

## VII.11 Life-Cycle Analysis of Criteria Pollutant Emissions from Stationary Fuel Cell Systems with the GREET Model

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### Objectives

- Conduct fuel-cycle analysis of stationary fuel cell (FC) systems (to help development of hydrogen production and FC technologies).
- Engage in discussions and dissemination of energy and environmental benefits of FC systems and applications.

### Technical Barriers

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

- (C) Inconsistent Data, Assumptions and Guidelines
- (D) Suite of Models and Tools
- (E) Unplanned Studies and Analysis

### Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes to achievement of the following DOE milestone from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development, and Demonstration Plan:

- Milestone 11: Complete environmental analysis of the technology environmental impacts for the hydrogen scenarios and technology readiness (2Q 2015).

### Accomplishments

- Conducted energy use and greenhouse gas (GHG) emissions analysis of FC systems for combined heat and power (CHP) and combined heat, hydrogen, and power (CHHP) generation, which showed that CHP and CHHP FCs offer significant reduction in energy use and GHG emissions compared to distributed combustion generation technologies.
- Conducted criteria pollutants emissions analysis of FC systems for CHP and CHHP generation, which showed that CHP and CHHP FCs offer reductions in criteria pollutant emissions compared to distributed combustion generation technologies.
  - FC systems for CHP and CHHP provide significantly less carbon monoxide (CO), particulate matter (PM), and oxides of nitrogen (NO<sub>x</sub>) emissions than conventional combustion generation technologies.
  - Utilization of byproduct heat is critical to the fuel-cycle emission performance of FC systems for distributed power generation.
  - CHHP FC systems provide better utilization of byproduct heat compared to CHP FC systems when heat is utilized for producing additional amounts of hydrogen.



### Introduction

The pathway to the application of FCs in hydrogen vehicles will be assisted by the introduction of FCs in markets with fewer technical challenges than automobiles. Distributed power generation and forklifts are near-term markets in which FCs can be successful. One of the issues associated with transforming the market of FCs to these early markets is their potential fuel-cycle energy use and emissions benefits – this issue is important because many sectors of the U.S. economy are becoming increasingly subject to reduction of energy use and emissions of GHGs and air pollutants. An earlier study by ANL examined the fuel-cycle energy use and GHG emissions of FCs for forklift propulsion systems and distributed power generation. In addition to polymer electrolyte membrane (PEM), FC technologies suitable for distributed power generation include phosphoric acid FCs (PAFCs) and molten carbonate FCs (MCFCs). The application of FCs to distributed power generation has the potential to produce excess hydrogen at a relatively low cost for local utilization. The excess hydrogen may be stored locally and used for

the refueling of FC forklifts in a nearby facility or for the generation of supplemental electricity to satisfy a facility's electric load during peak demand periods. The availability of a hydrogen co-product may also overcome one of the barriers to introducing hydrogen FC vehicles (FCVs) to some early FCV market places by facilitating a distributed source of hydrogen while effectively employing the primary energy source and the initial capital investment of the FC to serve a facility's demand for electric and heat energy.

This analysis evaluates the fuel-cycle criteria pollutant emissions, in addition to GHG emissions, associated with the application of PAFCs and MCFCs to CHP and CHHP generation. It also evaluates the fuel-cycle GHG and criteria pollutant emissions of other combustion technologies for CHP, such as internal combustion engines (ICEs) and microturbines (MTs). These FC and combustion technologies are compared against the conventional technologies that supply buildings with electricity and heat, such as the local grid generation mix and the combustion technologies typically used to meet the facility's heating demand. Three facility types, representing a hospital, a large office building, and a warehouse located in two different climatic regions (Chicago and Los Angeles), were evaluated for their carbon footprint and criteria pollutants emissions. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model has been expanded to address the fuel-cycle GHG emissions and criteria pollutant emissions associated with the application of FCs to CHP and CHHP generation.

## Approach

Fuel-cycle analysis of various power-generation technologies in this study calculates the energy use and emission occurrences per unit of consumed energy at end-use. These occurrences include the initial recovery, processing, and transportation of the primary fuels, as well as the generation of heat, hydrogen, and electricity. The energy use and emissions primarily depend on the energy conversion efficiency of each process in the fuel cycle pathway. Efficiency and emissions data for the distributed generation technologies of interest to this analysis are extracted from testing data reported by U.S. Environmental Protection Agency, as well as data provided by California Air Resource Board and industry sources. For CHP and CHHP FC systems, the efficiency data are extracted from the H2A power model developed by National Renewable Energy Laboratory, which simulates the hourly FC performance based on actual (load-following) performance data. These efficiencies, as shown in Table 1, are generally lower than those obtained from steady-state testing at peak performance or rated power due to performance degradation as a result of typical duty cycles and unsteady operation in the field.

