FUEL AND POWER COPRODUCTION THE INTEGRATED GASIFICATION/LIQUID PHASE METHANOL (LPMEOH™) DEMONSTRATION PROJECT

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ABSTRACT

Under a pending Agreement, the U.S. Department of Energy (DOE) and Air Products and Chemicals, Inc., plans to locate one of the Nation's 42 "showcase" Clean Coal Technology projects in the State of California. An estimated total of $213.7 million in Federal and private funds will be invested to build and operate a highly advanced methanol production unit employing Air Products Liquid Phase Methanol (LPMEOH™) technology.

This first-of-a-kind demonstration -- one of 13 projects selected under the third round of the DOE's Clean Coal Technology Program -- will be associated with the Texaco Cool Water Integrated Coal Gasification Combined Cycle (IGCC) Power Project at Daggett, California. The LPMEOH Technology that will be used in the demonstration has been developed specifically to lower the cost of electricity produced in IGCC power plants by efficiently storing energy in the form of methanol for use during periods of peak power demand. In addition to cleanly generating electricity, the Texaco Cool Water Project will help California meet its solid waste reduction goals by using municipal sewage sludge along with coal as a gasifier feedstock. The project also will provide methanol for a variety of fuel-use demonstrations in the Los Angeles Basin area.

The LPMEOH technology development and demonstration will permit the Once-Through-Methanol (OTM) production concept to be added to the very clean and efficient IGCC power generation technique. The IGCC/OTM demonstration meets key objectives of the National Energy Strategy. The methanol can be used to provide peak electric power when needed, or as a clean liquid coproduct that will be in increasing demand as the Nation turns toward cleaner alternatives. Successful demonstration of the combined IGCC/OTM technologies at Cool Water will advance an environmentally clean, coal-based alternative to natural gas for power plants and helps contain or lower electricity prices.

INTRODUCTION

This paper describes an advanced methanol production technology developed specifically to lower the cost of electricity produced in Integrated Coal Gasification Combined Cycle (IGCC) electric power plants. The technology is called the Liquid Phase Methanol (LPMEOH) process. The technology is used in a Once-Through-Methanol (OTM) configuration, a concept in which carbon monoxide (CO)-rich coal gas is directly and simply converted to methanol. The IGCC/OTM concept efficiently stores energy in the form of methanol -- cleanly derived from coal via gasification and conversion -- for use during periods of peak electric power demand. There are unusual efficiency and cost benefits realized with this type of energy storage, because of the fundamental fit of the OTM coproduction concept with the IGCC process. Unique power production load-following flexibility, not normally associated with coal-based power production plants, is available using IGCC/OTM.

Methanol can be substituted for conventional fuels in stationary and mobile combustion applications. In particular, methanol can serve as an excellent peaking fuel. Methanol contains no sulfur and has exceptionally low nitrogen oxides (NO_X) characteristics when burned. In fact NO_X emissions when methanol is burned as a fuel is substantially less than those of distillate oil fuel, and can be as much as 50% less than emissions from natural gas fired combustors. This is because methanol burns with a lower flame temperature than distillate oil or natural gas.

Methanol has been tested successfully as a gas turbine fuel [1,2,3,4]. In the tests conducted by both Florida Power Corporation and Southern California Edison Company, methanol burned in 26 MW gas turbine units showed the following:

1) Modest system modification requirements;
2) Improvements in heat rates of 1 to 2%;
3) Reduced NO_x emissions when compared to both distillate oil or natural gas; and
4) Cleaner gas turbine components (indicated by hot end inspections).

Despite these technical virtues, methanol has not yet been embraced as a substitute fuel. If fuel methanol could be economically produced from coal, the commercialization hurdle could be surmounted. This demonstration at Cool Water will show that methanol can be produced as a coproduct in an IGCC facility producing electric power. Coproduced methanol provides a cost competitive electric peak load energy storage system. This competitive edge is primarily due to the synergism between the IGCC and the OTM processes using the LPMEOH technology. The OTM process is a flexibility-enhancing add-on feature to IGCC electric power plants, with methanol being produced and stored during off-peak power demand periods, and used to provide backup fuel and peaking fuel during peak power demand periods.

