of funds forecast for the Kingsport portion of the LPMEOH™ Process Demonstration Project for the Phase 1 and Phase 2 tasks have been expended (as invoiced), as of 31 December 1996.

A. Introduction

The Liquid Phase Methanol (LPMEOH™) demonstration project at Kingsport, Tennessee, is a $213.7 million cooperative agreement between the U.S. Department of Energy (DOE) and Air Products Liquid Phase Conversion Company, L.P. (the Partnership). A demonstration unit producing 80,000 gallons per day (260 TPD) of methanol was designed and is being constructed at a site located at the Eastman Chemical Company (Eastman) complex in Kingsport. The Partnership will own and operate the facility for the four-year demonstration period.

This project is sponsored under the DOE's Clean Coal Technology Program, and its primary objective is to "demonstrate the production of methanol using the LPMEOH™ Process in conjunction with an integrated coal gasification facility." The project will also demonstrate the suitability of the methanol produced for use as a chemical feedstock or as a low-sulfur dioxide, low-nitrogen oxides alternative fuel in stationary and transportation applications. The project may also demonstrate the production of dimethyl ether (DME) as a mixed coproduct with methanol, if laboratory- and pilot-scale research and market verification studies show promising results. If implemented, the DME would be produced during the last six months of the four-year demonstration period.

The LPMEOH™ process is the product of a cooperative development effort by Air Products and the DOE in a program that started in 1981. It was successfully piloted at a 10-TPD rate in the DOE-owned experimental unit at Air Products' LaPorte, Texas, site. This demonstration project is the culmination of that extensive cooperative development effort.

B. Project Description

The demonstration unit, which will occupy an area of 0.6 acre, is being integrated into the existing 4,000-acre Eastman complex located in Kingsport, Tennessee. The Eastman complex employs approximately 12,000 people. In 1983, Eastman constructed a coal gasification facility utilizing Texaco technology. The syngas generated by this gasification facility is used to produce carbon monoxide and methanol. Both of these products are used to produce methyl acetate and ultimately cellulose acetate and acetic acid. The availability of this highly reliable coal gasification facility was the major factor in selecting this location for the LPMEOH™ Process Demonstration. Three different feed gas streams (hydrogen gas, carbon monoxide gas, and balanced gas) will be diverted from existing operations to the LPMEOH™ demonstration unit, thus providing the range of coal-derived syngas ratios (hydrogen to carbon monoxide) needed to meet the technical objectives of the demonstration project.

For descriptive purposes and for design and construction scheduling, the project has been divided into four major process areas with their associated equipment:

- *Reaction Area* - Syngas preparation and methanol synthesis reaction equipment.
- *Purification Area* - Product separation and purification equipment.
- *Catalyst Preparation Area* - Catalyst and slurry preparation and disposal equipment.
- *Storage/Utility Area* - Methanol product, slurry, and oil storage equipment.

The physical appearance of this facility closely resembles the adjacent Eastman process plants, including process equipment in steel structures.

- *Reaction Area*

The reaction area includes feed gas compressors, catalyst guard beds, the reactor, a steam drum, separators, heat exchangers, and pumps. The equipment is supported by a matrix of structural steel. The most salient feature is the reactor, since with supports, it is approximately 84-feet tall.

- *Purification Area*

The purification area features two distillation columns with supports; one is approximately 82-feet tall, and the other 97-feet tall. These vessels resemble the columns of the surrounding process areas. In addition to the columns, this area includes the associated reboilers, condensers, air coolers, separators, and pumps.

- *Catalyst Preparation Area*

The catalyst preparation area consists of a building with a roof and partial walls, in which the catalyst preparation vessels, slurry handling equipment, and spent slurry disposal equipment are housed. In addition, a hot oil utility system is included in the area.

- *Storage/Utility Area*

The storage/utility area includes two diked lot-tanks for methanol, two tanks for oil storage, a slurry holdup tank, a trailer loading/unloading area, and an underground oil/water separator.

C. Process Description

The LPMEOH™ demonstration unit is being integrated with Eastman's coal gasification facility. A simplified process flow diagram is included in Appendix A. Syngas is introduced into the slurry reactor, which contains a slurry of liquid mineral oil with suspended solid particles of catalyst. The syngas dissolves through the mineral oil, contacts the catalyst, and reacts to form methanol. The heat of reaction is absorbed by the slurry and is removed from the slurry by steam coils. The methanol vapor leaves the reactor, is condensed to a liquid, sent to the distillation columns for removal of higher alcohols, water, and other impurities, and is then stored in the day tanks for sampling before being sent to Eastman's methanol storage. Most of the unreacted syngas is recycled back to the reactor with the syngas recycle compressor, improving cycle efficiency. The methanol will be used for downstream feedstocks and in off-site fuel testing to determine its suitability as a transportation fuel and as a fuel for stationary applications in the power industry.

D. Project Status

The project status is reported by task, and then by the goals established by the Project Evaluation Plan for Budget Period No. 2 (see Appendix B). Major accomplishments during this period are as follows:

Task 1.2 Permitting

For this task the Project Evaluation Plan for Budget Period No. 2 establishes these goals:

- Issue the final Environmental Information Volume (EIV) to support the DOE's Environmental Assessment/Finding of No Significant Impact.
  - The NEPA review was completed 30 June 1995 with the issuance of an Environmental Assessment (DOE/EA-1029) and Finding of No Significant

Impact (FONSI). The Final Environmental Information Volume was approved by the DOE on 29 August 1996. Copies of the Final EIV were distributed in September of 1996.

- Obtain permits necessary for construction and operation.
    - The construction and operation permits have been obtained.

Task 1.3 Design Engineering

For this task the Project Evaluation Plan for Budget Period No. 2 establishes these goals:

- Prepare the Environmental Monitoring Plan (EMP).
    - The DOE approved the Draft Final EMP on 29 August 1996. Copies of the Final EMP were distributed in September of 1996.
- Complete the design engineering necessary for construction and commissioning. This includes Piping and Instrumentation Diagrams, Design Hazard Reviews, and the conduct of design reviews.
    - Task 1.3 Design Engineering is complete. During this quarter, the programming of the Honeywell Digital Control System (DCS) was completed.

Task 1.4 Off-Site Testing (Definition and Design)

The Project Evaluation Plan for Budget Period No. 2 establishes the following goal for this task:

- Prepare the fuel-use demonstration plan for Phase 3, Task 4 Off-Site Product Use Demonstration. This off-site test plan will be incorporated into an updated, overall (fuel and chemical) product-use test plan (in Phase 1, Task 5).

<u>Discussion</u>

The fuel-use test plan, developed in 1992 to support the demonstration at the original Cool Water Gasification Facility site, has become outdated. Since the site change to Eastman, the original fuel test plan under-represents new utility dispersed electric power developments, and possibly new mobile transport engine developments. The updated fuel-use test plan will attempt for broader market applications and for commercial fuels comparisons. The objective of the fuel-use test plan update will be to demonstrate commercial (e.g., economic) market applications (municipal, industrial and electric utility) replacing or supplementing (gasoline, diesel, natural gas) commercial fuels, based on expected (1998 to 2018) U.S. energy market needs when the technology is to be commercialized.

