

# **Fuel-Cycle Analysis of Fuel-Cell Vehicles and Fuel-Cell Systems with the GREET Model**

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May 19, 2009

Project ID an\_12\_wang

# Overview

## Timeline

- Start: Oct. 2002
- End: continuous
- % complete: not applicable

## Budget

- Total project funding from DOE: \$2.84 million through FY09
- Funding received in FY08: \$840k
- Funding for FY09: \$800k

## Barriers to Address

- Inconsistent data, assumptions, and guidelines
- Suite of models and tools
- Unplanned studies and analyses

## Partners

- NREL, ORNL, and other labs
- ANL PSAT team
- Industry stakeholders

# Objectives

- Expand and update the GREET model for hydrogen production pathways and for applications of FCVs and other early market FC systems
- Conduct well-to-wheels (WTW) analysis of hydrogen FCVs with various hydrogen production pathways
- Conduct fuel-cycle analysis of early market FC systems
- Provide WTW results for DOE OFCHIT activities such as the Hydrogen Posture Plan and the MYPP
- Engage in discussions and dissemination of energy and environmental benefits of hydrogen FCVs and other FC systems

# Approach

- Obtain data for hydrogen production pathways from:
  - Open literature
  - H2A simulation results
  - Process engineering simulations with models such as ASPEN
  - Interaction with hydrogen producers and others
- Obtain data for hydrogen FCVs and other FC Systems from:
  - Open literature
  - PSAT and H2A simulations
  - Data of available FCV models and fuel cell systems
  - Data from industry sources
- Expand and update the GREET model
- Conduct WTW or fuel-cycle simulations with GREET
- Analyze and present WTW results

# Milestones of Fuel-Cycle Analysis of Hydrogen Pathways and Early Market FC Systems

- The most recent GREET version – GREET1.8c – was released in March 2009
- Fuel-cycle studies were completed:
  - Energy and GHG effects of FC forklifts and distributed power generation in 2008
  - Energy and GHG effects of PHEVs including FC PHEVs in 2008-2009
  - Energy and GHG effects of fuel-cell systems for combined heat, hydrogen, and power (CHHP) generation (on-going)

# **A Completed Fuel-Cycle Analysis of FC Forklifts and FC Distributed Power Generation Shows GHG Benefits of the Two FC Early Market Applications**

- FC forklifts and distributed power generation are two early market applications to help development of hydrogen production and FC technologies
- The fuel-cycle analysis examined energy use and GHG emissions for these two applications relative to baseline alternatives
- Argonne's GREET model was expanded to estimate the fuel-cycle energy use and GHGs emissions of the two applications
- Two reports and one journal articles were published to document the analysis and findings
- Results showed that the two applications can achieve GHG reduction benefits as they paved the road for eventual FCV applications

