Western Governors' Association

Transportation Fuels for the Future

Coal to Liquids

WGA Coal To Liquids Team
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Final Report

The following report is based on the contributions of the individuals and organizations listed below. While the working group strived to reach consensus, this report does not represent a consensus view, but rather attempts to reflect the working group's spectrum of viewpoints on the state of the CTL industry and recommendations on its development and deployment. Appended to this document are statements of alternative viewpoints from working group members. These alternative viewpoints are also noted in the main body of the document to provide for a robust and thorough discussion of CTL.

As originally constituted the working group included a representative from the Natural Resources Defense Council (NRDC). However, the individual representing NRDC resigned from the working group in September after ascertaining that the report would not adequately represent their organization's views.

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PREFACE

High oil prices and our country's growing reliance on imported petroleum have created major opportunities — as well as challenges — to providing alternative transportation fuels using the West's abundance of coal, oil shale, and oil sands. The majority of these resources are located on federal lands[1], and it is the goal of the Western Governors' Association to find ways to maximize the benefits of developing these unconventional fuels, while balancing national, state and local interests.

The WGA coal-to-liquids (CTL) Working Group has proposed a framework for establishing the energy policies, programs and initiatives that would be necessary to accomplish this objective. Of primary interest in the drafting of this report to the Western Governors are the processes for providing liquid transportation fuels from coal, because they offer the greatest opportunity for developing alternatives to imported petroleum in the near term-term (5 to 10 years).

There is considerable public debate about the desirability of going forward with CTL technology because of climate-change concerns. The debate stems in large part from the growing recognition that deep reductions in total global CO_2 emissions may be needed by mid-century, especially in industrialized regions.[2] Such a goal within that time frame implies that total greenhouse gas emissions for transportation fuels[3] must be reduced to a small fraction of what they are now. Such goals for transportation fuels are problematic because fuel-cycle-wide greenhouse gas (GHG) emission rates for CTL are roughly double the rate for crude oil-derived products if the CO_2 is not captured and stored (CCS), and comparable to the rate with CCS. Clearly the ability to capture and store CO_2 is critical the future acceptance of CTL technology and its success in the market.

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[1] www.blm.gov/nhp/facts/index.htm

[2] Deep reductions in CO_2 emissions levels by mid-century are being called for in many political arenas as needed to keep the atmospheric CO_2 concentration at a safe level in a manner that is fair at the global level. For example, leaders in several Western states have recognized the need for deep reductions in GHG emissions in this time frame. Official mid-century goals for state-wide CO_2 emissions for states where action has already taken place to establish such goals are:

- 80% below the 1990 level by 2050 for California,
- 75% below the 1990 level by 2050 for Oregon,
- 50% below the 1990 level by 2050 for Washington,
- 75% below the 2000 level by 2050 for New Mexico,
- 50% below the 2000 level by 2040 for Arizona.

Other Western states, where a suitable process (*legislative initiative or executive order*) is in place, are working on measures that are consistent with these already-established goals. These goals are even more daunting when measured against current CO_2 emission rates. For the U.S. as a whole, the CO_2 emission rate in 2006 was 16% higher than in 1990 (See www.eia.doe.gov/neic/press/press272.html.) The Western Climate Initiative (made up of the above states and Utah as well as British Columbia and Manitoba in Canada) have established a regional goal of reducing greenhouse gas emissions in 2020 by 15% relative to the 2005 level.

[3] Transportation fuels are a major source of U.S. CO_2 emissions, accounting for about one-third of total USU.S. CO_2 emissions. (See www.eia.doe.gov/neic/press/press272.html.)

EXECUTIVE SUMMARY

At the request of the Western Governors' Association and under the guidance of WGA policy resolution 06-20 *Transportation Fuels for the Future,* we offer recommendations on a state, regional and national level that will help the coal-to-liquid (CTL) industry move towards future deployment in a manner that addresses both the opportunities and challenges associated with the three dimensions of energy security, environment and economic vitality.

On average, the United States currently spends more than $600,000 a minute on oil produced in foreign countries. CTL technologies and specifically Fischer-Tropsch (F-T) liquids, offer the potential for reducing energy security risks associated with a dependence on imported oil by making liquid transportation fuels from abundant and relatively low-cost domestic coal. The U.S has over 507 billion short tons of a demonstrated reserve base of coal, 275 billion short tons of estimated recoverable reserves of coal,[4] and estimated recoverable reserves of 19 billion short tons at active coal mines[5]. Approximately 59% of the total recoverable reserves and 65% of the recoverable reserves at active mines are in the Western states making Western coal a potentially plentiful substitute for petroleum-based transportation fuels. In addition to energy security benefits, the development of an industry that produces fuel domestically can provide obvious economic benefits to the Western states and the nation as a whole.

At this date, there are no domestic, commercial CTL facilities. Central to the challenges faced by the industry is uncertainty. This brings about focus on two primary elements: 1) the fact that this is not a mature industry in this country and, thus, there is no full-scale operational experience on which to firmly base industry operating conditions; and 2) how to best enable the development of a CTL industry under a carbon-constrained future.

Projected life-cycle CO_2 emissions (mine to wheels) from CTL transportation fuels are estimated to be roughly twice that of petroleum-derived transportation fuels if CO_2 from all plant processes is vented to the atmosphere (i.e. not captured and stored). However, CO_2 capture and storage, the use of CO_2 for enhanced oil recovery, and/or co-processing coal with biomass at a CTL plant can reduce the CO_2 emissions to levels that are comparable or below current petroleum-derived transportation fuels on a life-cycle basis.

While CO_2 is not currently regulated on a federal level, several states and regions in the U.S. have initiated this policy path (see footnote 2 above), as has Europe. In the West, these states (Arizona, California, New Mexico, Oregon, Utah and Washington) comprise more than half of the region's population, meaning that transportation fuels sold in these markets would be required to meet CO_2 standards, even in the absence of a federal policy. While the recommendations put forth in this report do not presume future regulation of CO_2, they acknowledge what is in place now, the significant public and political discourse that is focused on climate change, and the need to consider the ability of CTL plants to comply with potential carbon constraints.

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[4]Data from EIA: U.S. Coal Reserves 1997 Update, February 1999; Table A2. Includes data for all states.
[5] Data from EIA survey of mine operators in 2005. www.eia.doe.gov/cneaf/coal/reserves/reserves.html. Does not include data from Alaska, Arizona, and Washington to avoid disclosure of individual company data and there are no reported data for Idaho, Oregon and South Dakota.

In an effort to simultaneously address the issues of energy security, environmental performance and economic growth, we offer the following summary of our recommendations:

- Advocate for the federal government to promote CTL development through performance-based financial incentives that would provide public benefits and parity among alternative transportation fuels.
- Consider promoting alternative incentive structures in lieu of traditional incentives. These could include the establishment of off-budget incentives that would allow the market -- not government -- to pick winning transportation fuel technologies using approaches designed to account for climate, energy security and other public benefits and institutional challenges.
- Further incentivize development of co-firing/co-processing biomass in CTL plants.
- Clearly define the permitting process for CTL facilities, which reduce the uncertainty, time and cost required for permitting while retaining regulatory process and oversight.
- Seek to amend the federal mineral leasing statutes that require 1% of the reserves in the federal coal lease be produced within the tenth anniversary of the issuance of the lease, in order to allow additional time for the development and construction of advanced coal utilization facilities such as CTL plants.
- Undertake regional efforts to support the development of a state-based regulatory framework for CO_2 storage — including liability issues, measurement, and monitoring and verification (MMV) protocols.
- Consider promoting infrastructure development and incentives that would encourage early CTL plants to be sited in locations where captured CO_2 could be used for CO_2 storage demonstration projects, and/or enhanced oil recovery (EOR).
- Consider the creation of infrastructure improvement authorities and planning organizations to support the development of a CO_2 pipeline and storage infrastructure throughout the Western region.
- Collaborate with coal and biomass producers and the transportation industry to develop a robust biomass transportation infrastructure that will facilitate the development and maturity of a coal/biomass co-processing industry in the Western states.
- Encourage the federal government to update the nation's coal resource assessment.
- Ensure adequate funding and appropriate oversight of the coal industry. In addition states should evaluate their regulatory programs to ensure that they are well-functioning and sufficiently protective of worker safety, public health and the environment to the extent of their authority.
- Alleviate the severe shortage of trained and qualified workers for the CTL industry by increasing education and training opportunities for engineers and

skilled labor through universities, community colleges, trade schools, academies and web-based learning.

- Recommend that the federal government develop a roadmap for CTL R&D. Similarly, Western states should consider collaborative R&D efforts among universities and other research institutions. R&D efforts should include, but not be limited to:
    - F-T micro-channel technologies
    - F-T catalysts
    - Brines for CTL process water needs
    - CO_2 reforming and re-use
    - Advanced EOR using CO_2
    - Enhanced natural gas recovery (EGR)
    - Enhanced coal bed methane (ECBM) recovery

- Actively participate in integrating the efforts of the U.S. Department of Energy's Regional Carbon Sequestration Partnerships with the commercialization of CTL in the West by seeking to host CCS projects within the region and using CTL facilities as the source for CO_2.

- Undertake a full-scale demonstration of co-firing/co-processing coal with biomass using Western coals and biomass. This could provide the foundation for improving and optimizing technologies to help develop a mature industry, as well as provide a strategy for a net life-cycle reduction in CO_2 emissions from coal conversion.

- Encourage the establishment of a national laboratory in the West to conduct research on CO_2 storage. Such a facility would help establish the Western United States as a global leader in CO_2 research and create an array of economic benefits for the region.

- Encourage coupling CTL with Integrated Gas Combined Cycle (IGCC) power plants to allow for a more efficient use of both project's assets, lower capital costs for each project and result in reduced operating and maintenance costs for each entity.

- Target incentives for electric generators/utilities and encourage state regulatory agencies, such as public utility commissions, to explore options for rate recovery and reasonable rates of return for combined CTL and IGCC electricity generation projects.

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I. INTRODUCTION

At the request of the Western Governors Association and under the guidance of WGA policy resolution 06-20 Transportation Fuels for the Future, the Coal to Liquids (CTL) Working Group has prepared an analysis of the both the opportunities and the challenges associated with the development of a CTL industry. In doing so the Working Group has kept in mind three interrelated factors important to alternative transportation fuels: energy security, environmental impact and economic development.

Emerging alternative transportation fuels technologies such as CTL must meet the twin threats to our national security caused by unsustainable dependence on imported petroleum and global climate change. Utilizing domestic coal supplies for liquid transportation fuel production in order to supply a measurable percentage of our nation's transportation demand would lessen our dependence on non-domestic sources of energy, improve our balance of trade, and decrease the destabilizing influence that petroleum plays in our foreign policy, leading to an overall strengthening of our nation's energy security.

This report begins with a discussion of the potential for CTL to contribute to the U.S. mix of transportation fuels. This includes a discussion of the current status of our conventional transportation fuels sources; a description of the CTL technology; a summary of the current international and domestic CTL industry; a description of the coal (the primary CTL feedstock) resource; the potential markets for transportation fuels from CTL; and CTL transportation fuel characteristics.

The report then describes the potential ancillary opportunities from the development of a CTL industry such as the integration of CTL with an integrated gasification combined cycle (IGCC) power plant; the potential beneficial uses of the carbon dioxide (CO_2) generated in the coal gasification process that could be captured and used for enhanced oil recovery (EOR), enhanced natural gas recovery (EGR), or enhanced coal-bed methane recovery (ECBM); and the potential for co-processing (or co-gasification) of biomass with coal to reduce life-cycle CO_2 emissions.

The next section of the report identifies the barriers and challenges facing the development of a domestic CTL industry. In large part, these challenges involve mitigating the potential impact from the production of CO_2 - a greenhouse gas (GHG) that contributes to global climate change - which is a major byproduct of the coal conversion process and the combustion of the synfuel. The report also addresses the potential impact of the industry on the West's water resources. The CTL industry will also face significant financial challenges due to the high capital cost of CTL plants and, as a practical matter, may not fully mature without significant government financial support and a clear regulatory framework.

Finally, the report concludes with a set of recommendations that will move the CTL industry forward at a measured pace, taking into account both the urgency with which this country must act to replace imported petroleum as the mainstay of our transportation fuels balanced against the need to develop mitigation measures to protect our climate and environment.

II. THE POTENTIAL FOR CTL

The United States currently relies on conventional petroleum for approximately 95% of its transportation fuel. Much of that oil is imported from foreign nations whose relations with the United States are fragile at best and hostile at worst. Should our source of foreign oil be disrupted, we would have few alternatives to keep the wheels turning, the trains running and our planes flying.

In 2007 the U.S. will spend over $340 billion importing oil. This amounts to almost $1 billion a day. Domestic oil production peaked in 1971 and has declined in most years since.

There is also debate about the adequacy of international oil supplies. Some argue that if international oil production has not peaked, it will do so within 10 to 20 years. Regardless of these arguments, there is no question that international demand is growing as the 2.7 billion people in China and India move toward a modern energy intensive economy at ever increasing rates, putting further pressure on conventional oil supplies.

Coal-to-liquids (CTL) technologies, especially Fischer-Tropsch (F-T) liquids, offer the potential for reducing energy security risks associated with a dependence on imported oil by making liquid transportation fuels from abundant and relatively low-cost domestic coal. F-T diesel fuel is characterized as fuels made with the Fisher-Tropsch chemistry, which was discovered in 1923 by Hans Fisher and Franz Tropsch. The F-T Diesel fuel is a homogenous mixture of linear and branched paraffins with carbon chains from C_8 to C_{22}. These fuels have ultra-low sulfur and ultra-low aromatics, as well as high cetane. They are bio-degradable and have long shelf life due to inherent stability of the paraffins.

The West is home to over 59% of the country's recoverable coal reserves, making it a potentially plentiful substitute for petroleum-based transportation fuels. In addition to energy security benefits, the development of an industry that produces fuel domestically can provide obvious economic benefits to the Western States and the nation as a whole.

1. Coal-to-Liquids Production

Coal-based liquids are produced from a multi-step chemical process plant that converts coal to a synthesis gas composed mostly of carbon monoxide (CO) and hydrogen (H_2) that is subsequently converted into synthetic liquid fuels. This overall process that begins with coal gasification is called an indirect coal-to-liquids processing and is described below and shown in the diagram in Figure 1.[6]

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[6] Liquid fuels from coal can also be created via *direct* coal liquefaction. Direct liquefaction of coal may have a slight process efficiency advantage over indirect conversion, however, the liquids produced from direct liquefaction are a much poorer quality than those from the indirect process as the cyclic compounds and mixed hydrocarbons are still present in the fuel. With indirect coal liquefaction using F-T technology, the feedstock to make the fuels is a hydrogen and carbon monoxide-rich synthesis gas that has been purified removing nearly all sulfur, mercury and other contaminants. This pure stream of hydrogen and carbon monoxide allows the F-T catalyst to make the predominantly pure linear paraffins which are upgraded into F-T liquids such as diesel and jet fuel. Direct liquefaction is best suited for the production of lighter

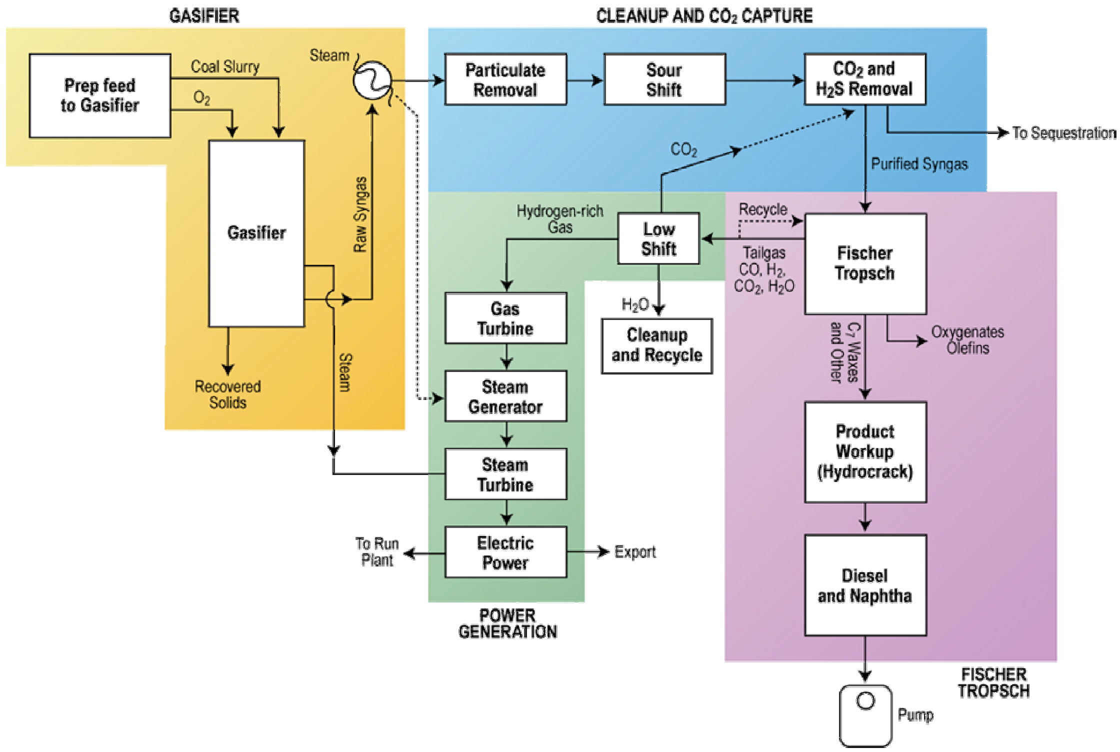

Figure 1 - Functional Block Diagram of a Typical CTL Plant

1) Pulverized coal (or other carbon-based feedstock) and oxygen are reacted in a gasifier, which produces synthesis gas (syngas), which consists mostly of carbon monoxide and hydrogen. Depending upon the type of catalyst used, the syngas is either sent directly to the gas clean-up stage and then on to the F-T catalytic reactor or it is reacted with water to produce additional CO_2 and hydrogen.

