VII.12 CO_2 Reduction Benefits Analysis for Fuel Cell Applications

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Project End Date: Project continuation and direction determined annually by DOE.

Objectives

- Perform analysis of topics of interest to the Fuel Cell Technologies (FCT) Program related to projected CO_2 benefits of fuel cell applications.
- Provide additional analytical support to the FCT Program to respond to departmental data requests and other needs.

Technical Barriers

(A) Future Market Behavior
(C) Inconsistent Data and Assumptions
(E) Unplanned Studies and Analysis

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to the achievement of the following DOE milestones from the Systems Analysis section of the FCT Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 22:** Completed the modification of the MARKAL model to include hydrogen analysis. (4Q, 2007)

Accomplishments

- Examined the impact of changes in various Program cost assumptions for fuel cell costs, cost of onboard storage, hydrogen distribution costs and carbon prices on market penetration of fuel cell vehicles and carbon emissions. The analysis was presented to the FCT Program.
- Analyzed the benefits of biomass-to-hydrogen in deep CO_2 emission reduction scenarios. This analysis demonstrated that the use of biomass-to-hydrogen with carbon capture and sequestration (CCS) can greatly reduce the cost of meeting deep carbon emission reduction goals. A paper has been written based on the results and will be submitted to a journal for publication.

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Introduction

The goal of this analysis is to explore the role that hydrogen technologies can play in reducing carbon emissions. Our analysis for the last two fiscal years include a sensitivity analysis of fuel cell vehicle market penetration to changes in production, distribution and vehicle costs and CO_2 prices, as well as analysis to examine the benefits of biomass-to-hydrogen in deep CO_2 emission reduction scenarios.

Approach

MARKAL Sensitivity Analysis

Our primary analytical tool is the 10 Region U.S. MARKAL model developed by BNL. The model was calibrated to the Energy Information Administration's (EIA's) 2009 Annual Energy Outlook. The first analysis under this project is the sensitivity analysis that we performed in Fiscal Year (FY) 2009 using our 10 Region U.S. MARKAL model. Our goal was to examine the impact of changes in various Program cost assumptions. The cost assumptions we looked at included: hydrogen distribution cost where we looked at the program goal of $1.00 per kg, as well as a $1.50 and $2.00. The next cost sensitivity was the cost of the fuel cell for vehicle applications where we tested the Program goal of $30 per kW, as well as costs of $40, $50 and $60 per kW. We also looked at the cost of on-board storage and the impacts of a ten year delay in the commercialization of fuel cell vehicles. Finally, we tested the impact of a range of carbon prices from $0 to $100 per tonne of CO_2, to see the impact of carbon prices on fuel cell vehicle market penetration, the desired hydrogen feedstocks and total CO_2 emissions.

Role of Biomass-to-Hydrogen in Deep CO_2 Emission Reduction Scenarios

The second analysis under this project is an analysis of the benefits of biomass to hydrogen in deep CO_2 emission reduction scenarios. This analysis also used the 10 region U.S. MARKAL model. For this analysis, we have two sets of technology scenarios. The first set is based primarily on the EIA assumptions, with the exception of light-duty vehicles where we have included the research and development (R&D) improvements from the Vehicle Technologies Program research in light weighting, hybridization and battery technologies. We then have a second technology scenario where we include the FCT Program's R&D goals for hydrogen production, distribution and stationary and mobile fuel cells. We used the CO_2 cap from the Waxman-Markey bill that was passed by the House of Representatives in 2009. We only modeled provisions directly related to the CO_2 cap and trade provisions. Other provisions, such as national renewable portfolio and appliance standards were not modeled. Since we wanted to explore the impacts of hydrogen technologies under more stringent carbon caps, we decided to look at what might happen if the domestic or international offsets were excluded from the legislation.

Results

MARKAL Sensitivity Analysis

The key results for the sensitivity analysis relate to impacts of carbon prices on the MARKAL model's choice of hydrogen production technologies and the impacts of increased fuel cell and onboard storage costs on fuel cell vehicle market penetration. As shown in Table 1, without a carbon price, the model primarily chooses to use central coal and distributed gas reforming to produce hydrogen. However, with increased prices of carbon, the model rapidly switches to using more biomass with CCS.

With respect to the impacts of alternative costs of vehicle fuel cells and on board storage, increasing the cost of either component will reduce overall market penetration of fuel cell vehicles. However, the impacts of changing the cost of onboard storage has a relatively minor effect, while increasing the cost of the fuel cell to $50 or more per kW has a dramatic impact on fuel cell vehicle market share (Figure 1).