# Argonne Began A WTW Analysis of Plug-in Hybrid Electric Vehicles (PHEVs) in Summer 2008

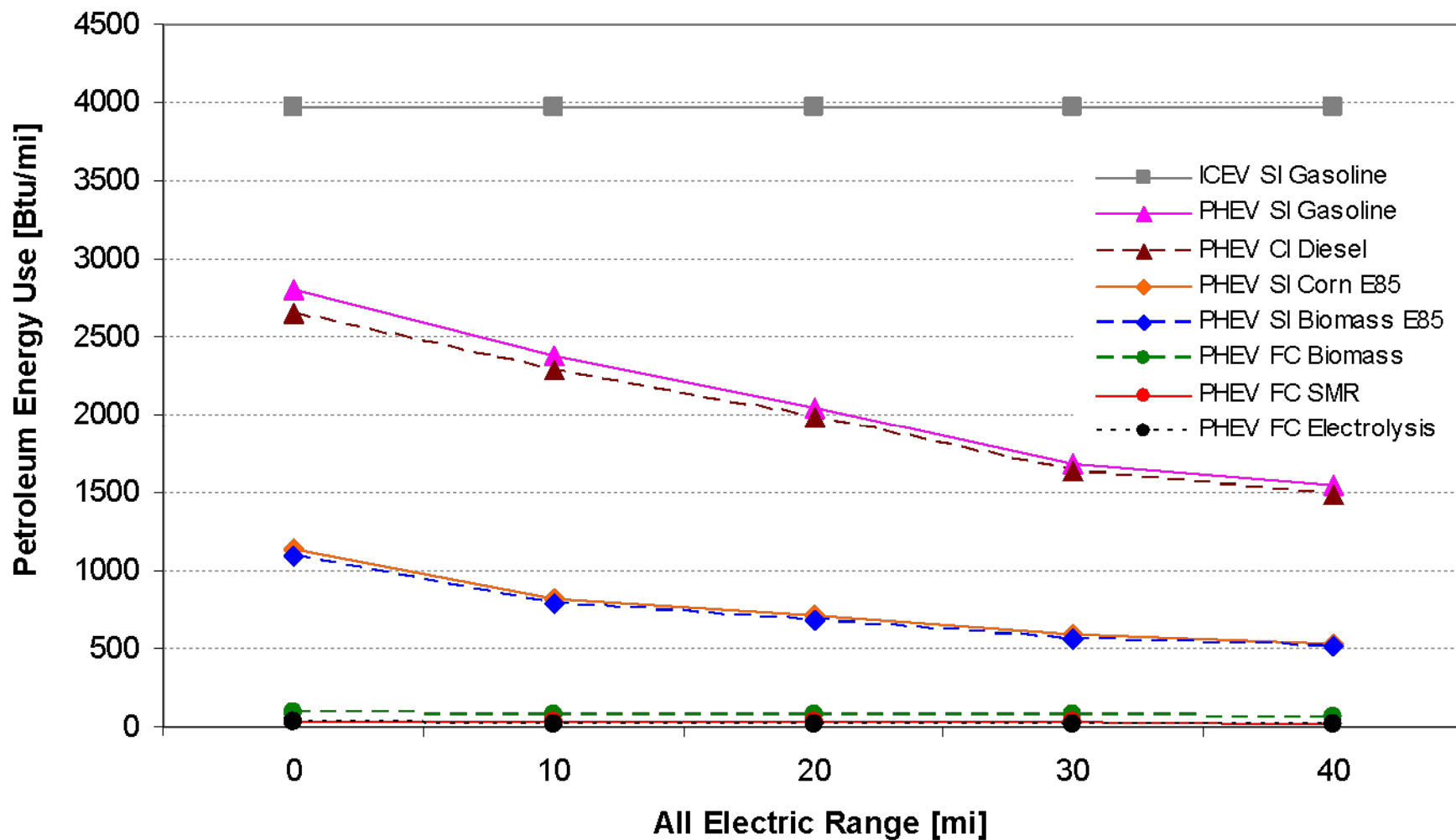
- To examine relative energy and emission merits of PHEVs; the vehicle types addressed are:
  - Conventional internal combustion engine vehicles (ICEVs)
  - Regular hybrid electric vehicles (HEVs)
  - ICE plug-in hybrid electric vehicles (PHEVs)
  - Fuel-cell PHEVs
- Fuel options:
  - Petroleum
    - ✓ Gasoline
    - ✓ Diesel
  - E85 with ethanol from
    - ✓ Corn
    - ✓ Switchgrass
  - Electricity with different generation mixes
  - Hydrogen with several production pathways

