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QUARTERLY PROGRESS REPORT

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PROJECT: Research Guidance Studies (DE-AC22-95PC95054)

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Section 1 Introduction

The Pittsburgh Energy Technology Center (PETC) of the United States Department of Energy contracted with the MITRE Corporation to perform Research Guidance Studies that will assist the Center in evaluating and prioritizing research in the areas of coal and natural gas conversion. MITRE was reorganized in December 1995, which resulted in the formation of Mitretek Systems Inc. Mitretek is performing this work on MITRE's behalf until completion of contract novation to Mitretek.

The overall objective of this project is to provide research guidance and quantification of research progress in the areas of direct and indirect coal liquefaction, coal/waste coprocessing, refining of coal-derived liquid fuels, and natural gas conversion. Specifically, the work is divided into two subtasks that relate to whether the technology application is direct or indirect. In subtask (a), *Direct Coal Liquefaction* technology is the subject of the analyses, and in subtask (b), *Indirect Liquefaction*, technologies will be evaluated in accordance with the priorities of the COR.

Mitretek Systems has been developing detailed computer simulation models of direct and indirect coal and natural gas conversion systems for several years. These models are constantly being updated and improved as more data and better cost information becomes available. These models also include detailed refinery models based on bench-scale upgrading data of coal derived liquid fuels to specification transportation fuels. In addition to the simulation models of actual conversion system configurations, Mitretek is able to simulate innovative process configurations for coal and gas conversion to fuels, power, and chemicals. To supplement these system models and to provide a context to investigate expected energy use scenarios when alternate coal and natural gas based fuels will be needed, Mitretek's staff has also developed world and country by country energy supply and demand models. This work will be accomplished by using the existing models where appropriate and by extending and modifying the system models where necessary.

Section 2 Project Activity Summary

General Overview of Technical Activities:

During this third quarter of the contract, the main emphasis continued to be work on the rationale and strategy project for the deployment of coal-derived liquid transportation fuels and on the concept of integrating both direct and indirect liquefaction technologies with existing refineries. During this quarter, the draft of the document entitled "Rationale and Proposed Strategy for Commercial Deployment of Coal-Derived Transportation Fuels" was completed and sent to DOE PETC and DOE HQ for comments and review.

The Rationale section of the project, that includes a detailed analysis of both the world and the United States conventional oil situation was completed. This analysis concludes that there will be an imbalance between world conventional oil demand and supply around the year 2015. At about this time, over half of the world's ultimate resources of conventional oil will have been used and oil production will have peaked and will be in *irreversible* decline because of resource limitations. However, liquid hydrocarbons will continue to be important transportation fuels well into the next century. Because they are so critically important to the social and economic infrastructure of the developed world and to the economic aspirations of the developing world, the resulting liquid fuels shortage, created by this imbalance, will be extremely serious.

Since a liquid fuels shortage can be expected within twenty years, actions to prepare for this must be initiated now, while there is still time to develop solutions in an orderly manner, rather than later when the crisis is upon us. It is, therefore, essential for the United States to simultaneously pursue a number of options to help mitigate this future domestic petroleum shortfall. Several options are already being pursued to various extents. These are: to continue domestic exploration and production using the best technologies available; to develop and deploy alternatively fueled vehicles; and, to improve efficiencies in all sectors of transportation. Yet, even with all of these options, this analysis concludes that the domestic demand for liquid fuels will still exceed our potential sources of supply.

This implies that options, in addition to those already initiated, will be necessary to ensure that the U.S. will have the necessary liquid fuels supply to be able to continue its economic growth into the 21st century. One of these additional options is to produce high quality liquid transportation fuels from our vast, domestic coal resources.

There are valid reasons to be concerned about the future petroleum situation. Currently, the world consumes over 65 million barrels of petroleum each day and the Energy Information Administration (EIA) projects that the world will be consuming 99 million barrels per day by 2015. The United States currently imports over 50 percent of its petroleum and is projected to be importing 68 percent by 2010.

