XI.11 Analysis of Fuel Cell Integration with Biofuels Production

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Project Start Date: May 1, 2012
Project End Date: July 1, 2013

Overall Objectives

- Identify opportunities for using fuel cells in biorefineries
- Analyze potential benefits of fuel cells in biorefineries
- Report the effects of integration on levelized costs, capital costs, and operating costs

Fiscal Year (FY) 2013 Objectives

- Finalize analysis which was performed in FY 2012
- Report on analysis

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(B) Stove-piped/Siloed Analytical Capability
(D) Insufficient Suite of Models and Tools
(E) Unplanned Studies and Analysis

Contribution to Achievement of DOE Systems Analysis Milestones

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

- Milestone 1.13: Complete environmental analysis of the technology environmental impacts for hydrogen and fuel cell scenarios and technology readiness. (4Q, 2015)
- Milestone 1.14: Complete analysis of the job impact from fuel cell growth in stationary power generation sector through 2020. (4Q, 2015)
- Milestone 1.16: Complete analysis of program performance, cost status, and potential use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
- Milestone 1.17: Complete analysis of program technology performance and cost status, and potential to enable use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
- Milestone 1.19: Complete analysis of the potential for hydrogen, stationary fuel cells, fuel cell vehicles, and other fuel cell applications such as material handling equipment including resources, infrastructure and system effects resulting from the growth in hydrogen market shares in various economic sectors. (4Q, 2020)
- Milestone 1.20: Complete review of fuel cell and hydrogen markets. (4Q, 2011 through 4Q, 2020)
- Milestone 3.3: Complete review of status and outlook of non-automotive fuel cell industry. (biennially from 4Q, 2011 through 4Q, 2019)

FY 2013 Accomplishments

- Analyzed potential of fuel cells for combined heat and power (CHP) and combined heat, hydrogen, and power (CHHP) application in emerging biorefineries by focusing on the cost competitiveness of molten carbonate fuel cells (MCFC) and phosphoric acid fuel cells (PAFC) systems in fast-pyrolysis biorefineries.
- Estimated effects on levelized costs of the product pyrolysis oil. None of the four basic fuel cell scenarios studied resulted in a levelized cost of the pyrolysis oil lower than the non-fuel cell case's $2.11/gal ($2005). With a pyrolysis oil levelized cost of $2.17/gal, the MCFC fuel cell in CHHP mode scenario had the lowest levelized cost of the four fuel cell scenarios. It was followed by the MCFC fuel cell in CHP mode scenario at $2.19/gal. The PAFC scenarios in CHHP and CHP modes resulted in levelized costs of $2.22 and $2.29/gal, respectively.
- Estimated effects on fixed capital investment (FCI) on the fast pyrolysis biorefinery. The FCI of the base case without a fuel cell is $172M ($2005). Adding a MCFC increases the FCI to $199M and $202M in CHP and CHHP configurations, respectively. Adding a PAFC system increases the FCI to $223M and $255M in CHP and CHHP configurations, respectively.

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INTRODUCTION

This study provides a preliminary examination of the possibility of inserting one or more fuel cells into a fast pyrolysis-based biofuels production facility. Biomass pyrolysis systems have the potential to produce liquid transportation fuels in an economically competitive manner. Wright et al. (2010) estimated that, for an nth generation fast-pyrolysis plant that purchased all of its hydrogen necessary for hydrocracking and hydrotreating from offsite, the fixed capital investment is $172M and the levelized cost (assuming a 10% discount rate) is $2.11/gal pyrolysis oil. Wright et al. considered two separate production scenarios.

As shown in Figure 1, fuel cell systems were added to the Wright case to estimate the potential of fuel cells within such processes. In each case, the fuel cell systems converted natural gas and fuel gas produced in the pyrolysis process to power and heat for use in the system thus offsetting all the power required during normal operation and much of the heat. Those scenarios are referred to as CHP scenarios. In some cases, the fuel cell systems also produced hydrogen offsetting merchant hydrogen purchased to upgrade the pyrolysis oil. Those scenarios are referred to as CHHP scenarios. Two types of fuel cell systems were analyzed: MCFC systems with reforming of hydrocarbons to hydrogen within the fuel cell and PAFC systems with an external reformer.