# A Few Key Issues Have Been Addressed in the PHEV WTW Analysis

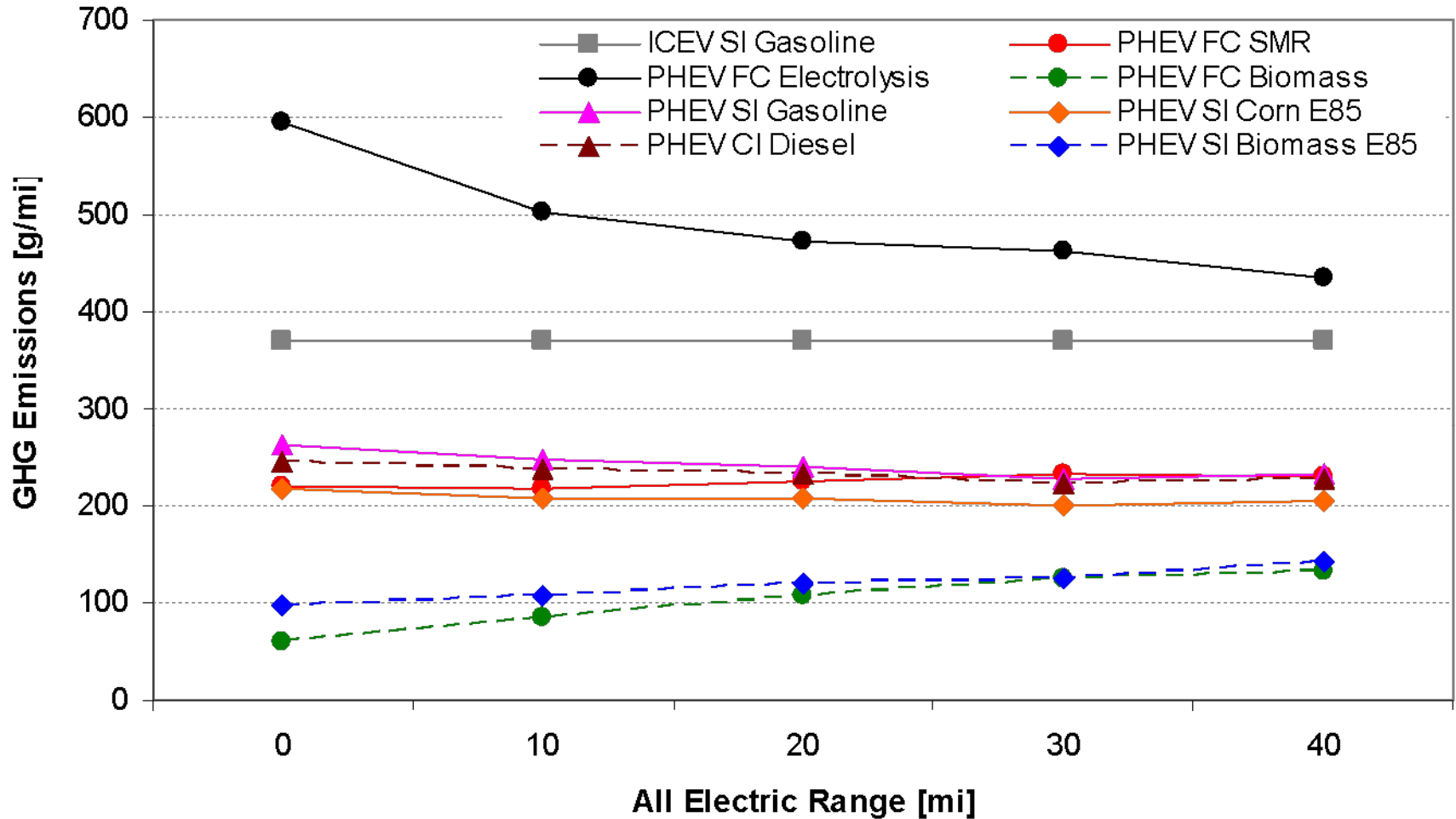
- Electricity generation mixes to charge PHEVs
  - Reviewed studies completed in this area and generated five sets of generation mixes for PHEV recharge
  - Efforts are under way to conduct electric utility dispatch for PHEVs
- PHEV performance evaluation included
  - PHEV operating strategies with the PSAT model
  - Fuel economy results for various PHEV configurations
  - Effects of all electric ranges (AER) of PHEVs
  - VMT shares by mode of operation for PHEVs
- GREET WTW simulations of PHEVs
  - Expanded and configured GREET for PHEVs
  - Conducted GREET PHEV WTW simulations