There are numerous reasons why concerns over oil shortages are more valid today than in the past. For a start, nearly all the major sedimentary basins worldwide have been explored to some extent. There have been significant technological advances in oil exploration and production in the last decade, yet no new major oil provinces have been found or developed for several decades. Campbell of Petroconsultants concludes " the whole world has been thoroughly explored so it has become clear that no new provinces comparable with the North Sea and Alaska await discovery." Although the quantity of *proven reserves* (oil that can be recovered from known reservoirs under current technological and economic conditions) have increased over the years, estimates of world ultimately recoverable oil (cumulative production when reservoirs are finally abandoned) have not changed significantly for the last 25 years. Ultimately recoverable oil falls into the range 2000 to 2400 billion barrels. Since over 750 billion barrels have already been produced, this leaves about 1650 billion remaining. By 2015 another 500 billion will be produced for a total cumulative production of 1150 billion barrels; over half of the high estimate of ultimately recoverable oil.

It is argued that, if there is an imbalance between oil demand and supply, oil prices will rise and the higher oil price will stimulate increased exploration and production activity. This, in turn, will increase reserves. Theoretically this is true, but historically increased activity resulting from higher prices have not resulted in significant additions to reserves. As James MacKenzie of the World Resources Institute points out, " from the early 1970s to the mid 1980s when world oil prices were $30 to $58 per barrel, exploratory and development wells in the U.S. increased dramatically, from 28,000 in 1973 to a peak of 90,000 in 1981. A high level of exploratory activity persisted until world oil prices crashed in 1986. Yet, during this entire period, proved reserves in the lower 48 states declined, from 25 billion barrels in 1973 to 20 billion in 1986, and crude oil production declined by 24 percent." Also, although exploration activity increased worldwide during this period of high oil prices, few new giant fields were found.

It is not a long term solution for the United States to continue to increase its reliance on oil imports to alleviate the shortfall. Besides concern for national security, economic factors may be limiting in the future. Currently, the U.S. share of the world GNP is about 25 percent, and, as the world continues to develop and the developing countries continue to increase their gross domestic product (GNP), the U.S. percentage of the world GNP will be significantly less than 25 percent by 2015. Increased competition for oil imports may result in the U.S. being unable to command the over 25 percent of total world exports that we currently import. Also, by 2015, this oil will be almost entirely from the Middle East, placing an inordinate reliance on that potentially unstable part of the world for our continued energy security.

The high WOP that results from this liquid fuels shortage will allow alternative sources of transportation fuels to become economically competitive with petroleum. One of these alternative sources is liquid transportation fuels derived from inexpensive, domestic coal. Both bituminous and low-rank coals can be converted into high quality transportation fuels by means of direct and indirect conversion technologies. These coal-derived fuels have the great advantage that they are high quality liquid fuels compatible with the existing infrastructure for refining, distribution and end-use. Liquids produced from indirect liquefaction, for example, produce excellent diesel fuels containing no sulfur or aromatics and having cetane numbers in excess of 70. This diesel is far less polluting than petroleum-derived diesel and will command a significant premium for refiners. Direct coal liquefaction produces an all-distillate product that can be refined into high quality gasoline and high-density jet fuels.

The Strategy section of the project details proposed paths for the commercial deployment of coal-derived transportation fuels from both indirect and direct coal conversion technologies. Partnerships between U.S. industry and the U.S. Department of Energy, over the last two decades, have fostered the development of highly efficient technologies for both indirect and direct coal conversion that can produce transportation fuels for about $34 per barrel crude oil equivalent for stand-alone plants. It is estimated that continued R&D in coal liquefaction can reduce the cost of these coal-derived fuels from $34 per barrel to about $27 per barrel for a grass-roots stand-alone commercial coal liquefaction facility. The ability to produce liquid transportation fuels from domestic coal for $27 per barrel could have the effect of capping the WOP at about this cost. When oil exporters know that alternatives to petroleum can be produced for $27 per barrel, they run the risk of losing market share for their product if their costs are higher.

In addition to these stand-alone, grass-roots plants, there is the opportunity to deploy coal liquefaction plants at existing facilities, for example at petroleum refineries and integrated coal gasification combined cycle (IGCC) sites with greatly reduced costs. These plants integrated with existing facilities are termed "entrance plants" and economic analyses that have been performed in the ongoing refinery integration project have shown that they can be competitive with crude at around $19-23 per barrel. This cost is within the range of current oil prices and thus, coal conversion integrated with refineries, can be considered a near-to-medium-term technology option that could be ready for deployment in time to help alleviate the liquid fuels shortfall expected in 2015.

This observation that "entrance plants" have the potential to be competitive with petroleum in the near-to-medium term presents an opportunity for the early commercialization of coal liquefaction. These "entrance plants" also provide a technology bridge to the eventual deployment of stand-alone coal liquefaction facilities.

