TESTIMONY

Policy Issues for Coal-to-Liquid Development

Addendum

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Policy Issues for Coal-to-Liquid Development[2]
Addendum

Submitted to the Committee on Energy and Natural Resources
United States Senate

June 26, 2007

The subsequent questions and answers found in this document were received from the Committee for additional information following the hearing on May 24, 2007 and were submitted for the record.

Questions from Chairman Jeff Bingaman (D-NM)

Question 1. *You advocate both for carbon capture and gasification of biomass with coal to meet greenhouse gas emissions targets. Using both together, you indicate there is a level where the total lifecycle emissions could theoretically be zero or even negative. Assuming that is with further technological development, what do you think are achievable standards today for percentage of carbon captured, biomass included, and lifecycle emissions?*

Answer 1. For first-of-a-kind CTL plants built in the United States, 80 percent capture of all plant CO_2 emissions is an achievable standard. This level of reduction should result in lifecycle emissions that are between 10 and 20 percent higher than motor fuels produced from conventional petroleum. This level of capture is consistent with the two lowest risk approaches for managing carbon in initial coal-based commercial plants, namely, co-firing of coal and biomass and the use of carbon dioxide for enhanced oil recovery. This emission factor is also appropriate for CTL plants that would capture carbon dioxide for use in a long-term demonstration of geologic sequestration.

This percentage reduction is possible without forcing a CTL plant to incorporate gas turbines that can accept a fairly pure hydrogen feed. Adding such turbines would allow at least 95 percent removal; however, it is our judgment that requiring hydrogen turbines would add considerably to

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the market uncertainties associated with the future course of world oil prices and the technical uncertainties associated with building, operating, and capturing carbon from a first-of-a-kind plant.

Question 2. *You advocate that any facilities that receive federal incentives should be at least comparable in greenhouse gas emissions to petroleum-derived fuels. Our recent renewable fuels bill included a standard requiring fuels have 20% less lifecycle emission than the fuels they replace. How feasible would a similar standard be for coal-derived fuels?*

Answer 2. Once initial production and carbon management experience is obtained, a similar, or even tighter standard, is feasible for fuels produced from a blend of coal and biomass. Such a standard is not feasible for the initial round of commercial plants because of the uncertainties discussed in the response to Question 1 above. Such a standard is also not feasible for plants that use only coal as a feedstock. The best that coal-only plants can achieve is parity with conventional petroleum-based fuels.

This question raises a broader issue regarding implementing energy policy objectives, namely, the efficacy of emission standards for first-of-a-kind fuel plants that are subsidized by the government. The proposed legislation is not intended to obtain early production experience but rather to promote strategically significant amounts of production. But for coal-to-liquids, as well as biomass-derived fuels based on Fischer-Tropsch or cellulosic conversion, what is most needed is initial commercial production experience. For the case of coal-based plants, such initial experience should include attaining reasonably achievable levels of carbon management, as discussed in the response to Question 1. Setting standards for lifecycle CO_2 emissions may be more appropriate once that initial experience is achieved.

Questions from Senator Bernie Sanders (I-VT)

Question 3. *The Intergovernmental Panel on Climate Change has recently issued its Fourth Assessment Report Summary for Policy Makers. In that Report they concluded that the evidence that global warming is real and caused by humans is unequivocal. The MIT study, "The Future of Coal," suggested that Carbon Capture and Storage (CCS) may increase the cost of electricity from coal by 20%, but an aggressive energy efficiency campaign could be conducted, so that less electricity is used, bringing our electricity bills down by 20% or more. What do you see as the cost of liquid fuel (diesel) and gaseous fuel from coal and/or coal-biomass with CCS versus conventional diesel and natural gas in the near term and long term?*

Answer 3. I confine my answer to diesel from coal, since RAND does not yet have available useful estimates on the costs of diesel from coal-biomass. Also, our research has not addressed the production of natural gas from unconventional resources.