# PHEV Options with Non-Petroleum Fuels Such As Hydrogen Reduce Petroleum Use Significantly



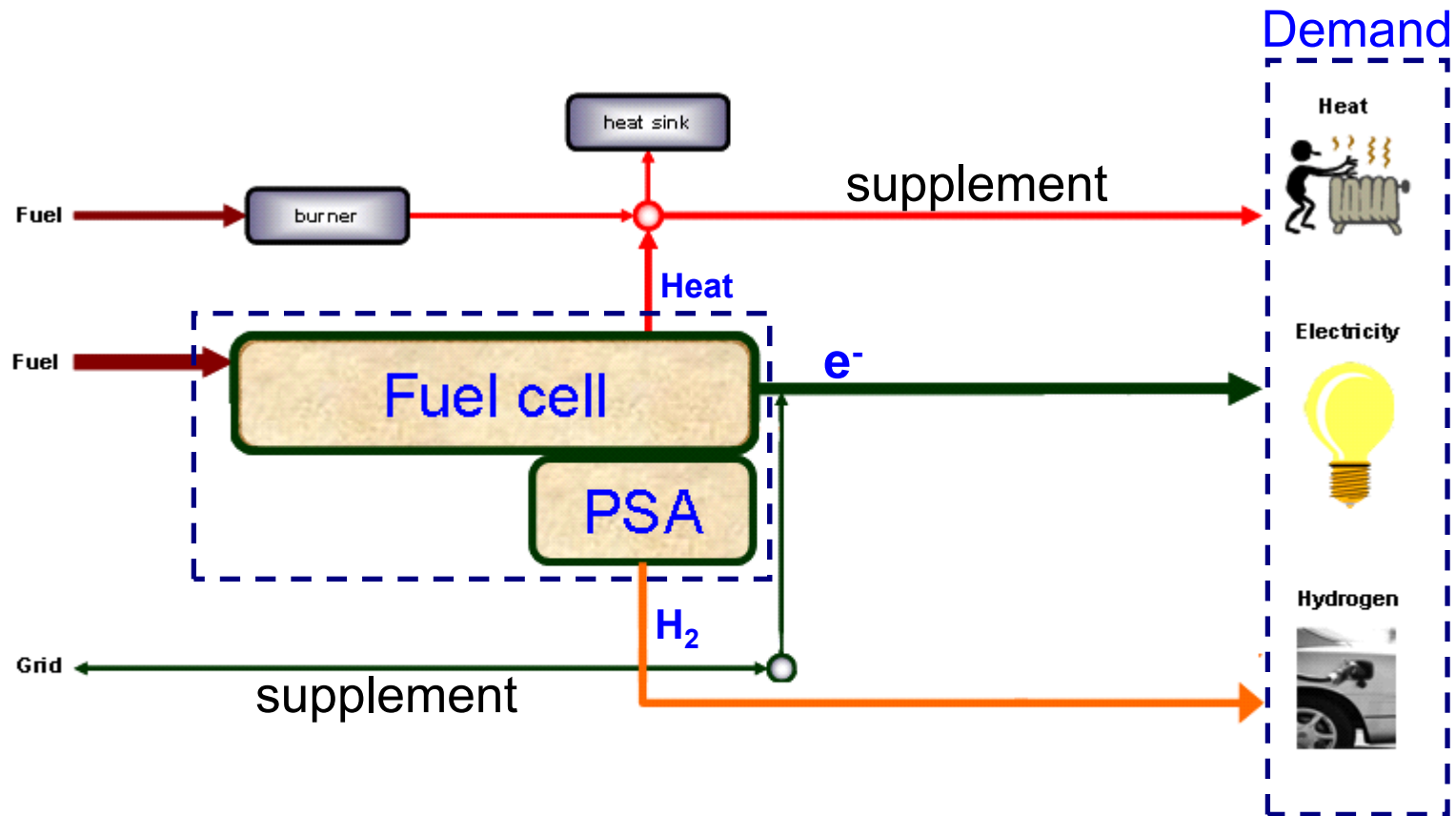
# WTW GHG Emissions of PHEV Options Vary Among Fuel Options (US Mix for PHEV Recharge)



