



Energeia

Efficient and Environmentally Sound Use of Our Domestic Coal and Natural Gas Resources

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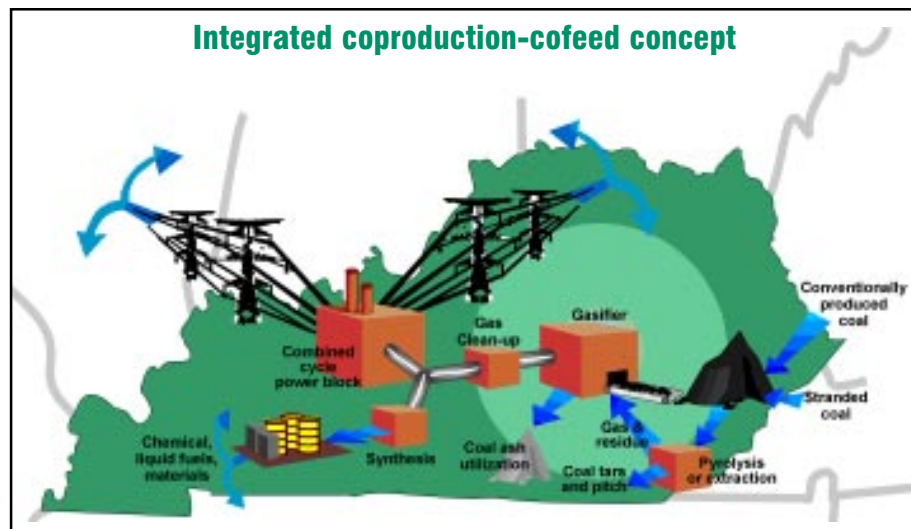
INTRODUCTION

There are presently wide disagreements among experts concerning the future availability and price of petroleum and natural gas both domestically and worldwide. If these resources are to be available to future generations at affordable prices, then the technological challenge is to use these resources in ways that offer the greatest economic benefit and the minimum environmental damage. Petroleum reigns supreme as the fuel for transportation, and from a carbon emissions perspective, natural gas is a desirable fuel for every application, with the possible exception of transportation, because of its high efficiency of use and low carbon emissions per unit of energy delivered.

However, no rational projection of world energy use suggests that oil and gas will be plentiful enough to permit coal to be eliminated from the energy mix in the near future. Even the Energy Information Administration (EIA), which is highly optimistic about the price and availability of oil and natural gas, projects that coal use in the United States (US) will increase by 20 percent between 1996 and 2015. Energy from non-fossil sources is predicted to actually decline over this period as a result of retirement of nuclear plants. EIA projections for the world energy mix forecast that coal use will increase by almost 50 percent from 5122 million tons annually presently to 7495 million tons in 2015. Only 10 percent of this increase is expected to occur in OECD countries and the former Soviet Union (FSU). In the developing world, coal use is forecast to increase by 100 percent. The best available evidence is, therefore, that coal will remain a major part of the energy mix both in the US and worldwide for at least one or two equipment generations of about 30 years.

In this real world, the challenge is to determine how to use the combination of oil, gas and coal most efficiently with the minimum environmental damage. Since coal is, by nature, a high carbon energy source, it will necessarily emit more carbon per unit of energy released than will oil or gas. If this inherently high carbon resource must be used to provide energy, then it becomes an environmental imperative to develop and implement technologies that permit coal to be used cleanly and efficiently.

The goal is to determine and encourage the optimum application of our mix of resources and technology to the mix of energy needs. The role of petroleum is obvious; our transportation infrastructure is based on oil: it has high energy density and it is easy to store and use. It is difficult to imagine transportation applications where oil does not have advantages over potential competing energy resources. The technological challenge is to continue to increase the quantity of transportation fuel from the crude barrel and to develop alternative transportation energy sources as demands exceed the available supply of oil.



The challenge for resources other than oil is much less formidable if one acknowledges that the objective is not to determine the optimum fuel for each application, but rather to determine the optimum mix of fuels for a mix of applications. It can easily be demonstrated that gas is superior to coal in most applications from a carbon

emissions perspective. This has led some to the conclusion that gas use should be emphasized in all applications. This is an erroneous conclusion unless one assumes that there is enough gas to satisfy all applications. If this is not the case and we are faced with the necessity of using a mix of gas and coal, then we must use the gas in applications where its advantages are greatest, and use coal in applications where its advantages are greatest, and our R&D effort should be targeted to assure that coal is utilized in the most efficient and environmentally acceptable manner.