As I testified, there are significant uncertainties regarding the costs of constructing and operating a first-of-a-kind coal-to-liquids production facility. There are also large uncertainties associated with the costs of developing and operating a facility for carbon sequestration. Using available design data, we estimate that the costs to produce a gallon of diesel from initial coal-to-liquid plants will be between $1.40 and $1.70 per gallon, assuming no carbon management. This is a plant gate cost, and should be compared to a refinery gate price, which for diesel is currently between $2.00 and 2.10 per gallon. Once the first commercial plants are operating and experience-based learning begins to take place, costs should drop below $1.40 per gallon.

With carbon capture and geologic sequestration, we estimate that the above cost range will increase to $1.60 to $2.10 per gallon. The broad range of all of our cost estimates reflects the fact that they are derived from highly conceptual engineering designs intended to provide only rough estimates of liquid fuel production costs and the cost uncertainties regarding geologic sequestration. We are also concerned that the recent large cost increases associated with the construction of major capital intensive projects are not adequately reflected in the above estimate. It is for these reasons that we recommended in our testimony that Congress consider cost-sharing options that would promote the development of a few site-specific designs that will provide reliable cost estimates.

For some carbon management options, such as using carbon dioxide in enhanced oil recovery, the operators of coal-to-liquids plants may be able to sell their carbon at a price that recovers the extra costs associated with capturing, compressing and delivering it to the user's site. In this case, the costs of producing liquid fuels would be close to, or slightly lower than, the estimated costs without carbon management.

The above ranges refer to production costs, including a reasonable return on investment. The actual prices will be based on future wholesale prices for diesel fuel (which is based on the world oil price and refining margins) and could be significantly lower or higher.

Question 4. *I join Senator Murkowski in her concern about the need to retrofit our existing coal fired power plants to address the issue of carbon capture and storage. Some of the testimony suggested that adding "oxyfuel" to these older plants would be the best path to take as this burns pure oxygen, instead of outside air, producing a carbon dioxide-rich exhaust stream, with little or* *no NOx, so the CO_2 is more concentrated and easier to capture for sequestration. Do you have any information on the ease/feasibility of retrofitting older coal plants or other coal-burning industrial facilities with "oxyfuel"?*

Answer 4. The feasibility of retrofitting older coal plants is an extremely important issue. Because RAND has not yet had the opportunity to investigate this problem, I am not able to provide you with an informed answer.

Questions from Senator Ken Salazar (D-CO)

Question 5. *It appears from the written testimony, that liquid fuels produced from coal combined with biomass can result in lower greenhouse gas emissions than conventional gasoline. What are the technology hurdles to overcome in mixing biomass with coal to produce liquid fuels? Has the combination of biomass and coal been used at any commercial plant? What is a realistic % of greenhouse gas emissions compared to petroleum that we can expect to achieve?*

Answer 5. The most efficient and economic gasifiers that are currently available for use in a Fischer-Tropsch system are entrained-flow gasifiers. Such gasifiers operate at pressures of about 30 atmospheres (450 pounds per square inch) and require a finely-sized feed, which is either blown or sprayed into the gasifier. The technical challenge is to devise the system that grinds, pressurizes, and feeds a stream of biomass or a combination of biomass and coal into the gasifier with high reliability and efficiency. This is a fairly minor technical challenge. It is an engineering problem focusing on performance and reliability, not a science problem. To establish the design basis for such a system requires the design, construction, and operation of one or a few test rigs. These test rigs need to be fairly large so that they are handling flows close to what would be the case in a commercial plant. This is because solids are involved and it is very difficult to predict performance and reliability of solids handling and processing systems when the size or throughput of the system undergoes a large increase. Such large-scale testing could be conducted during the design and construction of a full-scale plant for co-firing coal and biomass.