# A New Study Was Started in FY2009 to Evaluate Combined Heat, Hydrogen, and Power (CHHP) Generation Systems

- CHHP was identified as an early FC market application and to produce hydrogen for FCVs
- Argonne examines energy and GHG emission implications for different CHHP system configurations
  - Expansion and use of Argonne's GREET model
  - The goal is to estimate energy and GHG emission effects of CHHP introduction into FC early markets

# CHHP Systems Are Designed to Produce Heat, Hydrogen, and Power To Serve Demand for the Three in a Given Situation



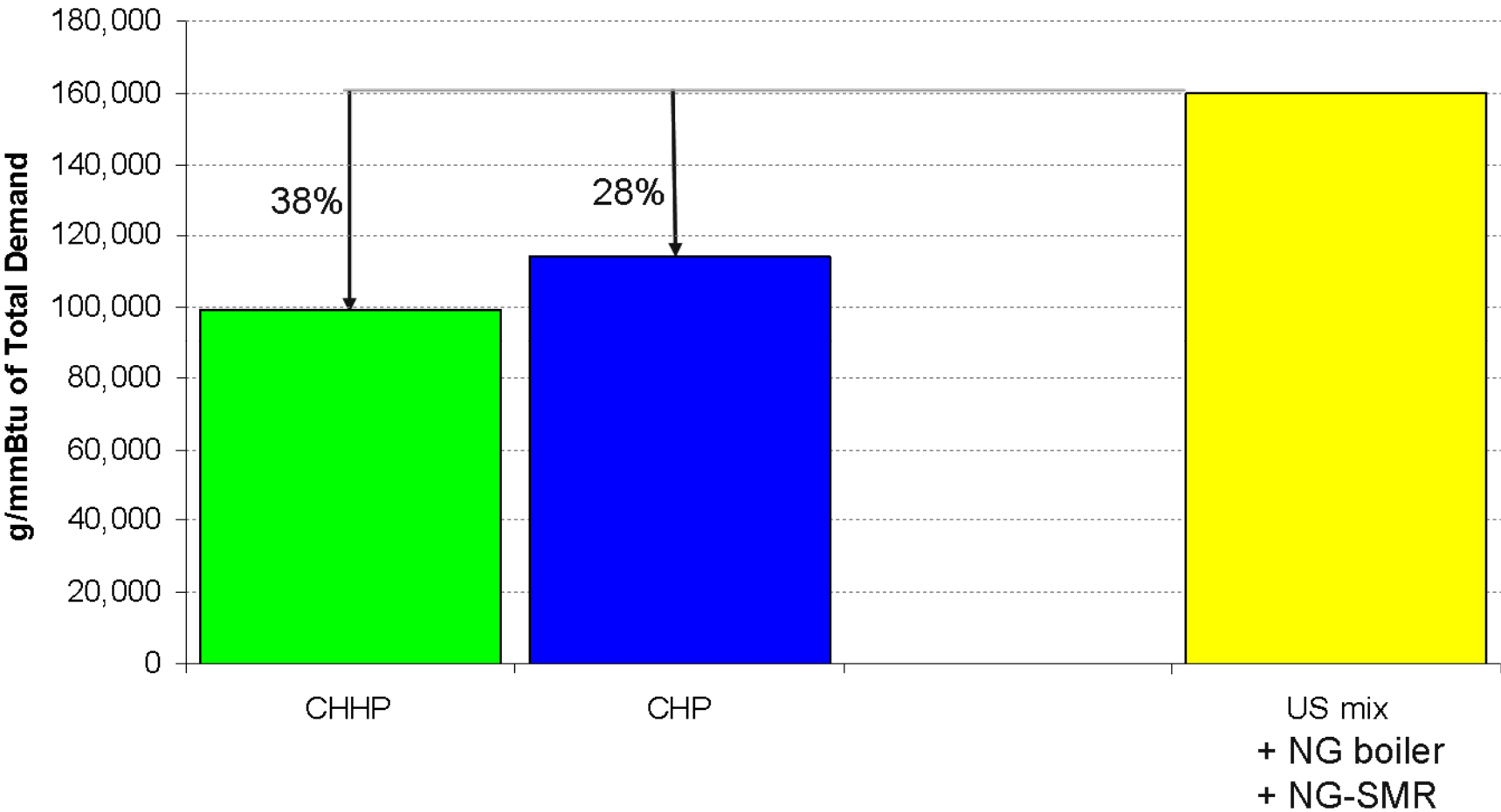
Reference: Darlene Steward (NREL)