To this end, the US Department of Energy (DoE) and Mitretek are evaluating a concept that combines the use of gas and coal for the highly efficient production of electric power and high quality transportation fuels. In its simplest form, this co-production co-feed (CoCo) concept consists of diverting coal-derived synthesis gas from the combined cycle power block of an Integrated Coal Gasification Combined Cycle (IGCC) unit to a liquid synthesis reactor. The unreacted synthesis gas from the liquid synthesis reactor, and imported natural gas, are then combusted in the downstream combined cycle power generation unit. Combining processes in this manner accomplishes the equivalent of natural gas to liquid synthesis while eliminating the conversion losses associated with the production of synthesis gas from natural gas. The advantages of this concept are described in detail in this paper. They include:

- 1) Significant reductions in capital cost compared to separate production of power using IGCC and production of transportation fuels from natural gas
- 2) Improvements in efficiency and significant reductions in CO₂ emissions compared to production in separate facilities
- 3) Improved availability of IGCC-power generation, since gas can be used during gasifier maintenance downtime
- 4) Use of natural gas in the transportation sector without the expensive vehicle modifications needed for direct natural gas use and with a savings in CO₂ compared to the direct use of compressed natural gas (CNG) and liquefied natural gas (LNG)
- 5) A hedge against uncertainty in future gas prices for developers
- 6) A major building block for future integrated energy facilities that can use a combination of fossil, waste, and renewable sources.

THE CONCEPT

The overall concept is illustrated in Figure 1. In a baseline IGCC power plant (solid lines), oxygen-blown coal gasification is used to produce synthesis gas. This synthesis gas is cooled in radiant gas coolers to produce high pressure steam, cleaned to remove sulfur compounds and other impurities, and combusted in gas turbines to produce electric power. The residual heat in the combustion gases exiting the gas turbines is used to produce steam. This together with the steam from the gasifiers, is used to create additional electric power in steam turbines. After providing internal power for plant facilities, the net output of the plant is sent to the power grid for distribution.

This concept of using both coal and natural gas to co-produce power and transportation fuels utilizes both feedstocks optimally. Coal cannot be combusted directly in gas turbines: it must first be converted into clean synthesis gas. Once gaseous, the high efficiencies associated with gas turbine performance become accessible to coal. This is the rationale behind the IGCC concept. However, once the synthesis gas has been produced from the coal, it is even more efficient to use this gas to produce liquid transportation fuels through Fischer-Tropsch (F-T) synthesis technology. Using a once-through F-T process, the inefficiencies of carbon dioxide removal and synthesis gas