THE OTM CONCEPT AND LPMEOH TECHNOLOGY DEVELOPMENT

The IGCC power process is an advanced clean coal technology with high thermal efficiency, superior environmental performance, and the ability to handle all coals (from lignite to high-ranked bituminous) and other (waste) hydrocarbon feedstocks. The Department of Energy states [5], "IGCC plants are viewed as superior to today's conventional coal plants and are almost certain to be one of the lowest cost fossil fuel sources of electric power generation in the 21st century. Compared to today's conventional coal burning methods, an IGCC plant can produce up to 25 percent more electricity from a given amount of coal. Air pollutants can also be removed more efficiently from gas produced in a pressurized IGCC system than from the flue gas which results when coal is burned directly." Integrated coal/waste gasification power plants are more efficient and cleaner than direct coal/waste combustion power plants. Integrated gasification also has the advantage of providing a replacement for natural gas in existing natural gas-fired combustion turbines, including cogeneration systems. Therefore, integrated gasification can be effective for hedging the risk of uncertain natural gas prices in the short term, and for replacing natural gas in the long term.

Air Products has had a continuing interest in and involvement with coal gasification, since this process requires oxygen and produces hydrogen. Coal gasification has had a substantive history in providing the 19th and 20th Century's industrialized world with fuel gas, chemicals, liquid fuels, and transportation fuels. Gasification technologies have continued to evolve and improve.

In the 1970's and 1980's the new high pressure oxygen blown coal gasifier technology was combined with the new combined cycle power plant technology to create the advanced IGCC power plant concept. The concept was first demonstrated at the 100 MW IGCC power plant demonstration at Cool Water from 1984 to 1989.

With the IGCC power process, the coal is gasified with oxygen under pressure, heat is recovered from the resultant fuel gas, the fuel gas purified, and the clean fuel gas fed to the combined cycle power plant gas turbines (Exhibit 1). The fuel gas consists mainly of hydrogen (H_2), CO, and some carbon dioxide (CO_2). Because coal gasification produces H_2 and CO; i.e., synthesis gas (syngas), methanol coproduction is a natural opportunity (Exhibit 2). It was this opportunity that attracted Air Products to develop the OTM concept based on the LPMEOH Technology. In particular, we were encouraged by the Electric Power Research Institute (EPRI) who had studied IGCC characteristics and electric utility requirements, and concluded that coproduction of methanol to provide energy storage had commercial potential. Subsequently, DOE became a major sponsor and, along with EPRI, nurtured the development efforts.

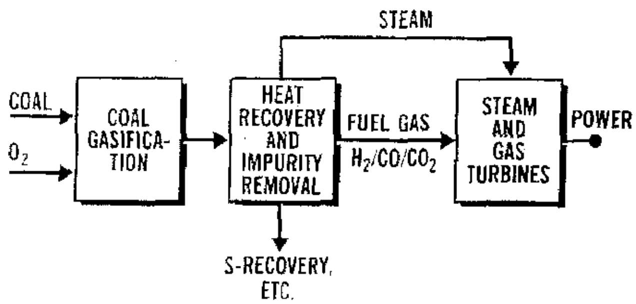

Exhibit 1. Electric Power by Integrated Coal Gasification Combined-Cycle (IGCC)

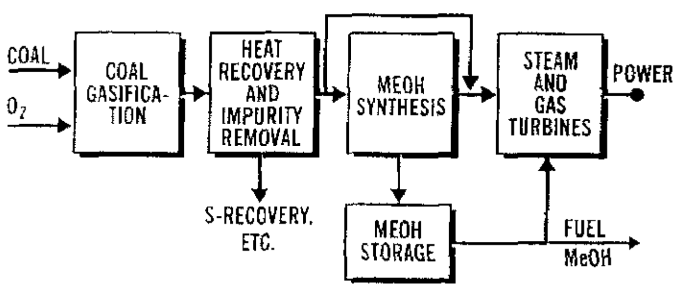

Exhibit 2. Coproduction of Power and Methanol via IGCC

There were two methanol coproduction options to be considered for development: conventional recycle methanol technology or the OTM concept (Exhibit 3). The OTM concept provided a better fundamental approach to fitting the requirements of the IGCC application, and was selected for development. The ideal methanol technology for IGCC/OTM applications must be able to directly process CO-rich gases produced by advanced coal gasifiers. Usually the CO concentration is high and the H_2 to CO ratio is low. CO_2 content is variable depending on the type of coal feeding system; i.e., dry coal or slurry. The ability of the methanol process to load-follow is key -- that is on a daily basis to start quickly, stop, and ramp rapidly. Finally, the process should be relatively simple and reliable, adding value to the IGCC operation, not detracting in any way from the high reliability expected on the IGCC installation. Conceptually the OTM synthesis step can be simply inserted in the IGCC flowsheet (Exhibit 4). In a OTM arrangement, a fraction of the fuel gas is converted to methanol, typically between 10% and 40% of the heating value. In an electric power cycling scenario, methanol is produced during low demand periods and accumulates in storage; during peak demand it is withdrawn and burned as peaking fuel. The front-end coal gasification section runs full-out all of the time.