2) The syngas is then cleaned of contaminants such as sulfur, mercury and amine compounds, as well as CO_2, and the cleaned syngas is then sent to the F-T catalytic reactor that produces three streams of products: 1) crude waxes 2) F-T liquids and 3) light gases.

3) Product upgrading (hydrocracking) converts the heavier, intermediate products into the desired liquid fuels including naphtha, diesel, and jet fuel.

In step 1, the raw syngas stream from the gasifier will be treated to separate CO_2 from the syngas. CO_2 is removed along with other constituents in the syngas stream (such as hydrogen sulfide and mercury) which would otherwise contaminate the F-T catalyst.

In step 2, there are two distinctly different F-T processes that produce synthetic liquid fuel. These processes are characterized by either high or low temperature F-T

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hydrocarbons such as naphtha (via an upgrading step) and is not well-suited for the production of mid- to higher-distillates that are used to produce diesel fuel or jet fuel.

conversion technology. The low temperature F-T process produces a product spectrum that is heavier and contains predominantly linear paraffins. This process is ideal for production of middle distillate fuels such as synthetic diesel and synthetic jet fuel. The higher temperature F-T process will result in a product spectrum that is lighter (fewer C atoms) with a significant amount of olefins, and is best for chemicals production. Both high and low temperature F-T processes produce a product that is suitable for post-processing (further refining) to create F-T diesel fuel.

F-T diesel fuel is considered a 'premium fuel' with high cetane, ultra low sulfur, and ultra low aromatics. For the transportation market, typical F-T diesel contains non-detectable levels of sulfur, and aromatics with a cetane[7] index of 74+. The high cetane, ultra low sulfur and aromatic characteristics of the fuel have been shown to have a significant effect on reducing all regulated exhaust emissions, such as oxides of nitrogen (NOx), particulate matter (PM), hydrocarbons (HC), and CO emissions, from combustion of the fuel in diesel engines.

2. Status of the CTL Industry

International CTL Industry

The only commercial full-scale CTL plants in the world are the Sasol Ltd. Plants I, II and III in South Africa. Over the last 50+ years Sasol has produced about 1.5 billion barrels of synthetic fuel from about 800 million tons of sub-bituminous coal and continues to supply about 28% of South Africa's transportation fuel needs from coal. The Sasol plants use old technology -- low temperature Lurgi dry ash gasification. Plants II and III have the capacity to produce in excess of 150,000 barrels of oil-equivalent liquids per day using coal as the feedstock. Sasol Plant 1 has been operating as a natural gas-to-liquid (GTL) synthetic crude plant since 2004. The Sasol plants are not as efficient as modern plants in capturing CO_2, and none of the CO_2 that is captured in current Sasol plants is stored.

Sasol has been discussing with India's Investment Commission the construction of a CTL plant. Sasol's investment in India could be up to $6 billion for a typical 80,000 barrel per day (bbl/day) plant. China has been involved in the CTL industry since early 2004 and is planning to initiate in 2008 the first of a three-phase project in Shenhua (Inner Mongolia) to produce liquid fuels from coal via direct liquefaction. Shell Gas and Power and Shenhua Ningxia Coal Industry Co. Ltd. signed a three-year agreement to study the technical and commercial feasibility of a 70,000 bbl/day CTL plant using Shell's technology for indirect liquefaction.

Anglo Coal Australia, a subsidiary of Anglo American plc, acquired the entirety of the Australian Power and Energy Limited (APEL) in late 2004, and the company was renamed Monash Energy Holdings Limited (MEHL). The MEHL project includes co-production of power and hydrocarbon liquids via indirect liquefaction from brown coal in the Labtrobe Valley in the state of Victoria, Australia. The initial phase of development envisions a 60,000 bbl/day plant with CO_2 capture and sequestration (CCS) via subsurface injection.

[7] The cetane index is a measure of the combustion quality of diesel fuel.

Headwaters Technology Innovation Group of Salt Lake City, Utah, recently announced an agreement to provide technology licenses, basic engineering design and technical services for the construction of a CTL plant based on indirect liquefaction in the Philippines to produce 60,000 bbl/day liquids.

Domestic CTL Industry
Currently, the domestic coal-to-liquids processing industry is still in its infancy with the first plants still in the early to middle stages of the planning, designing and permitting processes. There are a number of CTL plants under consideration in the United States, and these are shown in the table in Appendix A. In this table, the project status of the plants is identified as either design (front-end engineering design [FEED] initiated), feasibility (siting, economic and/or engineering studies underway); concept (partnership and/or announcement of plant), or pilot (constructed for testing and production of small quantities of product only). If available, the coal feed, gasifier and F-T technology proposed to be used at these plants is identified along with the announced liquids and net energy (if any) production. The planned capture and disposition of the carbon is also identified, if known. The estimated capital cost of the plant is given along with the latest date (month/year) those costs were published. The last column in the table provides a reference for the data in the table.

Appendix A also provides a list of the current providers of CTL plant technology.

3. Future Use of F-T Fuel

F-T diesel fuel can replace conventional petroleum-based diesel in all diesel engine applications while F-T jet fuels can replace the conventional petroleum-based jet fuels, as long as the final F-T fuel produced conforms to specifications set by engine manufacturers and end-users.[8] Specifications include, but are not limited to, lubricity, flash point, density/viscosity, freezing point, heating value and cetane index. Combined, they define key fuel properties, such as fluidity, stability, corrosivity, conductivity and energy content. Sasol has produced F-T jet fuel for the Johannesburg airport in South Africa for five years. This fuel is also certified by the British Ministry of Defence,

Over the past 20 years there have been many tests by the government agencies, Southwest Research Institute, engine manufacturers and Society of Automobile Engineers to test F-T diesel for all aspects of performance. A Mileage accumulation/durability emission testing program has been undertaken by the National Renewable Energy Laboratory (NREL) to evaluate maintenance for several light-duty diesel trucks fueled by conventional diesel and F-T diesel. In general, the trucks fueled with F-T diesel performed equal to or better than the trucks fueled with California Air Resources Board-specification diesel fuel. Operators reported no noticeable difference in acceleration or power. Although the fuel economy for the F-T-fueled trucks was 8% lower than the diesel group, analysis showed this difference was not statistically significant.

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[8]After an exhaustive multi-year multi-phase testing program, the U.S. Air Force recently certified a 50:50 blend of F-T synthetic fuel and JP-8 for use on all B-52H aircraft. The next aircraft scheduled to be certified for F-T fuel is the C-17 Globemaster III. The goal of the Air Force is to qualify F-T fuel for all military aircraft.

The low aromatic content of neat F-T fuel may cause problems for certain elastomers found in legacy vehicles, but not for newer vehicles. Replacement parts exist today that are compatible with F-T fuels. As with engine performance, there is a lack of data confirming the impact on seals and long-term tests are needed. In addition, the high paraffin content of unprocessed, 100% (neat) F-T diesel can result in unacceptable cold flow properties and oxidative stability lubricity. However, conventional upgrade technologies with isomerization can overcome the cold flow issues and can be tailored to meet specifications, such as the U.S. Department of Defense (DOD) jet (JP-8) fuel, which requires a freezing point below 47°C.

There are a number of lubricity packages that can be added to overcome the lubricity issue due to the lack of sulfur in F-T fuels. These include antioxidants, dispersants or detergents, foam inhibitors, and corrosion inhibitors. Biodiesel fuel at very low concentrations can also function as a lubricity additive for F-T diesel.

4. The Market for F-T Fuels

F-T diesel fuel is a blending component or direct substitute for petroleum diesel fuel and can help solve significant air quality problems. F-T diesel fuel derived from coal is an "Alternative Fuel" as defined under EPACT 2005, and it significantly reduces regulated emissions allowing commercial and government fleets to meet their implementation plans.

Petroleum refineries seek F-T diesel as a blend stock for their off specification diesel fuels that are high in sulfur or low in cetane. When blended with F-T diesel, conventional distillate streams that do not meet the ASTM D975 or California Air Resources Board (CARB) standards can be moved to market. In California, F-T fuels have been used as a blending stock by several refineries to meet the low aromatic CARB diesel standards.

The F-T diesel produced by the CTL process exceeds all new U.S. Environmental Protection Agency (EPA) and most European Union (EU) standards. F-T diesel is attractive to the transportation fuel industry as it can provide long-term, stable competitive pricing compared with the variations in petroleum diesel indexed to a volatile world oil price.

Although the demand for transportation fuels has been increasing in the U.S., oxygenated (ethanol) gasoline will continue to be the primary fuel for passenger cars beyond 2015. Nevertheless, demand for diesel and jet fuel will continue to grow, due to the continued expansion of the U.S. trucking fleet and rebuilding of the airline industry. Moreover, there appears to be a renewed interest in diesel technology for passenger cars.

As noted above, the DOD is also a potential end user for CTL fuels. The DOD currently uses as many as nine different petroleum-derived fuels for all its gas turbine and diesel engine applications. The Air Force represents approximately 10% of the total jet fuel market in the U.S. The Air Force realizes the significant advantages over conventional petroleum-derived fuels to provide greater sovereign options. F-T fuels can be manufactured to specifications that meet special needs or offer characteristics that are not available from petroleum-based fuels. The Navy has also shown recent interest in alternative transportation fuels for ships and aircraft from the standpoint of energy security. The Army is currently testing synthetic fuel in tactical vehicles and generators. In addition, NASA has acquired synthetic fuel to test engine emissions.

The Secretary of the Air Force has stated that their 2016 goal will be to acquire 50% of its fuel for use in the states from domestic sources by producing a synthetic fuel blend and using technology to capture and reuse the CO_2[9]. This equates in today's figures to 400 million (M) gallons/year of synthetic fuel or 800M gallons/year of synthetic fuel blend at the 50:50 level. In addition, American railroads purchase over four billion gallons of diesel fuel per year. Thus, the entire U.S. transportation sector would benefit from the production of domestic F-T fuels.

The marine diesel market is a significant market representing over two billion gallons per year. With new lower emission standards for river and port boats, F-T diesel can assist in meeting the standards and providing long-term stable pricing and fuel supplies.

An additional market that can be significant is refined product storage for first responders to emergency and disaster situations. The long-term stability of the fuel (DOD has estimated a minimum shelf life of 8 years) allows for storage at strategic sites for first responders. The fuel availability issues during the 9-11 terrorist attacks, and the Katrina and Rita hurricanes, has alerted many to the need for refined product storage in strategic locations and for emergency back-up power. The ultra pure nature of the fuels allows for operating within emission limits for long periods of time, and the long shelf life allows for prolonged storage compared to the three or four months currently for diesel fuel and biodiesel fuel blends. The bio-degradability of F-T diesel and jet fuel is also a significant safety factor in cases of hurricane damage and spills of fuels into waterways or wetland areas.

With a total diesel and kerosene aviation fuel market in the United States of over 1.6 billion barrels, as stated by the U.S. DOE Energy Information Agency (EIA) for 2005, , the market is potentially very large for F-T diesel and jet fuel. It will be a very long time before the F-T supply can meet the growing demand. However, as oil gets more precious and the need to import oil increases, F-T offers one of the many alternative energy sources that the U.S. will need.

5. The Coal Resource for CTL Plants

The most recent estimate of recoverable reserves by the EIA is 275 billion tons[10]. This represents over a 250 year supply at the current consumption rate[11]. Subtracting from the total 100 years of production for current uses would leave sufficient additional coal to support a mature 5 Mbbl/d CTL industry for several generations.

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[9]The official Air Force position is to capture and reuse 100% of the captured CO_2 rather than store (sequester) the CO_2.

[10] EIA, *US Coal Reserves: 1997 Update*, February 1999.

[11] Consumption of coal in the U.S. in 2006 was 1.1 billion short tons with 1.0 billion short tons (92%) consumed by the electric power industry. See http://www.eia.doe.gov/cneaf/coal/quarterly/html/t25p01p1.html

There is, however, some uncertainty over national (as well as regional) estimates. A recent National Research Council (NRC) report[12] cautions that coal reserves data have not been updated since the early 1970s, when DOE estimated that recoverable coal reserves are likely to be 16% of identified coal resources. This is the basis for the estimate above. However, the U.S. Geological Survey recently reexamined a sample of coal fields and found that the recoverable-to-identified ratio varied from 5% to 25%. This consideration highlights the importance of getting an improved understanding of the coal supply outlook by taking into account modern coal mining technology, which can impact the recovery ratio.

[12]National Research Council, *Coal R&D for National Energy Policy*, National Academy of Sciences Press, Washington DC, 2007.

III. ANCILLARY OPPORTUNITIES FROM A CTL INDUSTRY

Production of F-T diesel fuels with coal as the feedstock lends itself to several ancillary opportunities such as co-generation of electricity with a coal-fired IGCC power plant; use of captured CO_2 for enhanced fossil fuel recovery; and co-firing/co-processing coal with biomass as a strategy to reduce life-cycle CO_2 emissions.

1. Integration of CTL with IGCC Facilities

Co-locating a CTL facility with an IGCC power plant can allow for a more efficient use of both project's assets, lower capital costs for each project, reduce maintenance costs, increase plant availability, and provide the flexibility for plant owners/operators to manage their fuel costs and optimize their trading and hedging activities related to the various energy and fuels markets.

Co-locating IGCC and CTL projects allows for the sharing of the costs of common, non-specific infrastructure items, such as air separation units, coal preparation and handling equipment and water and waste-water treatment systems. This can potentially improve the economics for both projects, and in the case of regulated utilities, provide significant cost savings to their ratepayers. Block flow diagrams describing two potential configurations for a CTL-IGCC combined facility can be found in the appendix.

The current generation of coal gasifiers used in IGCC plants are not designed to be ramped up and down, which makes it difficult for an IGCC plant operator to align the plant's output with load-cycling requirements. However, the proper integration of a CTL plant with an IGCC power plant would allow the power generator to cycle generation down while maintaining steady gasifier operation by sending excess syngas to the CTL plant for F-T fuels production. In addition, the power producer, could fully utilize its spare gasifier to produce F-T liquids (or other products) when not needed for power generation. This would increase the IGCC plant's availability to approximately 90% and justify the cost of a spare gasifier. Additionally, this configuration would allow the IGCC plant's operator the ability to switch power production between syngas or natural gas based on price signals.

2. CO_2 Capture, Storage, and Potential End Uses

The WGA region has much to gain from improved technology relating to CO_2 capture, CO_2 storage, and use of captured CO_2 for enhanced oil recovery (EOR), enhanced natural gas recovery (EGR) and enhanced coal-bed methane (ECBM) recovery. Carbon capture and storage (CCS) research is currently supported primarily at the federal level through scientists working under the U.S. Department of Energy's Regional Carbon Sequestration Partnership Program[13]. These seven regional public–private partnerships have been tasked with determining the technologies, regulations, and infrastructure that would need to be put in place for a large scale deployment of CCS.

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[13] For more information, please see www.fossil.energy.gov/sequestration/partnerships/index.html

Not as well supported at the federal level are the research, development, and demonstration of advanced technologies relating to prospective uses of CO_2. Among opportunities for CO_2 usage are options for EOR, EGR and ECBMR.

CO_2 EOR technologies

Currently, 74 CO_2 EOR projects in the U.S. produce about 200,000 bbl/d of crude petroleum. Advances in CO_2 EOR technology can expand the CO_2 EOR potential and thereby extend the CO_2 EOR market opportunity for CTL plants that can offer CO_2 at relatively low cost. This enhanced market opportunity translates into an enhanced energy security benefit because with state-of-the-art CO_2 EOR technology two or more additional barrels of crude oil can be recovered using the CO_2 byproduct of producing each barrel of liquid fuel via CTL technology. The estimated economic potential of using CO_2 for EOR using state-of-the-art technology in the WGA region is given in Table 1.

Table 1 - Assessment of Economic CO2 EOR Potential for WGA Region (2006)

Basin/Area	Number of Large Reservoirs		Billions of Barrels of Oil		
	Assessed	Economic for EOR	Contained Oil		CO_2-EOR Economic Potential
			OOIP*	ROIP**	
Alaska	34	8	67.3	45.0	7.28
California	172		88.3	57.3	3.50
Permian Basin (*W. TX, NM*)	207	76	95.4	61.7	9.43
Central and East Texas (*onshore*)	199	104	53.2	34.1	7.88
Oklahoma	96		60.3	45.1	4.56
Rockies (*WY, CO, UT*)	162	54	18.1	12.2	2.08
Williston (*MT, ND, SD*)	93	16	7.3	5.1	0.40
Total	**963**		**390**	**261**	**35.1**

*Original Oil in Place **Recoverable Oil in Place

To provide a perspective on the potential of EOR, current U.S. proved crude oil reserves are 22 billion barrels (2005), and cumulative U.S. oil production is 172 billion barrels of the 582 billion barrels of original oil in place (OOIP). Conventional CO_2 EOR technology provides an additional 16 billion barrels,[14] but with state-of-the-art technology, the economic and technical potentials are estimated to be 47 billion barrels and 89 billion

[14] Dana Van Wagener (EIA), *Carbon Dioxide Enhanced Oil Recovery Modeling Workshop*, Washington, DC, 15 March 2007.

barrels, respectively.[15] Moreover, next generation CO_2 EOR technology could add another 40 billion barrels to U.S. oil reserves.[16]

Only four of the 74 current EOR projects use anthropogenic (human activity-created) CO_2, the remainder use CO_2 from naturally occurring CO_2 sources. Since 2001, the Dakota Gasification Company syngas plant in Beulah, North Dakota has been annually providing approximately 1 million tonnes of CO_2 for EOR at the Weyburn oil field in Saskatchewan, Canada[17] 205 miles away.