The fuel-use test plan will be developed to enhance the early commercial acceptance of central clean coal technology processing facilities, coproducing electricity and methanol to meet the needs of the local community. One of the advantages of the LPMEOH™ process, for coproduction from coal-derived syngas, is that the as-produced, stabilized (degassed) methanol product is of unusually high quality (e.g. less than 1 wt. % water) which may be suitable for the premium fuel applications. Cost savings (10 to 15%) of several cents per gallon of methanol can be achieved, if the suitability of the stabilized product as a fuel can be demonstrated. The applications: as a hydrogen source for fuel cells, and as a clean transportable, storable fuel for dispersed power, will require testing of the product to confirm its suitability.

A limited quantity (up to 400,000 gallons) of the methanol product as produced from the demonstration unit will be made available for fuel-use tests. Fuel-use tests will be targeted for an approximate 18 to 30-month period, commencing in the second year of demonstration operations. The methanol product will be available for shipment from the demonstration unit in Kingsport, Tennessee. Air Products, Acurex Environmental Corporation (Acurex), and the DOE will develop the final fuel-use test plan.

<u>Activity during this quarter</u>

- The fuel-use test plan is targeted to be updated by May of 1997. This will allow 12 months for proper implementation of the tests, which will be conducted for an 18 to 30 month period commencing in May of 1998. The Demonstration Test Plan (see Task 2.3) indicates methanol for testing (as-produced from CO-rich syngas) will first be produced in May of 1998.

- Air Products and Acurex met in November of 1996. The listing of fuel-use test prospects was reviewed, and responsibilities were divided up and assigned for initiating contact. In general, Air Products will contact the various Federal Departments (Defense, Transportation, Energy) who are involved in fuel cell, transportation, and stationary power plant developments. State and University contacts were divided between Acurex and Air Products, according to their local knowledge. The <u>Methanol Applications - Product Test Plan</u> document (see Appendix C) was prepared for mailing to interested product-use test participants. Milestones were established to complete initial contacts by January, and to have an initial listing of likely prospects by the end of February of 1997.

- The listing and result of initial contacts, especially those involved in Federal programs, will be prepared and reviewed with the DOE Federal Energy Technology Center (FETC) for possible follow-up action. DOE FETC is involved in other fuel cell and stationary power plant development programs, and the possibility of demonstrating coproduction from central power plants for distributed power generation facilities might be appropriate.

Task 1.5 Planning and Administration

Task 1.5.1 Product-Use Test Plan

The Project Evaluation Plan for Budget Period No. 2 establishes the following goal for this task:

- Update the (fuel and chemical) product-use test plan to better meet the technical objectives of the project and serve the needs of commercial markets.

  - Air Products and Eastman have updated plans for the on-site product-use demonstrations. The schedule for on-site product-use tests was established for August to October of 1997. Methanol product from the LPMEOH™ Process Demonstration Unit will be used as a chemical feedstock. Eastman will perform fitness-for-use tests on the methanol product for use as a chemical feedstock and provide a summary of the results.

Task 1.5.2 Commercialization Studies

The Project Evaluation Plan for Budget Period No. 2 establishes the following goal for this task:

- Complete economic studies of important commercial aspects of the LPMEOH™ process to enhance IGCC electric power generation. These studies will be used to provide input to the LPMEOH™ Process Demonstration Unit's Demonstration Test Plan (Phase 2, Task 3).

<u>Discussion</u>

A number of areas have been identified as needing development to support specific commercial design studies. These include: a) Product Purification options; b) Front End Impurity Removal options; c) Catalyst Addition/Withdrawal options; and d) Plant Design Configuration options. Plant sizes in the range of 300 TPD to 1800 TPD and plant design configurations for the range from 20% up to 70% syngas conversion will be considered. The Kingsport demonstration unit design and costs will be the basis for value engineering work to focus on specific cost reduction targets in developing the initial commercial plant designs.

The Process Economics Study - Outline has been prepared to provide guidance for the overall study work. The four part Outline is included in Appendix D. This Outline addresses several needs for this Task 1.5.2 Commercialization Study:

a) to provide process design guidance for commercial plant designs.
b) to meet the Cooperative Agreement's technical objectives requirement for comparison with Gas Phase Methanol technology. This preliminary assessment

will help set demonstration operating goals, and identify the important market opportunities for the Liquid Phase technology.

c) to provide input to the Demonstration Test Plan (Task 2.3).

d) to provide input to the Off-site Testing (Task 1.4) fuel-use test plan update.

Activities during this quarter

- Part One of the Outline - "Coproduction of Methanol" was issued, for review and comment, as a draft Topical Report. The 15 October 1996 transmittal memo is included in Appendix D. This Topical Report develops plant design options for the LPMEOH™ process, as an add-on to IGCC power plants for the coproduction of methanol and power. Part One also compares the LPMEOH™ (LP) process with gas phase (GP) methanol processes. Surprisingly, the LP technology can coproduce methanol at less than 50 cents per gallon, even at relatively small (400 to 1200 TPD) methanol plant sizes. LP's advantage over GP is 6 to 9 cents per gallon. Therefore, when baseload IGCC power is viable, the LP technology makes coproduction viable. Comments on the draft Topical Report have been received, and plans are to update, revise and reissue the next draft in April of 1997.

- The Demonstration Test Plan (see Task 2.3) has been updated to include all the important commercial aspects that were identified by this study.

- Part Four of the Outline - "Methanol Fuel Applications", is being used as the basis to update the fuel-use test plan (Task 1.4).

- Part Two of the Outline - "Baseload Power and Methanol Coproduction", is now being developed for incorporation into the paper, "Fuel and Power Coproduction", that is being prepared for presentation at the DOE's Fifth Annual Clean Coal Technology Conference in January of 1997.

Task 1.5.3 DME Design Verification Testing

The Project Evaluation Plan for Budget Period No. 2 establishes the following goal for this task:

- Perform initial Design Verification Testing (DVT) for the production of dimethyl ether (DME) as a mixed coproduct with methanol. This activity includes laboratory R&D and market economic studies.

Discussion

The first Design Verification Testing decision milestone, on whether to continue with DME DVT, is targeted for 1 December 1996. DVT is required to provide additional data for engineering design and demonstration decision-making. The essential steps required for decision-making are: a) confirm catalyst activity and stability in the laboratory, b) develop engineering data in the laboratory, and c) confirm market(s), including fuels and chemical feedstocks. The DME Milestone Plan, showing the DVT work and the decision and implementation timing, is included in Appendix E.

Action during this quarter included a recommendation to continue with DME DVT, Market Economic Studies, and Laboratory R&D.