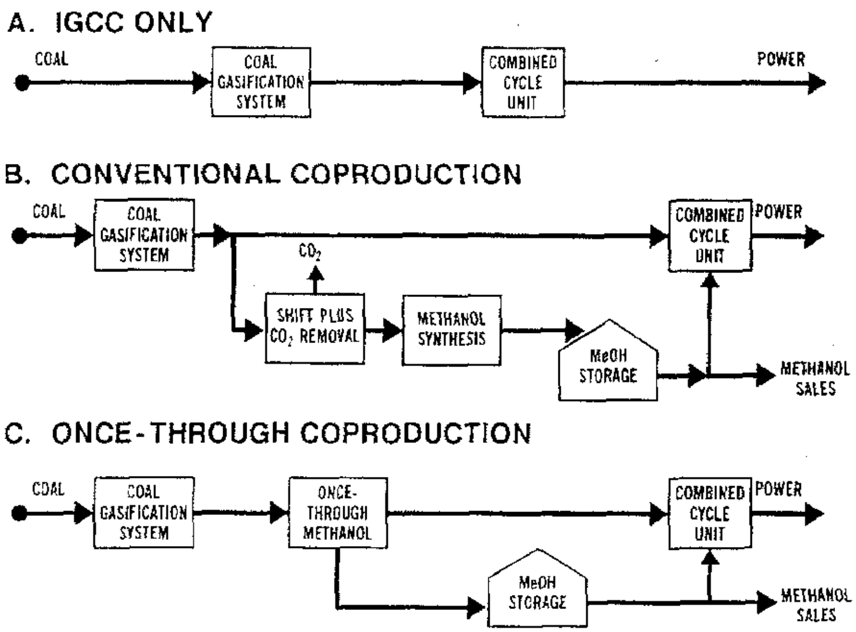

Exhibit 3. Options for Methanol Coproduction in Gasification Combined Cycle Power Plants

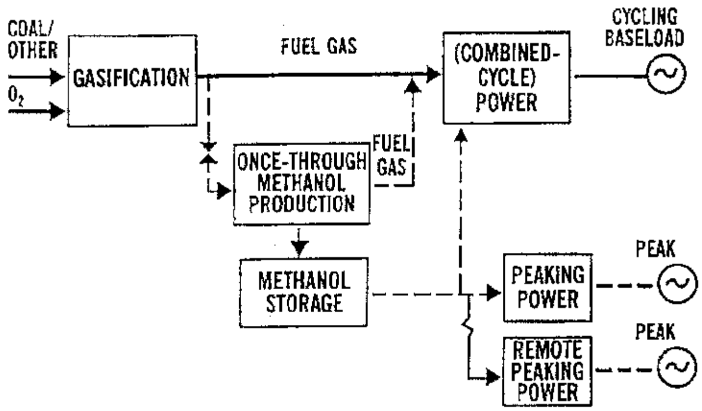

Exhibit 4. IGCC/OTM Power with Energy Storage

The fundamental characteristics of a liquid phase reactor, which is used in the LPMEOH technology, make it particularly suitable for these OTM needs. It is unlike the conventional gas phase reactors that use fixed beds of catalyst pellets and largely depend upon recycle diluent gas to both dilute the CO concentration and control the reaction exotherm. The LPMEOH reactor is a slurry reactor. The catalyst particles are very small, powder-size, and are suspended in an inert oil, a mineral oil. The synthesis gas bubbles up through the slurry. The H_2 and CO dissolve in the oil and diffuse to the catalyst surface where the methanol reaction occurs. The product methanol diffuses out and exits with the unreacted syngas. The inert oil acts as a heat sink and permits isothermal operation. The net heat of reaction is removed via an internal heat exchanger which raises steam. Unlike the gas phase reactors that limit the per-pass conversion to methanol to accommodate the reaction exotherm, the LPMEOH reactor meets the reaction exotherm head-on and maintains isothermal operation. And unlike the gas phase reactors, the LPMEOH reactor is tolerant to CO-rich gas. It does not require recycle. Shift and CO_2 removal are not required. Low H_2-to-CO ratios are acceptable -- and so also is any CO_2 content. Finally, in contrast to the gas phase reactor in which the catalyst is sensitive to flow variations and changes from steady-state, the LPMEOH reactor is eminently suited for load-following.