CO_2 Enhanced Natural Gas Recovery

CO_2 could potentially be injected into depleted natural gas reservoirs to enhance gas recovery through reservoir re-pressurization. However, the overall potential is likely to be much less than for CO_2 EOR, because up to 95% of original natural gas in place can be produced with conventional recovery techniques (in contrast to the oil, where only 25 to 35% of the OOIP can be recovered by conventional means). Moreover, some experts suggest that CO_2 injection might actually result in lower natural gas recovery, particularly at very heterogeneous fields. Enhanced natural gas recovery has only been implemented at a pilot scale. Given the importance of natural gas to the West, a comprehensive research, development and demonstration program aimed at understanding better how CO_2 injection could potentially enhance natural gas recovery is warranted, despite the prospective limitations of this opportunity.

CO_2 Enhanced Coal Bed Methane Recovery

Coal can physically adsorb many gases, and often contains large quantities of methane trapped in the pore spaces. Because coal has a greater affinity for CO_2 than for methane, the injection of CO_2 into un-mineable coal seams can displace methane, thereby enhancing coal bed methane recovery. CO_2-ECBM technology has the potential to increase the amount of methane produced to nearly 90% of the gas, compared to the recovery of 50% by conventional means. CO_2 has been injected successfully at the Allison Project in New Mexico. Further CO_2-ECBM projects are under consideration for China, Canada, Italy and Poland. In all, some 59 opportunities for CO_2-ECBM have been identified worldwide, with the majority existing in China.

The Allison Project showed evidence of significant coal-permeability reduction with CO_2 injection. This permeability reduction resulted in a two-fold reduction in injectivity, which compromised incremental methane recovery and project economics. Given the importance of coal bed methane to the West, finding ways to overcome and/or prevent this effect and realizing the full potential of CO_2-ECBM is an important topic for future research.

3. CTL and Biomass Co-Processing

[15] ARI (Advanced Resources International), Assessments for USDOE of Technical and Economic Potentials for CO_2–EOR in 10 US Basins/Regions, March 2006, available at www.fossil.energy.gov.

[16] Advanced Resources International, Evaluating the Potential for "Game Changer" Improvements in Oil Recovery Efficiency from CO_2 Enhanced Oil Recovery, report prepared for the Office of Oil and Natural Gas of the Office of Fossil Energy, US Department of Energy, and February 2006.

[17] Dakota Gasification Company. See http://www.dakotagas.com/Products/index.html

Recently there has been considerable interest in addressing the climate challenge for liquid fuels by co-processing biomass and coal in coal/biomass to liquids (CBTL) plants with CCS. This would allow simultaneous exploitation of: 1) the scale economies of coal energy conversion systems; 2) the relatively low cost of coal as the primary feedstock; and 3) the potential negative CO_2 emissions from photosynthetic CO_2 storage.
Studies carried out at Princeton University[18] investigating such systems indicate that the GHG emissions rate for F-T fuels production could be reduced substantially—even to zero—with co-processing of biomass. The studies also indicate good prospects that the fuels so produced would be less costly than fuels produced at CTL plants with CCS when CO_2 emissions are valued at $25 to $30 a tonne—the minimum price needed to make CCS cost-competitive for coal power plants.

A co-gasification approach (feeding both coal and biomass into the gasifier) is feasible, but it may not be the least costly approach over the long run because it requires costly processing of biomass to make very fine (1 mm) particles for co-feeding. An alternative would be to use a separate gasifier for biomass that would require much less biomass processing. Sufficiently large biomass gasifiers are not yet available, they but could be commercial by approximately 2015 with sufficient market drivers. An additional challenge to the use of biomass (co-feed or co-process) is the availability and delivered cost of sufficient quantities of biomass to make biomass co-feed economic.

Currently, Baard Energy is planning to build a CBTL plant in Ohio that will be capable of producing 50,000 bbl/day (processing up to 30% biomass by weight) and capturing and sequestering CO_2. Rentech has also indicated that it intends to include a biomass component at its plants under development in East Dubuque, Ill, and Natchez, Miss. In addition, Rentech will open a product development unit in Commerce City, Colo., that will be able to test various feedstock mixes, including biomass, to produce approximately 10 bbl/day of synthetic fuel. Early experience gained from these projects will help to facilitate the development of coal/biomass technology.

Additional information on coal/biomass co-processing is presented in Appendix B.

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[18] Larson, E.D., H. Jin, G. Liu, and R.H. Williams, "Zero-Carbon FT Liquids via Gasification of Coal and Biomass with CCS," *Sixth Annual Carbon Capture and Sequestration Conference*, Pittsburgh, PA, 7-10 May 2007.
Williams, R.H., E.D. Larson, and H. Jin, "Synthetic Fuels in a World with High Oil and Carbon Prices," *Proceedings of the 8th International Conference on Greenhouse Gas Control Technologies*, Trondheim, Norway, 19-22 June 2006.
Williams, R.H., S. Consonni, G. Fiorese, and E.D. Larson, "Synthetic Gasoline and Diesel from Coal and Mixed Prairie Grasses for a Carbon-Constrained World," *Sixth Annual Carbon Capture and Sequestration Conference*, Pittsburgh, PA, 7-10 May 2007.

IV. BARRIERS AND CHALLENGES

The following section outlines some of the barriers and challenges that the CTL industry faces in deployment. The barriers and challenges fall under four categories, which have a certain degree of intersection and overlap: 1) economic/financial challenges; 2) institutional and regulatory challenges; 3) environmental health and safety challenges; and 4) technical challenges. While these barriers and challenges represent a need for action, they also represent an opportunity to develop recommendations for overcoming these barriers and accelerating the development of a CTL industry.

1. Economic and Financial Challenges

Economic challenges emanate directly from the lack of experience in industry in full-scale CTL plant construction and operation and the sheer size of the investment required for a full-scale CTL plant. The strain on technical resources just described is also reflected in commodity and labor markets. The price of materials, such as steel and copper, have risen tremendously over the past several years as Asian countries are now importing resources instead of exporting them to the U.S. and other countries.

This is an example of one of the primary financial challenges and barriers to entry into the CTL sector, which is primarily associated with high and volatile development and capital costs, as well as tangible and intangible risks perceived by potential lenders. Even the pre-financing project development phase of a CTL plant presents additional financial risk for developers, which can cost $33 to $75 million, depending upon the plant's design and product output characteristics.

Many states offer financial incentives (such as loan guarantees, bonding authority, tax relief, etc.) for the development of alternative and clean energy resources, including CTL plants. A listing of these state incentives is given in Appendix C. Even with such incentives, the cost and associated risks for development of a full-scale plant is significant and remains a barrier. To give a perspective of this cost structure, table 2 provides a summary of the various development phases, tasks and costs.

Table 2 - CTL Plant Development Phases and Estimated Costs

Phase	Tasks	Estimated Timeline	Estimated Costs
Business Development	• Project concept • Proposed site identification and attribute evaluation • Evaluation of feedstock supply and product off-take/distribution opportunities • Evaluation of requisite transportation, electrical and other infrastructure items	3-6 months	<$100,000
Scoping	• Identify critical development tasks/milestones o Land use/entitlements o site access o gas and water pipeline, transmission line corridors and easement considerations o environmental and other required permits • Fatal Flaw Analysis o Local, state governmental/regulatory support or opposition o neighbor and other stakeholder support or opposition o CO_2 storage potential o More detailed feedstock and product market evaluation	4-6 months	$300,000-500,000
Feasibility	• Initial detailed evaluation from a technical perspective o Gasification technology selection o Basis of design determination o Process flow diagrams o Mass balances o Major equipment process data sheets o Balance of plant equipment o Plant performance and emissions profiles o Instrumentation and control system requirements o Plant layout o O&M estimates o Project schedules o High level EPC estimate o Site control finalized o Commence work on environmental permit applications.	9-14 months	$2–4 million

Phase	Tasks	Estimated Timeline	Estimated Costs
Pre-Financing / FEED	• The objective of this phase is to address all design and commercial aspects of the project in detail in order to satisfy corporate management and the project's lenders as to the project's commercial and financial viability. o Front End Engineering and Design (FEED) - a detailed engineering design effort o Environmental permit applications submitted and obtained o Financing plan finalized for both equity and debt financing o Site acquisition completed o Contracts for feedstock and products completed o All other detailed commercial and technical components addressed to assure project level financing.	12-18 months	$30-70 million

In addition to high up-front costs, the ability to attract the limited number of companies and potential equity partners and investors that are willing and able to bear the financial, technological and intangible risk profile required to develop projects is critical. The risk perceived by the financial sector is primarily attributed to:

- potential lender's concerns about the technology itself, which has not been demonstrated in the U.S.;
- EPC contractors reluctance to offer guarantees and associated liquidated damages given the current world-wide development environment;
- forward market pricing of fuels; and
- uncertainty surrounding current environmental regulations, such as a limit on greenhouse gas emissions.

Throughout the course of the development process, potential investors, partners and others in the corporate community monitor potential project risks — typically financial impacts — that are outside the control of the developer, but have the potential to raise the project's risk profile to unacceptable levels. Examples of such risks include oil and other commodity price fluctuations as well as uncertainties in government policies and regulations.

Specifically, many financiers perceive risk surrounding the general uncertainty of the regulation of CO_2. The long planning timeframes combined with the high financial risk nature of the development process reduces the number of entities willing and able to take such risks to a few companies that see the vision and opportunity.

2. Institutional and Regulatory Challenges

Institutional and regulatory challenges stem primarily from the inexperience in siting and permitting a full-scale CTL facility. Challenges also revolve around the uncertainty in the regulatory framework and policies yet to be established to regulate CO_2 emissions and site and monitor CO_2 storage locations.

CTL Plant Siting

Coal conversion plants (CTL plants) are neither a traditional chemical plant (e.g., a refinery), nor are they a traditional coal-fired power plant, and thus do not fit criteria for either type of project. However, it is possible that the coal conversion process may be treated as *both* a chemical plant and a power plant, and this could possibly significantly complicate the permitting process by requiring the gasifier/power block to obtain one permit and the co-production unit operations (e.g., the F-T process) to obtain a separate and distinct operating permit.

CTL Infrastructure

In a mature CTL or CBTL industry, a robust coal, biofuel and products transportation infrastructure is necessary to deliver feed to the CTL plant and transport liquid fuel, CO_2 and other products away from the plant to markets or to disposal sites.

The siting of a CTL plant will have a significant impact on the infrastructure requirements. Even a “mine-mouth” plant may require some form of limited-distance coal transportation and will certainly require a non-trivial transportation infrastructure for fuels, CO_2, waste products, and to accommodate construction. Additionally, if a mine-mouth CTL plant is co-fed with biomass, rail transportation will likely be necessary to deliver the quantities of biomass required for co-feed. The delivery of water, whether via well- or surface-water, via a pipeline system to the CTL plant, must also be considered. Thus, comprehensive infrastructure planning and development will play an important, if not critical, part in the development of a CTL industry.

For the purpose of illustration, a generic list of infrastructure requirements for a 20,000 barrels/day diesel plant (which could eventually be expanded at the same site to approximately 65,000 bbl/day) is as follows:

- Approximately 500 acres (0.78 square miles) of land. This allows for the CTL plant, plant support structures and on-site storage of byproducts (liquids, gases and solids) and waste products.
- An additional 100 acres (0.15 square miles) of land for a rail line, coal transfer, and 6 days of slot coal storage, if coal is transported to the site via rail. The site capable of receiving a 19,000 tons/day coal for a 20,000 bbl/day synthetic diesel fuel plant[19].
- Access to electrical transmission lines or transmission corridors, and a corresponding electric substation that can supply 50 to 75MW for plant startup as well as receive any excess power generated by the plant.
- Access to a commercial natural gas pipeline or construction of on-site natural gas or propane storage for plant startup.

[19]Assuming Powder River Basin Coal @9400 Btu/lb with ~30% moisture content.

- A potable water source. A discharge water treatment facility is included in the plant footprint requirements.
- A plant design for the West that employs dry cooling technologies so that water is required predominantly for meeting process needs.
- A process water source that can supply 500 to 2,000 gallons/minute. A process water treatment facility is included in the plant footprint.
- Transportation of plant byproducts to disposal sites or sites where the byproducts will be used. This includes liquids, solids and gases (CO_2).
- A surface (roads) transportation infrastructure (regional and local) that will allow transport of heavy and/or oversized equipment, such as a gasifier, air separation unit and steam generator.

The most critical of these infrastructure requirements discussed below are coal transport; liquid products transport; electrical transmission; water supply; and byproducts transport, including transport and storage of $CO_{2.}$

Coal Transport

A CTL plant that is sited somewhere other than a coal mine-mouth location will require transport of coal via rail. As previously mentioned, even a mine-mouth plant may require limited rail transport to accommodate the coal demand of a commercial-sized CTL plant. A 20,000 barrels/day synthetic diesel fuel CTL plant will require 19,000 tons/day of coal (5.9 million tons/year[20]); this is equivalent to an average of 1.3 unit coal trains per day.[21] The railroads may readily be able to accommodate these additional unit trains within their existing system given that, in Wyoming alone, approximately 80 unit trains per day leave the Powder River Basin coal mines to supply power plants across the United States.[22]

An expanded plant producing 65,000 bbl/day synthetic diesel fuel at a single site will require approximately 62,000 tons/day (19.2 million tons/year[23]) coal, or approximately 4.5 to 5 unit trains per day[24]. A fully mature CTL industry in the West producing 2,000,000 barrels/day of synthetic diesel fuel would require 150 unit trains/day hauling over 600 million tons/year of Western coal.[25] Such an increase would require a significant investment over time by the railroad industry in the West in both equipment and track. This increase in demand for Western Coal to support a CTL industry would be in addition to the anticipated increased demand for Western coal by the power generation industry over the next 10 years.

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[20]This assumes an 85% plant availability (plant capacity factor).

[21] Today's unit coal train is approximately 125 cars each hauling approximately 120 tons of coal and stretching approximately 1 mile long. A unit train will haul approximately 15,000 tons of coal.

[22] http://agecon.uwyo.edu/Econdev/PubStorage/Concise%20Guide%202006.pdf

[23]This assumes an 85% plant availability (plant capacity factor).

[24] A 100 car unit train carrying 15,000 tons of coal can unload the coal at a plant in ~1.5-2 hours with modern coal cars and unloading equipment. Thus, a 5 unit train/day delivery would require up to 10 hours/day of coal delivery/day or approximately 1 unit train arriving at the plant every 2 hours during a 24 hour day 365 days/year.

[25] Under this scenario, the West would be the location for 40% of the 5 million barrel/day production output nationwide assumed for a mature CTL industry.

Biomass Transport
In a configuration where biomass is co-fed with coal to produce liquid transportation fuels (see Section 4), the biomass must be transported to the CTL plant. Biomass is a relatively low-energy density co-feed, which will require a large infrastructure and large area for bio-mass collection. This would hold true even if the CTL plant were sited near a biomass source. Given the geography of the West, a CTL plant sited near a coal mine is likely to be some distance from an ample supply of biomass. Truck transport of sufficient biomass[26] may not be cost-effective in the West given the number of trucks required and the probability that the CTL plant will be sited on a secondary road (particularly if the CTL plant is sited near a mine mouth).

Previous experience by the railroads with electric utility generating stations shows it may be difficult for rail carriers to agree to backhaul biomass material in coal cars. However, a mutually-agreeable and economically beneficial strategy for rail hauling of coal and biomass could be explored depending upon the location of CBTL plants and amount of biomass feedstock required. An additional challenge is the low energy-density for biomass compared to coal.

Liquid Products Transport
The liquid products from a CTL plant for F-T fuels will include F-T diesel and F-T naphtha. The greatest volume of product to be transported to market will be F-T diesel followed by F-T naphtha. The most common and cost-effective means of transporting the fuels will be via pipeline from the plant to a refiner/blender or possibly end-user.

F-T diesel and naphtha can be transported like any other diesel or naphtha product via truck, rail, pipeline or barge. However, existing petroleum product pipelines (both crude and refined products) are near capacity and finding space on an existing pipeline may be difficult, particularly with the expected increase in high sulfur Canadian bitumen being transported to U.S. refineries in existing and future dedicated pipelines.