APPROACH

The techno-economic models developed for the merchant hydrogen scenario of Wright's study was the basis for this effort. The Fuel Cell Power (FCPower) Model—a techno-economic model for the analysis of high-temperature fuel cell systems in distributed applications—was added to Wright's model to incorporate fuel cell costs. Scenarios with both MCFCs and PAFCs were developed. Scenarios were also developed for each fuel cell type in two modes: CHP and CHHP. In each scenario, the fuel cell is integrated into the pyrolysis process. The fuel cell system uses merchant natural gas and fuel gas produced by the pyrolysis process to produce heat and electricity and, in some scenarios, hydrogen. Heat from the fuel cell is used directly in the pyrolysis reactor. Heat generated from the fuel cell offsets char combusted for heat thus increasing income from selling the char byproduct and reducing the capital and operating expenses of the char combustor. The fuel cell system is sized to meet all electricity requirements of the plant thus eliminating the need to purchase electricity.

In the CHHP scenarios with MCFCs, hydrogen produced by the fuel cell systems offset the hydrogen purchase but the amount of heat produced is reduced. In PAFC CHHP scenarios, hydrogen production is decoupled from heat and electricity production because reforming is external from the fuel cell; thus, the full hydrogen requirement is

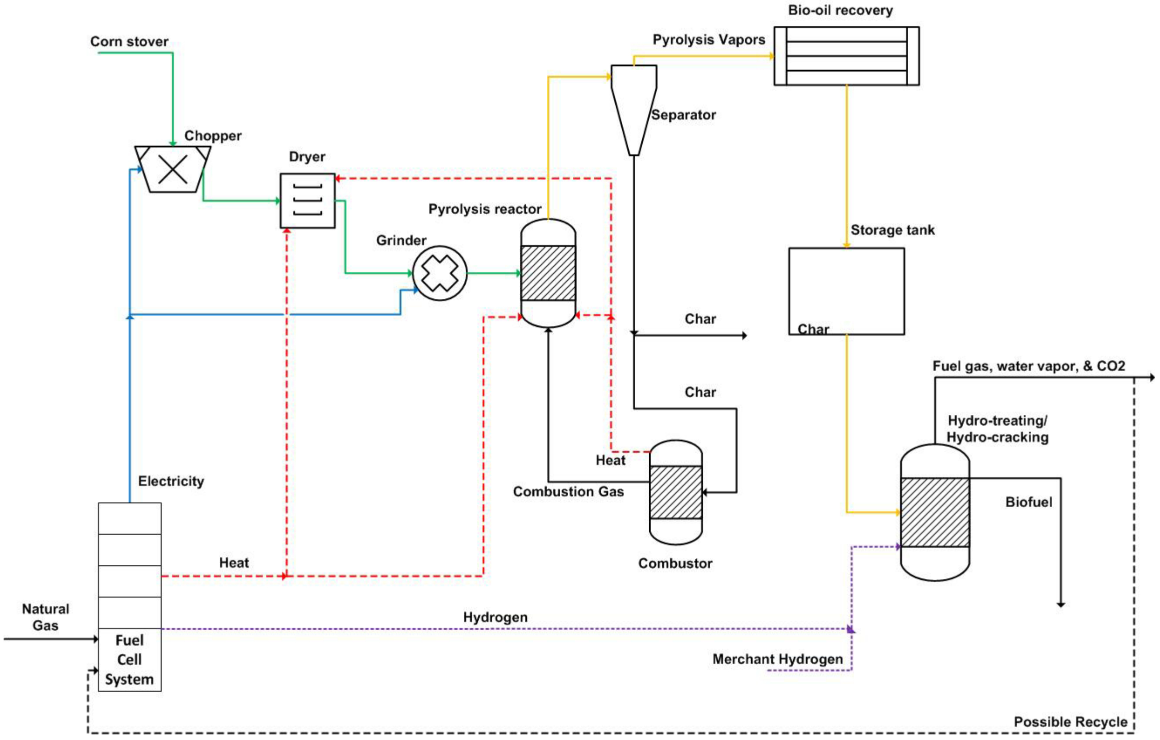

FIGURE 1. Process flow diagram for pyrolysis biorefinery integrated with fuel cell system. Red lines indicate heat flow, blue lines indicate electric power flow. All other lines are material streams.

met by the fuel cell system and no hydrogen is purchased. Sensitivity analyses were conducted on multiple parameters in each scenario.