Work on the development of the LPMEOH technology began in 1981, with a DOE contract to prove the concept at a small but representative engineering scale [6]. A pilot plant was constructed at Air Products' synthesis gas facility at LaPorte, Texas and nameplated at 5 TPD (Exhibit 5). In the final operating campaign concluded in 1989, we successfully tested the unit with very aggressive operating conditions [7]. Summarizing the results from LaPorte: We accumulated 7400 hours of synthesis operation, most on CO-rich gas. We achieved good catalyst life, and pushed catalyst concentration and methanol production rates well beyond original expectations. The LPMEOH reactor proved to have impressive start, stop, and ramping abilities. And while this is a test unit and LPMEOH is a pioneer technology, we achieved a 99%+ on-stream factor.

COMMERCIAL DEMONSTRATION OF THE LPMEOH PROCESS

The success of the LaPorte pilot plant operation, as well as the reactor modeling efforts and the broad laboratory testing base, has established a sufficient data base to allow for a confident move to the next scale of operation. The next step for LPMEOH technology is demonstration at commercial scale using coal-derived synthesis gas. Round III of the DOE Clean Coal Technology Program, provided the opportunity for the LPMEOH technology to make the move to the commercial scale. In response, Air Products proposed to design, construct, and operate a demonstration LPMEOH plant at a coal gasification facility. In December 1989, the DOE selected this proposal for negotiation.

Following months of negotiation, the initial coal gasification host site was no longer available to serve for the LPMEOH demonstration project. Air Products later announced plans to work with Texaco Syngas, Inc., to relocate the LPMEOH demonstration project to the Cool Water Coal Gasification Plant located in Daggett, California. The scale of the LPMEOH demonstration facility will be 150 tons-per-day of methanol. The project includes design, construction, and 4 years of test operation of the LPMEOH unit, as well as 3 years of fuel-grade methanol user tests. Start-up is planned for 1995. Air Products has signed the cooperative agreement, and the DOE forwarded the project's Comprehensive Report to Congress on 11 August 1992. Award of the cooperative agreement will follow a 30, in session day congressional review period.

Cool Water IGCC Facility Site

The advanced IGCC power plant concept was first demonstrated at the 100 MW Cool Water facility located at Southern California Edison's station at Daggett, California, from 1984 to 1989 using the slurry-fed oxygen-blown Texaco Coal Gasification process. The successful demonstration at the Cool Water IGCC facility made it recognized as an important large scale research and development center, uniquely suited to carry out advanced IGCC development, and development of associated technologies. At 1/3 to 1/2 of a commercial IGCC plant size, Cool Water is ideal for development and demonstration at reasonable costs. The Daggett site combines easy access to a major metropolitan area with a remote testing location (Exhibit 6).