DME DVT Recommendation

Air Products made a recommendation to continue with the design verification testing of DME, and to proceed with planning a proof-of-concept test run at the DOE's AFDU at LaPorte, Texas. A copy of the recommendation (dated 2 December 1996) is included in Appendix E. The recommendation was based on the results of the Market Economic Studies and on the LPDME catalyst system R&D work, and is summarized in the following.

The Market Economic Studies show that the LPDME process should have a significant economic advantage for the coproduction of DME for local markets. The Studies show that the market applications for DME are large. DME is an ultra clean diesel fuel; and an 80% DME mixture with methanol and water is now being developed and tested by others. DME is a key intermediate in a commercial syngas-to-gasoline process, and is being developed as an intermediate for other chemicals and fuels. An LPDME catalyst system with reasonable long-term activity and stability has been developed from the Laboratory R & D work. The markets and this catalyst system is sufficiently promising that proof-of-concept planning for the LaPorte AFDU is recommended. A summary of the DME DVT recommendation is:

- Planning for a DME test run at the LaPorte AFDU, in conjunction with other DOE Liquid Fuels Programs, should be initiated. Test plans, budgets, and a schedule for these LaPorte AFDU tests should now be developed. Up to $875,000 of Clean Coal Technology Program budget support, from the LPMEOH™ Project's FY-97 Cost Plan (budget), could be made available to support a suitable LPDME test run at LaPorte.

- An implementation decision, made mutually by the DOE's Clean Coal Technology Program (DE-FC22-92PC90543) LPMEOH™ project participants, and by the DOE's Indirect Liquefaction Program (DE-FC22-95PC93052) project participants, should be made in time to implement testing at LaPorte.

The recommendation to continue design verification testing of DME with proof-of-concept testing the LaPorte AFDU is now under consideration. LPDME is not applicable to H_2-rich syngas; and it is unlikely that a substantive LPDME demonstration will be recommended for Kingsport. Therefore, a convincing case that the test-run on CO-rich syngas at LaPorte will lead to successful commercialization must be made, prior to approving the final test-run plan. The strategy for commercialization must present the technical logic to combine the results of:

1) catalyst performance (productivity, selectivity, and life) for the LPDME catalyst system under CO-rich syngas from the proof-of-concept testing at the LaPorte AFDU; and
2) reactor performance (methanol catalyst activity and life, hydrodynamics, and heat transfer) from the LPMEOH™ Process Demonstration Unit

The productivity and life of an "acceptable" LPDME catalyst system must be better defined, and then confirmed in the laboratory. This definition and laboratory work are being undertaken, and review meetings on the DME implementation decision are planned for the next quarter.

Market Economic Studies

Work on the feasibility study for the coproduction of DME and electric power continued. The product DME would be used as a domestic liquid cooking fuel, to replace imported Liquid Petroleum Gas, for the China and Pacific Rim regions. The results to date, are included in the DME recommendation in Appendix E.

Laboratory R&D

Initially, synthesis of DME concurrently with methanol in the same reactor was viewed as a way of overcoming the syngas conversion limitations imposed by equilibrium in the LPMEOH™ process. Higher syngas conversion would provide improved design flexibility for the coproduction of power and liquid fuels from an IGCC facility. The liquid phase DME (LPDME) process concept seemed ideally suited for the slurry-based liquid phase technology, since the second reaction (methanol to DME) could be accomplished by adding a second catalyst with dehydration activity to the methanol-producing reactor. Initial research work determined that two catalysts, a methanol catalyst and an alumina-based dehydration catalyst, could be physically mixed in different proportions to control the yield of DME and of methanol in the mixed product. Proof-of-concept runs, in the laboratory and at the Alternative Fuels Development Unit (AFDU), confirmed that a higher syngas conversion could be obtained when a mixture of DME and methanol is produced in the liquid phase reactor.

Subsequent catalyst activity-maintenance experiments have shown the catalyst system utilized in the proof-of concept runs experienced relatively fast deactivation compared to the LPMEOH™ process catalyst system. Further studies of the LPDME catalyst deactivation phenomenon were therefore initially undertaken under the DOE's Liquid Fuels Program (Contract No. DE-FC22-95PC93052), was continued under this Task 1.5.3 through Fiscal Year 1996, and is now again being continued under the DOE Liquid Fuels Program. This LPDME catalyst deactivation research has determined that an interaction between the methanol catalyst and the dehydration catalyst is the cause of the loss of activity. Parallel research efforts--a) to determine the nature of the interaction; and b) to test new dehydration catalysts--was undertaken. In late 1995, the stability of the LPDME catalyst system was greatly improved, to near that of an LPMEOH™ catalyst system, when a new aluminum-based (AB) dehydration catalyst was developed. This new AB catalyst development showed that modification of the LPDME catalyst system could lead to long life. During this quarter, laboratory work continued on developing an LPDME catalyst system based on the AB series of catalysts.

Summary of Laboratory Activity and Results

- Laboratory testing of the dual catalyst system containing the new aluminum-based (AB) dehydration catalyst continued to show promise. LPDME tests were conducted at 240°C using Texaco-type syngas and AB02 catalyst. The results showed that good productivity and DME selectivity can be obtained at 240°C. Better stability of the methanol catalyst was also observed (as compared to the standard 250°C).

- AB05, one of the best aluminum-based samples, was successfully reproduced in another laboratory preparation.

- The stability of this new AB05 material was further improved by nitridation with ammonia at elevated pressure. An LPDME life test using this material is on-going. After 450 hours on stream, the methanol synthesis activity is close to the baseline synthesis activity for methanol catalyst in the absence of any dehydration catalyst.

- Observation that catalyst aging is enhanced using (Texaco-type) syngas as the feed allows the aging experiments to be performed faster and so that long-term aging for catalysts previously tested can be examined. This more rapid aging, as compared to (Shell-type) syngas, has been attributed to the higher water content (0.2 vs. 0.04 mol%). However, tests at higher water concentrations (0.33%) showed no further increase in methanol catalyst deactivation rate.

Task 1.5.4 Administration and Reporting

The Cooperative Agreement was modified (Mod A011; 8 October 1996), authorizing the transition from Budget Period No. 2 (Design and Construction) to the final Budget Period (Commissioning, Start up, and Operation). This modification provides the full $213,700,000 of authorized funding, with 56.7% participant cost share and 43.3% DOE cost share. A copy of the approval memorandum, dated 3 October 1996, is included in Appendix F.

A project review meeting was held on 3 and 4 December 1996 in Kingsport. Attendees from Air Products, Eastman, and DOE participated. The construction and commissioning status was reviewed, as were plans for Startup and Initial Operation. The construction site was visited, and the demonstration unit showed tremendous progress since the project review meeting in September. The C-120 vent stack was being erected, and the small bore piping was nearly all installed. The status of the updated fuel-use test plan, the recommendation for continuation of DME design verification testing, and other matters were reviewed. The meeting agenda, extracts from the meeting handouts, and the meeting notes are included in Appendix G.

