For energy security and greenhouse gas reductions, plug-in hybrids a more sensible pathway than coal-to-liquids gasoline

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Introduction

The House Committee on Energy and Commerce (2007) is considering enacting policies to subsidize the production of transportation fuel from coal-to-liquid projects (CTL). This policy would enhance national security by lowering oil imports, but encouraging plug-in hybrids is a less costly policy that also reduce oil imports and does more to lower greenhouse gas (GHG) emissions. This paper compares GHG emissions of CTL gasoline to the emissions of plug-in hybrid vehicles powered with electricity generated with coal. A life cycle approach is used so that all stages of the life cycle of each fuel, from production to use, are included. This analysis allows us to better identify benefits, or disadvantages, of an energy future that includes coal as a transportation fuel.

Coal-to-Liquids Method

Conventional vehicles can be fueled with gasoline produced from coal. The life cycle of this gasoline includes the production, processing and transport of the coal; the emissions at the CTL plant (including the emissions from producing the electricity used at these plants); the transport of the gasoline from the plant to the fueling stations; and finally the combustion of the gasoline. The GHG emissions associated with the mining, processing, and transport of the coal are obtained from Jaramillo, Griffin, and Matthews (Jaramillo, Griffin et al. 2007). According to Jaramillo et al, the total emission factor from these three stages of the coal life cycle range between 8.2 and 16.4 pounds CO_2 equivalents per MMBtu of coal (average is 11.6 pounds CO_2 equivalents per MMBtu of coal). This emission factor can then be converted to pounds CO_2 equivalents per MMBtu of liquid fuel produced using the amount of coal used at the CTL plant, as described below

CTL plants use coal to produce liquid fuels via the Fischer-Tropsch (FT) reaction. The conventional CTL plant design produces more diesel than gasoline, however catalysts can be added to the plant to upgrade some of the diesel and waxes produced in the Fischer-Tropsh reaction into gasoline. The overall efficiency of such plant is around 52% (HHV). Inputs and outputs to this plant can be seen in Table 1 (Bechtel 1993). CTL plants are ideal candidates for CCS. These plants have to separate the CO_2 from the gas stream before it enters the FTreactor, so the only requirement would be to add CO_2 compression to the plant. This would imply an energy penalty, as electricity is needed to perform this compression: Approximately 100 kWh per ton of CO_2 compressed.

Table 1: CTL Plant Inputs and Outputs (Bechtel 1993).

CTL Plant Inputs	
Coal (tons/day)	18,575
Methanol (tons/day)	209
Butanes (tons/day)	441
Purchased Electricity (no CCS) (MWh/day)	1,354
Purchased Electricity (80% CCS) (MWh/day)	3,750
CTL Plant Outputs	
Propylene (MMBtu/day)	12,306
Propane (LPG) (MMBtu/day)	6,119
Gasoline (MMBtu/day)	186,856
Diesel (MMBtu/day)	51,619
Carbon Lost (tons/day)	7,813

As seen in Table 1, electricity is used at the CTL plants. Our model includes the emissions from electricity generation. In our worst-case scenario, the current average electricity mix is used, with a power plant emission factor of 1.3 pounds CO2 Equivalent per KWh and an average upstream emission factor of 0.1 pounds CO_2 Equivalent per KWh. Accounting for the 9% losses in the electrical transmission system (EIA 2005) would yield a total electricity life cycle emission factor of 1.53 pounds CO_2 Equivalent per KWh. For our best-case scenario, CTL plants would buy electricity from low-carbon sources such as renewables or nuclear.

Adding the emission factors from coal mining, processing, and transport, with the emissions from the CTL plant and from the electricity consumed at the CTL plant, results in a well-to-plant emission factor. Since CTL plants produce more than one product, this well-to-plant emission factor needs to be allocated among the co-products. The allocation method presented in the GREET model is used: allocation is done by using the energy content of the co-products (Wang, Weber et al. 2001). The allocated well-to-wheel emission factor for our worst-case (no CCS, current electricity mix) CTL plant is 190 pounds CO_2 equivalent per MMBtu of gasoline and 50 pounds CO_2 equivalent per MMBtu of diesel. If 80% CCS is performed at the plant and a zero-carbon electricity source is used, the allocated emission factors would be 50 pounds CO_2 equivalent per MMBtu of gasoline and 15 pounds CO_2 equivalent per MMBtu of diesel.