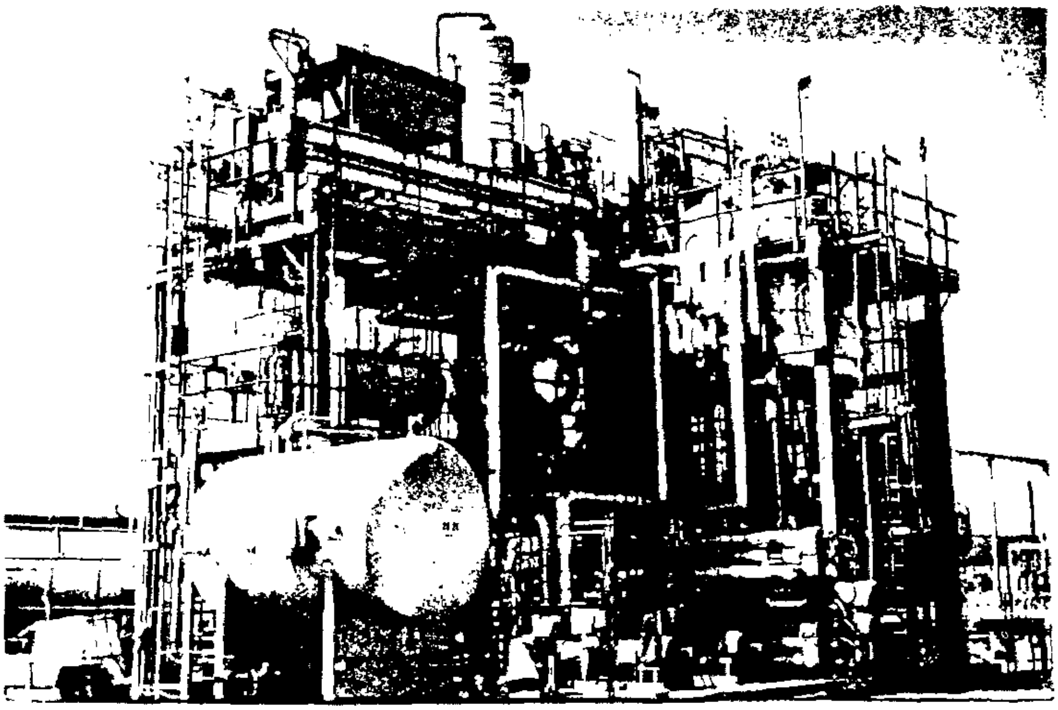

Exhibit 5. Liquid Phase Methanol Pilot Plant at LaPorte, Texas

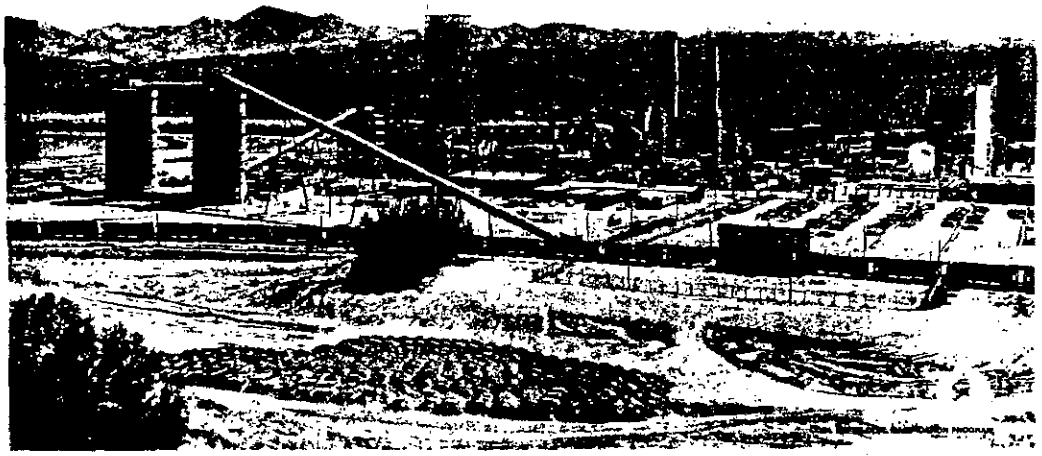

Exhibit 6. Cool Water Coal Gasification Power Plant, near Daggett, California

The Cool Water IGCC facility is presently an unemployed asset. Texaco proposes to acquire the facility from Southern California Edison, to upgrade it to meet new environmental standards, and to operate it to develop and demonstrate improvements to IGCC technologies. Two important IGCC enhancements will be demonstrated initially as part of the Texaco Cool Water Project:

- Destruction of municipal sewage sludge in an environmentally superior manner by gasification of the sludge with coal to produce a clean synthesis gas, and

- Using the clean synthesis gas to coproduce methanol and electric power, demonstrating the Once-Through Methanol process employing the LPMEOH technology.

The California Energy Commission (CEC) has identified these IGCC advancements as a California Research, Development and Demonstration goal.

Texaco is in the final stages of negotiations for purchasing the Cool Water Coal Gasification Power Plant from Southern California Edison. The operating permits are being amended through the CEC to allow continuing demonstration of the technology with incorporation of the gasification of sewage sludge, the production of methanol and other refinements. The facility has received it's Qualifying Facility (QF) certification from the Federal Energy Regulatory Commission (FERC) and Research, Development and Demonstration (RD&D) designation from the CEC. Texaco must complete negotiations for the sale of power that will be generated, and receive approvals from the CEC and the California Public Utilities Commission. Construction will commence after these approvals and receipt of the CEC Certification, with operation planned for 1995.

The Cool Water Integrated Gasification demonstration project is an important part of the DOE's Clean Coal Technology IGCC demonstration programs. The DOE plans to help demonstrate several IGCC systems as part of the Clean Coal Technology (CCT) program [5] in order to provide "a wide matrix of conditions for evaluation of future commercial projects. The projects range in size from 55 to 265 MWe capacity and include synthesis and combustion of methanol as a load balancing alternate." There are multiple technology suppliers and multiple operating (demonstration) facilities in order to provide a sound basis for evaluation and acceptance by the Electric Utility industry. The point of each demonstration is to advance the availability, acceptance, and penetration of IGCC and related technologies. Advancements of IGCC technologies are likely to lower electricity prices, and more importantly will promote an environmentally clean coal-based alternative to natural gas.