Combinations of biomass and coal have been used in commercial plants in the past, but only at low biomass-to-coal ratios and with a limited number of biomass types. I believe the highest ratio used in continuous gasifier operations was at the Nuon IGCC power plant in The Netherlands, which was mentioned by Mr. Jay Ratafia-Brown in his testimony on May 24. This plant used a biomass-to-coal ratio (energy input basis) of about 1 to 5. Whereas much higher ratios, about 1 to 1, would be needed to bring carbon emissions to well-to-wheels parity with petroleum-derived fuels, assuming no carbon capture and sequestration. Additionally, the Nuon plant did not use the types of biomass that are estimated to be most abundant in the United States.

The relative percent reduction of greenhouse gas emissions that can be achieved via combined biomass and coal use depends on the fraction of the feed that is biomass as compared to coal. Consider liquid fuel production plants without carbon capture and sequestration. At one extreme, imagine a plant that is fed only biomass. Greenhouse gas emissions are generated in cultivating, harvesting and transporting biomass, but these emissions are fairly small, so that using fuel from a biomass only plant would likely entail lifecycle greenhouse gas emissions that are less than 10 percent of those from conventional petroleum-based fuels. As we add coal to the plant, the lifecycle greenhouse gas emissions increase. At a 50-50 mix, the emissions levels would be comparable to conventional petroleum, and would increase to about 2.0 to 2.3 times conventional petroleum for plants using just coal.

The preceding discussion applies to liquid fuel production plants without carbon capture and sequestration. With carbon capture and sequestration, a 50-50 mix of biomass and coal should yield lifecycle greenhouse gas emissions that are close to zero. As the biomass ratio increases, the lifecycle emissions would become negative, and as the coal ratio increases, net emissions would increase until they reached a maximum that would be very close to that associated with conventional petroleum.

Question 6. *Even with the use of biomass, there are still substantial volumes of CO2 that must be captured and safely stored. Are there any recommendations this panel has on where to locate CTL facilities to facilitate the storage of CO2?*

Answer 6. RAND has not conducted research on the geologic and technical issues associated with site selection of facilities for the storage of CO_2, and therefore cannot provide an informed response to the main thrust of this question. We strongly recommend that the U.S. government take measures as soon as possible that are required to conduct multiple large-scale demonstrations of geologic sequestration at various sites across the United States. In addition to geologic and technical issues, the site selection process should consider proximity to major coal resources. We also recommend that the site selection process should promote extensive public participation, including inputs from state and local governments, industry, and non-governmental organizations.

Question 7. *Can you discuss the water requirements for a CTL plant? Are there opportunities for reusing/recycling water in the process?*

Answer 7. RAND has conducted research on water consumption and production in Fischer-Tropsch plants that use natural gas as a feedstock to produce liquid fuels. Based on this research, we estimate that at least 1.5 barrels of water would be consumed in a CTL plant for each barrel of liquid product produced. By consumed, we mean water either used to make hydrogen or lost through evaporation. We assume that no once-through cooling water is used. To obtain the minimum water usage, the plant would need to install dry cooling towers and incorporate extensive measures to minimize water losses in the power generation and oxygen production portions of the plant. The net result of designing such a plant would be an increase in investment costs and a reduction in the operating efficiency of the plant. As a result, such a plant would only be built in areas in which water, including suitable groundwater, was in very limited supply.

In areas in which water is abundant, we anticipate that as much as 10 barrels of water would be consumed in a CTL plant for each barrel of liquid product produced. Such a plant would likely use less expensive evaporative cooling towers. The change from dry cooling towers to evaporative cooling accounts for most of the additional water losses. The remaining losses are associated with less recycling of process water.

For most CTL plants, the water consumption will fall between 1.5 and 7 barrels of water per barrel of liquid product produced, with the actual amount depending on the cost, availability, and quality of local water supplies.