The Milestone Schedule Status Report and the Cost Management Report, through the period ending 31 December 1996, are included in Appendix H. These two reports show the current schedule, the percentage completion and the latest cost forecast for each of the Work Breakdown Structure (WBS) tasks. The demonstration unit is scheduled to be mechanically complete on 24 January 1997. Construction progress photographs, taken on 3 December 1996, are included in Appendix H. Ninety-one percent (91%) of the $38 million of funds forecast for the Kingsport portion of the LPMEOH™ Process Demonstration Project for the Phase 2 tasks have been expended (as invoiced), as of 31 December 1996.

The schedule for completion of the major Phase 2 Construction Tasks, has changed. Completion of pipe pressure testing has taken longer than expected. This has impacted completion of insulation and will delay completion of startup. Construction (Task 2.2) is now forecast for completion by 24 January 1997 (formerly 31 December 1996). Commissioning activities (Task 2.3) commenced in mid-October of 1996, and will be completed 24 January 1997 (formerly 17 January 1997).

The monthly reports for October, November, and December were submitted. These reports include the Milestone Schedule Status Report, the Project Summary Report, and the Cost Management Report. The Annual Cost Plan for Fiscal Year 1997 was submitted in October.

Task 2.1 Procurement

The Project Evaluation Plan for Budget Period No. 2 establishes the following goal for this task:

- Complete the bidding and procurement for all equipment and Air Products-supplied construction materials.

  - All the equipment items have been received at the site.
  - The prefabricated structural steel, for the reactor building and for the catalyst building, has been received at the site. The bulk materials (prefab piping, valves, instrumentation, and electrical) have also been received at the site.
  - Task 2.1 Procurement is complete.

Task 2.2 Construction

The Project Evaluation Plan for Budget Period No. 2 establishes the following goal for this task:

- Provide construction management for contractor coordination and compliance with design, construction, and quality control standards.

  - Air Products' construction site manager, lead electrical superintendent, lead mechanical superintendent, clerk and secretary are continuing to oversee the construction activities at the site.

- Erect the major equipment and structural steel. Install the large bore piping, electrical, and insulation such that instrument checkout and equipment commissioning work can be completed during the 60-day Continuation Application approval period.

  - The equipment is installed. The vent stack installation was completed in December. The process building structural steel is installed, only minor punch list work remains. The catalyst building roofing and siding are being installed, and should be complete in mid-January. The Mechanical Contractor has installed all of the large and small bore piping, and has completed hydrostatic pressure testing of all of the pipe circuits, except one. Completion of pipe circuit pressure testing has taken longer than expected. This has impacted completion of insulation and will delay startup.

  - The Instrument and Electrical (I&E) Contractor is 96% complete. The prefabricated analyzer building was set in place, and cable runs to the Distributed Control System building were completed. Permanent power to the Motor Control Center building was energized, and the instrument air dryer system was commissioned in order to begin instrument loop checking. Wiring of the reactor and reduction vessel Nuclear Density Gauges remains to be completed.

  - The Insulation and Fireproofing Contractor has completed the equipment items, and should complete the piping insulation by 21 January 1997.

- Complete mechanical construction so that checkout and commissioning can be started in Budget Period No. 3.

  - Construction is 97% complete as of the end of December of 1996. The targeted Mechanical Completion date has slipped about three weeks, to 24 January 1997. Commissioning activities started in mid-October and should be complete by mid-January. Startup, of the utility systems, are scheduled to begin 20 January 1997.

Task 2.3 Training and Commissioning

The Project Evaluation Plan for Budget Period No. 2 establishes the following goals for this task:

- Prepare a four-year test plan for Phase 3, Task 2 - Operation.

  - The four-year Demonstration Test Plan (DTP) was approved and issued in September of 1996.

- Prepare the operating manual and initiate the operator training program.

  - The operator training was completed during this quarter. Four, one-week sessions, were held in November and December.

Commissioning activities started in mid-October. The Commissioning and Startup Schedule is included in Appendix I. Instrument loop checking is 62% complete. Final function tests of the instrumentation and interlocks will begin in January. Commissioning of the steam and other utility systems, and final system cleaning will also be in mid-January. Mineral oil loading and the introduction of syngas are forecast to occur at the end of January.

Task 2.4 Off-Site Testing (Procurement and Construction)

The Project Evaluation Plan for Budget Period No. 2 establishes the following goal for this task:

- Prepare the final off-site product-use test plan.

    - The off-site product-use test plan update is being reported under the Task 1.4 Off-Site Testing (Definition and Design).

Task 2.5 Planning and Administration

The Project Evaluation Plan for Budget Period No. 2 establishes the following goals for this task:

- Prepare annually an updated (Partnership) plan for the remaining activities. The first annual plan will update the remaining Phase 1 and Phase 2 activities, and the second will include an update of the Phase 3 Demonstration Test Plan.

    - The first update of the Partnership Annual Operating Plan was prepared and submitted in September of 1995 (See Quarterly Technical Progress Report No. 5). The main goal and objective for this first annual plan was to continue construction so that the LPMEOH™ demonstration unit would be ready for commissioning and start-up in 1996; and to complete the Project Evaluation Report and to submit it to the DOE along with the Continuation Application for Budget Period No. 3.

    - The second update of the Partnership Annual Operating Plan was prepared and submitted in November of 1996 (see Appendix J). The main goal and objective for this second annual plan is to initiate Phase 3 - Operation of the LPMEOH™ demonstration unit and to achieve 30 weeks of operation (Task 2.1.1 Operation) by September of 1997 in accordance with the Demonstration Test Plan. Other objectives include continuation of DME design verification testing, and updating the plan for Off-site Product-use Testing.

- Submit all Project status, milestone schedule, and cost management reports as required by the Cooperative Agreement.

    - The DOE reporting tasks are being performed and reported under Task 1.5.4 (Administration and Reporting).

E. Planned Activities for the Next Quarter

- Complete Phase 2, Task 2 Construction.
- Complete Phase 2, Task 3 Equipment Commissioning.
- Complete Phase 3, Task 1 demonstration unit startup , including the utility systems, carbonyl burnout, and catalyst reduction.
- Initiate Phase 3, Task 2.1 Methanol Operation.
- Initiate planning for a DME proof-of-concept test run at the LaPorte AFDU, and obtain approval to proceed.
- Prepare a draft update of the Off-site Product-use Test Plan, for review and comment.
- Present the "Fuel and Power Coproduction" paper at the 5th Annual Clean Coal Technology Program Conference.
- Hold a Project Review/Update Meeting in Kingsport in March, with the DOE, Eastman, and Air Products.

F. Summary

The Cooperative Agreement was modified (Mod A011) on 8 October 1996, authorizing the transition from Budget Period No. 2 (Design and Construction) to the final Budget Period (Commissioning, Start up, and Operation). This modification provides the full $213,700,000 of authorized funding, with 56.7% participant cost share and 43.3% DOE cost share.