In order to obtain a well-to-wheel emission factor for gasoline from coal, the emissions from the transport of this gasoline to the refueling stations and the emissions from the combustion of the gasoline must be added to the well-to-plant emission factor previously described. According to GREET the emissions from transporting gasoline are 1.2 pounds CO_2 equivalent per MMBtu of gasoline. In addition the combustion emissions from the gasoline produced at our CTL plant (carbon content of 46.17 pounds C per MMBtu) are 170 pounds CO_2 equivalent per MMBtu of gasoline. The total well-to-wheel emission factor is then 360 pounds CO_2 equivalent per MMBtu of gasoline in our worst-case scenario and 220 pounds CO_2 equivalent per MMBtu of gasoline in our best-case scenario. To covert these into an annual emissions numbers, as shown in Figure 1, an energy content for gasoline of 0.11 MMBtu per gallon was used, as well as a vehicle efficiency of 34 mpg and an annual driving distance of 12,000 miles.

Plug-in Hybrid Method

A plug-in hybrid vehicle uses a storage battery to travel solely by electricity until the battery is depleted, then operates as a traditional gasoline-electric hybrid vehicle (Frank 2007). To determine average annual life cycle GHG emissions from plug-ins, the combustion and fuel cycle impacts for both electricity and petroleum are estimated.

Impacts from electricity

This analysis assumes two separate scenarios for electricity generation used to charge plug-in hybrids – bituminous coal in a pulverized coal power plant and bituminous coal in an integrated gasification combined cycle power plant with carbon capture and sequestration (IGCC w/ CCS). Using the carbon and heat content of bituminous coal and adjusting for the fraction oxidized, coal contains 204 pounds of CO_2 per million BTU of combusted fuel (HHV) (EPA 2006). Assuming a 39% pulverized coal plant efficiency (Rubin, Rao et al. 2004), this yields 1.78 pounds CO_2 per kWh of electricity at the plant gate. Additional fuel is required to account for the approximate 9% losses in electrical transmission and distribution (EIA 2005), yielding a total CO_2 content of electricity of 1.95 pounds CO_2 per kWh delivered to the wall outlet. Upstream impacts from the coal fuel cycle, which account for methane and CO_2 released during mining, processing, and transportation are taken from Jaramillo, Griffin, and Matthews (Jaramillo, Griffin et al. 2007) as described in the previous section. Incorporating the fuel cycle impacts, total life cycle emissions from a pulverized coal plant at the wall outlet are 2.06 pounds CO_2 Equivalents per kWh.

CO_2 emissions from an IGCC w/ CCS plant assume a 32% plant efficiency (due to the additional energy required for capture and storage) (Rubin, Rao et al. 2004), and assumes 80% of the CO_2 emissions from combustion are recovered and sequestered. Electricity at the IGCC w/ CCS plant gate has an emissions factor of 0.43 pounds CO_2 Equivalents per kWh. Including the upstream fuel cycle and transmission losses as above, total life cycle emissions from an IGCC w/ CCS plant at the wall outlet are 0.61 pounds CO_2 Equivalents per kWh.

For electrical efficiency of the plug-in hybrid, this analysis uses 3.5 miles per kWh (EPRI 2001). This figure represents plug-to-wheel efficiency and includes losses in the battery and charger.

Impacts from gasoline

Life cycle GHG factors from gasoline are used in estimating impacts from the gasoline portion of plug-in hybrid travel and for the gasoline base case for a conventional sedan. A well-to-wheels analysis is employed to estimate life cycle emissions from gasoline. Gasoline has a combustion emissions factor of 19.42 pounds CO_2 Equivalents per gallon using higher heating values (EPA 2006). Using the GREET 1.6 model, upstream emissions from petroleum extraction, refining, and transportation result in an additional 6.4 pounds CO_2 Equivalents per gallon (Wang 2001). Plug-in hybrids are assumed to have an average gasoline fuel economy similar to a Toyota Prius, 44 mpg (EPA 2006), while the conventional sedan is assumed to have a fuel economy of 34 mpg.