Question 8. *The auto industry has developed plug-in electric hybrids, and this committee has heard testimony about all-electric cars. Can you discuss the advantages and disadvantages of using coal to produce liquid fuels vs. using coal to generate electricity to charge batteries for electric cars and hybrids?*

Answer 8. With progress in technology, electric vehicles and plug-in hybrids could be cost effective as alternatives to conventional fuels and a means of reducing greenhouse gas emissions. At present, however, the status of battery technology is such that all-electric cars are expensive and limited in acceleration and range, and therefore have a very limited market in the United States. Likewise, shortfalls in current battery technology limit the ability of plug-in hybrids to offer significant fuel savings at reasonable costs, especially compared to current and emerging non-plug-in hybrids.

If the battery problems can be overcome, the extent to which greenhouse gas emissions would be reduced would still depend on the CO_2 emissions associated with producing the electricity used to charge the batteries. If the electricity is produced from fossil fuels, these emissions could be mitigated with carbon capture and sequestration.

Whether and when sufficient progress in battery technology will occur remains an open question. As such, electric cars and plug-in hybrids, as well as hydrogen-powered vehicles, are research concepts that are deserving of federal support. However, it would be imprudent to delay measures to address global climate change or energy security based on the prospect that any of the advanced concepts are the “silver bullet.”

Questions from Senator Craig Thomas (R-WY)

Statement 9. *In terms of emissions, your testimony focuses on greenhouse gases. There are many other substances, however, that Congress has deemed appropriate to regulate and reduce. They include mercury, sulfur dioxide, nitrous oxide, particulate matter, and others.*

Question 10. *How do coal-derived fuels perform in these categories relative to the conventional fuels that they will replace?*

Answer 10. This answer addresses emissions that would occur at the plant site at which coal-derived liquids would be produced. The answer to Question 11 addresses emissions from the use of the fuel.

The front end of an FT coal-to-liquid fuel production plant is very similar to power plants that would be based on coal gasification. The primary difference is that the FT catalysis reactor is extremely sensitive to trace amounts of mercury and sulfur, so that extensive removal of compounds containing these elements will occur before the synthesis gas is allowed to enter the FT reactor.

For mercury, we anticipate that commercially available mercury control systems can capture between 90 and 95 percent of the mercury that would otherwise enter the FT reactor. This would reduce net plant mercury emissions to between 5 and 10 percent of the level that would result if the same amount of coal were burned in a conventional power plant.

For sulfur, commercially available removal systems are able to reduce sulfur concentrations to parts per billion. Net emissions of all gaseous sulfur compounds to the atmosphere would be negligible, namely, well under a hundredth of what would be released by a modern power plant meeting current standards and burning the same amount of coal.

With regard to particulate emissions, these would come from various sources within a CTL plant. Without recourse to a front-end engineering design, we are unable to provide a numerical estimate. However, it is our judgment that, given the performance of commercially available equipment for controlling emissions, particulate emission levels are unlikely to be a deciding factor on the ability to site a CTL plant.

The only significant sources of nitrogen oxide emissions are the gas turbines used to produce power used within the CTL plant and for sale. The amount of fuel consumed by the gas turbines can vary significantly based on how the CTL plant is designed. A reasonable range for a CTL plant is that 70 to 150 MW of gas turbine capacity will be in operation for each 10,000 barrels per day of liquids production capacity. Nitrogen oxide emissions from these units should be comparable to the state of the art for turbines designed for combined-cycle power plants designed for natural gas or coal.

Question 11*. Specifically, does the use of FT coal-derived diesel products have an improved footprint for nitrous oxide, particulate matter, sulfur dioxide, volatile organic compounds, and mercury over traditional sources of diesel? Please quantify the per gallon differences for criteria pollutant emissions that would result from consumption of FT coal-derived diesel products versus traditional, petroleum-derived, diesel fuel.*

China is aggressively pursuing development of a CTL industry. If the U.S. does not, is it possible that we will be importing CTL fuels from China in the future? What implications does this have for U.S. national security?