RESULTS

Each configuration's resulting fuel cell cost, fuel cell system cost (including reforming), combustion system cost, total installed equipment cost, FCI, and levelized cost of the product pyrolysis oil are summarized in Table 1. The MCFC CHP configuration that is sized to meet the pyrolysis plant's electricity requirement of 11.49 MW requires 86 MMBtu/hr natural gas or fuel gas. The system produces 7.8 MW of usable heat and reduces char utilization by 1,027 kg/hr and ash production by 196 kg/hr. The MCFC CHHP configuration requires the same size MCFC system and thus the fuel cell cost and natural gas requirement are the same as the CHP configuration. Because 65% of the available heat is used for hydrogen production, 152 kg/hr of hydrogen are produced but the production of usable heat is only 2.7 MW. The hydrogen production offsets a portion of the 2,041 kg/hr hydrogen required for hydrotreating. The reduced heat production results in a reduction in char utilization of only 359 kg/hr.

The PAFC CHP system that is sized to meet the pyrolysis plant's electricity demand of 11.49 MW requires 105 MMBtu/hr natural gas or fuel gas. The system produces 8.8 MW of usable heat and reduces char utilization by 1,146 kg/hr and ash production by 219 kg/hr. The PAFC CHHP configuration requires the same size fuel cell but the reformer is sized to meet the full hydrogen demand. As a result, the reformer has four times the capacity of the one for the CHP system and four times as much natural gas is required. The resulting fuel cell system's natural gas requirement is 407 MMBtu/hr. Note that the reformer in the PAFC CHHP case needs to be four times larger than that in the CHP case because of the high demand for hydrogen for treating the pyrolysis oil. Also, note that the increased proceeds from additional sales of char and reduced ash disposal costs (not shown) are small when compared to other costs.

The levelized cost for all fuel cell configurations is higher than the base case because the effects of a higher capital cost more than offset the lower operating costs in those cases. A key reason the capital cost is higher in each fuel cell configuration is that the combustion system's size and cost are reduced but not fully eliminated in the fuel cell system configurations. Note that the levelized costs in the CHHP configurations are lower than those in the corresponding CHP configurations because reducing the amount of hydrogen, which is purchased at $5.00/gasoline gallon equivalent (gge) in the base case, is financially beneficial.

Figure 2 displays levelized fuel cost results from single-point sensitivities in the base case (above the solid, horizontal line) and the MCFC CHHP configuration (below the solid, horizontal line). A high electricity price of $0.10/kWh results in a higher cost for the base case system than for the MCFC CHHP because the MCFC case produces all of its own electricity in the fuel cell. In addition, if the natural gas price is low ($2.00/MMBtu is shown in the figure) or the 30% federal tax credit is allowed, the levelized cost difference between the base case and the MCFC CHHP case becomes small as well (about $0.03/gal pyrolysis biofuel). Because fuel gas is a byproduct from the pyrolysis process, a high value such as $8.00/MMBtu results in a lower levelized cost of pyrolysis oil than a low value such as $3.00/MMBtu.

Figure 3 displays a similar sensitivity analysis for the PAFC CHHP configuration. Even though the difference between the baseline costs for the base case and the PAFC CHHP configuration are greater than the MCFC CHHP configuration, there are scenarios where the PAFC CHHP configuration are the lowest cost. One of those scenarios is high-cost merchant hydrogen. If the merchant hydrogen cost is $2.50/gge instead of $1.50/gge (as in the base case) the no