# Ways of Dealing with Multiple Products in Fuel-Cycle Analysis of CHHP Systems Are a Key Issue

- Two potential methods
  - Fuel cycle analysis from facility operator's point of view (that is, to meet a given mix of demand for heat, power, and *hydrogen*) – the total demand approach
    - ✓ Fuel cycle analysis function unit: per mmBtu of electricity, heat, and hydrogen combined for a given mix of the three demands
  - The displacement approach
    - ✓ Fuel cycle analysis function unit: per mmBtu of electricity (assuming that it is the main product; heat and hydrogen are by-products)
- Other approaches such as allocation on the energy output basis may not be appropriate for CHHP system evaluation

# CHHP, As Well As CHP, Offers GHG Reductions Relative to Conventional Systems

Fuel Cycle GHG Emission (MCFC)



# Preliminary Results of CHHP Fuel-Cycle Evaluation

- In general, fuel-cell-based CHHP and CHP provide energy and GHG reduction benefits compared to a conventional system of providing heat, hydrogen, and power
- Even if CHHP provides small incremental or no benefits compared to CHP, CHHP provides the opportunity of serving the market transition to H2 FCVs by generating H2
- For CHHP, system overall efficiency and the percentage of electricity demand satisfied by the CHHP system are the two most important parameters impacting energy use and GHG emissions

# Future Work

- Add new hydrogen production options
  - Biogas/landfill gas to hydrogen
- Continue the PHEV WTW analysis
  - Modeling of electric utility dispatches to serve PHEVs
- Complete fuel-cycle analysis of FC CHHP systems
- Expand GREET for new hydrogen production pathways and for FC early market applications
- Develop GREET with a new programming platform for easier expansion and use