Life cycle CO_2 emissions from plug-in hybrids

Plug-in hybrids can have various configurations, battery capacities and electric ranges. This analysis assumes a plug-in hybrid built on a Toyota Prius platform in a parallel configuration with an all-electric range of 60 miles. There are several firms who will perform aftermarket conversions of existing Priuses to plug-in hybrids, and it a reasonable assumption that a similar body and architecture would be used on original equipment manufacturer models. A 60-mile electric range is at the upper end of the expected ranges for plug-ins, and is chosen to provide a comparable alternative to coal-to-liquids in reducing petroleum consumption.

The average annual percentage of travel powered by electricity is required to estimate life cycle emissions from a plug-in hybrid. The National Household Transportation Survey performed by the U.S. Department of Transportation in 2001 estimated that about 60% of vehicles travel less than 30 miles per day (USDOT 2003). To determine the fraction of vehicle travel powered by electricity or gasoline, the percentages resulting from the cumulative distribution function of daily vehicle miles traveled constructed in Samaras and Meisterling are used (Samaras and Meisterling 2007). The distribution was constructed with data from the USDOT survey and from Sanna (Sanna 2005) and estimates electricity would power about 85% of average annual vehicle travel for a plug-in hybrid with a 60-mile electric range, assuming vehicles are charged once per day. Vehicles are assumed to travel 12,000 miles per year (USDOT 2006). Applying the electricity emissions factor to 85% of annual average travel and gasoline emissions factors to the remaining 15%, life cycle emissions from plug-in hybrids are estimated.

Results and Discussion

Figure 1 shows the annual life cycle GHG emissions for conventional sedans using CTL gasoline and for plug-in hybrid vehicles. It can be seen that gasoline derived from CTL plants with no CCS could increase GHG emissions from vehicles by almost 60%. If CCS is available, then a reduction of less than 6% could be obtained. It is important to note, once again, that in this best-case CTL scenario, not only is there CCS at the CTL plant, but also a low-carbon electricity source is used for CTL production. This might not be a very realistic assumption, but is presented here to show that at *best* we could only obtain a very small reduction in GHG emissions following a path of increased CTL production.

Plug-in hybrids look more promising as a pathway for reduction of GHG emissions. Even if coal electricity without CCS is used, plug-in hybrids could lead to a GHG emissions reduction of almost 25%. This demonstrates the *worst* case for plug-in hybrids, as GHGs would be further reduced with a low-carbon electricity portfolio. It is important to note however, that this analysis does not include the emissions from manufacturing the storage battery used in plug-in hybrids. If GHG emissions from lithium-ion batteries for plug-in hybrids are included, total annual GHGs from plug-ins would increase by about 800-1,500 pounds of CO_2 Equivalents, depending if a twelve or eight-year vehicle life is assumed (Samaras and Meisterling 2007). Battery technologies are difficult to predict, but even when emissions from current battery production are included, plug-in hybrids result in substantially lower emissions than CTL pathways.

In this analysis we assumed that conventional sedans have achieve an efficiency of 34 mpg, while plug-in hybrids have an gasoline efficiency of 44 mpg and an electric range of 60 miles. Fuel efficiency and vehicle types will affect the results, however a conventional sedan would have to achieve 69 mpg before emissions from coal-to-liquids gasoline are comparable with plug-in hybrids at their current fuel efficiency. Similarly, electrical efficiency of plug-ins would have to fall by 50% to 1.6 kWh per mile for emissions from plug-ins to be comparable to coal-to-liquids.

Enhancing energy security is the main argument in favor of supporting CTL developments. CTL will help the U.S. decrease its demand for foreign sources of oil. We find, however, that plug-in hybrids could also help the U.S. achieve this goal. Since about 60% of passenger vehicles travel less than 30 miles per day (USDOT 2003), plug-in hybrids can travel on electricity for nearly all of daily travel, displacing up to 85% of gasoline use in vehicle travel each year. For these reasons, plug-in hybrids are better suited than CTL fuels to simultaneously achieve the goals of energy independence and reducing GHG emissions, and a major program to subsidize CTL may not make much sense.