However, private investors and process developers are not likely to design and construct an "entrance plant" until technical, economic, and regulatory risks are acceptable. These risks can be made acceptable by following a development path from bench-scale research to the construction of a pioneer plant. Continued bench-scale and proof-of-concept testing of coal liquefaction technologies will be essential together with conceptual design studies, so that sufficient data will be available to design and construct pioneer plants.

Pioneer plants will be small-scale, commercial plants that will demonstrate sustained integrated performance and the ability to successfully scale the integrated technologies. It is the demonstration of the technologies through these pioneer scale plants that will reduce technical and economic risks, and identify those regulatory issues critical to future permitting of such facilities. Once these risks are shown to be acceptable by successful operation of pioneer plants, larger "entrance plants" can be confidently permitted, constructed and operated. Eventually, when the most appropriate sites for "entrance plants" have been utilized, the technologies have continued to mature and improve, and the WOP has continued to increase, stand-alone, grass-roots commercial facilities will be deployed.

However, technical risks in commercializing these technologies, even at a pioneer plant scale, are high, and potential investors and developers will require incentives to mitigate this risk before they would be willing to provide the capital to build and operate these plants. Several potential economic incentive schemes have been analyzed in this report including accelerated depreciation and the exemption of the State and Federal fuel excise tax from fuels produced by these plants. Detailed economic analyses of these plants show that these tax exemptions will be sufficient to allow the investors to recover in excess of 15 percent return on their equity over the commercial life of the plant. These analyses further show that, in spite of fuel tax exemptions, these plants could provide considerable revenue and economic benefits to both those states in which they were located and to the federal government. These plants will create high paying jobs in coal mining, construction and in operations and also provide indirect jobs in the service sector. Revenue to the states and to the federal government will result from payroll and corporate taxes. Creating a domestic industry based on using U.S. coal to produce high quality liquid transportation fuels will thus generate wealth within the country rather than exporting dollars overseas, thereby increasing our balance of payments deficit.

An analysis of the overall level of carbon dioxide emissions from coal-based liquid transportation fuels systems has also been performed during this quarter. It is concluded that the carbon dioxide emissions from coal-derived fuels are similar to those from coal-based electric power generation. In fact, until all current conventional power plants are replaced by advanced IGCC systems the penalty for using coal in the power sector will be higher. Production of coal derived liquid transportation fuels using natural gas to produce hydrogen is, in fact, lower in carbon dioxide emissions than coal-based IGCC power systems. If, in the future, the reduction of carbon dioxide emissions becomes a priority, then it would be preferable to use natural gas in power generation and coal for liquid fuels production. Furthermore, carbon dioxide penalties for using coal derived liquid fuels for transportation will be no more than for heavy oils and oil sands if coal/resid coprocessing technology is used and natural gas is used for hydrogen production. If coal/waste plastic coprocessing is used, carbon dioxide emissions will be lower than those from conventional petroleum.

The successful development and commercial deployment of U.S. technologies for the conversion of coal to transport fuels will give U.S. industry a competitive advantage in coal-derived liquid fuels technologies worldwide. There is an increasing demand for transportation fuels in the developing world, especially in India and China that have large coal reserves and limited resources of petroleum. Technology to cleanly convert their coal reserves into high quality fuels would help alleviate their transportation fuel shortfall and also allow their coal resources to be used in an environmentally responsible manner. Other countries like Japan and South Africa are developing coal conversion technologies, and they are eager to market these technologies worldwide. The U.S. currently has the technological lead in some of these technologies and, with continued reduction in R&D funding, this lead position is in danger of being lost.

It is concluded that domestic coal is a viable future alternative feedstock to petroleum for the production of high quality transportation fuels compatible with the existing liquid fuels infrastructure. These fuels are high quality distillates that in many cases are higher quality than current petroleum fuels. It is recommended that the current program of research and development sponsored by the U.S. Department of Energy in cooperation with the private sector be continued and expanded so that sufficient performance data can be obtained for the design of "pioneer" plants. These plants would be located adjacent to existing facilities, for example, refineries or IGCC plants, and would be constructed and operated to demonstrate the integrated technical feasibility of the configurations. These plants would be constructed with private capital and, although incentives may be provided by state or the federal government, net revenues to state and federal government, over the life of the plant, as a result of taxes on net profits would be positive. Once technical, economic, and regulatory risks have been reduced as a result of "pioneer" plant operations, the continued deployment of coal liquefaction technologies would proceed with no further government involvement based on economic feasibility under market conditions.