Answer 11. Published test data indicate that using FT-derived diesel fuel in existing heavy and light duty diesel engines yields reduced emissions of nitrogen oxides, particulate matter, sulfur oxides, and volatile organic compounds as compared to ultra-low sulfur diesel fuel derived from petroleum. Reported reductions are generally in the range of 15 percent for nitrogen oxides and between 25 to 50 percent for particulate matter. Somewhat greater levels of nitrogen oxide and particulate matter reductions are possible in engines modified or specifically designed for FT fuel use. While FT fuel has less than a tenth of the sulfur of the typical ultra-low sulfur diesel fuel currently being sold, we do not anticipate a full ten-fold or greater reduction in sulfur oxide emissions, since other sources of sulfur, such as lubricating oil, become noticeable contributors at these very low levels. We are still evaluating the literature results for volatile organic compounds and carbon monoxide. The results that we have already seen indicate no significant changes. Vehicular fuel use, including gasoline and diesel, is not viewed as an important source of mercury emissions.

Both the national security and economic interests of the United States would benefit from China's development of a CTL production capability. By using China's coal resources to produce CTL, China will need to import less fuel from the Middle East. This should lead to lower world oil prices and thereby, savings to all oil users, including American users, and lower export revenues to OPEC members, a number of whom are governed by regimes that do not support American foreign policy objectives.

It is highly unlikely that China will export CTL fuels since even a very large CTL industry in China is unlikely to be able to meet the shortfall between China's domestic production of crude oil and its demand for liquid fuels.

Question 12. *CTL fuels are the only currently available "drop in" replacements for military and civilian aviation fuel. Civilian aircraft flying in and out of Johannesburg, South Africa have been using CTL fuels for years. What specific actions do you believe Congress can and should take to facilitate development of a U.S. CTL industry to assist the U.S. aviation industry?*

Answer 12. RAND research shows that the benefits of developing a CTL industry in the United States do not accrue to any specific types of fuel users, but rather to all fuel users, including military and civil aviation. This is because the main benefit of producing any unconventional fuel is that it reduces demand for conventional petroleum and thereby reduces world oil prices.

Coal-derived liquids have certain performance properties that allow them to command a premium price in certain markets. In particular, because CTL fuels are nearly free of sulfur and have a very high cetane number, CTL fuels will command a premium when used as automotive and truck fuels. But these two characteristics offer less value when considering aircraft applications. As such, we believe that commercial aircraft are not a likely market for CTL fuels produced in the United States over the foreseeable future.

Our finding is that any federal actions to promote CTL use in commercial aircraft would not be productive. The critical path for CTL development is obtaining initial commercial operating experience and use in automotive applications.

Question 13. *Mr. Fulkerson testified that "If the excess CO2 produced is sequestered instead of vented then the coal synfuels process can be equivalent to petroleum in net CO2 emissions." Ms. Herzog's testimony seems to dispute this. How do we reconcile these differences of opinion?*

Answer 13. At RAND, we have conducted extensive research on this topic. Our analyses show that net CO_2 emissions from CTL plants with sequestration range from slightly less than to slightly more than petroleum. What drives the differences in our calculations are assumptions regarding the degree of carbon capture (the last few percent of removal costs much more than the first 95 percent on a $ per pound basis), the efficiency of the CTL plant, and the emissions associated with the refining of conventional petroleum. Additionally, most CTL plants co-generate electric power. This electric power will displace a conventional power plant. Assumptions regarding whether the displaced power would be from an uncontrolled coal-fired power plant or from a plant using carbon capture and sequestration also influence how CTL emissions are calculated.

Question 14. *In addition to financial incentives, in the form of tax credits, appropriations, and other tools at Congress' disposal, what regulatory approaches do you believe can be taken to advance the development of a domestic coal-derived fuel industry? Please address not only liability issues associated with carbon dioxide sequestration, but permitting of the actual plants, obstacles to construction of infrastructure, and other issues that you believe could be addressed from a regulatory, rather than a financial, standpoint.*

Answer 14. A great deal of research suggests that the most cost-effective approach for addressing both energy security and greenhouse gas reduction is through a broadly applied market-based approach that stimulates changes in energy production and consumption through increases in the costs of using petroleum-derived energy and through increases in the costs of energy uses according to their greenhouse gas emissions. An example of this approach would be an energy security tax on all petroleum-derived liquid fuels and a tax on all fossil energy fuels based on their net greenhouse gas emissions, taking into account any reductions in emissions from sequestration. This approach would help to level the playing field among different energy forms based on their potential energy security and greenhouse gas impacts. Under this approach, a domestic coal-derived (or coal and biomass-derived) fuel industry would develop to the extent that such a fuel lifecycle was economically advantageous over other options, taking into account the security and greenhouse gas taxes.