DOE plans to provide 43 percent, over $90 million, of the funding for the technology demonstration. The remainder of the funding comes from the private industry participates, and from revenues generated by the sale of the produced methanol. This demonstration meets DOE goals to advance IGCC commercialization, by providing: a) energy storage for electric load-following; b) distributed load capability, i.e., clean methanol distributed to small use point power plant sites (Exhibit 4); and c) clean liquid fuel from coal and sludge wastes. Additional IGCC advancement benefits, which will result from the initial operation of the Texaco Cool Water Project, include low NO_x burner technology, gasifier slag beneficial uses, and sulfur and carbon dioxide recovery and commercial use. Proximity to Los Angeles means that a wide variety of sludge waste oil and other feedstocks are available in quantity, and California offers a wide range of suppliers of advanced energy technologies, such as fuel cells. Long term benefits could include demonstrations of gasification of other wastes, coproduction of other once-through liquid fuel products (a DOE R&D objective, Ref. 8), and testing of the coproducts in advanced power production technologies such as fuel cells for electricity and/or transportation.

Details of the DOE Cooperative Agreement

Although it caused a delay in project initiation, the move to the new host site at Cool Water is advantageous. At this site, the LPMEOH technology will be demonstrated in its commercial configuration -- as an integrated IGCC/OTM facility that produces methanol on a once-through basis for use as a turbine peaking fuel within the IGCC power plant or as an export for commercial sale. During peak electric demand periods, the syngas produced by the facility will be used to generate electricity. During off-peak demand periods, about 15% of the syngas will be diverted from the power plant's turbines to produce methanol. A portion of the methanol will be stored to provide additional fuel to the electric power plant during peaking hours. The remainder will be available for California's market needs.

The specific objectives of the LPMEOH technology demonstration include the following:

- To achieve long-term operation of the LPMEOH facility on synthesis gas produced by coal gasification;

- To demonstrate the cost effectiveness of the LPMEOH technology in a commercial embodiment, IGCC/OTM;

- To demonstrate the quality of the methanol product by user tests in transportation, boiler, and combustion turbine applications;

- To demonstrate scale-up of the LPMEOH slurry reactor fluid dynamics.

APPLICATIONS -- ENERGY STORAGE FOR ELECTRIC POWER PRODUCTION

Now -- shifting to the commercial application -- we can review how OTM coproduction can enhance the economics and flexibility of power production. There are a number of ways. The OTM process can be used for energy storage, operating in the traditional sense to convert off-peak energy into high-value peak energy. Conventional energy storage technologies -- such as pumped hydroelectric, compressed air, and battery -- are generally known for their ability to provide economic and strategic benefits to electric utilities (Exhibit 7). All of these technologies take excess electric power from base-load generating units, store it, and deliver power during peak demand periods. The IGCC/OTM energy storage concept provides the opportunity to design energy storage into load-following coal-based power plants. The OTM process can also be used to coproduce backup fuel for base-load power plants, which can be used to increase the power plant on-stream time. Examples on how IGCC/OTM can directly enhance coal-based electric power production follow:

CONCEPT	DUTY CYCLE	HOURS OF STORAGE	MODULE MW
PUMPED HYDRO	"BASELOAD"	10	500-1500
COMPRESSED AIR	INTERMEDIATE / BASELOAD	10	110-220
BATTERY	PEAKING	3	10
IGCC / OTM	INTERMEDIATE / BASELOAD	4 - 10	100-600

Exhibit 7. Conventional Energy Storage Concepts

1. Load-Following Coal-Based Power Plants

New power plant capacity additions, when added to diversified utility systems, must dispatch effectively. The impact of a new IGCC/OTM power plant on a typical power pool (Exhibit 8) can provide great operating and dispatch flexibility for the utility. Examples of the flexibility a moderate size OTM plant (2.0 ton-per-day of methanol per net MW of base load power) can provide to a utility system is shown in Exhibits 9 and 10. Peak to valley power production ratios greater than two can be easily provided; while allowing the capital intensive gasifier to operate effectively at 100% load. The peaking power plant can be located on-site or remotely, since methanol is easily stored and transported.

Studies [9,10] have shown capital savings (smaller gasifier) and operating efficiencies can provide an electricity cost advantage approaching 10% for an IGCC/OTM energy storage power plant, relative to load-following with an IGCC power plant.