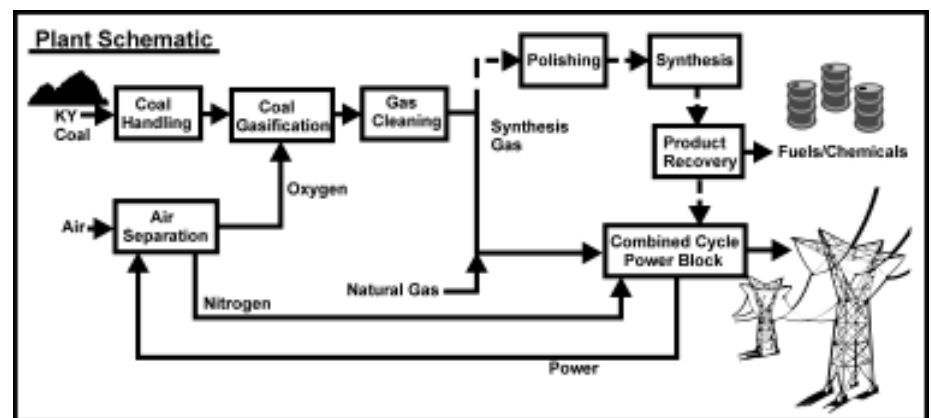


Figure 1. Coproduction Cofeed (CoCo) Configuration

In addition to electric power, this plant can also co-produce valuable chemicals and clean transportation fuels. In this co-production configuration (dotted lines), instead of directly combusting the clean synthesis gas from coal in the gas turbines, as was the case in the baseline IGCC facility, it is passed through a synthesis reactor where the carbon monoxide and hydrogen are catalytically combined to form high value chemicals and ultra-low emission transportation fuels. After fuels and chemicals recovery, the unconverted synthesis gas is then sent to the combined cycle power block to produce electric power. A large portion of the synthesis gas that had previously been used to produce electric power has now been used to produce fuels and chemicals. Thus, in order to produce the same electric power output as the baseline IGCC facility, natural gas is imported to the plant and combusted in the gas turbines to compensate for the synthesis gas used to coproduce fuels and chemicals. In this way, the total plant electric power output can be kept the same as the baseline IGCC facility.

recycle can be avoided and the unconverted synthesis gas can be directly combusted in the gas turbines thereby benefitting from the high efficiency of gas turbine power production. This sequence of coal-derived synthesis gas utilization to produce fuels and power is thus optimized. For natural gas, optimum efficiency is realized by direct combustion in the gas turbines as in the concept described here. Thus both coal and natural gas are optimized. Making F-T fuels from natural gas first requires the natural gas to be reformed to synthesis gas at an efficiency penalty. Only then can this natural-gas-derived synthesis gas be used to produce fuels using F-T synthesis.

In the future, as the price of natural gas increases, additional coal gasifiers can be installed. This will allow the phasing out of expensive natural gas and the greater utilization of cheaper coal. This phased technology implementation (PTI) approach significantly reduces risks to project participants associated with first-of-a-kind plants.

Impact of the Co-production Co-feed (CoCo) Concept on Carbon Emissions

To quantify the advantages of the concept of co-feeding both coal and natural gas to the facility to produce both power and transportation fuels, it is necessary to compare this concept to the alternatives for producing electric power and fuels in separate facilities. First, the impact on carbon use and hence on the carbon dioxide emissions spawned during energy production is considered.

Figure 2 shows simple schematics for the production of 6,000 BPD of F-T diesel fuel from 50 million cubic feet per day (MMSCFD) of natural gas feed, and production of 400 MW of power from 3,200 TPD of coal using separate facilities. For separate production, the total carbon used in both coal and

natural gas feeds is 3,141 TPD. Production of 400 MW from coal using IGCC requires 2,272 TPD of carbon. Therefore, the net carbon attributable to liquids production is 0.143 tons per barrel. Since there are 187 million barrels in a quad of transportation fuels, the net carbon emissions for production and end-use of one quad of fuels from this case is 27 million tons.

Now consider the bottom half of Figure 2. This shows the coproduction of power and fuels using the CoCo concept of cofeeding natural gas and coal in one integrated facility. In this case, the same quantity of coal is used (3,200 TPD) as in the separate case described above. The same quantity of products is produced as in the prior case (400 MW and 6,000 BPD) but now, in the integrated facility, only 34 MMSCFD of natural gas is required. The net carbon attributable to the liquids pro-

duction in this case is, therefore, the total carbon fed to the system (2,861 TPD) minus the carbon used to produce the 400 MW of power (2,272 TPD). This is equal to only 0.097 tons per barrel compared to 0.143 tons of carbon per barrel for the prior case of separate production. On a quad basis, this is equal to 18 million tons of carbon compared to 27 million for the prior case. This concept, therefore, represents a very significant contribution to reducing potential greenhouse gas emissions by optimizing the use of both coal and natural gas as feedstocks.

The schematic in Figure 3 illustrates coproduction if coal by itself were to be used to coproduce 400 MW of power and 6,000 BPD of liquid fuels. In this single feedstock coproduction case, 4,760 TPD of coal would be required, equivalent to 3,381 TPD of carbon. The net carbon attributable to liquids production would be the total carbon feed to the system (3,381 TPD) minus the carbon used to produce the 400 MW of power (2,272 TPD). This is equal to 0.1823 tons of carbon per barrel, or 34 million tons per quad. Thus the cofeeding of natural gas to the integrated facility significantly reduces the carbon emissions compared to the single feedstock coal plant.