Electrical Distribution and Transmission
Electrical distribution and transmission lines are required to provide electricity for plant startup as well as for transporting electricity generated from the CTL plant. As with any chemical plant or petroleum refinery, a CTL plant will require a 50-75MW backfeed for a 'black' startup of the process equipment, primarily the air separation unit. As for any electricity generation station (power plant), the power must be conveyed over adequate-capacity transmission lines to deliver the electricity to the grid. Depending upon the size and configuration of the CTL plant, and the CTL developer's ability to enter into an electric off-take agreement with a utility or other electric load, several hundred net MW of electricity could be placed on the electric grid for sale. To accomplish this, a substation may need to be constructed and transmission lines would likely need to be run from the CTL plant to a nearby transmission system capable of accepting the excess load from the CTL plant.

Plant Byproducts Transport
A CTL plant will create products, other than liquid transportation fuels, that must be transported from the plant site and disposed of or used to produce other marketable products. This includes slag from the gasifier, spent catalyst from the F-T reactor,

[26] ~6,000 tons/day for a 15% co-feed of biomass on a Btu basis.

mercury- and other trace metal-containing activated carbon, and elemental sulfur (or alternatively sulfuric acid if that is the end sulfur-containing product). The mercury-containing activated carbon will need to be transported via certified hauler via truck and disposed of in an approved hazardous waste disposal site. The sulfur (or sulfuric acid) and slag could be sold as feedstock to produce secondary products and would be hauled via truck or rail depending upon the quantities produced. The spent catalyst is not considered hazardous waste, but will need to be trucked offsite and disposed of in a landfill.

Carbon Dioxide Management and Regulation

The large quantity of CO_2 produced from gasification of coal for this industry poses a very significant challenge to the potential development of the industry without consideration for siting and CO_2 solutions by the plant developers. Total production-related emissions from a two million barrel per day CTL industry could be on the order of a half gigaton of CO_2 per year.

Because CO_2 injection is already a commercial practice in the U.S. to help increase oil production via EOR, there is a significant knowledgebase regarding how to handle CO_2 and inject it into deep geologic structures. In fact, much of the understanding of the infrastructure requirements for CCS already exist, including CO_2 capture, transportation via pipeline and deep underground injection.

The transport of large volumes of CO_2 via pipeline is already a well established practice within segments of the oil and gas industry. At present there are over 2,500 kilometers of dedicated CO_2 pipelines[27] within North America delivering CO_2 to commercial CO_2-driven EOR projects in areas such as the Permian Basin of West Texas and southeastern New Mexico; the Rocky Mountain Region of Utah, Wyoming, and Colorado; Louisiana; and the Weyburn Field in Saskatchewan (see Figure 2). With the exception of the CO2 from the Dakota Gasification Plant, all CO2 is naturally occurring.

[27] Table 4.1, p. 183 in IPCC Special Report on CCS

Figure 2 - Carbon Dioxide Sources and Pipelines in the United States.

3. Environmental Challenges

There are several environmental challenges to the development of a mature CTL industry given the potential for emissions of GHG as well as the requirement for process water in an arid West.

Overall Environmental Impacts

Perhaps the single largest set of challenges the CTL Industry faces are related to environmental concerns. For the CTL sector to provide a meaningful incremental solution in terms of reducing dependence on imported oil, the industry will need to produce millions of barrels of product per day. To be successful to that magnitude, the industry must be proactive in addressing the variety of environmental concerns head-on, and work with the environmental community to address and substantially mitigate environmental impacts to acceptable levels.

The production of F-T fuels from coal raises three principal environmental concerns:

- In light of the central role climate change is coming to play in public policy planning, those new transportation fuels are likely to be favored with promotional policies that offer substantial climate-change mitigation benefits relative to today's petroleum-based fuels—a consideration that must be central to the planning of an evolutionary strategy for synfuels derived from coal.

- Sufficient water resources to support the development of a CTL facility will be critical, particularly in the West where water is typically a constrained resource.

- Since Western coal reserves will be principally relied upon to support the development of a coal-to-liquids industry in the West, the issues related to a likely increase in coal production will also need to be addressed.

Greenhouse Gas Emissions

While CTL projects are relatively clean with regard to regulated (criteria) emissions, uncertainty arises with respect to currently unregulated CO_2 emissions. The CO_2 issue will undoubtedly be a very important component of CTL development. The large quantity of CO_2 produced in the gasification/water-gas shift processes (see the 'Cleanup and CO_2 capture block in Figure 1) makes this issue particularly important for the CTL industry.

To assess the global warming implications of coal-to-liquids, the total life-cycle (or "mine-to-wheels") emissions of these new fuels must be examined. Currently available models for calculating life-cycle emissions from CTL plants provide relatively crude estimates of some components of emissions and have yet to be validated. Therefore, it is important to improve and validate these models and undertake and plant-specific, life-cycle studies *for all alternative fuels* to more adequately compare impacts relative to petroleum.

When coal is converted to F-T fuels, the end result is that two streams of CO_2 are produced: one as a result of the production process at the coal-to-liquids plant and the second as a result of burning that fuel for transportation purposes. When added together these streams constitute the main greenhouse gas life-cycle emissions of coal-to-liquids.[28]

There have been several carbon life-cycle analyses undertaken for CTL. These studies have produced slightly different numbers but can be generalized as follows: [29]

- Absent the capture and storage of carbon dioxide from the plant, use of liquid fuel derived from coal will roughly double the CO_2 emissions compared to conventional petroleum on a life-cycle basis[30].

- With capture and storage of most of the carbon dioxide from the plant, greenhouse gas emissions will be comparable to emissions from conventional petroleum on a life-cycle basis

As previously discussed, a potential strategy that can be employed to significantly reduce the life-cycle greenhouse gas emissions associated with CTL plants is to co-fire/co-process biomass with the coal. By capturing and storing the carbon dioxide generated -- in part, as a result of the biomass, in the production process -- net life-cycle greenhouse gas emissions of the liquid fuel are much improved over a liquid transportation fuel derived solely from coal. ,,.

Coal Mining, Health, Safety and Environmental Issues

Using coal to produce a liquid fuel will require additional coal to be mined.[31] The development of a Western-based CTL industry will require coal from Western coal mines. Given the need for additional Western coal to supply Western CTL plants, it is appropriate to consider what additional coal mining would mean for rural Western communities, and what would be the consequences to the West's land and water and environmental attributes.

A given unit of CTL product will require a significant amount of coal. As noted above, a 20,000 bbl/day diesel fuel plant will require approximately 5.9 million tons of coal per

[28] A true life-cycle analysis would also include greenhouse gas emissions from mining the coal and transporting the liquid product. However, these contributors to total life-cycle emissions are small compared to the emissions resulting from production of the product and end use combustion.

[29]An EPA analysis concluded that the mine-to-wheels greenhouse emissions of CTL, if there were no carbon controls at the plant, was 119%, more than the equivalent well-to-wheels greenhouse gas emissions of conventional petroleum, dropping to 4% more than conventional petroleum with carbon controls at the plant. A recent Carnegie-Mellon study (www.lacenter.org/lnLCA2007/presentations/79.pdf)using the Argonne National Laboratory GREET model for both diesel fuel and gasoline, found that for diesel, CO_2 emissions for coal-to-liquids were 125% more and 20% less than conventional diesel fuel, depending on the existence of plant carbon controls, and for gasoline, CO_2 emissions were 66% more and 11% less than conventional gasoline, again depending on control of carbon at the plant. Other analyses have produced similar findings. For example, a Princeton study estimates that without carbon controls at the plant, CTL would produce CO_2/gallons, 1.89 times as much GHG missions as the crude oil products displaced and that with CCS the emission rate would be reduced to 1.01 times the rate for crude oil derived products displaced. However, the mixed results of the studies clearly demonstrate uncertainty, the need for improved models, and 'real-world' operational data.

[30]Commercial technology exists and will be deployed to significantly reduce GHG emissions from CTL plants. Specifically, carbon capture technology will control CO_2 emissions from both coal gasification and from the water-gas shift streams.

[31] This statement assumes that coal use for electricity production does not diminish in the foreseeable future.

year, and a fully mature CTL industry producing 2 million bbl/day[32] will require 500 million tons of coal per year.[33]

To put these numbers in context, current coal production in the West is nearly 640 million tons.[34] The State of Wyoming alone produces a little over 440 million tons of coal per year, more than one-third of total U.S. production, and about nine times more than the second largest Western state coal producer, which is Texas at 45 million tons.[35]

Most Western coal comes from surface mining. In 2006, 586 million tons of coal, or 92% of the total coal mined in the West, was from surface mining.[36] Western coal tends to be found relatively close to the surface in areas that are arid and predominantly unforested. To access the coal, draglines and other heavy equipment must remove the "overburden" and any vegetation.

Seeking to ensure the availability of coal to meet our nation's energy needs, yet concerned about the environmental effects from surface coal mining, Congress enacted the Surface Mining Control and Reclamation Act (SMCRA)[37]. SMCRA establishes strict standards for operators and regulators. Foremost among these, as the title of the Act indicates, is reclamation standards. Reclamation mitigates the adverse impacts of coal mining. While reclamation cannot duplicate pre-mining conditions, as Congress stated in SMCRA, it can "minimize so far as practicable the adverse social, economic, and environmental effects of … mining operations."[38]

Western coal operators take reclamation seriously. In just two years – 2004 and 2005 – Western coal mines were recipients of nine awards from the United States Department of Interior, Office of Surface Mining for excellence in surface mining reclamation.[39]

Due to current funding issues, the ability of state regulatory authorities to exercise sufficient oversight over coal mining is in jeopardy. A recent study by the Western Interstate Energy Board concluded that diminished federal funding for Western state regulatory programs are creating a crisis in administering those programs. Nor have the states made up the shortfall. The report concludes:

> Left unresolved, the funding crisis will diminish the capability of Western state regulatory programs to efficiently execute responsibilities under the

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32 84,000,000 gallons/day or 30,660,000,000 gallons/year or approximately 5% of the total U.S. transportation fuel requirement in 2006.

33 Obviously, however, there is no reason to think if such an industry developed it would be limited to the West. Accordingly, the coal to supply such an industry would come from across the nation.

34 Data for the states of AK, AZ, CO, MT, NM, ND, OK, TX, UT, WA, and WY. *See* http://www.eia.doe.gov/cneaf/coal/page/acr/acr_sum.html

35 *Id*.

36 *Id*.

37 33 U.S.C. 1201 *et seq*. If a state wishes to assume regulatory responsibility for surface mines within its borders, the state must enact a program at least as rigorous as that set forth in SMCRA. *See* 33 U.S.C. 1253

38 33 U.S.C. 1201 (e).

39 2004 and 2005 awards went to: the Seminoe No. 1 and Jacobs Ranch mines in Wyoming, the San Juan mine in New Mexico, the Martin Lake mine in Texas, the Kayenta/Black Mesa mines in Arizona, the Freedom Ranch mine in North Dakota, the Rosebud and Spring Creek mines in Montana, and the Trapper mine in Colorado. *See* http://www.osmre.gov/awardwin1.htm

> Surface Mining Control and Reclamation Act. This will delay issuance of permits and bond release, reduce the quality of inspections and set in motion a cascade of events. Regulatory uncertainty for the industry will increase. Public concerns about whether mines are being operated and reclaimed in compliance with the law will rise. Such concerns may translate into opposition to mining and appeals of regulatory decisions and litigation, ultimately increasing the costs of producing coal to fuel the economy.[40]

There are similar regulatory safety and health concerns related to underground mining.

A large surface coal mine brings economic benefits to an area. So, too, will a CTL facility.[41] Since Western mines are usually located in rural areas that are relatively less well-off, a coal mine and its associated facilities is often seen as a provider of good paying jobs and a benefit to a community. This view, however, is not shared by all communities in the surrounding area. Certainly, there are trade-offs involved.

Fugitive dust emissions occur during nearly every phase of surface coal mining. The most significant sources of these emissions are removal of the overburden through blasting and use of draglines and other heavy equipment, truck haulage, road work and wind erosion of reclaimed areas. There are also particulate matter emissions from diesel trucks and equipment used in mining.

Coal mines seek to minimize particulate matter emissions and must apply for an air quality permit for fugitive dust emissions. The use of baghouses at coal crushers, dustless transfer points, spray bars, watering haul roads, use of surfactants, and minimizing drop heights from dragline buckets are just some of the techniques employed. In addition to minimizing emissions site-wide, operating coal mines more narrowly focus on seeking to limit their workers' exposure to harmful emissions. Methods to protect employees include using positive pressure in cabs of trucks, shovels, draglines and, if needed, personal protection devices.

Water Use and Availability

Water usage and availability is an important environmental issue in large portions of the Western United States. Surface water supplies are limited and, in recent years, drought has made this situation even worse. The region's growth in population and economic activity will put increasing pressure on scarce hydrological water supplies. Accordingly, the availability of consumable water can be a major consideration that is a factor in the location, design, efficiency and overall cost of CTL projects and, thus, may limit the number of locations at which CTL plants can be operated.[42]

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[40] http://www.westgov.org/wieb/reclamation/2006/12-01finalrpt.pdf.

[41] A 20,000 barrel/day CTL plant will require an investment of $1.5 to 2 billion to construct. During the development, engineering and construction phase, ~2,000 direct jobs will be created, most of which are on-site construction workers. Plant construction will generally take 5 to 7 years. A local workforce of 300-350 will be required to operate and maintain the plant once full-scale operation is underway.

[42] In testimony before the Senate Energy and Natural Resources Committee, James Bartis of the Rand Corporation stated: "the environmental impacts associated with certain types of coal mining and water usage requirements, especially in the West, may limit the number of locations at which F-T coal-to-liquid plants can be operated." http://energy.senate.gov/public/_files/BartisTestimony.pdf

The CTL industry believes it is possible to significantly reduce the demand for water by using designs incorporating a combination of dry-fed gasifier technology, air cooling (also known as dry cooling) and other water enhancement techniques similar to those used in power plant applications. Furthermore, a CTL plant does not require "first use" water. Rather, non potable water and other, alternative sources of water can be utilized, including gray or secondary use water, such as effluent/process water/municipal waste-water return flows, and deep or non-potable groundwater supplies.

At least two generic studies exist that quantify the volume of water needed to convert Western coal to liquid transportation fuels. A 1998 Bechtel study found that the ratio of water consumption to product was 5 to 1. Similar results were reported in a 2005 Parsons study, analyzing the water needs for a 50,000 bpd F-T facility (4.9 units of water to 1 unit of F-T liquid). While neither of the foregoing studies specifically considered the use of modern dry-cooling technology utilized by power producers in the West, a preliminary engineering study conducted by the State of Wyoming, Rentech, Inc. and Jacobs Consultancy published in June 2005[43] specifically considered water usage in the context of a water-constrained environment. They found that through the use of dry-fed gasifier technology, dry cooling and other water mitigation measures that water use in a proposed Wyoming CTL plant could be decreased to a ratio of less than 1 to 1 (water to product). Moreover, the study found that employing the technologies to reduce water demand to this level would not be prohibitively expensive.

Table 3 presents a side-by-side comparison of water consumption, using two water ratios 1 to 1 and 5 to 1 for a 20,000 bbl/day CTL plant operating at an 85% capacity factor, and actual water use at selected power generation facilities and by small and mid-sized Western cities[44].

Table 3 - Water Use Comparisons for Selected Processes

Process	Plant Type/Size	Water Use million gallons/day	Water Use Acre-ft/yr	Notes
CTL 1:1 Water to Product	20,000 bbl/day	0.7	800	Capacity factor = .85
CTL 5:1 Water to Product	20,000 bbl/day	3.5	4,000	Capacity factor = .85
Colstrip Generation, MT	2094 MW PC	25.6	28,652	Data from 2005
Dakota Gasification, ND	170 MMcf/day	6.7	7,494	Data from 2004
City of Helena, MT	27,000 users	5.2	5,872	2002-2005 average

[43] Study dated June 2005 found that water consumption from a 10,200 BPD CTL plant would be approximately 250 GPM (0.8:1 ratio) when dry cooling technology is employed. The study can be obtained from the Wyoming Business Council or from Rentech, Inc.

[44]Note that the wastewater treatment effluent from the water consumed by Western cities could be a potential source of process water for a CTL plant as discussed.

City of Billings, MT	102,000 users	20.5	23,016	Data from 2003
City of Denver, CO	1.1 million users	212.5	238,000	Data from 2002

4. Technical Challenges

Technical challenges related to the development of a mature U.S. CTL industry are primarily the result of the lack of U.S.-based experience in CTL plant engineering and construction. This is compounded by uncertainty in the regulatory process for siting, constructing and operating CTL plants where few U.S. plants have been through the entire siting and permitting process.

Limited Plant Construction Labor Resources

CTL projects are large, technically complex facilities that require several years to design and construct. At an average cost of $100,000 per daily barrel of synthetic fuel, a 20,000 bbl/day plant will exceed $2 billion in capital investment.[45] This compares with an estimated capital cost of $15,000 to $20,000 per daily barrel of oil refined for a state-of-the art refinery.[46]

The current level of refinery and chemical plant construction, refinery upgrade projects, power plant construction, and the current level of overall worldwide energy development -- including the massive industrial process and energy projects that are taking place in the Middle East, India and China -- are creating a significant resource constraint with respect to availability of design and process engineering firms. As a result, the number of qualified engineering and construction firms that can respond to a CTL opportunity is extremely limited. This problem is compounded by the current high level of worldwide activity in industrial process and energy projects.