TASK 1: (subtask (a)): Direct Coal Liquefaction:

During this quarter, the detailed techno-economic analysis of the direct pioneer plant was completed. This plant, sited adjacent to a refinery, consists of a single train of the Catalytic Two-Stage Liquefaction (CTSL) process and a single train of gasification to produce hydrogen for the plant and for the adjacent refinery. The direct liquefaction train is designed to allow flexibility in processing different feeds that will include coal, heavy oils and resids, and waste plastics. The concept is to gasify petroleum coke from the refinery to produce the necessary hydrogen and fuel gas for both the CTSL plant and the adjacent refinery. Coal and waste plastics are prepared and fed to the CTSL reactor train where they are converted into distillate products and unconverted coal and ash. The distillate is separated and the unconverted coal and ash are further separated in a critical solvent deashing (CSD) unit. The bottoms from the CSD unit are sent to the gasifier for conversion to synthesis gas. The distillate product is sent over the fence to the refinery where it is upgraded to transportation fuels. This concept allows a refiner to dispose of low value petroleum coke to produce high value hydrogen and allows low value coal and waste plastic to be converted into high value liquid transportation fuels. In the configuration analyzed here, if a 50:50 weight ratio of coal and waste plastic is processed (about 1,000 tons per day each of coal and plastic), the pioneer plant will produce about 11,000 BPD of distillate and about 35 MMSCF per day of hydrogen for the adjacent refinery. The overall conclusion from this analysis was that expected ROIs of 25 percent could be achieved if the fuel could command a premium of 10 cents per gallon over conventional petroleum and a state tax exemption equivalent to about 17 cents per gallon was applied.

Subtask (b): Indirect Liquefaction:

The two pioneer plant configurations investigated for indirect liquefaction were also completed during this quarter. One of these plants is located adjacent to an existing petroleum refinery and uses petroleum coke as feed to a gasification/gas cleaning plant to produce clean synthesis gas. In the simplest case, petroleum coke would probably be used as the feed but, if the plant is to be increased in size, coal can be introduced into additional gasifiers. Because the pioneer plant is located adjacent to a refinery, it is assumed that the plant will utilize some of the existing refinery facilities. In this case it is assumed that acid gas from the gas cleaning section can be processed in the existing refinery Claus unit for sulfur recovery. Also the refinery is assumed to process the waste water from the pioneer plant. The clean synthesis gas from petroleum coke gasification is passed once-through a slurry Fischer-Tropsch reactor to produce liquid fuels that are recovered in product separation, and the tail gas is sent to power generation. The pioneer plant sells electric power to the refinery and the liquid fuels are sent over the fence to the refinery for upgrading and blending. In the configuration analyzed here, 3,500 BPD of naphtha, diesel, and wax are produced together with 42 MW of power.

The location for the second type of indirect pioneer plant would be an existing IGCC facility. An independent power producer (IPP) may want to coproduce fuels and chemicals in addition to power. This can be achieved by adding an indirect liquefaction facility to the existing IGCC power plant and produce coproducts. The additional units required include a polishing reactor for residual sulfur removal, the F-T reactor, product recovery, and a cracker for the wax product. In this case, the IGCC plant would coproduce about 4,200 BPD of fuels in addition to 250 MW of power. Because the synthesis gas from the coal gasifier is now being fed to the F-T unit, natural gas must be imported for combustion in the gas turbines to keep the power output at 250 MW. The synthesis gas is passed once-through the F-T reactors and the tail gas, after product separation is used in the turbines. As the future cost of natural gas increases, it would be less expensive to add additional coal gasifiers and phase out use of the natural gas.

The economic analyses for both of these indirect pioneer plants shows that the return on investor's equity (ROE) would be over 15 percent if it is assumed that these high quality F-T liquids can command a premium of 20 cents per gallon ($8.40 per barrel) over conventional petroleum. If the average of the nation's state fuel tax (17 cents per gallon) is exempted, effectively making the total incentive 37 cents per gallon, then the ROE rises to over 20 percent. If both state and federal fuel taxes are exempted, then a ROE of over 25 percent would be realized from this investment. Although exemption of fuel taxes would appear to result in a net loss in revenue to the government, the economic payback analysis clearly shows that when corporate and payroll taxes are used to offset the incentives, the net revenue to the government is always positive.