Figure 4 summarizes the emissions per quad of transportation fuel produced and consumed; and compares them to the baseline carbon emissions from crude oil. Also shown are carbon emissions from utilizing natural gas used directly in transportation as either compressed natural gas (CNG) or as liquefied natural gas (LNG). It can be seen that carbon emissions from F-T liquids produced from natural gas are about equal to crude oil, while carbon emissions produced using the CoCo concept are about equal to those from the direct use of natural gas. When these emissions are compared on a relative carbon-emissions-per-mile basis (Figure 5), the CoCo concept produces the lowest emissions, even lower than the direct use of CNG. The CoCo concept achieves these low carbon emissions and produces high quality liquid transportation fuels compatible with the existing liquid fuels infrastructure. In contrast, CNG use requires expensive vehicle modifications and the introduction of a CNG-based infrastructure for distribution. If the cost of modification to utilize CNG is \$3,500 per vehicle, then the total cost of modifying enough vehicles to use 6,000 BPD of fuels is about \$590 million, which approaches the total capital cost of the CoCo plant. This amount is about seven times the capital needed to modify an existing IGCC plant to coproduce liquids fuels.

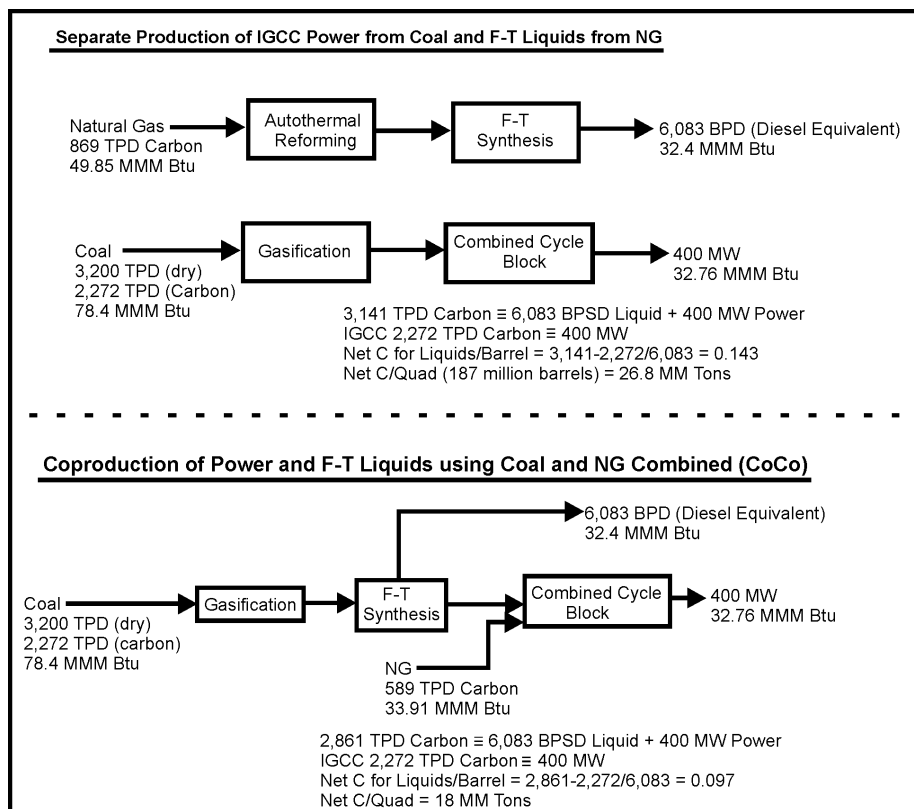


Figure 2. Separate Production vs. Coproduction of F-T Liquids and Power

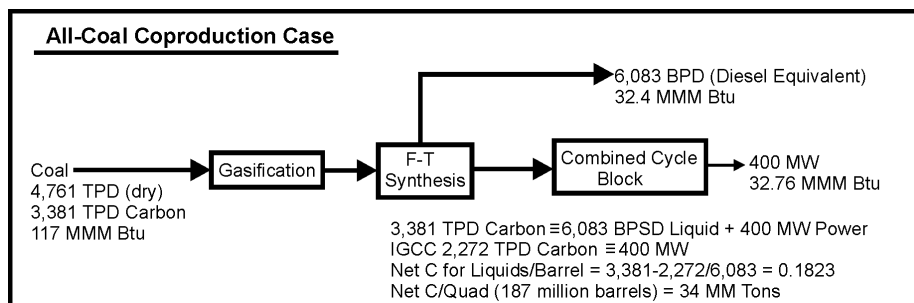


