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The implications of using hydrocarbon fuels to generate electricity for hydrogen fuel powered automobiles on electrical capital, hydrocarbon consumption, and anthropogenic emissions

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ABSTRACT

This paper considers some of the impacts of adopting hydrogen fuel cell powered electric automobiles in the US. The change will need significant adjustments to the electrical generation industry including additional capital and hydrocarbon fuel consumption as well as impacting anthropogenic greenhouse emissions. Examining the use of three fuels to generate hydrogen fuels, using three production methods, distributed in three geographic scenarios, we determine that while the change reduces anthropogenic greenhouse emissions with minimal additional electrical generation capital expenditures, it accelerates the use of natural gas. Electrolysis provides a sustainable, longer-term solution, but requires more capital investment in electrical generation and yields an increase in anthropogenic greenhouse emissions.

1. Introduction

This paper estimates the economic disruption and change in anthropogenic greenhouse gas emissions resulting from the electrical industry using hydrocarbon fuels to generate electricity for firms producing enough hydrogen fuel for a full market conversion from gasoline-fueled engines to hydrogen-fuel-cell-powered electric motors without reducing current miles driven given assumed automobile hydrogen-fuel efficiency. Further, it presents estimates of the additional capital investment required, the increase in hydrocarbon fuel consumed, and the net change of emissions of CO_2 and N_2O produced by the generation of the electricity needed to achieve that goal. Increases in electrical generation capital and hydrocarbon fuel consumption reflect some of that economic disruption, and changes in the net emissions of CO_2 and N_2O combine to estimate the impact on anthropogenic greenhouse gas emissions under the same conditions. Finally, we estimate the CO_2 produced by the reforming process if industry does not capture it.

2. Methodology

Given the large-scale increase in electrical generation required, we assume a modular approach to capital implementation and technology. In this case, firms build sufficient new generation capacity using current plant design capacities and characteristics. Doing so avoids detailed microeconomic issues regarding specific plant marginal productivities and marginal costs. Further, as this effort restricts itself to non-price issues, the model need not consider the impact of the increase in consumption on the market price for electricity.

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This model estimates resource consumption and anthropogenic greenhouse gas emissions based on the additional generation; the type of hydrocarbon fuel used for that generation; and the technical fuel efficiency of the electrical generation plants, such that:

$$Emissions = f(Electrical\ Generation\ Produced,\ Hydrocarbon\ Fuel\ Type,\ Electrical\ Generation\ Fuel\ Efficiency)$$

$$Resource\ Consumption = f(Electrical\ Generation\ Produced,\ Hydrocarbon\ Fuel\ Type,\ Electrical\ Generation\ Fuel\ Efficiency)$$

The quantity of driving demanded, the fuel efficiency of hydrogen-fuel cells at the wheels, and the cost of electrical production all directly affect the quantity of electrical generation produced. The cost of electrical production also indirectly affects the quantity of driving demanded by impacting the price of hydrogen fuel. The cost of electrical production depends on the type of hydrocarbon fuel used to generate the desired electricity and its fuel efficiency.

$$Electrical\ Generation\ Produced = f(Quantity\ Driving\ Demanded,\ Fuel\ Efficiency\ of\ Hydrogen\text{-}Fuel\ Cells,\ Marginal\ Cost\ of\ Electrical\ Production)$$

$$Quantity\ Driving\ Demanded = f(Price\ of\ Hydrogen\ Fuel)$$

$$Price\ of\ Hydrogen\ Fuel = f(Quantity\ of\ Driving\ Demanded,\ Marginal\ Cost\ of\ Electrical\ Production)$$

$$Marginal\ Cost\ of\ Electrical\ Production = f(Hydrocarbon\ Fuel\ Type,\ Electrical\ Generation\ Fuel\ Efficiency)$$

We assume that the conversion to hydrogen fuel cells occurs voluntarily. In order for this to occur, the average price per mile traveled for hydrogen-fuel-cell-powered electric motors must equal that of gasoline engines, including the average fixed cost per mile travelled for the act of refueling. By setting the price of hydrogen fuel such that the cost of using it equals the cost of using gasoline, we eliminate the impact of the price of hydrogen fuel on the quantity of driving demanded and assume that the quantity of driving demanded remains constant. Additionally, limiting our focus to the physical concerns of greenhouse emissions, electrical generation's hydrogen fuel consumption, and capital investment in nameplate capacity allows for the assumption that the cost of fuels used to generate the electricity remains constant. Therefore, this model assumes constant costs of electrical production reducing it to:

$$Emissions = f(Fuel\ Efficiency\ of\ Hydrogen\text{-}Fuel\ Cells,\ Hydrocarbon\ Fuel\ Type,\ Electrical\ Generation\ Fuel\ Efficiency)$$

$$Resource\ Consumption = f(Fuel\ Efficiency\ of\ Hydrogen\text{-}Fuel\ Cells,\ Fuel\ Type,\ Electrical\ Generation\ Fuel\ Efficiency)$$

Finally, the assumption of current technology enables this estimation by utilizing known production abilities rather than prospective ones with uncertain operating characteristics in large-scale use.

This model examines the impact of hydrogen production in three geographic production scenarios. The first geographic scenario assumes that each state produces hydrogen fuel for its own use (All States Scenario). The second assumes only the states bordering the Mississippi and Saint Lawrence Rivers produce hydrogen fuel to satisfy national demand (River States Scenario). The third assumes that only the states bordering the Atlantic Ocean, Pacific Ocean, and the Gulf of Mexico produce hydrogen to satisfy national demand (Coastal States Scenario). In each of these scenarios, we assume that municipalities do not invest in the infrastructure required to recapture the water exhaust from the hydrogen fuel cells. Each geographic scenario is modeled with the assumption that they exclusively use coal, natural gas, or fuel oil to generate the necessary electricity and three hydrogen fuel production methods resulting in 27 models that we use to measure the relative sensitivity of the estimates to production methodology, geographic scenario, and fuel choice.

To conduct the analysis, we collect secondary data from the websites of the US Energy Information Administration (EIA). Detailed state data of energy generation and some of the energy consumption data as well as pollution emissions data come from the *Electric Power Annual, 2009*.[1] Other energy consumption data is from *Energy Consumption Estimates for Major Energy Sources in Physical Units, 2008*.[2] Finally, emissions data is gathered from either *Emissions of Greenhouse Gases Report, 2008*[3] or *Emissions of Greenhouse Gases in the US, 2008*.[4]

To estimate the net impact of the full conversion of the automotive market on the amount of electrical generation capital, first evaluate each state's impact independently and then examine the impact of the states within each production scenario in combination. In the All States production scenario, each state produces just enough hydrogen fuel to maintain their states current driving activity. In the more centralized production models (River and Coastal States Scenarios), we assign hydrogen production to each state proportional to that state's share of existing generator nameplate capacity in megawatts within the production scenario.

1 http://www.eia.gov/electricity/data/state/.
2 http://www.eia.gov/emeu/OLD_states/states/sep_sum/plain_html/sum_use_tot.html.
3 http://www.eia.gov/oiaf/1605/ggrpt/nitrous.html.
4 http://www.eia.gov/oiaf/1605/ggrpt/pdf/0573%282008%29.pdf.