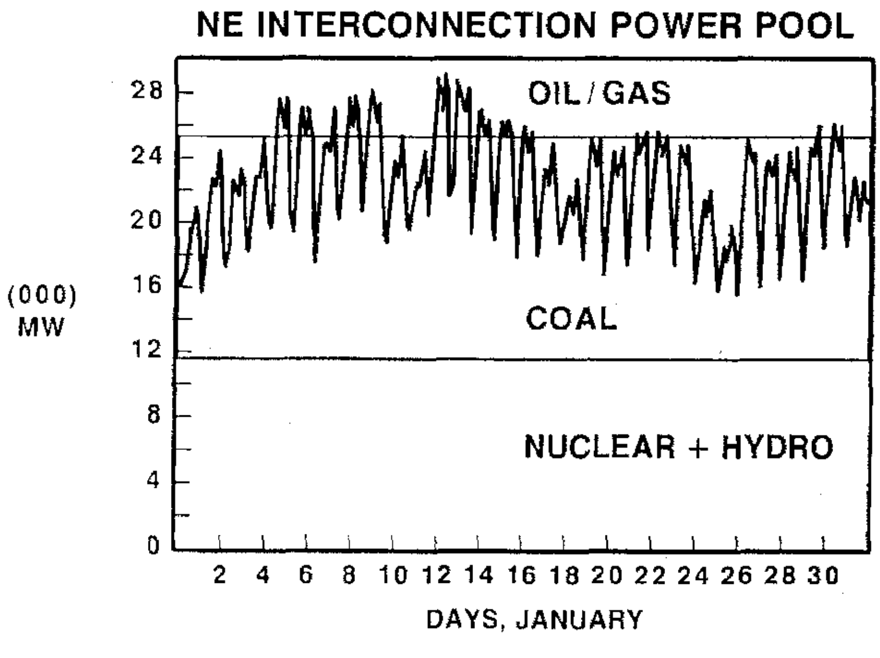

Exhibit 8. Monthly Load Curve - Winter/NE U.S.