Figure 3. Coproduction Using Coal-only as Feedstock

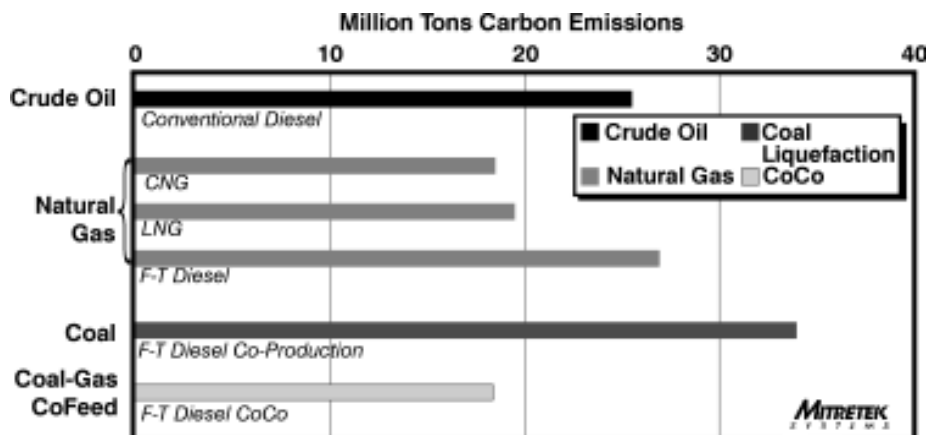


Figure 4. Carbon emissions per quad transportation energy supplied

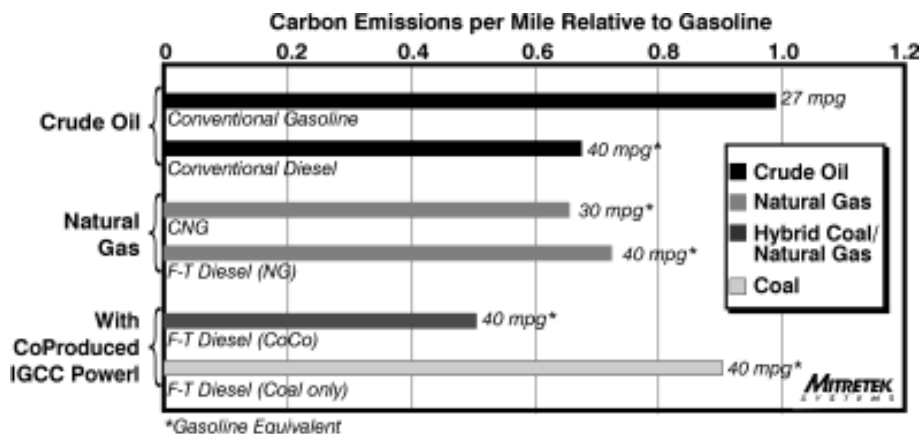


Figure 5. Carbon emissions per mile relative to gasoline (includes production, combustion, and relative engine efficiency)

IMPACT OF THE COPRODUCTION COFEED CONCEPT ON ECONOMICS

To compare the relative economics of the CoCo concept, it is first necessary to examine the economics of the alternatives. A natural gas combined cycle plant for the production of power would be the lowest capital cost option (in the range \$500-\$600 per kW) if electric power was the only desired product. The required selling price (RSP) of the power is very dependent on the cost of the natural gas feed. For example, if natural gas is \$2.50 per MMBtu, then this RSP for power is \$0.027 per kWh, for a 15 percent return on equity (ROE) and 33 percent equity financing. As natural gas price increases, the RSP of the power increases. When natural gas is \$4.00 per MMBtu, the RSP of the power rises to \$0.037 per kWh.

If the power were to be produced using IGCC technology, the capital cost of the plant would be significantly higher (in the range \$1,400-\$1,500 per kW). Using the same economic assumptions as for the natural gas plant, the RSP of power from the IGCC plant, if coal is \$24 per ton, would be \$0.037 per kWh, the same as power from the natural gas com-

binized cycle plant if the natural gas price is \$4.00 per MMBtu.