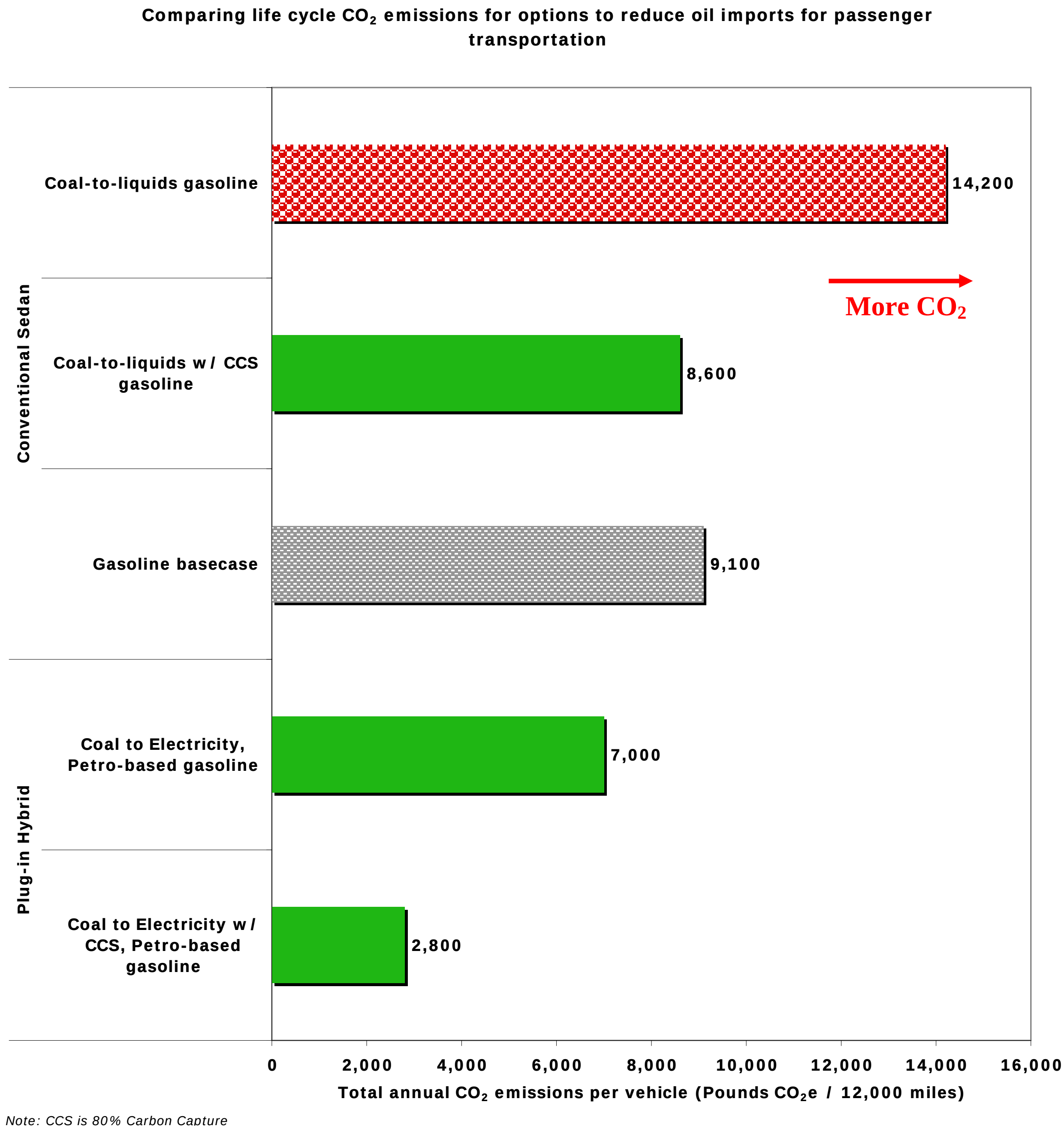

Figure 1 – Comparing life cycle CO_2 emissions from plug-in hybrids, coal-to-liquids gasoline, and conventional gasoline

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