A draft Topical Report on Process Economics Studies was issued for review. This shows that methanol coproduction, with IGCC electric power utilizing the LPMEOH™ process technology, will be competitive in serving local market needs. The study results are also being incorporated into a paper "Fuel and Power Coproduction", which will be presented in January at the DOE's 5th Annual Clean Coal Technology Conference.

A recommendation to continue with DME design verification testing was made. DME design verification testing studies show the LPDME process will have a significant economic advantage for the coproduction of DME for local markets. The market applications for DME are large. An LPDME catalyst system with reasonable long-term activity and stability is being developed. Planning for a proof-of-concept test run at the LaPorte AFDU was recommended; and a decision to proceed is pending.

The off-site product testing plan is to be updated by May of 1997. During this quarter, Air Products and Acurex initiated contacting prospective Federal, State, and University product test participants who are involved in fuel cell, transportation, and stationary power plant developments.

A project review meeting was held in Kingsport in early December. The equipment is installed, and installation of the demonstration unit showed tremendous progress since the project review meeting in September. Programming of the instrument control system was completed during this quarter, and design engineering is now completed. The construction and operation permits have been obtained. Operator training was completed during this quarter, and final plans for startup and initial operation have been made.

Construction (Task 2.2) is 97% complete, as of the end of December 1996. Completion of pipe pressure testing has taken longer than expected. This has impacted completion of insulation and will delay completion of construction by about three weeks. Commissioning activities (Task 2.3) commenced in mid-October of 1996, and will be completed late in January of 1997. Startup, of the utility systems, is also scheduled to begin late in January.

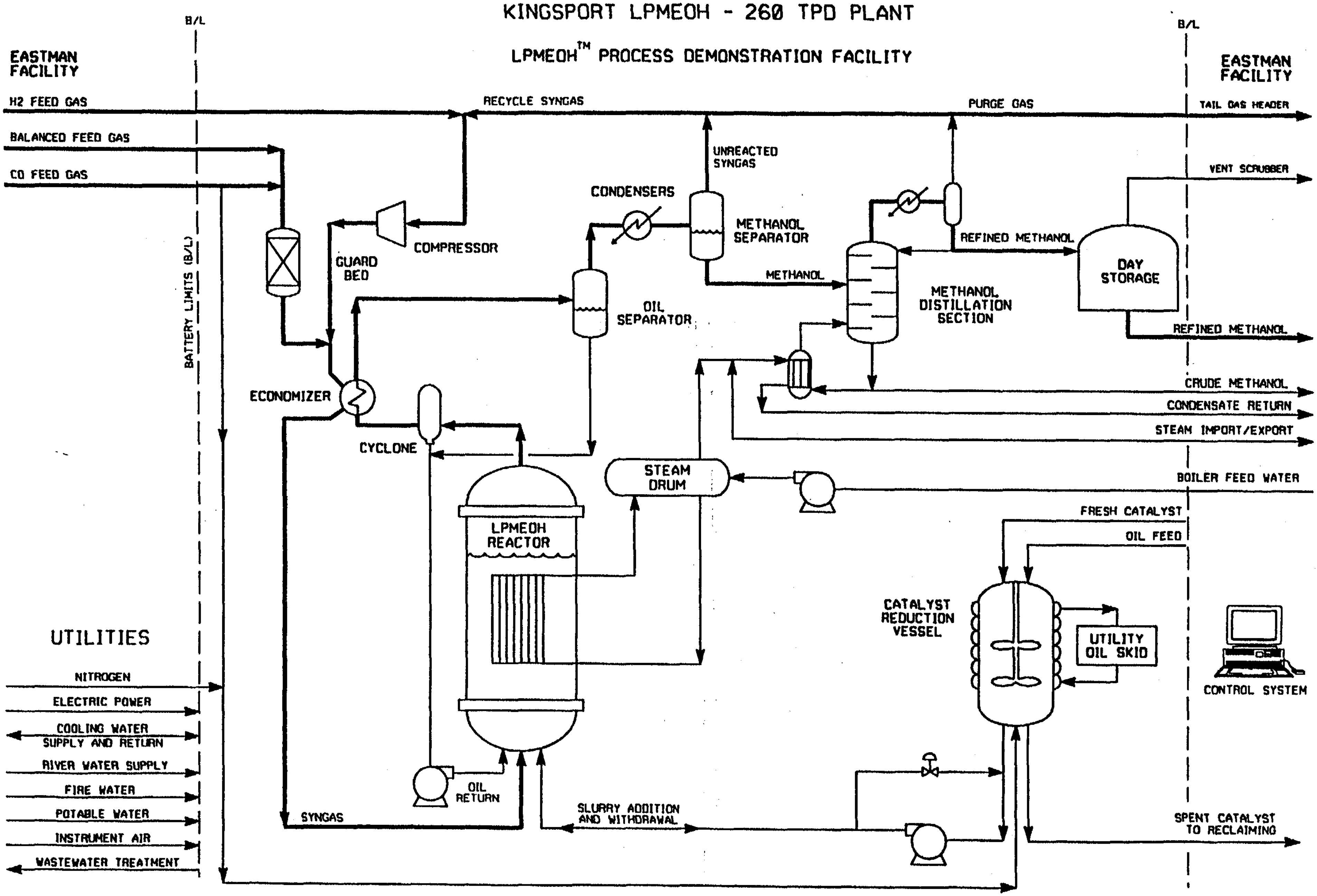
The demonstration unit is scheduled to be mechanically complete on 24 January 1997. Ninety-one percent (91%) of the $38 million of funds forecast for the Kingsport portion of the LPMEOH™ Process Demonstration Project for the Phase 1 and Phase 2 tasks have been expended (as invoiced), as of 31 December 1996.

APPENDICES

APPENDIX A - SIMPLIFIED PROCESS FLOW DIAGRAM
1 PAGE

SIMPLIFIED PROCESS DIAGRAM
KINGSPORT LPMEOH - 260 TPD PLANT

LPMEOH™ PROCESS DEMONSTRATION FACILITY



APPENDIX B - PROJECT EVALUATION PLAN FOR BUDGET PERIOD NO. 2
4 PAGES

COMMERCIAL-SCALE DEMONSTRATION OF THE LIQUID PHASE METHANOL (LPMEOH™) PROCESS COOPERATIVE AGREEMENT NO. DE-FC22-92PC90543

PROJECT EVALUATION PLAN FOR BUDGET PERIOD NO. 2

The work to be performed during Budget Period No. 2 consists of Phase 1 Design and Phase 2 Construction of the LPMEOH™ Process Demonstration Facility at Eastman Chemical Company's integrated coal gasification facility located in Kingsport, TN. Completion of these Budget Period No. 2 activities will essentially ready the LPMEOH™ Process Demonstration Facility for commissioning, startup, and operation to begin in the final Budget Period No. 3. The Statement of Work for the Project subdivides these Phase 1 and Phase 2 activities into Tasks. This Project Evaluation Plan for Budget Period No. 2 will meet the following criteria aligned by the Statement of Work tasks:

1. **Phase 1 - Task 2 - Permitting**

   - Issue the final Environmental Information Volume to support the U.S. Department of Energy's (DOE's) Environmental Assessment/Finding of No Significant Impact.