The capital cost for the CoCo plant is less than the capital needed for production of the power and liquid fuels in separate facilities from coal and natural gas. For a CoCo plant coproducing \$400 MW of power and 6,000 BPD of liquids (see Figure 2), the capital cost is about \$670 million. Production of 400 MW of power using IGCC technology would cost about \$600 million, and production of 6,000 BPD of fuels from natural gas would cost about \$150 million for a total of around \$750 million. However, if an existing IGCC facility were to be modified to include an F-T unit for liquid fuels production, then the additional cost to accomplish this would be only a fraction (about 10-15 percent) of the capital of the IGCC facility. This is equivalent to a capital cost of fuels of about \$12,000 per daily barrel compared to \$25,000 per daily barrel for stand-alone natural gas to liquids facilities.

The economics of the CoCo concept facility are shown in Figure 6. In this figure, the RSP of the F-T liquids are

shown as a function of the natural gas price. Also shown is the wholesale value of electric power as a function of the natural gas price. The required revenue of the plant comes from sales-of-power, at the power value for a given natural gas price, and sales of liquid fuels. If natural gas is \$2 per MMBtu, then power can be sold for \$0.027 per kWh and the RSP for the liquid fuels must be \$26 per barrel to accrue the required revenue. As natural gas prices rise, the value of power increases so that the RSP of the liquid fuels can decrease and still maintain the same revenue. For example, if natural gas is \$3.50 per MMBtu, the value of power is \$0.033 per kWh, and the RSP of liquid fuels drops to about \$22 per barrel.

It must be emphasized that these F-T fuels are of a high quality, unattainable by refining conventional petroleum. Engine tests conducted by South West Research Institute show tail pipe emissions from these fuels that have 40 percent less hydrocarbons, 46 percent less carbon monoxide, and 30 percent less particulates than emissions from petroleum diesel. As a result of this high quality and the consequent environmental benefits, F-T fuels will command a premium over crude oil.

Costs of fuels produced from this type of coproduction facility are, therefore, almost competitive with the price of crude oil. However, because of the technical and economic risks associated with deployment of First-of-a-Kind plants, incentives would be required to provide an acceptable rate of return for potential developers. Examples of incentives that could be used to promote this technology include: section 29 of the tax code, accelerated depreciation, and total or partial exemption of state or federal fuel excise tax on the fuels produced in the plant. The incentives needed to make this concept a profitable proposition are much lower than incentives currently being used to promote ethanol and other alternative fuels. For this CoCo facility, a fuels excise tax exemption of about 20 cents per gallon or an investment tax credit of 20 percent would be sufficient to yield a 15 percent return on equity for developers at current oil and gas prices, and still permit power to be sold competitively at less than 3 cents per kWh.

Although the granting of state or federal incentives may appear to result in a net loss of revenue to government, economic analysis has shown that revenues returned to state and federal