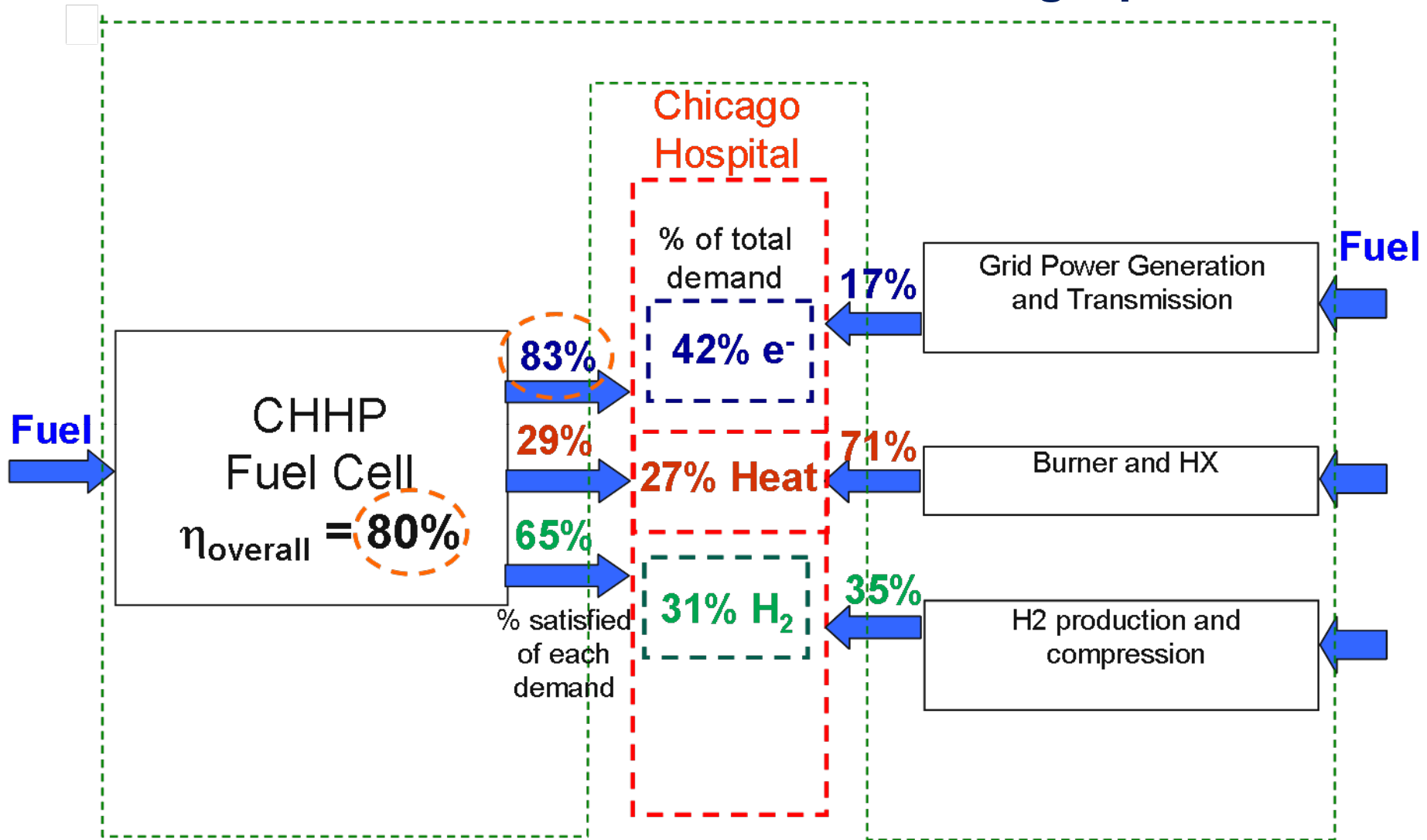


# Summary

- Fuel cycle analysis is an integral part of examining energy and environmental effects of H2 FCVs and other FC systems
- The GREET model has been developed as a standard tool to examine energy and emission benefits of FC technologies
- H2 FC forklifts and distributed power generation achieve energy and GHG reduction benefits
- H2 FC PHEVs may offer energy and GHG reduction benefits
- FC CHHP systems may offer opportunities for early market introduction of FC technologies with GHG benefits