   - Obtain permits necessary for construction and operation.

2. **Phase 1 - Task 3 - Design Engineering**

   - Complete the design engineering necessary for construction and commissioning. This includes Piping and Instrumentation Diagrams, Design Hazard Reviews, and conducting design reviews.

   - Prepare the Environmental Monitoring Plan.

3. **Phase 1- Task 4 - Off-site Testing (Definition and Design)**

- Prepare the fuel-use demonstration plan for Phase III, Task 4 Off-site Product Use Demonstration. This off-site test plan will be incorporated into the overall product-use test plan (in Phase 1, Task 5).

4. **Phase 1 - Task 5 - Planning, Administration and DME Verification Testing**

- Update the (fuel and chemical) product-use test plan, that will better meet the technical objectives of the Project and serve the needs of commercial markets.

- Complete economic studies of the important commercial aspects of the LPMEOH™ Process to enhance Integrated Gasification Combined Cycle (IGCC) electric power generation. These studies will be performed by Air Products and Chemicals, Inc. and the Electric Power Research Institute, and used to provide input to the LPMEOH™ Process Demonstration Facility operating test plan (Phase 2, Task 5).

- Perform initial Design Verification Testing for the production of dimethyl ether (DME) as a mixed coproduct with methanol. This activity includes laboratory R&D and market economic studies.

- Submit all Project status, milestone schedule, and cost management reports as required by the Cooperative Agreement.

5. **Phase 2 - Task 1 - Procurement**

- Complete the bidding and procurement for all equipment and Air Products supplied construction materials.

6. **Phase 2 - Task 2- Construction**

- Complete mechanical construction so that checkout and commissioning can be started in Budget Period No. 3.

- Erect the major equipment and structural steel. Install the large bore piping, electrical, and insulation such that instrument checkout and equipment commissioning work can be completed during the 60-day Continuation Application approval period.

- Provide construction management for contractor coordination and compliance with design, construction, and quality control standards.

7. **Phase 2 - Task 3 - Training and Commissioning**

- Prepare a four (4)-year test plan for Phase 3, Task 2-Operation.

- Prepare the operating manual and initiate the operator training program.

8. **Phase 2 - Task 4 - Off-Site Testing (Procurement and Construction)**

- Prepare the final off-site product-use test plan.

9. **Phase 2 - Task 5 - Planning and Administration**

- Prepare annually an updated plan for the remaining activities. The first annual plan will update the remaining Phase I and Phase II tasks. The second annual plan will include an updated Phase III Operating Plan, identifying specific goals and milestones for the first twelve months of operation, and a general plan for the remaining years to achieve the Project's market penetration objectives.

- Submit all Project status, milestone schedule, and cost management reports as required by the Cooperative Agreement.

Completion of the above work activities will essentially ready the LPMEOH™ Process Demonstration Facility for commissioning, startup, and operation to begin in the final Budget Period No. 3. These criteria will be the basis of the Project Evaluation Report which shall be submitted to the DOE for approval along with the Project Continuation Application, at least 60 days before the end of Budget Period No. 2. Construction of the Facility will be essentially completed during the 60-day approval period for the Continuation Application.

At the time that the Project Evaluation Report for Budget Period No. 2 is submitted with the Continuation Application; Air Products will also prepare an update on the expected technical and economic performance of the mature unit. This update will demonstrate the commercial potential of the LPMEOH™ process technology to enhance IGCC electric power generation with coproduct methanol. This IGCC enhancement is expected to reduce the cost of electricity for retrofit, repowering, replacement, and new applications for electric power generation from coal.

WRB/jjs/Proeva.

APPENDIX C - TASK 1.4 - METHANOL APPLICATIONS - PRODUCT TEST PLAN
1 PAGE

Methanol Applications - Product Test Plan

Methanol coproduction studies have indicated that the Liquid Phase Methanol (LPMEOH™) process can produce a clean methanol product at less than 50 cents per gallon. The methanol product is coproduced with electricity at central IGCC power plants. The LPMEOH™ process, utilizing the IGCC plants carbon-oxide rich gases, produces a clean stabilized product. By not distilling the stabilized product to "chemical grade" methanol purity, the production costs become even lower. The advantage for using the methanol, as coproduced from abundant, non-inflationary local fuels at central IGCC power plants, can be substantial.

The application opportunities are:

1. Co-firing methanol in the gas turbines of the IGCC facility, for use as a back-up or peak power fuel.
2. Using the co-produced methanol as environmentally advantaged fuel for dispersed electrical power generation. Small packaged power plants (combustion turbine, internal combustion engine or fuel cell based) can provide power and heat locally, at the use point, eliminating gas pipelines and/or high voltage power lines.
3. Co-produced methanol may be an economical hydrogen source for small fuel cells, which are being developed for transportation applications.
4. Co-produced methanol, when reformed under mild conditions, may be an economical source for the supply of hydrogen or carbon monoxide to industrial complexes.
5. Co-produced methanol may be able to be used as a chemical building block in various chemical manufacturing processes.

Fuel Methanol Test Plan Objectives

Whereas the above applications are developed using "Chemical Grade" methanol, the use of the co-produced (Fuel Methanol) product in these applications has only been partially explored. From the attached envisaged specification for Fuel Methanol it is clear that the amount of residual water , higher alcohol's, etc. is the key difference with chemical grade methanol.

Regarding the successful use of Fuel Methanol as a liquid fuel in combustion applications (gas turbine to power, internal combustion engines to produce power or to serve as automotive drive) a large quantity of valuable information is available. Hence these combustion applications are not explicitly considered in the scope of the Fuel Methanol Test Plan Objectives, unless publicity/public relation reasons dictate otherwise.

Considerations to be given to the Fuel Methanol Test Plan Objectives are:

1. In fuel cell applications, preferably all fuel cell types, sufficient range in capacity and length of operation are to be covered.
2. In methanol reforming applications satisfactory catalyst performance over at least 1 year life-cycle should be obtained.
3. For applications requiring vaporized (gaseous) methanol, sufficient range and length of operation are to be covered
4. In chemical applications, by-product formation caused by trace constituents in the Fuel Methanol, should be closely observed/evaluated.
5. For the totality of the Fuel Methanol Test Plan 400,000 gallons of fuel methanol can be made available (FOB) from the LPMEOH™ process demonstration facility in Kingsport, Tennessee.
6. Air Products can partially cost-share to the various test programs through the DOE Cooperative Agreement for the LPMEOH™ demonstration program. More details about the Cooperative Agreement's requirements will be provided to interested parties.