Accordingly, today's engineering and construction contractors are charging premium rates, while taking few, if any, risks for project performance. This has moved potential lenders out of their comfort zones, which has further complicated the design and engineering, procurement and construction (EPC) contracting process. In an effort to compete for the limited engineering and construction resources available today, China and other sponsors of world projects are not requiring liquidated damages and other project performance and financial risk mitigations, which have typically been borne by EPC contractors and are generally required in the U. S. by project lenders. As a result, the large world class contractors qualified to engineer and build CTL projects have their choice of which projects to support.

The worldwide activity in large plant construction projects combined with a historically decreasing skilled labor pool to design, construct and operate these plants, has placed a severe constraint on the availability of labor (at any cost) to supply the needs of a mature CTL industry. It is estimated that on a national level, 45% of the engineering sector's labor will be eligible to retire in the next 5 years.[47] This results in long lead times for

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[45]Cost is based on the Table in Appendix A and the report from the "Fact Sheet: Coal to F-T Liquids Technology, National Petroleum Council, July 2007 (see http://www.npchardtruthsreport.org/topic_papers.php)

[46] Paul VanEden, Altius Minerals Corp. July, 2007. See www.altiusminerals.com.

[47] Megawatt Daily. June 13, 2007.

design, engineering and construction and subsequent increased cost for an already premium-cost plant.

Limited Federal Investment in Basic Research and Development

Historically, federal research and development (R&D) in the CTL industry has not been sustained nor of sufficient magnitude to accelerate the development of a U.S.-based industry. And, given the lack of mature, broad-based and full scale U.S. experience in gasification and F-T technology, there is considerable basic research and development (R&D) that needs to be undertaken to improve efficiency of individual unit operations, as well as in entire plant configuration. Of particular importance is an accelerated R&D effort to advance the promising CBTL technology. The European experience can become the foundation for U.S.-based R&D, including constructing demonstration and pilot-scale facilities to test gasifiers, feedstock ratios and co-firing configurations.

In addition, specific R&D is needed to develop and test new and improved gasification technology (including the coal feed process); capture in a more cost-effective way gas stream contaminants; reduce the parasitic energy consumption of current processes; and improve catalysts for the F-T process, making them more efficient, cost-effective, and longer lasting.

V. ACTIONS TO ACCELERATE DEPLOYMENT AND DEVELOPMENT OF A COAL TO LIQUIDS INDUSTRY

Based on the material presented above and under the guidance of WGA policy resolution 06-20 *Transportation Fuels for the Future,* a set of comprehensive state, regional and national recommendations have been developed to help the CTL industry move towards future and mature deployment in a manner that addresses both the opportunities and challenges, while understanding the interrelationship between energy security, environmental performance/climate change and economic growth.

The portfolio of recommendations to help bring this industry to maturity is based on the following premises:

> First, in order to fully understand and optimize technologies and fulfillment of the goals of energy security, environmental performance and economic development, standards and regulations that are promulgated should promote parity amongst all fuels and seek to develop the industry in a manner that provides public benefits. A regulatory framework for the CTL industry should be considered that treats the first number of facilities as 'laboratories' so the second generation facilities can benefit from that experience.
>
> Second, while CO_2 is not currently regulated on a federal level, it is worth noting that several states have initiated this policy path, including WGA member states. While these recommendations do not presume future regulation of CO_2, they acknowledge what is in place now and the significant public and political discourse that is underway - and will continue to take place - on climate change and, specifically, the reduction of GHG emissions.

The recommendations are broken down into four distinct areas: 1) financial; 2) institutional and regulatory; 3) environmental health and safety; and 4) technical.

Financial

Support Federal Incentives - The WGA should advocate for the federal government to promote CTL development through financial incentives that are performance-based on the ability to provide appropriately deemed public benefits. This should be done in a manner that is consistent with other alternative transportation fuels, in order to achieve parity. While there is broad agreement on the principle of parity in offering performance-based incentives, we could not agree on the characterization of the specific performance-based approaches, goal(s) and timeline for implementation. Please see the appendix for a further discussion.

Incentives that could be offered include expanded existing self-pay loan guarantees, long-term off-take agreements for products, floor pricing with a cap for crude oil, accelerated investment tax credits for CCS equipment, and tax incentives for the fuel, similar to those that currently exist for ethanol, bio-diesel, compressed natural gas, methanol and other alternative transportation fuels.

Create Incentives for Developing a Coal-Biomass to Liquids (CBTL) Industry - Co-processing/co-firing coal with biomass to produce liquid transportation fuels can reduce the life-cycle CO_2 emissions as compared to petroleum–based fuels. On the road to commercialization for CTL, Western Governors should further incentivize development of co-firing/co-processing biomass in CTL plants using Western coals. Such incentives might include federal and state incentives for bonus depreciation structures, long-term guaranteed off-take agreements, preferred provider consideration, allowance of capital costs to be expensed in the year incurred, and/or accelerated depreciation.

Develop/Promote Alternative Incentive Structures - We recommend that the WGA consider promoting alternative incentive structures in lieu of traditional incentives. These could include the establishment of off-budget, performance-based incentives using approaches designed to account for climate, energy security and other public benefits and institutional challenges. Some approaches may include an energy security standard, low-carbon fuel standard, CO_2 cap and trade, carbon tax or CO_2 sequestration tax credits for industry, and feebate systems[48].

Institutional and Regulatory

Develop Clearly-Defined Permitting Processes for Siting, Constructing and Operating a CTL Plant - A clearly defined permitting process for CTL facilities will reduce the uncertainty, time and cost required for permitting, while retaining regulatory process and oversight. The Western states should work with local, state, tribal and federal agencies to establish a well-defined permitting process for the siting, construction and operations of a CTL plant. This would include all environmental impact documentation and permits related to air, water, land, product transport, mining, community impact and safety/health.

Allow for an Extension on Advanced Coal Lead Times in Federal Lease Statutes - WGA should seek to amend the federal mineral leasing statutes that require 1% of the reserves in the federal coal lease be produced within the 10th anniversary of the issuance of the lease, in order to allow additional time for the development of advanced coal utilization facilities, such as CTL plants. A recommendation would be to allow the coal leaseholder to apply to the Bureau of Land Management for an extension of the diligent development deadline beyond 10 years upon demonstration that an extension is needed for an advanced coal utilization facility.

Establish Carbon Storage Regulations and Requirements - A regional effort to support a state-based regulatory framework for CO_2 storage — including liability issues, measurement, monitoring, and verification (MMV) protocols -- is recommended. All carbon storage sites in the region should incorporate well-defined MMV protocols to ascertain CO_2 leakage rates. A state regulatory framework for initial projects could be modeled on the recent policies under consideration by the states of Texas and Illinois for carbon storage related to the FutureGen Project. State and regional initiatives should

[48] Feebate is a financial incentive structure that charges users of socially or environmentally undesirable items (e.g., low gasoline-mileage vehicles) and distributes that money toward more socially or environmentally desirable items (e.g., hybrid vehicles).

also coordinate with the federal government when developing policies for permitting and monitoring carbon storage sites.

Encourage Initial Siting of CTL Plants to Take Advantage of Enhanced Oil Recovery (EOR) Opportunities - Due to the availability of pure CO_2 streams captured from CTL facilities, the WGA should consider promoting infrastructure development and incentives that would encourage early CTL plants to be sited in locations where captured CO_2 could be used for EOR. Benefits of such a strategy include a ready-market for the sale of CO_2, ownership of the EOR/CO_2 storage process by the oil well producers, and enhanced energy security through the production of domestic oil.

Facilitate the Development of a Carbon Pipeline and Storage Infrastructure - The WGA should consider the creation of infrastructure improvement authorities and planning organizations to support the development of a CO_2 pipeline and storage infrastructure throughout the region. The development and management of such an infrastructure could be modeled after the Texas Water Board, the Wyoming Pipeline Authority or similar institutions. This public entity would have the authority to raise bonds to finance infrastructure (pipeline and pumping stations), and promote a carbon storage industry.

Develop a Biomass Supply and Transportation Infrastructure for CBTL via Co-Gasification/Co-Processing - CBTL can be launched in the market with local biomass resources throughout the West. To evolve a large scale industry, it will be necessary to bring in biomass supplies from biomass rich regions. The WGA should collaborate with coal and biomass producers, synfuel producers, and the transportation industry to develop a robust biomass transportation infrastructure that will facilitate the development and maturity of a coal/biomass co-processing industry in Western states.

Update the Nation's Coal Resource Assessment – The DOE EIA U.S. coal resource estimate of estimated recoverable reserves (275 billion tons) was last updated in 1997, and amounts to 16% of identified coal resources. The estimated recoverable reserves at active mines (about 19 billion short tons) is from data gathered in 2005. Recently, the U.S. Geological Survey has used more modern estimation techniques to evaluate a sample of coal fields and found that the ratio of estimated recoverable reserves to identified resources varies from 5% to 25%. Additionally, exploitable coal supplies may also increase with advanced production technologies. The combination of both technology advances and the discrepancy in resource estimates demonstrates the need for an updated and comprehensive analysis of coal reserves by DOE using modern technology and methodologies.

Environmental, Health and Safety

Evaluate Health, Safety, and Environmental Policies for Coal Mining - A recent study by the Western Interstate Energy Board (WIEB) concluded that "due to funding issues, the ability of state regulatory authorities to exercise sufficient oversight over coal mining is in jeopardy." Coal will be the primary feedstock for a mature CTL industry resulting in significant increases in coal production, thus it is important to provide adequate funding to ensure appropriate oversight of the coal industry. In addition states should evaluate their regulatory programs to ensure that they are well-functioning and sufficiently protective of worker safety, public health and the environment to the extent of their authority.

Technical

Develop a Qualified Labor Pool - The worldwide activity in large plant construction projects combined with a decreasing skilled-labor pool to design, construct and operate these plants, has placed a severe constraint on the availability of labor to supply the needs of a growing CTL industry. It is estimated nationally that 45% of the engineering sector's labor will be eligible to retire in the next five years.[49] The Western states can help alleviate the severe shortage of trained and qualified workers for the CTL industry by increasing education and training opportunities for engineers and skilled labor through universities, community colleges, trade schools, academies and web-based learning. Collaboration between the states and industry to attract, educate and train workers is vital for the development and sustainability of a CTL industry. Commercializing alternative transportation fuels, such as CTL, will create and sustain a skilled job base over the long-term.

Focused Fundamental Research and Development (R&D) for CTL and Related Technologies - R&D will enhance the long-term sustainability of the CTL industry. The federal government should be encouraged to develop a roadmap for CTL R&D. Similarly, Western states should consider collaborative R&D efforts among universities and other research institutions. Specifically, we recommend undertaking R&D that is focused on:

- **F-T micro-channel technologies** - F-T micro channel technology offers the potential for smaller, more economical and higher efficiency F-T process technology. ,

- **F-T catalysts** - R&D is needed to develop methods to modify the product distribution from F-T reactors by a combination of reaction engineering and improved catalysis. This may be realized through the development of new engineered catalysts combined with careful control of mass transport effects. With new catalysts and optimal control of F-T reactor operating conditions, the distribution of products could be tailored and/or maximized to meet market demands and thus maximize CTL plant operations.

- **Brines for CTL process water needs -** Hydrological water supplies represent a scarce resource in the West, however brackish or briny fossil water supplies are abundantly available deep underground. Substantial quantities of such waters are produced in conjunction with both coal-bed methane and CO_2 EOR projects. In addition, such waters might be extracted from deep saline formations in which the CO_2 produced from CTL plants might be stored, thereby possibly facilitating CO_2 storage in such formations.

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[49] Megawatt Daily. June 13, 2007.

R&D is needed to identify the potential for - and costs of - desalinating and transporting brackish or briny waters to meet CTL plant-process water needs.

- **CO_2 reforming and reuse** - Production of hydrogen from carbon dioxide reforming (CDR) of methane becomes a more attractive way to utilize (reuse) CO_2 from CTL plants, as well as transform methane, another important GHG, into useful chemicals and/or transportation fuel. One barrier to this process is catalyst deactivation due to carbon deposition and metal sintering. R&D is necessary to develop more effective catalysts that can be deployed in pilot-scale facilities as a means to accelerate the commercial application of the CDR.

- **Advanced EOR** - R&D is needed on advanced CO_2 EOR technologies. As has been noted, advanced technologies can expand the CO_2 EOR potential and thereby extend the CO_2 EOR market opportunity for CTL plants that can offer CO_2 at relatively low cost. This enhanced market opportunity translates into an enhanced energy security benefit as a result of the additional domestic oil that could be produced.

- **Enhanced gas recovery (EGR) -** Although, as has been noted, the overall potential for CO_2 enhanced gas recovery is likely to be much less than for CO_2 EOR, a comprehensive research, development and demonstration program aimed at understanding better how CO_2 injection could potentially enhance natural gas recovery is warranted, because of the importance of natural gas to the West.

- **Enhanced coal bed methane (ECBM) recovery -** ECBM technology using CO2 from CTL plants has the potential to increase the amount of methane produced to nearly 90% of the gas, compared to the recovery of 50% by conventional means. However, as has been noted, experience has shown evidence of significant coal-permeability reduction as a result of CO_2 injection. Given the importance of coal bed methane to the West, it is desirable to find ways to overcome and/or prevent this effect. R&D, including laboratory and pilot-scale demonstration, is needed on CO_2-ECBM to understand CO_2 storage capacity, and the applicability of CO_2-ECBM production technology to promising Western coal beds best suited for CO_2 storage.

Promote the Use of CTL for Early Megascale CO_2 Storage Projects - The CTL industry offers the opportunity to utilize the pure CO_2 stream generated and captured at the facility to conduct megascale CCS projects. The capture cost for CO_2 for CTL plants is substantially less than current capture costs for coal combustion plants, and accordingly is a very cost-effective and significant source of CO_2 for these demonstrations. Accordingly, WGA should actively participate in integrating the efforts of the DOE Regional Carbon Sequestration Partnerships for the commercialization of CTL in the West by seeking to host CCS projects within the region and using CTL facilities as the source for CO_2.

Demonstrate Co-Processing of Coal with Biomass - Co-processing or co-firing modest amounts of biomass with coal (with CCS) makes feasible fuel-cycle-wide GHG emissions rates that are much less than those for the crude oil-derived fuels displaced. This strategy would allow simultaneous exploitation of: 1) the scale economies of coal energy conversion systems; 2) the low cost of coal as the primary feedstock; and 3) the potential net negative CO_2 emissions of photosynthetic CO_2 storage. A full-scale demonstration of this technology using Western coals and biomass would provide the foundation for improving and optimizing technologies to help develop a mature industry, as well as provide a strategy for a net life-cycle reduction in CO_2 emissions from coal conversion.

Establish a National Laboratory in the West for Fundamental Research on CO_2 Storage - Given the vast array of opportunities for CO_2 storage in the West, the previously stated need for increased emphasis on R&D and megascale demonstration projects, and concerns related to liability, we recommend that WGA encourage the establishment of a national laboratory in the West to conduct research on CO_2 storage. Such a facility would help establish the Western United States as a global leader in CO_2 research and create an array of economic benefits for the region. A potential location for such a facility could be Teapot Dome/Rocky Mountain Oilfield Testing Center in Wyoming.

Encourage Coupling CTL with IGCC - Co-locating a CTL facility with an IGCC power plant can allow for a more efficient use of both project's assets, lower capital costs for each project, reduced operations and maintenance, increased plant availability, and an opportunity for plant operators to optimize electricity generation and CTL products for the marketplace. Governors should target incentives for electric generators/utilities and encourage state regulatory agencies, such as public utility commissions, to explore options for rate recovery and reasonable rates of return for combined CTL and IGCC power generation projects.

APPENDIX A

CTL TECHNOLOGY PROVIDERS AND U.S.-BASED CTL PROJECTS

There are currently no U.S.-based "turnkey" providers of an operational full-scale commercial plant to produce liquid fuels from American coal. Baard, DKRW, Rentech and CleanCoal are planning and designing plants now.

There are a number of U.S.-based providers of gasification technology (for producing syngas from coal) and Fischer-Tropsch technology (for producing liquids from the syngas).

Gasifier Technology

ConocoPhilips (E-Gas) (www.coptechnologysolutions.com)**:** ConocoPhillips' newest addition to its Technology Solutions portfolio is the E-Gas Technology for Gasification. Acquired in July of 2003, this technology is deployed for converting coal or petroleum coke into a hydrogen rich synthesis gas, ideally suited for refining, power and chemicals application. With over 15 years of commercial experience in Integrated Gasification Combined Cycle (IGCC) application, this technology provides a highly efficient coal-supplied power alternative. In a refinery setting, the technology can process high sulfur petroleum coke into power, steam and hydrogen for the refinery and surrounding markets.

GE Energy (www.gepower.com**):** GE Energy is a provider of license agreements that include the gasification process design package, process and instrumentation design review with engineering, procurement and construction, start-up support, operator training, on-going technical support and products supply. GE will tailor gasification and power block equipment to assist customers to meet the needs of project requirements. Currently, there are 62 plants – including more than 120 gasification vessels – operating GE's technology.

Shell (www.shell.com**):** The Shell Group has almost 30 years of experience in developing and using coal gasification and the technology has been proven in three pilots in the Netherlands, Germany and the USA, and in the full-scale Buggenum plant (2000 tonnes/day coal capacity) in the Netherlands. The Buggenum plant uses syngas from coal gasification in a combined cycle plant to generate electricity.