Role of Biomass-to-Hydrogen in Deep CO2 Emission Reduction Scenarios

The Waxman-Markey cap and trade provision is a market-based program for reducing greenhouse gas emissions. The ultimate goal is to reduce emissions by 83% below 2005 levels by 2050. However, small utilities are exempt from the regulation and covered entities can secure permits by purchasing domestic and international carbon offsets. Overall, up to 2 giga-tonnes of CO_2 offsets can be used annually. Also, banking and trading of permits is permitted. The net effect of the allowing offsets and exempting small utilities is that the effective CO_2 emissions cap is much higher than advertised. Since we wanted to explore the impacts of hydrogen

TABLE 1. Impact of CO_2 Price on Hydrogen Production

Hydrogen case + $0 per tonne CO2

PJ of H2	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	0.000	0.000	0.000	0.005	0.016	0.039	0.098	0.197	0.396
Biomass w/CCS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Central coal	0.000	0.000	0.000	0.042	0.182	0.481	0.985	1.598	2.494
Central coal w/ CCS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Natural gas	0.000	0.001	0.020	0.059	0.180	0.425	0.907	1.944	2.389
Total	**0.000**	**0.001**	**0.020**	**0.106**	**0.378**	**0.945**	**1.990**	**3.738**	**5.280**

Hydrogen case + $100 per tonne CO2

PJ of H2	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biomass w/CCS	0.000	0.000	0.000	0.073	0.288	0.766	1.749	2.808	3.238
Central coal	0.000	0.000	0.000	0.006	0.015	0.015	0.015	0.015	0.039
Central coal w/ CCS	0.000	0.000	0.000	0.000	0.060	0.260	0.497	0.966	1.616
Natural gas	0.000	0.001	0.021	0.031	0.026	0.058	0.073	0.346	0.665
Total	**0.000**	**0.001**	**0.021**	**0.109**	**0.389**	**1.098**	**2.334**	**4.134**	**5.559**

Hydrogen case + $20 per tonne CO2

PJ of H2	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biomass w/CCS	0.000	0.000	0.000	0.063	0.191	0.503	1.042	1.248	1.691
Central coal	0.000	0.000	0.000	0.013	0.068	0.192	0.483	0.799	1.283
Central coal w/ CCS	0.000	0.000	0.000	0.000	0.047	0.094	0.094	0.130	0.213
Natural gas	0.000	0.001	0.021	0.033	0.074	0.151	0.376	1.569	2.104
Total	**0.000**	**0.001**	**0.021**	**0.109**	**0.380**	**0.942**	**1.995**	**3.747**	**5.292**

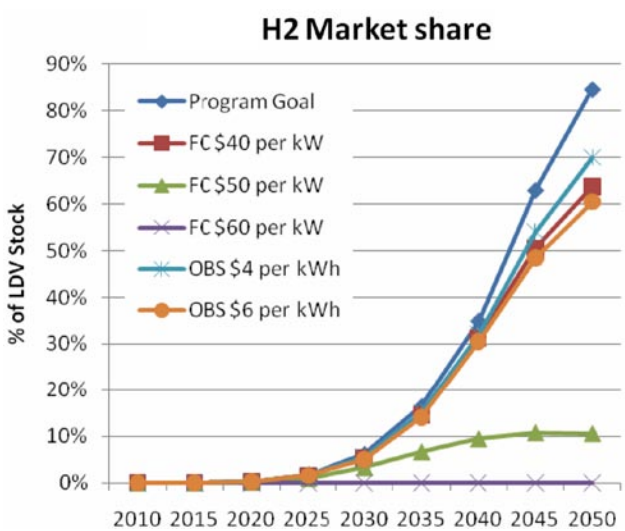

FIGURE 1. Sensitivity of Fuel Cell Vehicle Market Share to Fuel Cell and On Board Storage Costs

technologies under more stringent carbon caps, we decided to look at what might happen if the domestic or international offsets were excluded from the legislation.

A total of eight cases were run. They are:

- Reference Case: **Ref. Case**
- Reference with Carbon Cap: **Ref. w/CC**
- Reference with Carbon Cap Without International Offsets: **Ref. w/CC w/o IO**
- Reference with Carbon Cap Without Any Offsets: **Ref. w/CC w/o AO**
- FCT Program: **FCTP Case**
- FCT Program with Carbon Cap: **FCTP w/CC**
- FCT Program with Carbon Cap Without International Offsets: **FCTP w/CC w/o IO**
- FCT Program with Carbon Cap Without Any Offsets: **FCTP w/CC w/o AO**

Comparing the Reference Case with the FCT Program Case without a carbon policy, there is a 37% reduction in direct transportation sector emissions. However, this is partially offset by an increase in industrial sector emissions, where we account for the direct emissions from producing hydrogen. Overall, there is a 10% reduction in carbon emissions relative to the reference case (Figure 2).