APPENDIX D - TASK 1.5.2 - PROCESS ECONOMIC STUDY
6 PAGES

Process Economics Study - Outline
(Draft - 10/15/96 - four pages)

and

LPMEOH™ Process Economics - for IGCC Coproduction
(Memo - 15 October 1996 - two pages)

Process Economics Study - Outline
LPMEOH™ Process, as an add-on to IGCC for Coproduction

Part One - Coproduction of Methanol

1. Introduction

1.. Process Design Options.

- Develop process flow diagram and plant design options for the LPMEOH™ process, for design variables such as: a) feed gas pressure, b) feed gas compositions, and c) % syngas conversion.

2. Liquid Phase (LP) Methanol Advantage versus Gas Phase (GP) Methanol.

2.1. Syngas Conversion Cost for Methanol Production from CO-Rich syngas.

- For the various LPMEOH™ process (LP) design options (from 1.1) develop plant capital and conversion costs derived from the Kingsport Project costs and design basis. Develop conversion costs for:
    - 500 t/d Plant size, with 500 psi feed gas pressure;
    - 500 t/d Plant size, with 1000 psi feed gas pressure
    - Impact of Plant Size on Conversion Costs

- Summarize in a series of graphs, conversion costs, in cents per gallon over the range of syngas conversion from 18% (LP - Once-through) to 94% (GP), for baseload annual coproduction operation. This will show LP's advantage at higher feed pressures and lower conversions; and will highlight areas for LP design development/demonstration improvements. *(For future: include plant size impact on product distribution (freight) cost, assuming that local markets are served. Freight cost will increase with plant size, as the distribution radius increases.).*

2.2. Methanol Product Purification Cost.

- Develop capital and operating costs for these product purification design alternatives:
    - MTBE Grade;
    - Fuel Grade;
    - Chem. Grade;

Over a range of feed gas compositions, summarize LP's advantage versus the GP process (in cents per gallon), especially for MTBE and Fuel Grade from CO-rich feed gas at low syngas conversions.

2.3. Feedgas (Syngas) Composition Variations: (Impact on LP vs. GP).

- Higher Sulfur content in the feedgas will have a negative cost impact on LP at low syngas conversion, relative to GP at high conversions. Conversely, higher feedgas inert content will have a negative relative cost impact on GP.
    - Sulfur content variation; over the above range of syngas conversion
    - Inert gas content variation; over the above range of syngas conversion

2.4. Syngas Usage (Btu per Gallon) - Impact on IGCC Power Plant.

- Summarize differences in syngas utilization (Btu per gallon of methanol), and in mass flow loss/gain to the combustion turbine (kwh production loss/gain per gallon of methanol); for the cases in 2.1 above.

2.5. Summary of Cost Advantage(s) - (LP Vs GP).

- Summarize the cost impact (cents per gallon) of the above design variables and syngas utilization differences. Show the impact of methanol plant size on the conversion costs. Also (separately show) the impact of 90% and 70% annual load utilization for use with Section 4. - "Intermediate Load Coproduction and Stored Energy" of this Economics Study.

2.6. Recommendations for Further Study.

- Recommend areas for process design value engineering work; and areas for demonstration at Kingsport.

Part Two - Baseload Power and Methanol Coproduction

3. Baseload Coproduction with Methanol Sales - Impact on Electric Power Cost -

For baseload coproduction, the gasifier must be sized for both the power and methanol products. The results of Part One indicate the LP technology can make coproduction economic, even at small methanol plant sizes (400 to 1200 TPD) suitable to serve local markets near the power plant.. The LP technology's advantage (over GP) is also greatest at the lower (up to 34%) Syngas Conversions which are consistent with these methanol plant sizes. A matrix of power plant and methanol plant sizes of interest, at up to 34% Syngas Conversion to methanol, is shown in the following tables. These examples are based on Advanced Gas Turbine Technology *(reference (G.E.'s) published paper)* with the base gasification plant sized for two gasifiers, of about 1525 x 10^6 Btu(HHV)/hr. output each.

3.1 Gasification Plant Size Fixed

- **With a given gasification plant size,** the methanol plant and power plant can be sized to accommodate a range of Methanol to Power output ratio's.

Syngas Conversion	Power Plant Size	Methanol Plant Size	Methanol to Power Ratio	Gasification Plant Size
0 %	500 MW	0 T/D	0 T/D per MW	Base
20%	400 MW	651 T/D	1.6 T/D per MW	Base
33%	333 MW	1086 T/D	3.3 T/D per MW	Base

3.2 Power Plant Size Fixed

- **With a given power plant size,** the gasifier size may be increased to accommodate the coproduction of methanol. For Gasification Plant size increases of up to 50% (to say, three x 1525 x 10^6 Btu(HHV)/hr. gasifiers), the methanol to power coproduction ratio's could be:

Syngas Conversion	Power Plant Size	Methanol Plant Size	Methanol to Power Ratio	Gasification Plant Size
0.0 %	500 MW	0 T/D	0 T/D per MW	1.00 x Base
16.7 %	500 MW	651 T/D	1.3 T/D per MW	1.20 x Base
25.0 %	500 MW	1086 T/D	2.2 T/D per MW	1.33 x Base
33.3 %	500 MW	1629 T/D	3.3 T/D per MW	1.50 x Base

- The impact of coproduction on electricity generation costs will be shown in graphs of electricity cost Vs. methanol net back price.

End of Part Two.

Process Economics Study - Outline
LPMEOH™ Process, as an add-on to IGCC for Coproduction

Part Three - Coproduction for Intermediate Electric Load Following.

4. Intermediate Load Coproduction and Stored Energy.

4.1. Syngas Value.

4.1.1 Syngas value as a function of (time of day) Power Value.

Our earlier load following work indicates that an LPM coproduction add-on optimizes for intermediate peak-load power in the 1000 to 2500 hr./yr. range. This means the methanol plant operates during "off--peak" power in the 7760 (88% utilization) to 6260 (71% utilization) hr./yr. range (8760 hr./yr. = 100% = total hr./yr.), with up to 200 annual daily stop/start operations for the daily on/off peaks.

- *Time of day example: A given Lambda Curve might provide data at 2000 and 1500 peak hr./yr. such as: a)* 3.4 cent off-peak power (6760 hr.) plus 7.8 cent intermediate-peak power (2000 hr.) equals 4.4 cent baseload power (8760 hr.). b). 3.5 cent off-peak (7260 hr.) plus 8.6 cents intermediate-peak power (1500 hr.) equals 3.6 cent baseload power (8760 hr.). Time of day syngas values can be derived, based on the alternative value of using syngas for power (in CC or CT power plants).