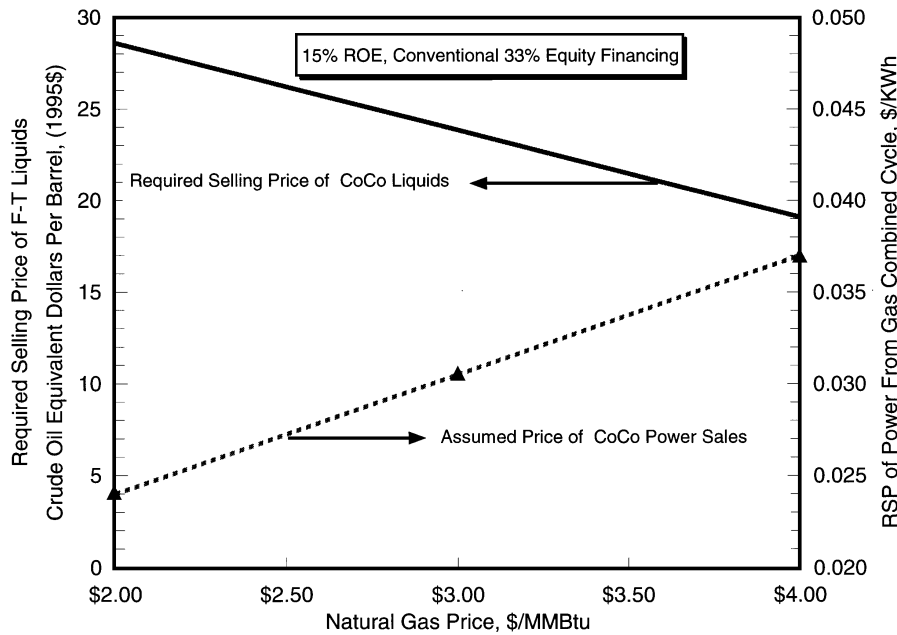


Figure 6. Required selling price of F-T liquids from CoCo facility vs. price of natural gas

government from corporate and salary taxation as a result of such projects are much higher than funds applied to incentives. Deployment of such projects results in considerable benefits to both state and country, including creation of new jobs associated with the deployment of domestic industries based on use of indigenous materials and resources. These technologies can utilize waste and stranded coals for the production of clean, high efficiency power and ultra-low emission transportation fuels from domestic resources. These alternative fuels qualify under the 1992 Energy Policy Act for use in state or federal vehicle fleets. Because these fuels are compatible with existing infrastructures for distribution and end-use, no costly vehicle modifications are necessary to use them. This savings alone would be more than the lost revenue from fuel tax exemptions needed to assure the profitability of the first pioneer plants. Also, it has already been shown that the CoCo concept described here has a significant impact on reducing potential greenhouse gases. Deployment of this technology will improve U.S. competitiveness by promotion and development of advanced technologies to produce clean, efficient power and transportation fuels from coal that can be deployed worldwide.

NATIONAL IMPLICATIONS OF DEPLOYING THIS TECHNOLOGY

Figure 7 shows the potential impact of deploying this CoCo concept on a

national scale with respect to production of power, high quality F-T liquid fuels, and reduction in emissions of carbon dioxide. Referring to Figure 7, the first set of bars shows the amount of electric power produced from coal and natural gas in trillion kWh in 1995. In 1995, 17.3 quads of coal and 3.32 quads of natural gas were used to produce 1.7 and 0.3 trillion kWh (TkwH) of power respectively. EIA projects that by the year 2015, 20.9 quads of coal will be used to produce 2.05 TkwH of power in conventional pulverized coal (PC) plants, and 8.7 quads of natural gas will be used to produce 1.18 TkwH of power for a total of 3.24 TkwH. This projection is shown in the second set of bars.

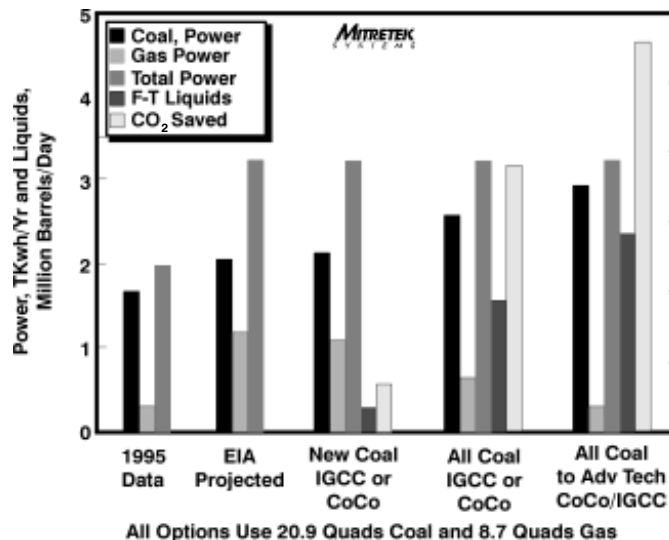


Figure 7. Impact of implementation of CoCo Technology Liquids produced, CO₂ saved in year 2015