When we add the Waxman-Markey CO_2 cap, we see a significant difference between the reference and hydrogen technology scenarios. With the FCT Program assumptions, there is a dramatic reduction in transportation and industrial emissions due to efficient fuel cell vehicles and the "negative" carbon emissions from biomass-to-hydrogen with CCS. Figure 3 shows that the 2050 carbon emissions from the power generation sector are higher than with the reference technology scenario. With the increased savings in the industrial and transportation emissions other sectors can emit more and still comply with the overall CO_2 cap. In this case, the model finds that the biomass-to-hydrogen technology has much lower marginal cost than some of the power sector technologies that were chosen in the Reference with Carbon Cap case.

Looking at 2050 carbon emissions by sector for the two technology scenarios and under the different carbon caps, Figure 4 shows a significant reduction in transportation and industrial carbon emissions for the advanced hydrogen cases on the right side of the chart, than for the reference case technology cases on the left.

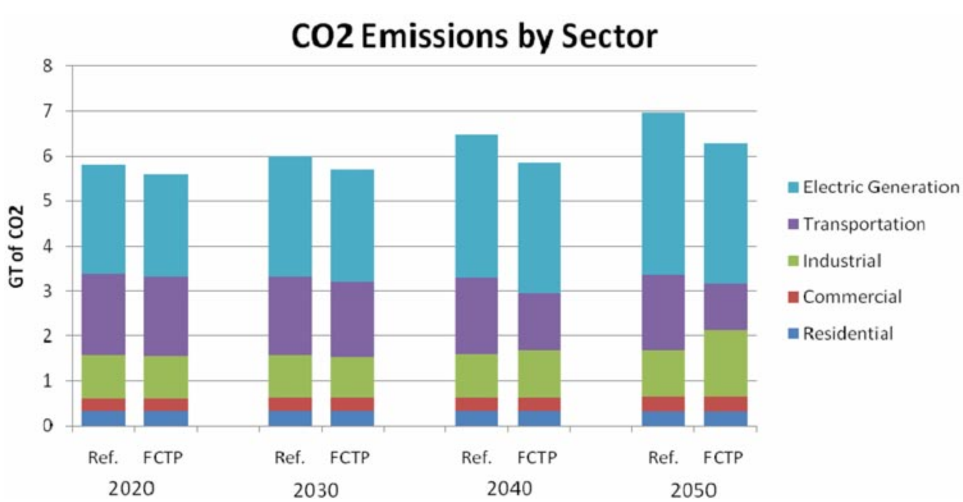

FIGURE 2. Impact of FCTP Assumptions on Carbon Emissions

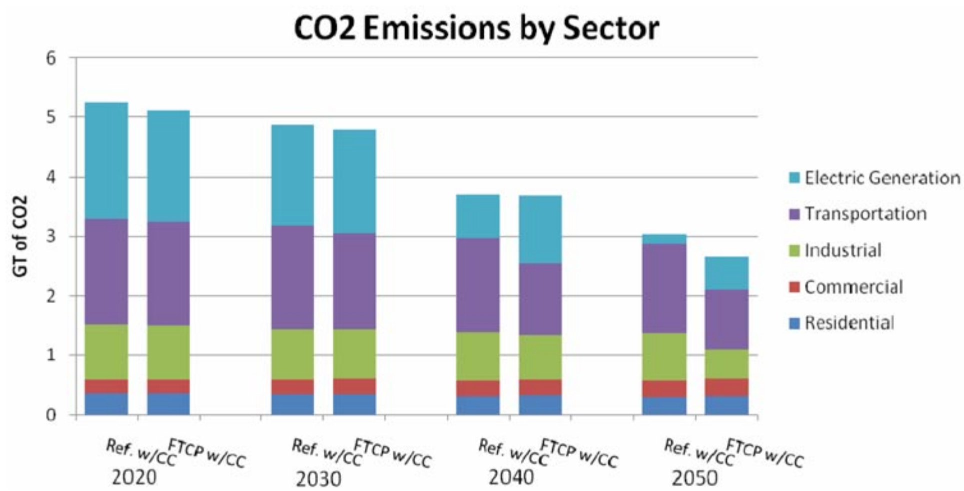

FIGURE 3. Impact of FCTP Assumptions on Carbon Emissions Under Waxman-Markey CO_2 Cap