Siemens Power Generation (PG) Group (www.powergeneration.siemens.com**):** Siemens PG group acquired Sustec's coal gasification activities in mid-2006 in order to supplement its power plant business with products and services related to coal gasification. The acquisition comprises the German firm Future Energy GmbH as well as a 50% stake in a Chinese joint venture with the Shenhua Ningxia Coal Group. Siemens gasification technology is a dry-feed entrained-flow pressure gasification system that gasifies a stream of pulverized coal with oxygen. The Siemens gasifier can also utilize biomass as well as petroleum coke and refinery residues as feedstocks.

Fischer-Tropsch Technology

U.S.-based companies with F-T technology that can be used in conjunction with a gasifier using either coal (CTL) or natural gas (GTL) as a feedstock include:

ExxonMobil (www.exxonmobil.com/corporate/):ExxonMobil is focusing primarily on GTL technologies for "stranded" gas using their F-T process with proprietary catalysts to produce chemicals, other liquids, and associated gas products (hydrogen, CO_2). Most of its GTL activities are in the Middle East. ExxonMobil recently cancelled construction of a GTL plant in Qatar.

Headwaters Technology Innovation Group, Inc. (www.htigrp.com): Headwaters Technology Innovation Group (HTIG) is a wholly-owned subsidiary of Headwaters Incorporated (www.headwaters.com) that promotes and licenses technology for CTL projects using F-T technology. HTIG is currently involved in the projects noted in Table A1.

Rentech Inc. (www.rentech.com): Rentech began developing F-T fuels technology in 1981. Rentech has its patented F-T technology and is currently deploying that technology in the United States with active development of five major projects It has designed F-T plants in the range of 2,000 to 40,000 bpd for potential projects in the United States. Rentech is currently involved in the projects identified in Table A1.

Syntroleum Corporation (www.syntroleum.com): Syntroleum develops, owns, and licenses proprietary processes for converting synthesis gas via the Fischer-Tropsch process to synthetic liquid hydrocarbons (the Syntroleum® process) and refining the synthetic liquids hydrocarbons into middle distillate products (the Synfining® process) such as diesel and jet fuel. Syntroleum has applied its technology in the conversion of natural gas into synthetic hydrocarbons, known as gas-to-liquids (GTL) technology, and Syntroleum is demonstrating its Fischer-Tropsch technology with coal-derived synthesis gas processing technology. In early 2007, Syntroleum announced that it had further extended its technology to utilize renewable sources of feedstock as well.

Table A1- U.S.-Based CTL Plants Under Consideration

Project Name	Location	Project Status	Feedstock	Gasifier	F-T Technology	Estimated Fuel Production (bpd)	Electricity Production (net MW)	Carbon Management Strategy	Estimated Capital Cost $ Billion (Date)	Reference
DKRW-WY	Medicine Bow, WY	Design	Sub-bituminous	GE	Rentech	13,000	100	CCS/EOR	1.4 – 1.5 (06/06)	Rentech, Inc.
WMPI, Inc.	Gilberton, PA	Design	Anthracite culm	Shell	Sasol	5,000	40+	CCR	1.0 (03/07)	Internationa Freiberg Conference
Rentech Energy Midwest	East Dubuque, IL	Design	Bituminous/Bio-mass co-feed	Conoco Philips	Rentech	1,800	0	CCP, BIO	0.8 (10/06)	Gasification org
Rentech	Natchez, MS	Design	Bituminous Petcoke/Bio-mass co-feed	N/A	Rentech	25,000	N/A	CCP/EOR, BIO	2.5 (07/07)	Rentech, Inc.
Ohio River Clean Fuels, (Baard Energy)	Wellsville, OH	Design	Bituminous/Bio-mass co-feed	Shell	N/A	50,000	200	CCS/EOR, BIO	5/7 (07/07)	Baard Energy
Alaskan Industrial Development and Export Authority	Cook Inlet, AK	Feasibility	Sub-Bituminous	Shell or Sasol	Shell or Sasol	80,000	N/A	CCS/EOR	5.0+ (10/06)	Alaska Journal
Rentech	Mingo County, WV	Feasibility	Bituminous/Bio-mass co-feed	N/A	Rentech	20,000	N/A	CCS/EOR, BIO	2.0 (12/06)	Rentech, Inc.
Peabody/ Rentech	IL/KY	Feasibility	Bituminous/Bio-mass co-feed	N/A	Rentech	30,000	N/A	CCS, BIO	N/A	Gasification org
Rentech	Commerce City, CO	Pilot	Sub-bituminous Bituminous	N/A	Rentech	10–15	0	CCR	N/A	Rentech, Inc.

Project Name	Location	Project Status	Feedstock	Gasifier	F-T Technology	Estimated Fuel Production (bpd)	Electricity Production (net MW)	Carbon Management Strategy	Estimated Capital Cost $ Billion (Date)	Reference
Headwaters, Inc Consul Energy	Multiple	Concept	Bituminous	N/A	Headwaters	N/A	N/A	N/A	N/A	CONSOL Energy
American Lignite Energy	Beulah, ND	Concept	Lignite	N/A	Headwaters	32,000	N/A	CCS/EOR	N/A	Great River Energy
Illinois Clean Fuels	Oakland, IL	Concept	Bituminous Biomass	N/A	N/A	25,000	N/A	CCS	N/A	Cleancoalfuels.com
Peabody/ Rentech	MT	Concept	Sub-bituminous	N/A	Rentech	10,000	N/A	CCS, BIO	N/A	Gasification.org
Synfuels, Inc.	Ascension Parish, LA	Concept	Lignite	GE (?)	N/A	N/A	N/A	N/A	5.0 (06/06)	The Feedstock .com
Headwaters, Inc	Hopi Nation, AZ	Concept	Sub-bituminous	N/A	Headwaters	10,000 – 50,000	N/A	N/A	N/A	North American Coal Corporation
BNSF	MT	Concept	Sub-bituminous	N/A	N/A	N/A	N/A	N/A	N/A	The Billings Gazette

N/A=Not Available
CCR=Carbon Capture Ready
CCS=Carbon Capture and Storage
EOR=Enhanced Oil Recovery
CCP=Carbon Capture as Product
BIO=Biomass co-feed

APPENDIX B

CBTL TECHNOLOGY DESCRIPTION

A CBTL plant with CCS would gasify both coal and biomass, make synthetic fuels from the coal/biomass-derived syngas, and store underground the relatively pure CO_2 co-product—as in the case of a CTL plant with CCS. Per unit of liquid fuel produced about the same amount of CO_2 would be stored as for a CTL plant with CCS—but all the biomass-derived CO_2 stored underground would represent negative CO_2 emissions because that CO_2 was originally extracted from the atmosphere during photosynthesis. This “negative emissions” potential makes it feasible to realize a low emission rate with a relatively modest amount of biomass.

CBTL technology does not make economic sense when CO_2 emissions have zero market value, because, for many years to come, the price of biomass per unit of energy will be considerably higher than the coal price. But in the presence of a CO_2 price ~ \$25 to \$30 per tonne of CO_2, which is likely to be a minimum emissions price under a serious climate change mitigation policy, synfuels produced with near-zero GHG emissions in CBTL plants with CCS would be competitive with CTL plants with CCS and with CO_2 vented (Williams et al., 2006; Williams et al., 2007; Larson et al., 2007).

CBTL plants that involve co-gasification of coal and biomass (see Figure B1) could be built today based on dry-feed entrained-flow coal gasifiers that are also well suited for gasification of the low-rank coals (sub-bituminous coals and lignites) that dominate western coal supplies. This biomass/low rank coal synergism suggests the importance of advancing CBTL technology using western coals.

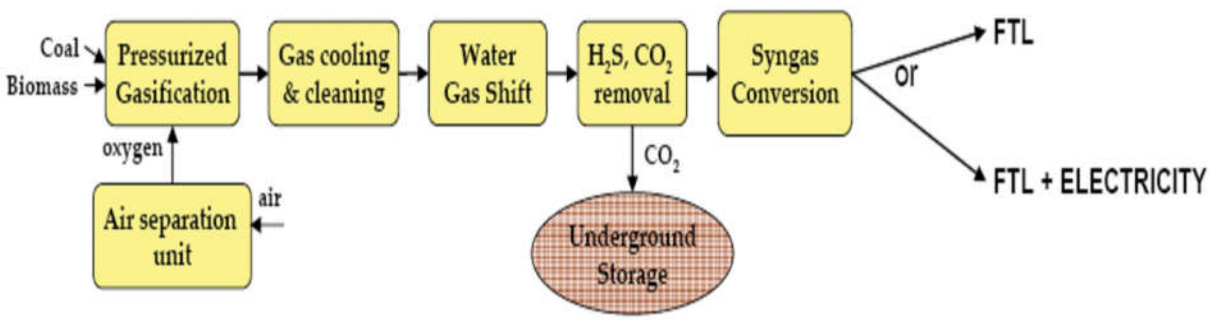

Figure B1: Co-gasification Options for Making Low Carbon Energy from Coal and Biomass

Future CBTL technologies might be able to offer superior performance relative to that for the co-gasification option shown in Figure B1, which requires that biomass particles be reduced to small sizes via costly preprocessing.[50]

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50 For this gasifier coal and biomass particles must be reduced in size via preprocessing to 0.1 and 1.0 millimeters, respectively. The larger allowable sizes for biomass arise because biomass is much more reactive than coal. But preprocessing coal to 0.1 mm is typically easier and less costly than processing biomass to 1 mm.

Figure B2 shows a system for making low carbon F-T liquids (FTL) + electricity that uses separate gasifiers for coal and biomass. Producing 17,800 barrels per day of FTL (*gasoline equivalent*) + 460 MW_e this system would have a GHG emission rate for FTL that is 21% of that for the crude oil-derived fuels displaced and for electricity that is 13% of that for a coal IGCC plant with CO_2 vented when fired with 28% switchgrass and 72% bituminous coal on an energy basis (Williams et al., 2006). Raising the switchgrass input to 36% (*energy basis*) would reduce the FTL GHG emission rate to zero (Larson et al., 2007).

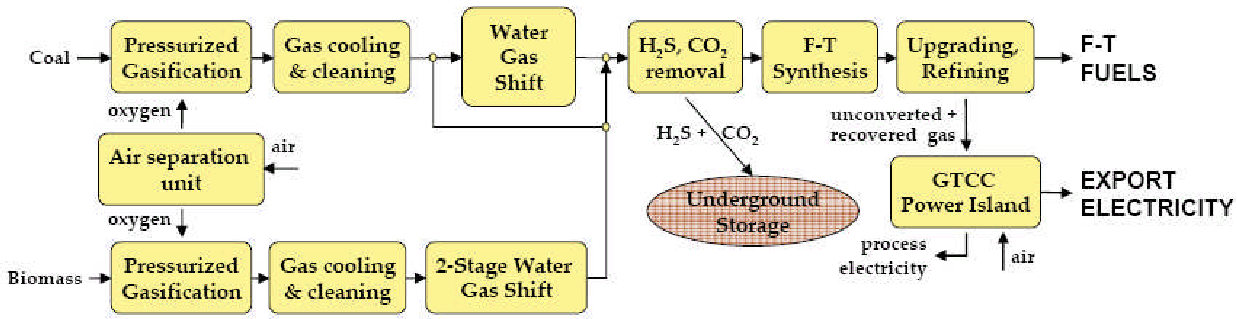

Figure B2: Low Carbon FTL + Electricity Using Separate Gasifiers for Coal and Biomass

Figure B3 shows a variant of the Figure B2 system that uses mixed prairie grasses (MPGs) grown on carbon-depleted soils instead of switchgrass, so as to exploit additional photosynthetic CO_2 storage via the buildup of soil and root carbon (Tilman et al., 2006). If this option could be successfully deployed in wide applications it could reduce dramatically the quantity of biomass needed to realize zero net GHG emissions for FTL.

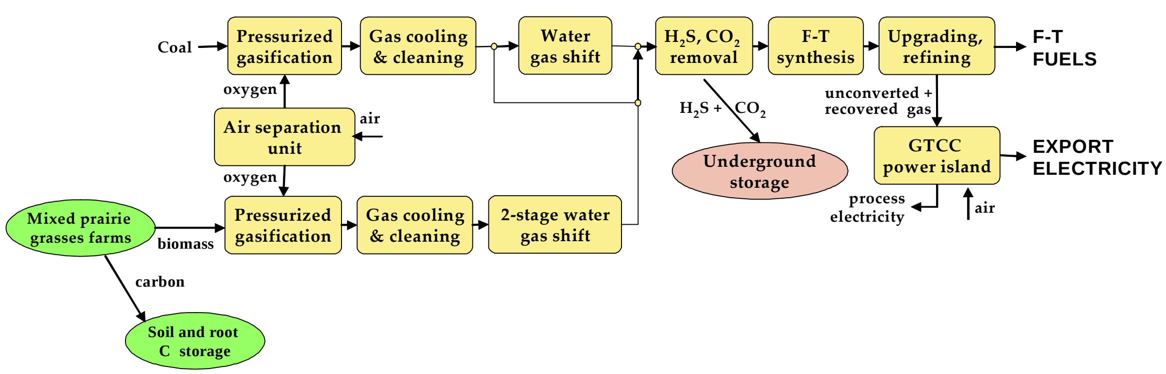

Figure B3: FTL + Electricity from Coal + MPGs with Two Carbon Storage Mechanisms

For a system using 16 MPGs this system could achieve zero net emissions for FTL when fed with only 21% biomass on an energy basis (Williams et al., 2007). An important characteristic of this system is that only a modest amount of biomass needed to make zero GHG-emitting FTL—less than 1/3 as much biomass as would be required with cellulosic ethanol (see Figure B4). This implies both that scarce biomass supplies can have a much larger impact in mitigating climate change and that the producer is likely to get a better price for biomass than with conventional biofuels (Williams et al., 2007).

Of course there are uncertainties as to the widespread applicability of the soil/root carbon storage concept. However, even with zero credit for soil and root C storage, the GHG emission rate for a system fired with 21% biomass would be only 45% of that for the crude-oil-derived fuels displaced.

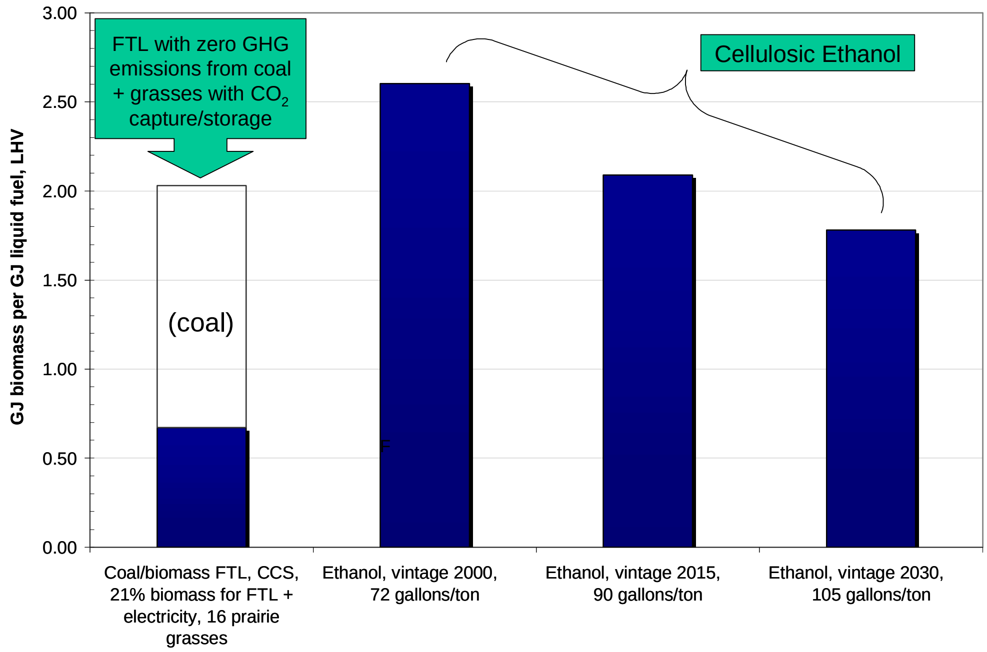

Figure B4: GJ of MPGs Required to Provide 1 GJ of Zero GHG-Emitting FTL Compared to Biomass Required to Make 1 GJ of Cellulosic Ethanol[51]

Much of the coal that might be used for CBTL plants in Western states is in arid regions where biomass supplies are relatively scarce. The very first plants might use various local crop and other biomass residues. However, to support a large-scale CBTL industry, additional supplies of biomass would have to be brought in from biomass-rich regions in ways that are cost-effective under a carbon policy constraint.

[51] Coal use for FTL bar = total coal use by the plant – coal required to make the same amount of electricity in a stand-alone IGCC power plant with CCS.[0]

Appendix C

STATES OFFERING INCENTIVES FOR CLEAN/ALTERNATIVE ENERGY FACILITIES

Many states across the nation are providing incentives for development of new, cleaner alternative energy (such as clean coal-fired generation) with particular attention paid to associating the development of the energy projects with management of CO_2 emissions. States are competing to attract energy projects through not only financial incentives and tax credits, but also cost recovery, regulatory waivers and liability limits.