The third set of bars in Figure 7 shows the impact of using the CoCo concept by 2015, assuming the same consumption of coal and natural gas as in the EIA projection. The year 2015 is taken only as an example to be consistent with the EIA projections. Actual deployment of CoCo technology could occur over a longer span of time depending on demand and economics. In this analysis, it is assumed that the additional 3.7 quads of coal used by 2015 will be used in IGCC plants (42 percent efficiency) rather than in conventional PC plants (33 percent efficiency) as assumed in the EIA projection. Under this assumption, this amount of coal produces more power than in the EIA scenario. This allows 0.58 quads of natural gas previously used for power production in the EIA scenario to be used in the CoCo concept. When used in this configuration, 280,000 BPD of liquid fuels can be produced. Thus, the same total quantity of power can be produced together with 280,000 BPD of liquid fuels for the same quantities of coal and natural gas as in the EIA projection for 2015. Since the same amount of coal and natural gas has been used, the same quantity of carbon is emitted as carbon dioxide. Thus, the 280,000 BPD of liquid fuels is produced for **no** additional carbon emissions. A total reduction in carbon emissions occurs in this case equal to the carbon associated with the production and use of 280,000 BPD of petroleum from crude oil. This is equivalent to 14 million tons of carbon annually, which is twice the carbon emissions savings that would be achieved by converting one million homes to self sufficient solar power.

If **all** the existing and projected coal-fired electric power capacity were replaced with IGCC technology by 2015, then sufficient natural gas could be diverted from direct power production and used in CoCo configurations to produce 1.5 million BPD of liquid fuels with no additional increase in carbon emissions. This is shown in the fourth set of bars in Figure 7. Carbon emissions in this case would be reduced by the amount of carbon contained in the crude oil needed to produce 1.5 million BPD of fuels: 76 million tons annually.

If the IGCC plants were to use advanced technologies including oxygen membrane (OM) air separation technology so that the overall efficiency of power generation was increased to 48 percent, then over 5 quads of natural gas could be diverted for use in the CoCo concept, to produce 2.35 million BPD of liquid fuels. In addition, if the capital cost for IGCC could be reduced by using these advanced technologies to about \$1100 per kW, the resulting cost of liquid fuels from a CoCo facility would be competitive with the current price of oil.

The production of 2.35 million BPD of high quality liquid fuels would save over \$25 billion per year in our balance of trade, equivalent to the capital cost of 38 CoCo plants. Deployment of these plants would reduce carbon emissions by 111 million tons annually. EIA projects that U.S. emissions of carbon will increase by 375 million tons per year by 2015, thus deployment of CoCo technology could reduce this amount of one third.

CONCLUSIONS

A concept for the efficient use of coal and natural gas to coproduce electric power and high quality liquid transportation fuels in one integrated facility has been proposed. This concept combines

Integrated Coal Gasification Combined Cycle (IGCC) technology with slurry-phase Fischer-Tropsch (F-T) synthesis in a configuration that uses once-through F-T to produce liquid fuels and the tail gas is sent to the combined cycle power block for power production. Natural gas is used to supplement the power cycle by direct combustion in the gas turbines. This integrated coproduction cofeed (CoCo) concept, produces 33 percent fewer carbon emissions than production of the same quantity of power and liquid fuels in separate facilities at a lower cost.

This concept allows transportation fuels from coal to be produced and used for 50 percent fewer carbon emissions per mile than transportation fuels from conventional petroleum, and 23 percent less than from direct use of natural gas in transportation. A CoCo plant coproducing 400 MW of power and 6,000 BPD of liquid fuels could be built for about \$650 million. If the cost of modification to utilize CNG is \$3,500 per vehicle, then the total cost of modifying enough vehicles to use 6,000 BPD of fuels is \$590 million; approaching the total capital cost of the CoCo plant.

Liquid transportation fuels from this CoCo plant can be produced for about \$26

per barrel on a crude oil equivalent basis if natural gas is \$2.50 per MMBtu. Costs of fuels produced from this type of coproduction facility are, therefore, almost competitive with the current price of crude oil. However, because of the technical and economic risks, incentives would be required to provide an acceptable rate of return for potential developers. Much lower incentives than are currently being used to promote ethanol and other alternative fuels would be needed to make this concept a profitable proposition. For example, a fuels excise tax exemption of about 20 cents per gallon or an investment tax credit of 20 percent would be sufficient to yield a 15 percent return on equity for developers at current oil and gas prices, and still permit power to be sold competitively.

If this CoCo concept were used with advanced clean coal power systems and deployed nationwide to utilize all current coal-fired power plants, 2.35 million barrels per day of high quality liquid transportation fuels could be produced with a reduction of carbon emissions equal to over 20 percent of the current carbon emissions from the transportation sector.

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