TABLE 1. Financial Comparison of MCFC- and PAFC-Based Systems with the Base Case

PARAMETER ($2005)	MCFC CHP	MCFC CHHP	PAFC CHP	PAFC CHHP	Base Case (no fuel cell)
Fuel Cell Uninstalled Cost	$16,600,000	$16,600,000	$24,900,000	$24,900,000	N/A
Fuel Cell Installed Cost	$19,900,000	$19,900,000	$28,600,000	$28,600,000	N/A
Fuel Cell System Uninstalled Cost	$16,800,000	$16,800,000	$31,100,000	$49,100,000	N/A
Fuel Cell System Installed Cost	$20,200,000	$20,200,000	$35,800,000	$56,500,000	N/A
Combustion System Uninstalled Cost*	$14,400,000	$14,900,000	$14,300,000	$14,300,000	$15,200,000
Combustion System Installed Cost*	$43,500,000	$45,100,000	$43,200,000	$43,200,000	$45,900,000
Total Installed Cost, Complete Pyrolysis Plant	$128,300,000	$129,900,000	$143,700,000	$164,400,000	$110,600,000
Total Fixed Capital Investment	$199,300,000	$201,800,000	$223,300,000	$255,400,000	$171,800,000
Levelized Cost of Pyrolysis Oil ($2005/Gallon)	$2.19	$2.17	$2.29	$2.22	$2.11

* Does not include fuel cell cost

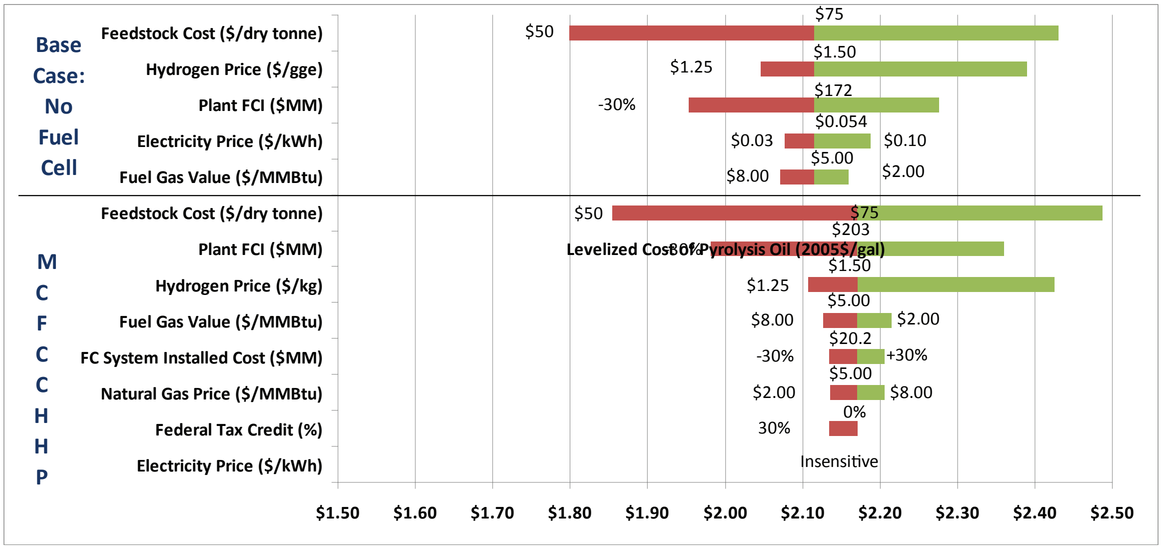

FIGURE 2. Sensitivity analysis of single points in the base case and the MCFC CHHP case.