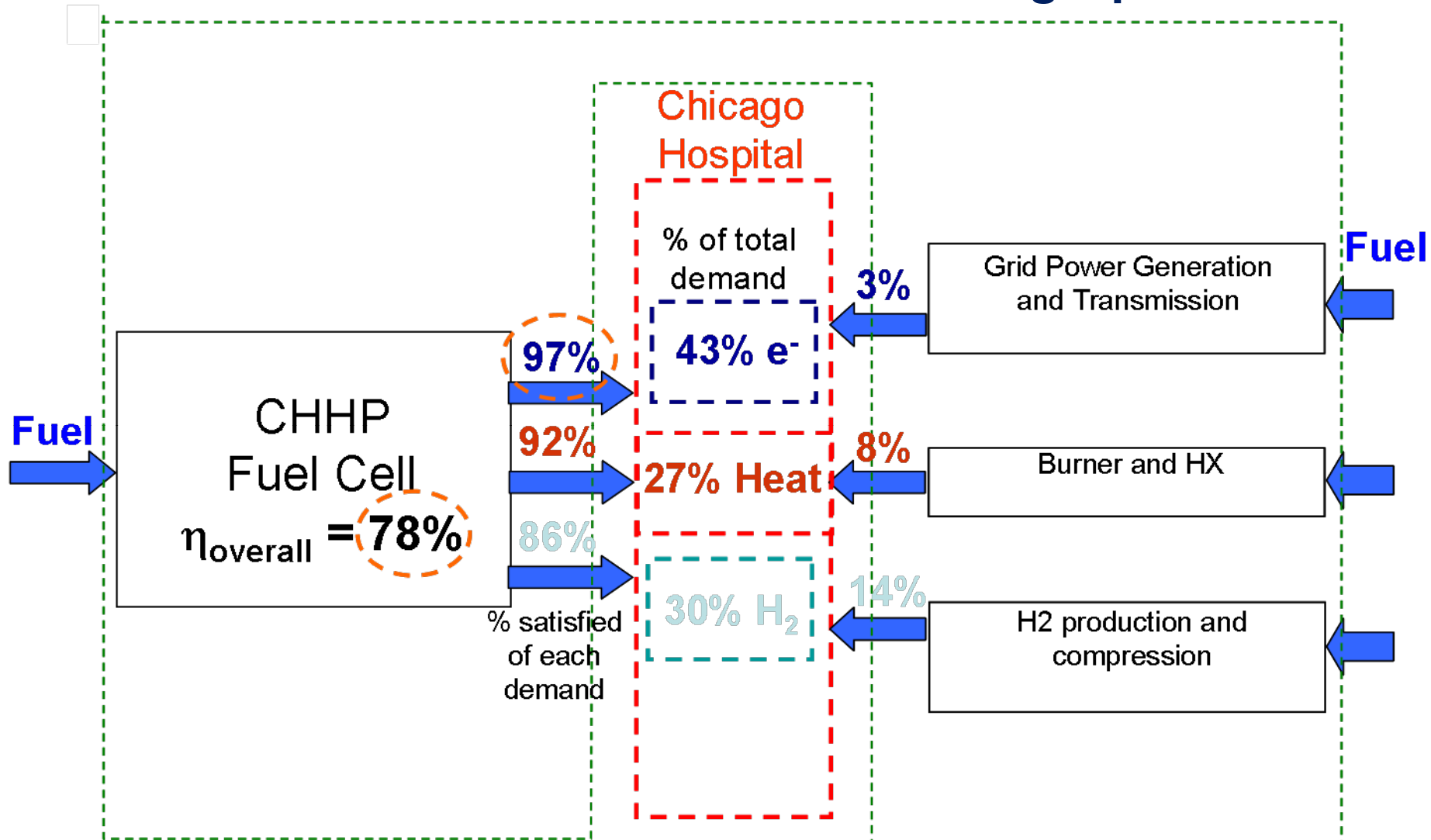
# **Backup Slides**

# Facility Demand and Fuel Cell Performance Characteristics— MCFC CHHP for Electric Load Following Operation



For comparison, MCFC **CHP** system satisfies 85% of electric demand and 45% of heat demand.

# Facility Demand and Fuel Cell Performance Characteristics— PAFC CHHP for Electric Load Following Operation



For comparison, PAFC **CHP** system satisfies 32% of electric demand and 76% of heat demand.

# GHG Emissions of CHHP, CHP, and Conventional Systems

Fuel Cycle GHG Emission (PAFC)