The reported thermal efficiencies in Table 1 assume that the entire amount of recoverable waste-heat is utilized.

Two different approaches for fuel-cycle analysis of CHP and CHHP applications have been considered in this analysis: a total demand approach and a displacement approach. The total demand approach compares the impact of various technologies in satisfying a facility's demand for electricity, hydrogen and heat. It accounts for the energy use and emissions associated with the on-site generation of power, heat, and hydrogen, as well as the energy use and emissions associated with the generation of supplemental heat, hydrogen, and grid power. The system boundary for this approach includes the FC and the supplemental systems that satisfy the building's excess electricity and heat demands. The energy use and emissions for this approach are evaluated per one million Btu (mmBtu) of combined electric, heat, and hydrogen demand. The displacement approach compares different technologies for the on-site generation of electricity and hydrogen, and calculates credits for the heat byproduct. The system boundary for this approach only includes the distributed generator system and assumes full utilization of any heat byproduct. The energy use and emissions for this approach are evaluated per one million Btu of net electricity and hydrogen generation. The credit of by-product heat is calculated from the displacement of equivalent amount of heat from a typical standalone heating system. The displaced heat is assumed to be produced from a natural gas (NG)-fired heater with 90% efficiency. A major difference between the two fuel cycle approaches is the percentage utilization of the heat byproduct. In the displacement approach, the entire amount of heat available from the generators is assumed to displace conventional heat production from NG-fired burners, although a significant amount of heat could be rejected by the facility because generators often produce more heat than required by the instantaneous demands, and the facility is assumed not to have a heat storage tank. Thus, while the effect of heat utilization (HU) is properly captured in the total demand approach, the displacement approach assumes 100% utilization of heat byproduct. The fuel-cycle results presented below are based on the displacement approach.

## Results

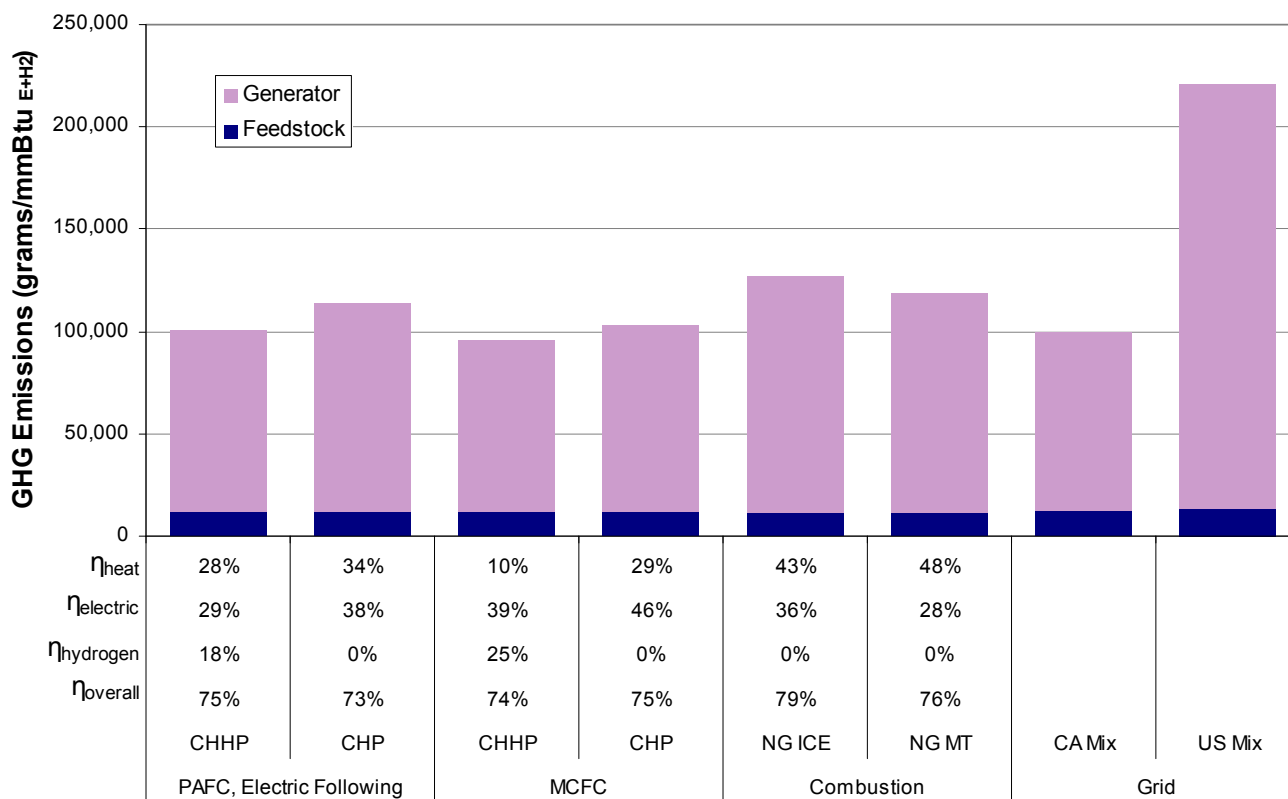
The fuel-cycle results for various distributed generation technologies were examined based on estimates of efficiency and emission factors shown in Table 1. Figures 1-5 show the fuel-cycle GHG and criteria pollutant emissions associated with different generation technologies using the displacement approach. The relative benefits of the CHP and CHHP systems compared to other generation technologies depend on the efficiency and carbon intensity of the displaced grid mix. In general, CHHP FCs are shown