Before this or any other approach based on financial incentives can be effectively applied, however, we believe that the government needs to support early, but limited commercial operating experience for coal-based liquids production so that both industry and government are better prepared to act wisely as further information becomes available regarding world oil prices, the viability of carbon capture and sequestration, and the future requirements associated with addressing energy security and greenhouse gas emissions. The approach we are recommending is somewhat akin to insurance, or paying for an option to make a future investment even if it is decided later that the investment is not needed. For this measured approach, we see a need for financial incentives, but we see no need, at this time, for special legislation or regulatory actions to accelerate permitting or to address obstacles to construction of infrastructure.

I am unable to provide an informed comment on the regulatory issues associated with siting and operating carbon dioxide sequestration facilities, since neither I nor others at RAND have conducted sufficient research on this topic.

Question 15. *What specific technology gaps need to be closed by DOE and private industry working together to reduce the technical and economic risk of coal-derived fuel plants?*

Answer 15. In my testimony, I listed four important measures that the federal government can take, in cooperation with industry, to reduce the uncertainties in the costs and performance of coal-derived fuel plants. The first of these measures is to cost-share in the development of a few site-specific front-end engineering designs of commercial plants based on coal or a combination of coal and biomass. The second is to foster early commercial experience by firms with the technical, financial, and management wherewithal to successfully bring a project to fruition and most importantly to capture and exploit the learning that will accompany actual operations. The third of these measures is to conduct multiple demonstrations and, by way of such demonstrations, develop the regulatory framework required for a commercial sequestration industry. And the fourth of these measures is to support research, development, testing and evaluation of concepts for integrating coal and biomass for the production of liquid fuels. An early low-risk, high-payoff opportunity in this last area is the construction and operation of test rigs and/or pilot plants for evaluating the performance subsystems for co-feeding coal and biomass into entrained-flow gasifiers.

Question 16. *I have been told that coal-derived fuels have a higher cetane level. Please explain the benefits, environmental and otherwise, that are to be derived from that fact.*

Answer 16. The *cetane number* is a measure of how readily diesel fuel ignites. The higher the cetane number, the sooner a fuel will start to burn after it is injected into the combustion chamber. Coal-derived fuels from the Fischer-Tropsch process will generally have a cetane number from 70 to 80. This is significantly higher than refinery diesel, which generally ranges from 40 to 55.

In general, fuels with higher cetane numbers make starting a cold engine easier and reduce hydrocarbon and soot pollutants generated in the minute or so following a cold start. Higher cetane number fuels also tend to reduce NOx and particulate emissions, although the amount of such reductions is dependent on engine design.

Fuels with high cetane numbers are generally lower in aromatics. Coal-derived fuels based on the Fischer-Tropsch method have extremely low levels of sulfur and aromatics and these two attributes offer improved environmental performance with regard to both particulate and hydrocarbon emissions and should extend the operating life of catalytic converters used to remove pollutants from diesel exhaust.

Question 17. *We are told that Fischer-Tropsch fuels require no modifications to existing diesel or jet engines, or delivery infrastructure including pipelines and fuel station pumps. Is that true?*

Answer 17. This is true, so long as additives are allowed. In general, the additive package would be similar to that associated with conventional fuels intended for use in diesel or jet engines. For unblended (i.e., 100 percent Fischer-Tropsch liquids) coal-derived fuels, additional additives may be required to assure adequate lubricity and to protect seals.