Below is listing of these incentives by state:

- The Alaska Industrial Development and Export Authority provides bond financing assistance for, among other things, advances in new methods of exploration, development, production and transportation of energy.
- Arizona's Clean Coal Technology Task Force is supposed to develop a strategic plan for advanced coal power plants. The task force is expected to submit a report by the end of 2007.
- California's Air Resources Board (CARB) is preparing a scoping plan for reducing greenhouse gas emissions. A report should be submitted to the Legislature by Nov. 1 with recommendations on geologic sequestration.
- Colorado is considering proposals by Colorado electric utilities to construct integrated gasification combined-cycle power plants using Western coal and carbon capture and sequestration with cost recovery.
- Idaho has formed a carbon sequestration advisory committee. The panel is seeking ways to quantify and verify CO_2 sequestration on farmland and woodlands with an eye toward a future CO_2 marketing or trading program.
- Illinois is making financial assistance and tax incentives available to coal gasification or IGCCs linked to the creation of Illinois coal mining jobs. In addition to the U.S. Department of Energy's FutureGen project, Illinois is pursuing a number of clean coal technology incentive programs, including coal-to-liquids promotion.
- Indiana is making available timely cost recovery and financial incentives for qualifying energy projects.
- Kansas is offering tax credits for IGCC construction-related expenses. The state is also looking to exempt certain IGCC assets from property taxes.
- Kentucky is providing a tax credit of $2 per ton of eligible coal purchased for use at a "certified" clean coal power plant.
- Minnesota provides incentives for "innovative generation technology utilizing coal as a primary fuel in a highly efficient combined-cycle configuration" with significant reductions in various pollutants. For example, qualified projects would not be required to obtain a certificate of need.
- Ohio co-funds development of technology that can use Ohio's high-sulfur coal. The government has announced a plan to invest almost $1 billion in energy programs, such as fuel cells, clean coal and renewable energy.
- Oklahoma is researching CO_2 sequestration and underground injection that can enhance oil and gas recovery from marginal and abandoned wells.
- Pennsylvania is counting IGCC technology among alternative energy sources that must account for a certain percentage of energy sold by in-state electric utilities.
- Rhode Island gives priority to energy generation projects that use renewable fuels, including coal processed by clean coal technology.

- Texas offers incentives, not only for the FutureGen project (www.futuregenalliance.org), but also coal gasification and biomass mixtures. The Texas Railroad Commission would also acquire title to CO_2 captured as part of the FutureGen project.
- Virginia has indicated that it wants to facilitate development of clean coal projects.
- West Virginia offers various rate incentives for utility investment in qualified clean coal generation and air control technology projects that use at least 75% West Virginia coal. During its 2007 regular session, the West Virginia Legislature considered, but did not act upon, a study on regulation and sequestration of greenhouse gases.
- Wyoming has a number of state incentives to encourage development of new coal gasification or CTL facilities.

APPENDIX D

STATEMENTS OF ALTERNATIVE VIEWPOINTS

Robert Williams
Princeton University

Coal has a major potential role in providing synthetic fuels to reduce oil import dependence and mitigate climate change. I agree with many findings and recommendations of the CTL Working Group report, but I do not agree with some key points or with some of the major recommendations. Here I identify the main areas of disagreement.[52] I highlight uncertainties regarding resource issues that suggest caution in promoting early CTL deployment—*i.e.*, is there enough pore space, water, coal, and biomass to support a major synfuels industry for a carbon-con-strained world? And I propose policy options to enhance prospects for a robust synfuels future.

Incentives for Commercialization

Federal support for synfuels technology development is warranted for projects with characteristics consistent with meeting specified public benefits goals, with an emphasis on carbon mitigation. Also, a distinction must be made between incentives for facilitating construction of some early plants and incentives for routine deployment.

Some argue that conditioning federal incentives on meeting specified public benefits (*primarily carbon mitigation*) would cripple the development of a coal-based synfuels industry. That is not true. The CTL Working Group was told by several developers that the synfuel projects they are planning will go forward whether or not new federal subsidies are forthcoming. But, for reasons discussed below, providing federal incentives only for plants whose deployment is consistent with meeting specified public benefits goals will likely accelerate development of coal-based synfuels and ultimately enable a larger role for coal-based synfuels.

Incentives for routine deployment: Policymakers should strive to use policy instruments promoting routine deployment that: (*i*) let the market (*not the government*) choose the techno-logy mix (*so that oil and alternative fuel options would compete on a level playing field*); (*ii*) are off-budget; and (*iii*) enable elimination of existing routine fuel subsidies. But the availability of such routine incentives must be conditional on a technology's being able to provide specified public benefits—*with an emphasis on carbon mitigation*. While CTL technologies can provide security benefits by reducing oil security risks, carbon mitigation technologies will also provide security benefits owing to the huge security risks inherent in climate change.[53]

There are many ways to provide carbon mitigation incentives. Economy-wide measures such as cap-and-trade and a carbon tax are the most-discussed approaches. But high CO_2 market prices are needed to induce shifts to low-C fuels in transportation and

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[52] Because of space constraints, I am not able to present here all of my concerns about the main report. I am also concerned, for example, that success of a CTL/CBTL industry implies a major expansion of coal production that dictates the importance of periodic review *at the federal level* to ensure that public goals relating to coal mining health and safety and the environment are not compromised by this expansion. The main report stresses the more limited objective of ensuring that states have adequate financial support to enforce regulations—a necessary but not a sufficient condition for making feasible the viability of a CTL/CBTL industry over the longer term.

[53] CNA Corporation, *National Security and the Threat of Climate Change*, Alexandria, Virginia, 2007.

widespread adoption of CCS technologies for coal-energy-conversion systems. Skepticism that the needed high prices would be realized in the near term under economy-wide measures have led to proposed sectoral policies to facilitate early carbon mitigation action in addressing the most daunting challenges as complements to economy-wide policies—at least for the early years. Market-oriented sectoral policy instruments for facilitating a transition to low carbon fuels of promise are a Low-Carbon Fuel Standard (*LCFS*) and a revenue-neutral feebate.[54]

Incentives for early plants: Early synfuels plants will be operating until 2050 and will have to comply with whatever carbon policy is in place throughout the period. In contrast to the suggestion that early plants be considered "laboratories," grandfathering with regard to carbon mitigation should not be allowed. Retrofitting plants built early on for improved carbon mitigation is costly. Planners should craft incentives for early plants that would inspire designs that would enable early plants to remain competitive and not later be converted into stranded assets. Thus a prudent policy for facilitating the building of a few plants over the next decade or so is one that restricts incentives to those projects offering the greatest carbon mitigation benefits.

Federal incentives should be offered to enable the construction of a small number of synfuels plants that are built early on—to help accelerate the development of a synfuels industry. The winning projects should be determined via competitive bidding. An economically efficient approach would be to ask project developers to compete by submitting business plans developed in the context of specified synfuel qualities (*so that the synfuel would be able to satisfy market needs for fuel quality*), a specified oil price (*to facilitate evaluation of competing business plans*), and a specified shadow price on CO_2 emissions. The winning projects would be those that could compete best under these conditions in providing synthetic fuels.

A critical issue is the appropriate shadow CO_2 price. Prudent planning will simultaneously promote a sustainable future for coal-based synfuels and assume a price that is consistent with enabling economy-wide deep reductions in GHG emissions for the US by mid-century.[55] Deep reductions cannot be realized without de-carbonizing (*via*

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[54] A LCFS and a revenue-neutral feebate are, respectively, quantity-specified and price-specified approaches for reducing GHG emission rates for transport fuels. The GHG emissions reduction goal is specified in the LCFS, but the GHG emissions price implicit in implementing the goal cannot be known with precision. With the feebate, the emissions value is specified, but the emissions reduction quantity is not known. It might be politically easier to eliminate existing subsidies with the feebate because of the uncertain economic benefits offered by the LCFS.
A feebate would provide a rebate as an incentive for performance, the cost of which would be shared among a specified set of stakeholders via a fee. A feebate might be designed to reward alternative fuel options in proportion to the GHG emissions reduction offered in displacing crude oil-derived fuels, and the fee to pay for the rebate might be levied against all oil consumption.
[55] Stabilizing atmospheric CO_2 at a level less than a doubling of the pre-industrial level (*which still may not be adequate to prevent "dangerous anthropogenic interference with the climate system," as required under the UN Framework Convention on Climate Change, to which the US is a Party*) requires for the period to mid-century stabilizing global emissions at about the current rate (S.W. Pacala and R.H. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, **305**: 968-972, 13 August 2004). This in turn requires by mid-century deep reductions in the CO_2 emission rates of industrialized countries (R.H. Socolow and S.W. Pacala, "A Plan to Keep Carbon in Check," *Scientific American*, **295**(3): 50-57, September 2006). These notions

CCS) most coal power generation before mid-century—an activity that is likely to set the US market price on CO_2 emissions. As is well known, a minimum price of \$30/t CO_2 or more is needed to induce CCS for *new* coal power plants;[56] moreover, for retrofits, the minimum price is likely to be ~ \$50/t CO_2.[57] Because the market price for CO_2 emissions would be set at the marginal CCS cost, an appropriate shadow price is therefore ~ \$50/t CO_2.[58] Coal-based synfuels characterized by emission rates that are more or less than for average crude-oil-derived products would accordingly be less or more competitive, respectively, than average conventional crude oil-derived products. Such a CO_2 price would be a powerful incentive for project developers seeking incentives to design synfuel plants that realize a high level of CO_2 capture[59] and process modest amounts of biomass along with coal to make synfuels. Project developers who would do both would be strong competitors to suppliers providing crude oil-derived products under these market conditions and thus would not end up as stranded assets. So doing would be feasible even for plants built early on.[60]

Exploiting the Low Incremental CO_2 Capture Cost for CTL/CBTL Plants to Help Ascertain the Gigascale Viability of CO_2 Storage as a Carbon Mitigation Strategy

A robust future for CTL/CBTL technologies depends on the gigascale viability of widespread CO_2 storage as a carbon mitigation option, but there are uncertainties as to the "gigascale" viability of the CO_2 capture and storage option for mitigating climate change. The current state of geologic science is guardedly optimistic but ambiguous on

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are well understood by public policymakers in the WGA region: states accounting for ½ of the region's population have already established for mid-century official state CO_2 emissions reduction goals of 50% to 80% relative to 1990-2000 levels.

[56] See, for example: J. Deutch, and E.J. Moniz et al., *The Future of Coal: Options for a Carbon-Constrained World*, an Interdisciplinary MIT Study, 2007. This study also showed that a world-wide CO_2 emissions price introduced at \$25/t CO_2 in 2015 and rising exponentially thereafter to \$100/t CO_2 by 2050 (in constant 1997 dollars) would both induce widespread adoption of CCS technologies for coal power and lead to stabilization of the global CO_2 emission rate at about the current level through mid-century—which is consistent with the emissions stabilization goal advanced by Socolow and Pacala in their seminal 2004 *Science* article, as discussed in the previous footnote.

[57] See: P.S. Reinelt and D.W. Keith, "Carbon capture retrofits and the cost of regulatory uncertainty," *Energy Journal*, **24** (4), 2007, in press.

[58] This implies that diesel derived from coal would face a shadow carbon-equivalent penalty of almost \$0.75 a gallon if its emission rate were the same as for "US average" conventional crude oil-derived diesel.

[59] With current technology, CTL plants *designed with a tough carbon mitigation goal in mind* can capture and store at low incremental cost 85% or more of the coal carbon not contained in the liquid fuel products. See, for example: D. Gray, C. White, and G. Tomlinson (Noblis), M. Ackiewicz (TMS), and E. Schmetz, J. Winslow (LTI), *Increasing Security and Reducing Carbon Emissions of the U.S. Transportation Sector: a Transformational Role for Coal with Biomass*, report prepared for the U.S. Air Force and National Energy Technology Laboratory, DOE/NETL-2007/1298, 24 August 2007.

[60] Baard Energy plans to build a 50,000 barrels per day CBTL synfuels plant in Ohio that would be co-fired with 70% bituminous coal and 30% biomass (*weight basis*), and for which it is hoped that production will commence during 2011-2012. For this plant it has been estimated that the GHG emission rate would be ~ 30% less than for the crude oil-derived products displaced [see Statement by R.D. Boardman (Energy and Environmental Science and Technology Division, Idaho National Laboratory), before the Subcommittee on Energy and Environment of the Committee on Science and Technology of the US House of Representatives, 5 September 2007].

this point. Regarding the global prospects for secure geological storage of CO_2 the 2005 *Special Report on CCS* of the Intergovernmental Panel on Climate Change says that : "…worldwide, it is virtually certain that there is 200 Gt CO_2 of geological storage capacity and likely that there is at least about 2000 Gt CO_2…"

The US should proceed cautiously with policies promoting CTL/CBTL technologies until policymakers have much more confidence that geological CO_2 storage is viable at "gigascale." If the lower IPCC global estimate of secure CO_2 storage capacity proves to be the more valid, there is no significant global potential for expanding coal use into CTL/CBTL realms (*because the CO_2 storage capacity would have to be restricted to exploitation by existing coal conversion industries—notably coal power generation)*. But if instead the 2000+ Gt estimate of CO_2 storage potential proves to be closer to the mark, then CTL/CBTL technologies can have significant roles in providing synthetic fuels in a carbon-constrained world.

With current knowledge we do not know how much secure CO_2 storage capacity can be planned for with confidence, and we cannot learn what the true potential is for secure CO_2 storage with-out carrying out worldwide a substantial number (*10-12*) of megascale CO_2 storage projects[61] in a variety of geological formations and simultaneously making detailed "bottom-up" assessments of storage capacity on a region-by-region basis.[62] The needed megascale projects are in addition to the ~ 7 CO_2 US storage projects being planned by the NETL Regional Partnerships on Carbon Capture and Sequestration discussed in the main report—projects that are likely to be announced before the end of 2007, each of which will store ~ 1 million tonnes of CO_2 over three years.

So, the CTL/CBTL industry should be doing what it can to help ascertain, as soon as possible, the gigascale viability of CO_2 storage as a major carbon mitigation option. It has a strategic opportunity to help close the CO_2 storage knowledge gap by offering to governments the use of low-cost CO_2 captured at early CTL/CBTL plants for use in such megascale storage projects.

Water Scarcity

The main report highlights the fresh water scarcity issue for CTL in the West, calls attention to the fact that the bulk of the needed water is associated with use of with wet cooling towers, and highlights the opportunities of shifting from wet to dry cooling (*which can reduce water needs to somewhere in the range 1 to 3 barrels of water per barrel of synfuels*) and of processing brackish or briny fossil water instead of fresh water for meeting residual process needs. But the severity of the challenge needs greater emphasis—specifically, prospects that fresh water supplies are likely to decline in the West as a result of global warming[63] and that the impacts of declining fresh water supplies will be exacerbated by the expected population and economic growth in the WGA region. The rapidly growing opposition to expansion of coal energy conversion in the West on the part of many ranchers and farmers is motivated to a large extent by

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[61] Each of which stores at a routine rate at least 1 million tonnes of CO_2 per year.

[62] See, for example, J. Deutch, and E.J. Moniz et al., *The Future of Coal: Options for a Carbon-Constrained World*, an Interdisciplinary MIT Study, 2007.

[63] The adverse effects of climate change on fresh water supplies in the West are likely to be substantial and have already been have measured. See, e.g., S. Saunders and M. Maxwell, *Less Snow, Less Water: Climate Disruption in the West*, report of the Rocky Mountain Climate Organization, Louisville, CO, September 2005.

concerns that the global warming impacts of this expansion will further constrain water availability to meet their needs.

These considerations imply that dry cooling and use of fossil water for meeting water needs are essential. A prudent public policy would make incentives for synfuels plants in the West contingent on not using hydrological (*fresh*) water supplies for cooling or process needs.

Adequacy of WGA Coal Resources

One rationale for creating a CTL industry is the prospect of huge recoverable coal reserves in the WGA region. The main report recommends, in light of findings of a recent National Research Council report that recoverable coal reserves might be less or more than current estimates, that a detailed reassessment of recoverable coal reserves be carried out. The fact that if prospective supplies turn out to be at the low end of this uncertain range there would be essentially no room for new coal uses such as CTL underscores the urgency of carrying out this reassessment.[64]

Strategic Importance of the CBTL Option for Biomass Energy Development

The main report highlights the importance of CBTL with CCS in enabling coal to provide liquid fuels in a climate-friendly manner, but the strategic importance of this option for biomass energy development should be emphasized more.[65]

CBTL with CCS makes it feasible to provide near zero GHG-emitting liquid fuels with much less biomass than is needed in making conventional biofuels (see Appendix B)—an important attribute because of the land-use intensity and thus inherent scarcity of the biomass resource. Moreover, the CBTL option would use ligno-cellulosic biomass and thus can help accelerate a shift from food biomass to ligno-cellulosic biomass in providing liquid fuels.[66] There is a strategic opportunity for the WGA region to help bring about this shift. This opportunity arises because most western coal resources are low-rank coals. These coals can be gasified to make CTL products with commercially available technologies only with dry-fed gasifiers. With current technology only these dry-fed gasifiers can accommodate significant biomass co-firing with coal.

Conclusion

A prudent public policy to promote synfuels would be carefully crafted to respect environmental and resource constraints. It would avoid using public monies in ways that

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[64] According to the Energy Information Administration, estimated recoverable reserves in the WGA region are 162 billion tons or a 260-year supply at the current production rate (based on surveys carried out in the 1970s). Subtracting from the total 100 years of production for current uses leaves enough additional coal to support 4 MMB/D of CTL (~ 20% of current US oil consumption) for 100 years. Recently, the US Geological Survey reexamined a sample of coal fields in the US and found that recoverable coal reserves might be as low as 0.3 times or as high as 1.6 times the 1970s estimate. Pessimistically applying the 0.3 factor to coal reserves in the WGA region would reduce the exploitable supply from 260 years to 80 years at the current production rate.