**TABLE 1.** Energy Efficiency and Emission Factors for Distributed Power Generation Technologies

Technology	Type	Efficiency			Emission Factors (grams/mmBTU of fuel input)				
		Electric	Hydrogen	Overall	VOC	CO	NOx	PM10	SOx
PAFC	CHHP	29%	18%	75%	1.204	2.558	4.108	1.354	0.269
	CHP	38%	0%	73%					
MCFC	CHHP	39%	25%	74%					
	CHP	46%	0%	75%					
NG ICE with aftertreatment	CHP	36%	0%	79%	76.89	302.0	19.10	3.465	0.269
NG MT	CHP	28%	0%	76%	0.779	25.26	34.35	3.341	0.269

to provide more reduction in energy use and GHG emissions compared to CHP fuel cell systems due to the better utilization of byproduct heat in making hydrogen (Figure 1). Criteria pollutant emissions are comparable for CHP and CHHP FC systems, but are significantly less than those for all other generation systems (Figures 2-5). The amount of displaced heat for the different generators is critical to their overall performance. This is apparent in Figure 2 for CO emissions where the displaced heat results in negative emissions for FC systems (i.e., a net credit). The credit for CHHP FCs is less compared to CHP FCs due to the utilization of

the coproduced heat to make hydrogen, and thus less heat byproduct is produced and displaced. FC systems produce an order of magnitude less NOx compared to combustion generation technologies as shown in Figure 3. They also produce significantly less PM compared to other distributed generation technologies and grid generation mix in U.S. and California (Figure 4). All distributed generation technologies powered by NG produce much less oxides of sulfur (SOx) compared to the grid generation mix in the U.S. and California, mainly due to the much low sulfur content of NG (Figure 5).