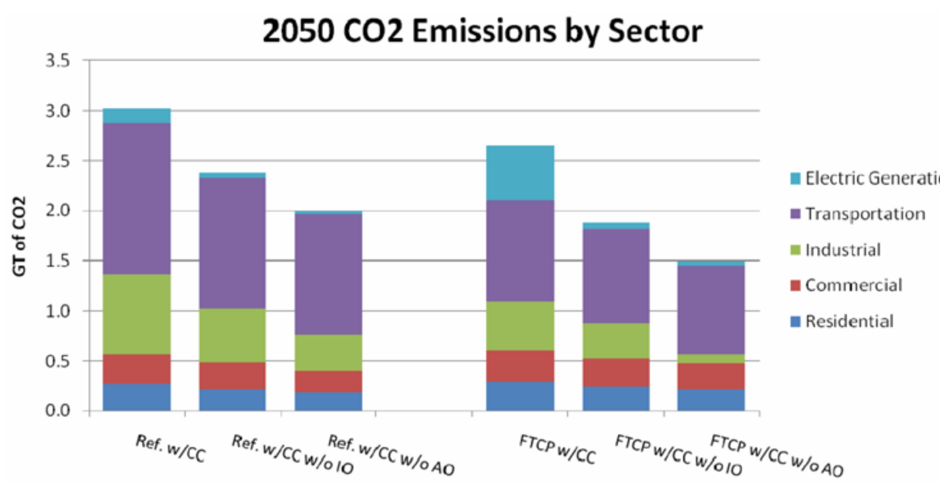

FIGURE 4. 2050 Carbon Emissions by Sector Under the Stricter CO_2 Caps

You can also see total carbon emissions are lower for the FCT cases due to a reduced use of offsets and banking of carbon credits.

With the introduction of the Waxman-Markey cap (with offsets), there is a significant increases in use of biomass in both cases. With the FCTP assumptions, we get significant increase in the overall consumption of biomass, due to the use of biomass to hydrogen with CCS. However, under the more stringent carbon caps where we don't allow international or any offsets, the reference technology set biomass consumption catches up with the advanced hydrogen technology cases. The primary difference is that under the reference technology set, the model relies on biomass-to-liquids with CCS, where the FCT Program cases use both biomass-to-liquids and biomass-to-hydrogen with CCS (Figure 5).

Conclusions and Future Directions

- The use of biomass-to-hydrogen with CCS can greatly reduce the cost of meeting deep carbon emission reduction goals.
- Biomass-to-liquids with CCS generates "negative" CO_2 emissions, however, the hydrogen pathway generates deeper reductions per ton of biomass used.
- Under the two most stringent CO_2 caps, both biomass-to-liquids with CCS and hydrogen with CCS are needed.
- While the transport sector may be a more difficult sector to achieve deep CO_2 emission reductions, with a successful R&D program, deep CO_2 emission reductions can be achieved with a significant reduction in cost of meeting the CO_2 cap.

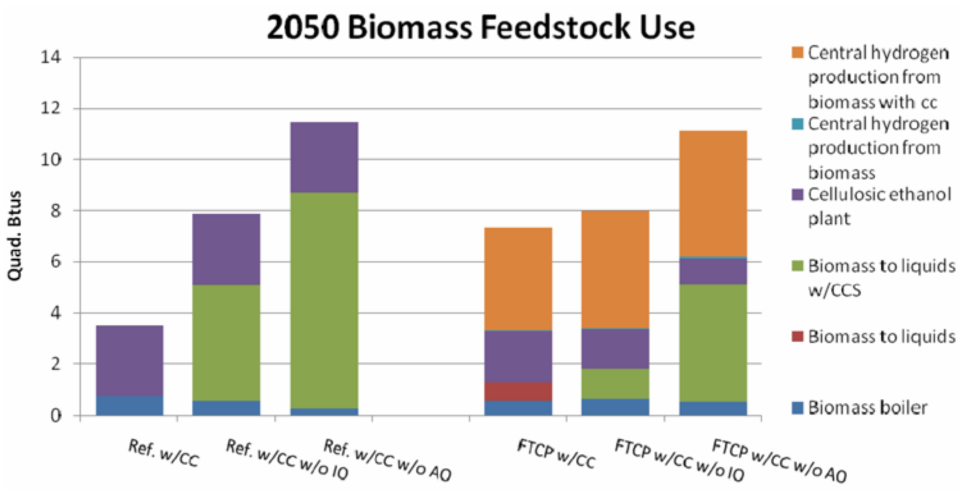

FIGURE 5. 2050 Biomass Consumption by Sector under the Stricter CO_2 Caps

FY 2010 Publications/Presentations

1. "Role of Biomass-to-Hydrogen in Deep CO2 Emission Reduction Scenarios", P. Friley, T. Alfstad and S. Politis, ETSAP Semi Annual Meeting, Stockholm, Sweden, June 24, 2010.

2. "Role of Biomass-to-Hydrogen in Deep CO2 Emission Reduction Scenarios", P. Friley, T. Alfstad and S. Politis, forthcoming.