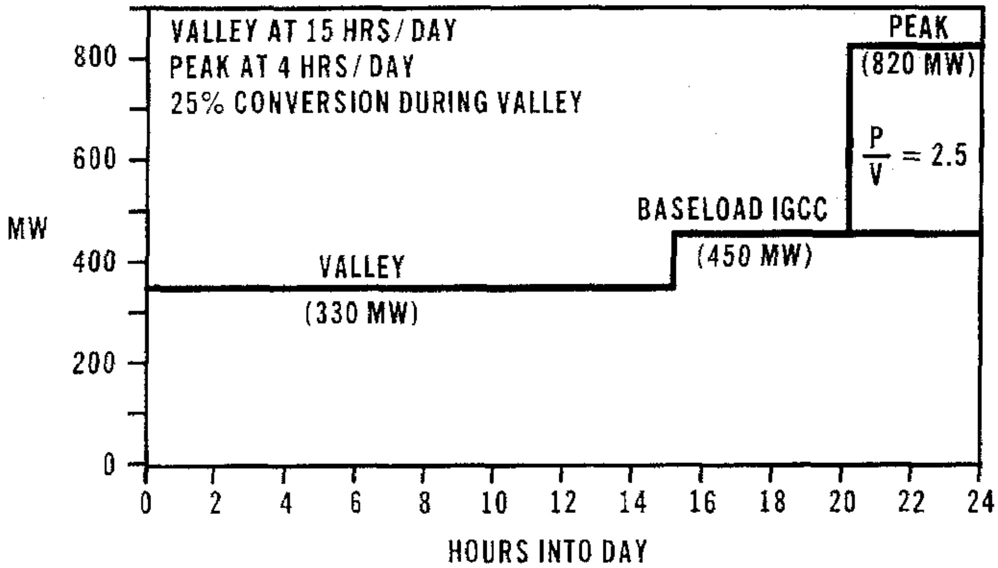

Exhibit 9. **Example IGCC with OTM Energy Storage**

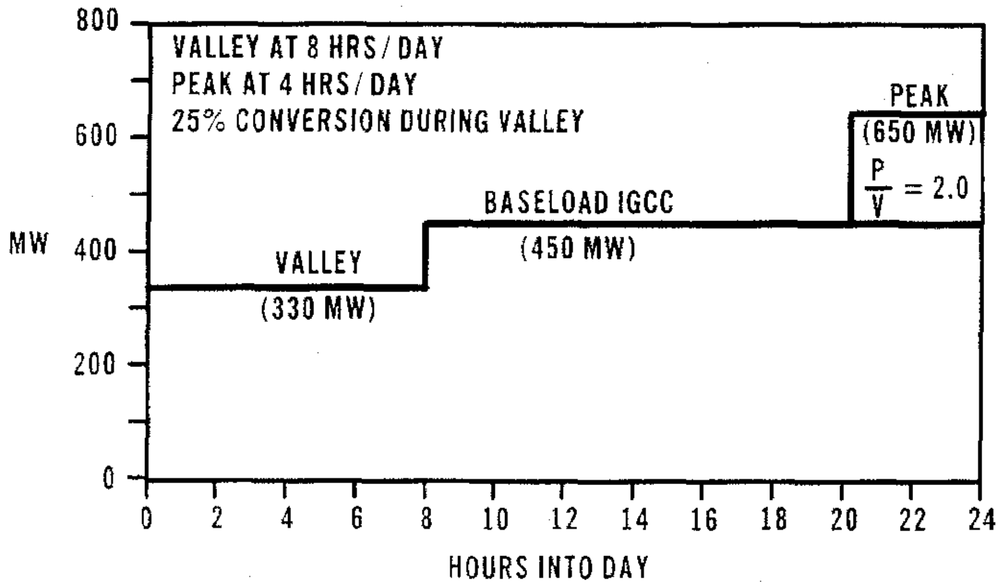

Exhibit 10. **Another Example**

2. Base-Load Power Plants

For base-load power plants, one study [11] compared an IGCC power plant with no spare gasifiers to an IGCC power plant with one 'spare' gasifier plus an OTM plant. The IGCC/OTM plant configuration increased the power plant equivalent availability from 86% to 93%. The methanol coproduction and the increased net power production off-set the cost of the spare gasifier and the OTM plant. The methanol plant investment was only 4% of the total plant investment. The IGCC/OTM plant design included the same number of gas turbines, and was developed for actual dispatched utility operation. At peak capacity, the levelized cost of electricity for the IGCC/OTM case was estimated to be one mill per kwh lower than that for the IGCC case, and the savings were even greater over the range of plant turndown.

The benefits of this IGCC/OTM coproduction scheme for base-load power were found to include:

- Unscheduled gasifier outages - syngas to the methanol plant can be immediately diverted to the power block; (e.g., the backup fuel is syngas) since the LPMEOH technology provides instant shutdown and fast restart capability of the OTM plant.

- Planned gasifier train shutdowns - stored methanol can be used effectively for the power block when syngas is not available, since the gasification train has to be shutdown for a longer period of time than the power block for planned maintenance.

- The methanol produced and stored, can also help reduce the risk of lower than expected gasifier availability. If in any year the gasifier component availability should decrease from 96% (the design basis) to as low as 84% (unlikely event), sufficient methanol would be available to maintain the power block operation at its 93% plant equivalent availability.

This interesting base load IGCC power plant study showed that a small (0.7 tons-per-day of methanol per MW net power) OTM plant can provide operating flexibility and reduce the cost of electricity from base-load IGCC facilities. It would be interesting for a future study to marry the base-load spare gasifier/OTM concept with the load-following peak power IGCC/OTM concept.

CONCLUSION

The LPMEOH technology was primarily developed to allow OTM plant capability to be added to IGCC power plants to help reduce electricity costs and to improve the flexibility of electric power production. When incorporated in an IGCC power plant, the IGCC/OTM process provides energy storage and clean coproduct capability in the form of methanol, using the Nation's abundant coal reserves. The zero emission of sulfur and the low emissions of NO_x when burning methanol make it attractive for industrial boilers, combustion turbines, fuel cells, and transportation vehicles.

The commercialization of the LPMEOH technology requires a comprehensive data base that demonstrates the performance, reliability, emission control capabilities, and cost effectiveness of the technology. This demonstration conducted under the Clean Coal Technology Program will test all operational phases of the LPMEOH technology that are anticipated to be encountered in commercial-scale facilities. The demonstration of the LPMEOH process at the Texaco Cool Water Project is consistent with the objectives of the Clean Coal Technology Program and provides an excellent mean to fulfill the goals of the National Energy Strategy.

To summarize, LPMEOH technology provides an energy storage concept specifically for IGCC power plants. LPMEOH process is simple, efficient, and reliable. The LPMEOH technology can be readily deployed in the future as an OTM add-on to IGCC facilities. For a relatively modest investment, OTM greatly enhances the operational flexibility of a IGCC facility. Beyond traditional energy storage ability, IGCC/OTM can provide back up and transportable peaking fuel from base load feedstock. The technology has performed well at the pilot scale and is now advancing toward the demonstration scale via the Clean Coal Technology III Program.

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