4.1.2. Syngas value as function of seasonal opportunity fuels/feeds.

- *Natural gas may be available seasonally, for use in the CC power plant, allowing syngas to be used for conversion in an LPM add-on. Other feeds?*

4.2. Intermediate Load Coproduction - for Methanol Sales.

- For all intermediate load coproduction cases, redundant investment to utilize syngas on/off-peak is required; so that when the methanol plant shuts down during peak power periods, all of the syngas can be converted to electric power. There are many intermediate load coproduction power plant design choices; a) CC power plant turned down, or b) baseload CC power plant with CC or CT power plant(s) for peak; which may be combined with c) many methanol plant choices such as size/% conversion/and on-off operating hours. To do these studies properly, we need to have good time of day power values (also called Lambda Curves) as well as the Section 2. (above) Methanol Plant design choices completed.

4.3. Intermediate Load Stored Energy Production, with Methanol Fuel for Peak Power Production.

- The design optimization for this is quite complex. The IGCC/OTM plant design has an additional variable: the peaking power plant size and hours of operation is an independent variable. We may be able to use a specific (--) study with a published paper as a goal. An alternative study option is to compare ourselves (IGCC/OTM) to the various published EPRI (IG-Cash, et. al.) studies, which provide Lambda Curve examples for energy storage.

  When other back up fuels are not available, or are too expensive, then methanol may also be used to enhance power plant availability. Coproduction with multiple gasifier trains may also be used to enhance power plant availability. (e.g. - Three by 50%, where Baseload Power = 2 x 50%; Peaking Power = 1x 50% plus methanol fuel; Methanol Plant = 1 x 50%, but operates only when all three gasifiers are operating and peak power is not required.)

4.4. Intermediate Load Stored Energy Production, with Methanol for Dispersed Energy.

- Methanol transported to remote **existing** or new power plants on the Utilities grid system.

End of Part Three.

Process Economics Study - Outline
LPMEOH™ Process, as an add-on to IGCC for Coproduction

Part Four - Methanol Fuel Applications

5. Premium Methanol Fuel Applications

- At 46 cents per gallon, methanol as a fuel ($6.90 per mmBtu) will not compete with oil in most applications ($20/bbl crude = $3.30/mmBtu; $24/bbl diesel = $4.00 /mmBtu). However, methanol coproduced at a central IGCC power station, may be a valuable premium fuel for two evolving developments: as an economical Hydrogen source for small fuel cells, and as an environmentally advantaged fuel for dispersed electric power.

- "Central clean coal technology processing plants, making coproducts of electricity and methanol; to meet the needs of local communities for dispersed power and transportation fuel" - meets the DOE Clean Coal Technology Program's objectives. Serving (initially) small local fuel markets also builds on LP's (the LPMEOH™ process) strengths; good economics at small methanol plant sizes, fuel grade product distillation savings, and a freight advantage in local markets vis a vis large off-shore remote gas methanol. Baseload methanol coproduction studies show that 46 cent per gallon methanol can be provided from an abundant, non-inflationary local fuel source.. *We need to show when (at what oil price) we can compete, and to arrange fuel tests to confirm the dispersed energy environmental advantage.*

5.. Hydrogen Source for

- Hydrogen fuel cells, being developed for transportation applications, can achieve 65% system efficiency, as compared to 45% for diesel IC engines and 32% for gasoline IC engines. Methanol is a storable, transportable liquid fuel which can be reformed under mild conditions to provide H2. For small H2 applications, *and at low utilization factors,* methanol reforming is a more economical source of hydrogen than : a) natural gas reforming, b) distillate (oil) reforming; and is cheaper than LH_2.

5.1.1. Fuel Cells for Transportation

5.1.2. Fuel Cells for Stationary Power

(See also dispersed power below).

5.1.3. Industrial Applications - Small Hydrogen Plants

Small pressurized methanol reformers for transportation applications may be suitable for adapting to meet the needs of small commercial hydrogen gas requirements.

5.2. Dispersed Power

- Dispersed power is getting a lot of favorable publicity. . The world wide package (0.2 MW to 10 MW) power plant market is large. A variety of technologies (combustion turbine, internal combustion engine, fuel cell) are being packaged to provide power and heat locally, at the use point. Environmental and Economic advantages include Methanol for Fuel Cells = clean stationary local power; no need for natural gas pipelines; no new high voltage power lines.

5.3. Dimethyl Ether as an Enhancement to Methanol in Premium Fuel Applications

Can coproduced mixtures of methanol and dimethyl ether improve upon methanol, in the above?

End of Part Four.

Memorandum

AIR PRODUCTS

To:	Distribution	Dept./Loc.:	
From:	W. R. Brown	Dept./Ext.:	PSED, X17584
Date:	15 October 1996		
Subject:	LPMEOH™ Process Economics - for IGCC Coproduction		

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c: D. M. Brown - APE (Hersham)
R. J. Allam - APE (Hersham)

The second draft of the DOE Topical Report on LPMEOH™ Process Economics (Part One) is attached for your use (review, comment). This Topical Report develops plant design options for our LPMEOH™ process, as an add-on to IGCC power plants for the coproduction of methanol and power. Part One also compares our LPMEOH™ (LP) methanol process with the gas phase (GP) methanol process.

LP's advantage over GP is 6 to 9 cents per gallon; when the syngas conversion is low (less than 34%), and when the feed gas pressure is high (greater the 750 psig), and when the methanol plant size is relatively small (400 to 1200 TPD). Surprisingly, even at these small plant sizes, the LP technology can coproduce methanol at less than 50 cents per gallon (good). The GP technology is over 50 cents per gallon (not good). Therefore, when baseload IGCC power is viable, **the LP Technology makes coproduction viable**

The DOE Topical Report (Part One) looks specifically at:

- Determining and optimizing **conversion costs** for our LP technology as a function of feed gas pressure and % syngas conversion. (See graphs on pages A - 9, 12, 15, 16, 17).
- Determining **purification (distillation) costs** for "Fuel", "MTBE", and "Chemical" grade methanol. (See graph, page A - 24). *Distillation savings are a significant part of LP's advantage.*

- Comparing LP with GP technology. (See the above graphs, plus Summary Table on page 12).
- Listing of **future LP design improvements**, expected from actual operation (see page 12), or that are recommended for further engineering study (see pages 13,14).

Parts Two, Three and Four of the DOE Topical Report are planned for the future (an outline is available). **Part Two** will examine the impact of baseload coproduction on electric power costs. **Part Three** will look at time-of-day energy values: a) intermediate load coproduction (e.g.- off-peak methanol production), and b) methanol as stored energy for peaking and/or dispersed electric power. **Part Four** of the Topical Report plans to look at Methanol Fuel Applications, where locally produced (non-inflationary) methanol, at less than 50 cents per gallon, could be a viable source of hydrogen for industrial or fuel (cells) power applications. Serving (initially) small local fuel markets builds on LP's strengths; good economics at small plant sizes, fuel grade product distillation savings, and a freight advantage in local markets vis-a-vis large off-shore remote gas methanol.

Your comments on this draft of the Topical Report(Part One) would be appreciated.

Bill