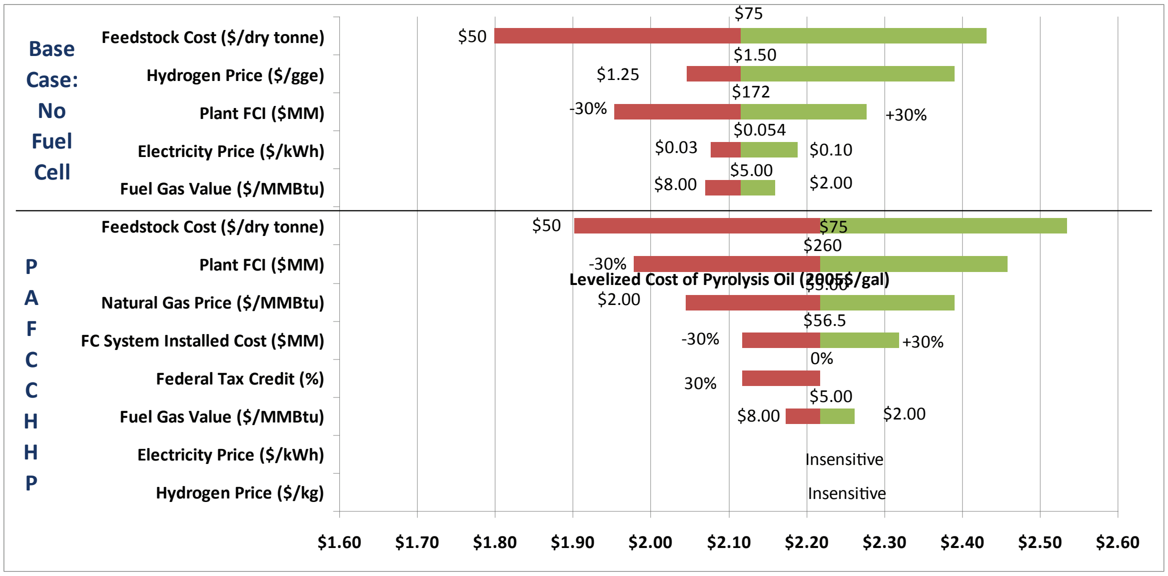

FIGURE 3. Sensitivity analysis of single points in the base case and the PAFC CHHP case.

fuel cell configuration levelized cost increases to $2.39/gal where the PAFC CHHP case stays at $2.22/gal because its hydrogen demand is met internally as is the electricity demand. As with the MCFC CHHP system, if the 30% federal tax credit is allowed, the difference between levelized costs for the fuel cell and non-fuel cell systems converge.

CONCLUSIONS AND FUTURE DIRECTIONS

None of the four basic fuel cell scenarios studied resulted in a levelized cost of the pyrolysis oil lower than the non-fuel cell case's $2.11/gal. With a pyrolysis oil levelized cost of $2.17/gal, the MCFC fuel cell in CHHP mode scenario had the lowest levelized cost of the four fuel cell scenarios. It was followed by the MCFC fuel cell in CHP mode scenario at $2.19/gal. The PAFC scenarios in CHHP and CHP modes resulted in levelized costs of $2.22 and $2.29/gal, respectively. MCFC's scenarios resulted in lower levelized costs than PAFCs because they are more efficient and CHHP scenarios resulted in lower levelized costs than CHP scenarios because of the value of produced hydrogen.

A key reason the fuel cell systems resulted in higher levelized costs is that they require a larger capital investment. The fuel cell costs were partially offset by reducing the char combustion system size; however, since the combustion system could not be completely eliminated without producing much more electricity than the system needs, both systems were still required. A second reason the fuel cell systems resulted in a higher levelized cost is that they produced electricity and hydrogen (in the CHHP cases) that are competing against projected costs of $0.054/kWh electricity and $1.50/gge for hydrogen.

Sensitivity results show that fuel cell system configurations may be more cost competitive if the electricity cost is closer to $0.10/kWh than the initial estimate of $0.054/kWh; the hydrogen cost is closer to $2.50/gge than the initial estimate of $1.50/gge; or a 30% federal tax credit for fuel cells is in place (not assumed because the projected startup year in this analysis is 2017 which is after the current tax incentive expires). When determining if a fuel cell system should be included in the design or not, the plant designer needs to consider confidence levels in each of those estimates as well as the desire to hedge costs to prevent losses if electricity or hydrogen prices were to change unexpectedly.

No additional work is planned; however, if funding were available activities should be considered including:

- Quantification of other benefits of fuel cell systems within biorefineries. Benefits such as potential greenhouse gas emission reductions; the ability to hedge against potential electricity and H_2 market volatility; and improvements to system reliability and resilience should be considered.
- CHP opportunities for near-term biomass processes should be investigated. Those processes include both first generation (e.g., corn dry mills) and second generation (e.g., lignocellulosic ethanol production) facilities. Ideally, the focus of such analyses should be on processes that produce biogas that can be used as feed to the fuel cell system.
- Identification of additional options where fuel cells can be used in conjunction with other renewable energy technologies.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. Annual Merit Review Presentation on May 14, 2013.