**FIGURE 1.** Fuel Cycle GHG Emissions of Different Generation Systems

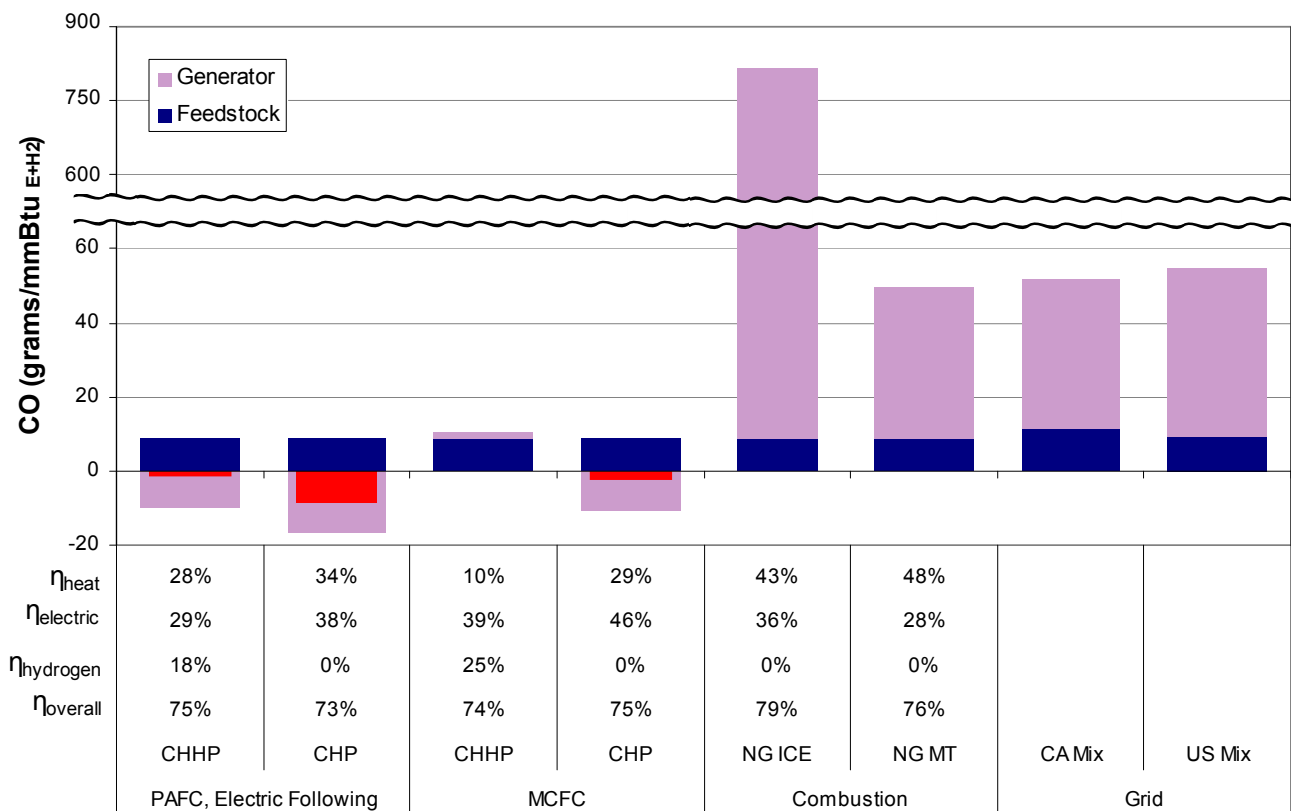


FIGURE 2. Fuel Cycle CO Emissions of Different Generation Systems

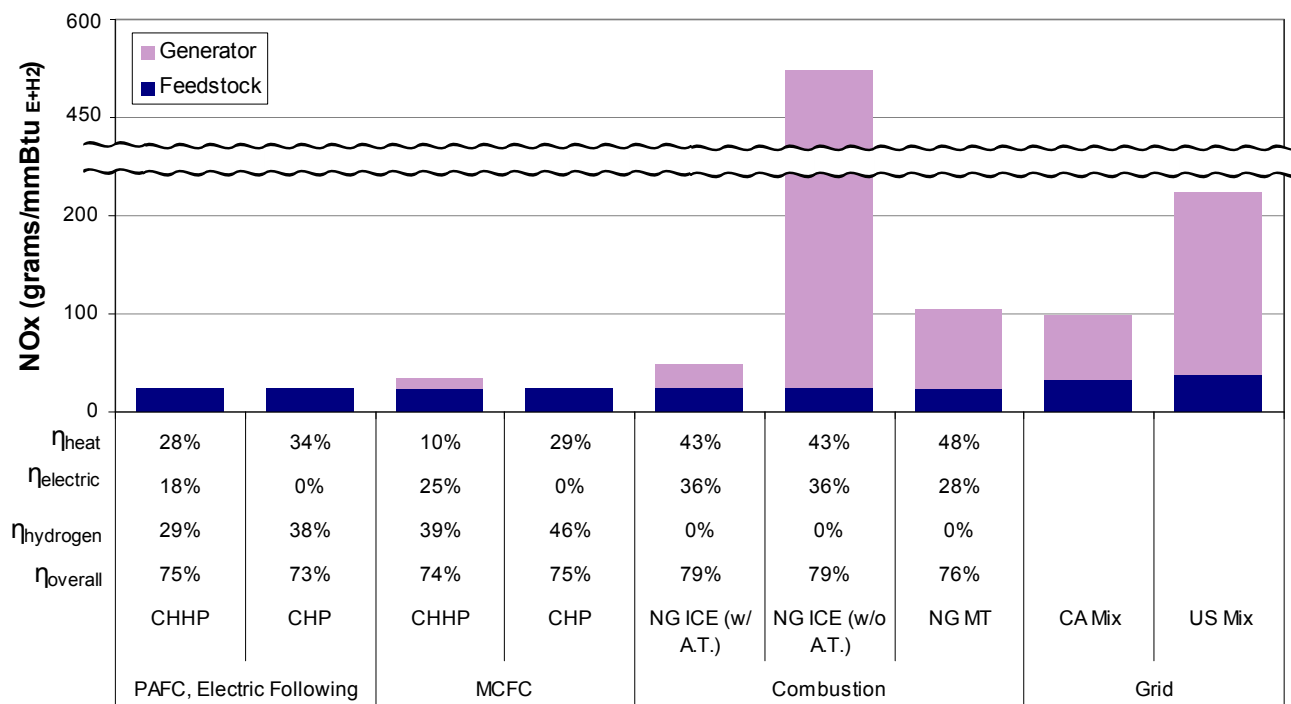


FIGURE 3. Fuel Cycle NOx Emissions of Different Generation Systems

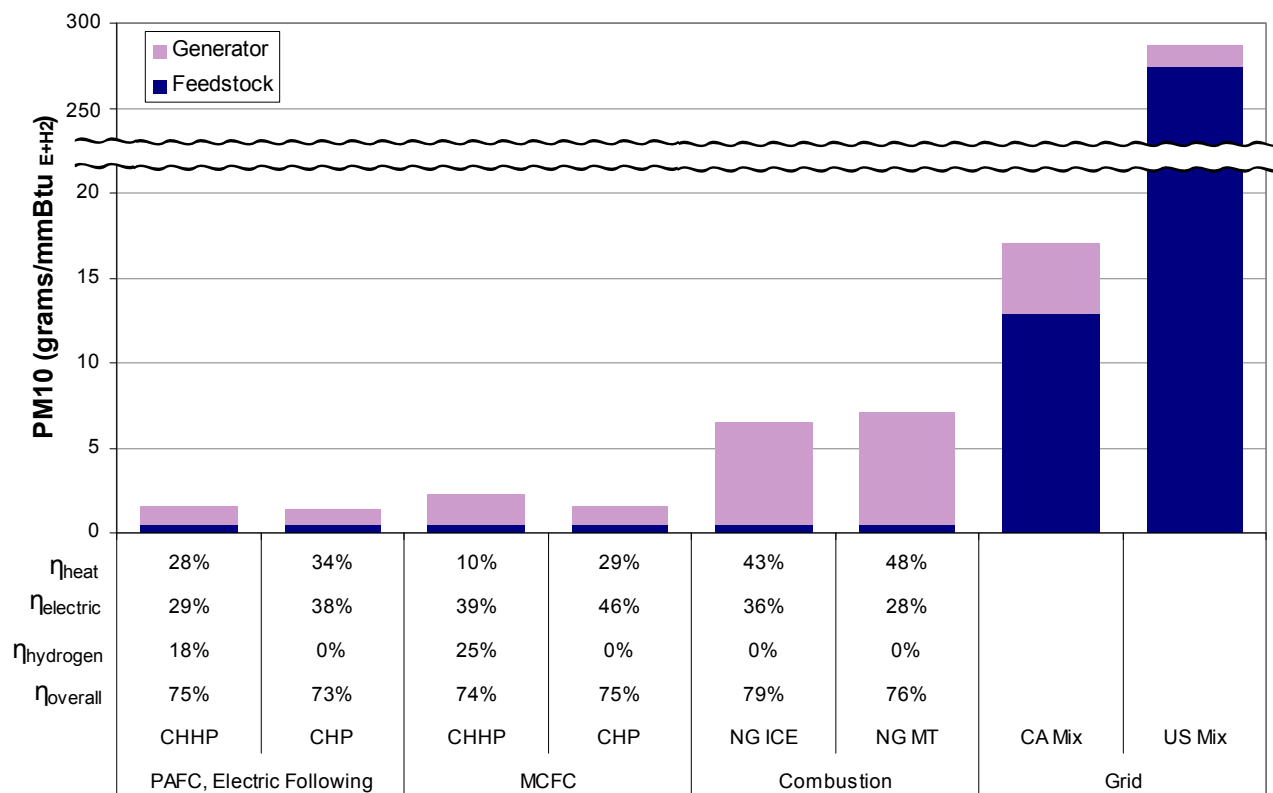


FIGURE 4. Fuel Cycle PM Emissions of Different Generation Systems

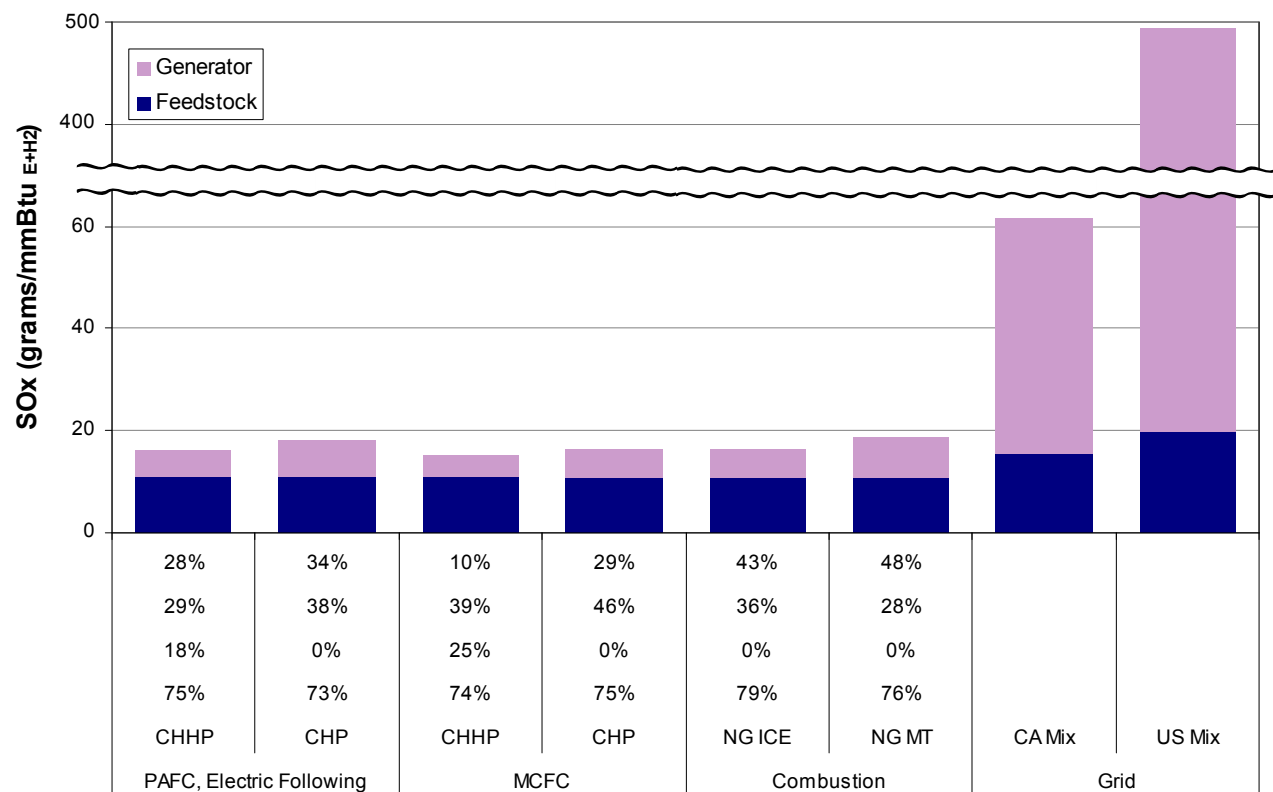


FIGURE 5. Fuel Cycle SOx Emissions of Different Generation Systems

## Conclusions and Future Directions

### Conclusions

FC systems for distributed power generation in CHP or CHHP achieve significant reductions in criteria pollutant emissions:

- FC systems for CHP and CHHP provide significantly less CO, PM, and NO<sub>x</sub> emissions compared to conventional generation technologies.
- Utilization of byproduct heat is critical to the fuel-cycle emission performance of FC systems for distributed power generation.
- CHHP FC systems provide better utilization of byproduct heat compared to CHP FC systems.

### Future Work

- Complete fuel-cycle analysis of FC CHHP systems for criteria pollutants as well as energy use and GHGs.

### FY 2010 Publications/Presentations

1. Han, J., A. Elgowainy, and M. Wang, 2009, "Fuel Cycle Analysis of Fuel Cells for Combined Heat, Hydrogen, and Power Generation", ASME International Mechanical Engineering Congress and Exposition, November 13–19, IMECE2009-10256, Lake Buena Vista, FL.