[65] The report does point out the economic benefits to biomass of coal/biomass co-processing via exploitation of the scale economies of coal energy conversion and the low cost of coal as a feedstock.

[66] In energy planning circles it is now widely understood that a market shift must be made as soon as possible from food biomass to ligno-cellulosic biomass as the primary feedstock in making liquid fuels from biomass.

might generate stranded assets. It would seek to enhance prospects for a robust synfuels future.

Dick Sheppard/Dave Perkins
Rentech, Inc.

The US is in an energy crisis due to reliance on imported crude oil and finished fuel products. Reliance on foreign energy sources for over 60% of our energy needs puts the economy and well being of the American population at risk, both from a national military security perspective as well as an economic security perspective. However, North America is endowed with significant resources that could enable the region to become less reliant on foreign energy resources. Figure D1 shows the energy endowment for the United States. Coal is by far the most available energy source for the next 100+ years, which is essentially the same amount of time that the world has been using crude oil for its major transportation energy needs.

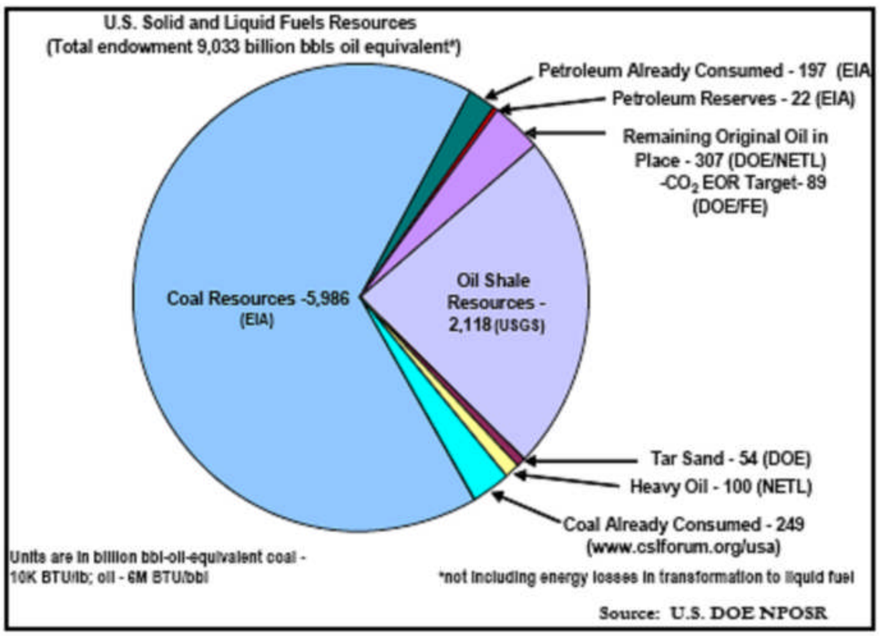

Figure D1 - America's original endowment of solid and liquid fuels resources

While the U.S. may believe that significant volumes of crude are available from neighboring countries, it should be noted that China has already begun to tap into these resources by agreeing to construct a pipeline from Alberta to Vancouver to access Canadian tar sands derived crude oil; reached agreement with Venezuela to operate oil fields in exchange for long term supply agreements; and is negotiating for a long term supply of crude from Mexico's PEMEX national oil company. It should also be noted that India's oil consumption is increasing exponentially, and India is likewise competing for the supply of conventional crude oil in the world's oil markets. In addition, both China and India are looking to unconventional oil supplies to meet their dramatically increasing energy demands.

In addition to a reduced dependence on foreign energy sources, development of a domestic CTL industry will provide significant economic benefits to the economy. A primary benefit is the reduced risk due to energy supply disruptions and price volatility. There are also direct benefits related to a reduced foreign trade deficit and increased domestic economic activity. Also of importance is maintaining and increasing the knowledge and experience base of the American technical and labor forces which have been declining as skilled labor jobs have transferred to foreign countries.

Developing a Coal-To-Liquids industry offers solutions to all of the economic risks discussed above as well as offering real solutions to U.S. air quality concerns and the current debate related to carbon dioxide emissions and pending carbon dioxide emissions constraints.

Energy Security

- The United States Spends >$350 Billion per year on importing foreign oil or over $600,000 per minute
- In 2006 Department of Defense Purchased >114 million barrels of Fuel
- The Fuel cost was over $13 billion compared to less than $3.9 Billion in 2002
- The heavy dependence on foreign oil puts the United States at risk!

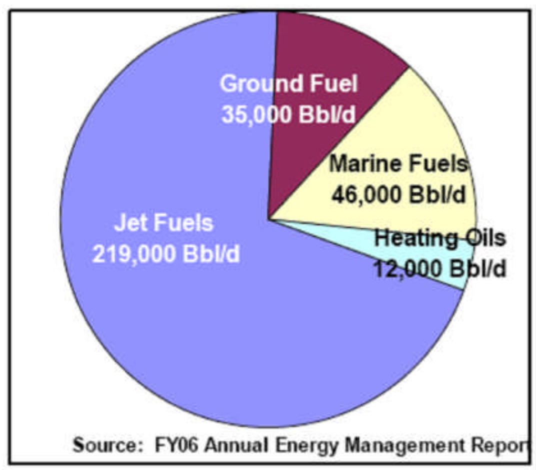

Figure D2 - DOD Fuels Purchases in

The only Government agency that has recognized the serious energy security threat is the Department of Defense (DOD). DOD has instituted the Assured Fuels Initiative. This program will certify unconventional fuels for military use which will reduce dependence on foreign fuel supplies. The first synthetic fuel to be certified is Fischer-Tropsch (F-T) jet fuel which can be produced from coal resources by integrating coal gasification technology with the Fischer-Tropsch synthesis process (known as coal to liquids "CTL"). The US Air Force has already flight tested a B-52 bomber on a 50:50 blend of F-T jet fuel and conventional jet fuel. The entire fleet of military aircraft will be certified to use F-T synthetic jet fuel blends by 2011. The DOD has the goal of acquiring 50% of its fuel needs from domestic sources by 2016. F-T jet fuel derived from coal gasification is the only viable domestic fuel source capable of meeting the DOD's volumetric requirement related to the Assured Fuels Initiative requirements.

In addition to being certified by the DOD, F-T jet fuel is being certified for use in domestic aircraft. Jet fuel derived from coal is already in use in South Africa's Johannesburg (Tambo) International Airport. F-T jet fuel is approved for use in commercial aircraft at up to a 50% blend with conventional jet fuel. In the US, the American Society for Testing Materials (ASTM) is currently concluding its approval process for domestic use of F-T jet fuel.

Economic Benefits

The benefits to the local, regional and national economy for building a CTL industry will be substantial. Economic multiplier effects vary from region to region, but many of the projects currently under consideration are in under developed regions of the country where the benefit of projects the size of CTL facilities will be multiplied several fold.

It is estimated that each of these facilities will cost in excess of $4 billion in capital costs. Such projects take 3 to 5 years to develop and 3 to 4 years to construct, creating 1,500 to 2,000 construction jobs per project. Permanent employment for each facility will be about 300 to 400 highly paid, skilled heavy industry workers who receive health benefits and retirement plans. The job multiplier effect for CTL projects is in the range of from 4 to 6. Such related jobs will include the mining and transportation of the feedstock, the delivery of the products to the market as well as ancillary jobs related the daily operations and maintenance activities.

Local and Regional Benefits related to the siting of a CTL project include:

- Increased tax base directly related to the value of the project, as well as ad valorum taxes, severance taxes and royalties on coal produced.
- Major capital project / investment in the community
- Local employment
    - Large temporary increase in employment during construction (3-5 years)
    - Permanent increase in employment
        - Skilled operations and maintenance staff
        - Management and Administrative staff
- Contribution to local education
    - Increase in property tax revenues will directly benefit the schools in the community
    - Economic Growth in the community related to the need for added homes, businesses and infrastructure.
    - Need for skilled labor will mandate support of local education
    - Need for research and engineering will mandate support of higher education
    - Increased tax revenues will make education infrastructure growth possible

National Benefits

- Domestic energy security
- Balance of Payments
- Reduced foreign debt
- Increased technical capabilities
    - Skilled labor force
    - Engineering talent pool
    - Scientific research and development skills
    - Manufacturing facilities and skills

These are but a few of the direct and indirect benefits of building a CTL fuels manufacturing base in the US. By committing less than one months expense on foreign oil purchases - $35 billion – a domestic CTL industry can be well under way that will allow these many benefits to be realized,.

Environmental Benefits

When developing new energy sources, environmental benefits and impacts have to be at the core of the decision-making process and balanced with economic and security benefits. Developing a Western States CTL infrastructure will contribute to the environment due to the inherent design features of CTL plants and the properties of the fuels produced by these plants. While mining activities are outside the scope of this report, it should be noted that proper management of coal mine sites and rehabilitation of the sites after use are already mandated and the industry has had a good track record of working to be very good stewards of the environment and meeting or exceeding the mandates for mine reclamation. Studies of rehabilitated mine sites show that biodiversity has actually increase after rehabilitation indicating that the sites are properly managed.

The CTL process will reduce regulated and unregulated emissions from all aspects of the project as compared to existing power generation and fuels production plants. A CTL plant design incorporates the cleanest method for coal utilization: coal gasification. In this process, coal and oxygen are mixed in such a manner that synthesis gas, CO and Hydrogen (H2) is produced along with CO_2 and contaminant gases such as hydrogen sulfide and nitrogen compounds. Prior to introduction to the Fischer-Tropsch reaction, the synthesis gas (syngas) is scrubbed to remove CO_2 and other contaminant gases. The CO_2 produced in this stage of the process can be compressed and made available for sequestration via several options: Enhanced Oil Recovery (EOR), Enhanced Natural Gas Recovery (ENGR), Coal bed methane recovery, or geologic sequestration in several types of underground structures that are stable and secure for the foreseeable future. CO_2 can also be captured from other units of the plant including the F-T reactor. The CO_2 that is used for EOR, ENGR and Coal bed methane production actually offers a multiplier affect to the benefits of the CTL facility. For Example the Rentech facility in Natchez Mississippi will provide its CO_2 to EOR and that will result in rehabilitation of oil wells that have been shut in and abandoned. This opportunity will produce an additional 30,000 to 50,000 barrels of oil per day from Domestic resources that had previously been written off, further enhancing the United States Energy picture and the Economic benefits.

By the very nature of their design requirements, CTL facilities are the first commercial fuels production facilities to capture CO_2 and reduce the greenhouse gas emissions from transportation fuels. For example, Rentech Inc. is developing plant designs such as their proposed CTL facility in Natchez, MS that show a lifecycle GHG emissions profile lower than for conventional fuels. The research on the emissions profile from this plant are still under internal and external review, the results to date show that CTL fuels reduce GHG emissions compared to conventional fuels and that incorporation of biomass co-feed in the process can reduce GHG emissions further.

Co-feeding of biomass to a CTL facility (CBTL) is a desirable feature of CTL plants, and will be part of the future as the technology and resources are developed.

F-T fuels from coal, natural gas, and biomass have been tested by the Environmental Protection Agency (EPA), DOD, DOE, California Energy Commission (CEC), plus many international government and industrial testing facilities and laboratories. All demonstrate the same results: the use of ultra clean fuels such as CTL derived fuels will result in significant reductions of all regulated emissions, being the emissions EPA has regulated for the past 20+ years that have been shown to create health hazards. In addition, recent testing of F-T fuels has demonstrated that because FT diesel contains less carbon than conventional diesel the unregulated CO_2 emissions are reduced when burned in conventional diesel engines.

Recently, DOD conducted emissions testing of FT fuels in both diesel and turbine engines, and demonstrated the significant reductions of emissions as a result of using ultra-clean FT fuels. Results of these tests are shown in Figures D3 and D4. Inasmuch as F-T fuel contains essentially no sulfur or aromatics, the fuel is inherently low toxicity and is biodegradable. Oral, dermal, and aquatic toxicity of F-T fuels has been reported and the fuel is EPA registered.

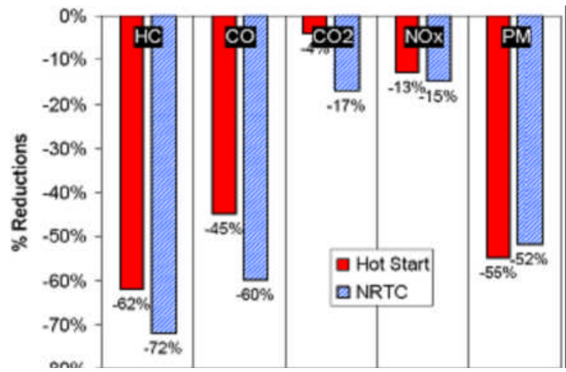

Figure D3 - Diesel engine emissions

One significant aspect of F-T fuels is that it is compatible with the current fuels distribution infrastructure. No new storage tanks, pipelines, engines or equipment will be needed to use F-T diesel and jet fuel. And the benefits to emissions reductions from existing equipment are immediate and verifiable. In addition, the fuel is compatible with advanced emissions control devices and will make those devices function more effectively, longer and lower costs, as the engine-out emissions are reduced.

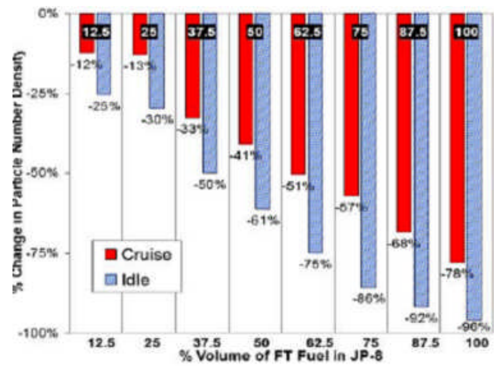

Figure D4 - Turbine Engine emissions reductions

California is implementing a Low Carbon Fuels Standard that will help that state meet its goals of reducing its dependence on crude oil and reduce the overall emissions of greenhouse gases. CTL fuel which already will have carbon capture and sequestration as part of the overall plant design will help reduce GHG emissions from fuels. F-T fuels have the highest energy content per pound and the lowest carbon content per amount of energy of any liquid hydrocarbon fuel. A comparison of GHG emissions from CTL fuel and conventional diesel fuel is shown in Table D1. GHG emissions comparisons include fuel production and fuel use. For conventional fuels, increased regulations and degradation of crude oil quality will steadily increase overall emissions of GHG's from crude derived fuels. However, improvements in technology will reduce the GHG emissions from CTL fuels.

Table D1 - Comparison of energy and GHG emissions for FT fuels

Property	F-T Diesel	EPA Diesel	CARB Diesel	European Diesel
MJ/kg	43.99	42.74	43.10	43.19
Grams CO2/kg Fuel	3114	3186	3161	3153
Grams CO2/MJ	70.8	74.5	73.3	73.0
% Difference in CO2 Emissions vs. EPA Diesel	-5.04%	0.00%	-1.61%	-2.06%

Figure D5 summarizes the well-to-wheels emissions for CTL diesel compared to diesel produced using different crude oil sources. Note that crude quality is degrading as resources are being utilized and that future crude oil will be derived from sources such as Venezuelan heavy crude and Canadian oils sands, both of which are of lower quality and require more energy to produce than light sweet crude oils.

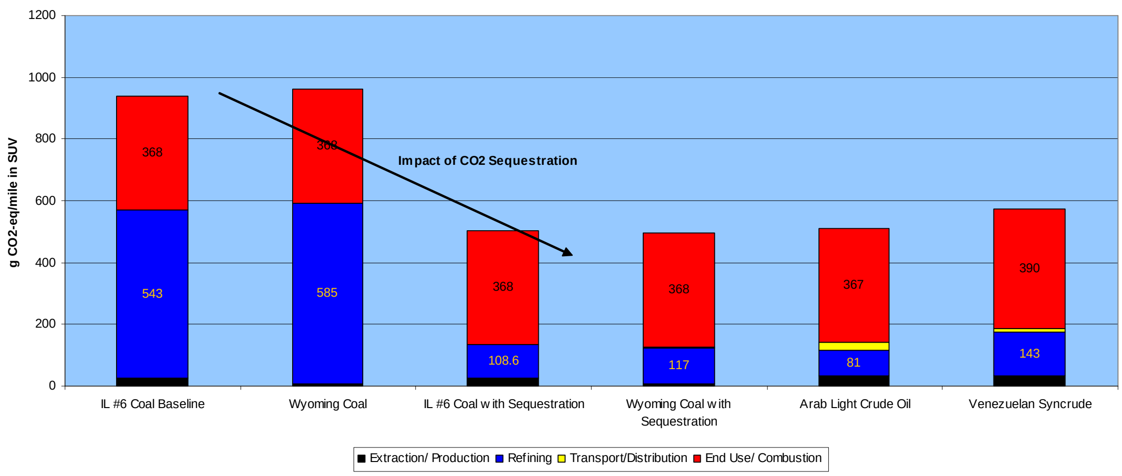

Figure D5 - Impact of Carbon Capture and Sequestration on the overall GHG emissions of diesel fuel production from coal compared to diesel produced from

In conclusion, implementing an effective energy policy is critical and the resource that can meet the challenge is Coal through the use of the CTL or CBTL technology which provides the most benefits in the time frame needed to help meet the needs of the United States for energy, economic security while balancing and improving the environment.