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

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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

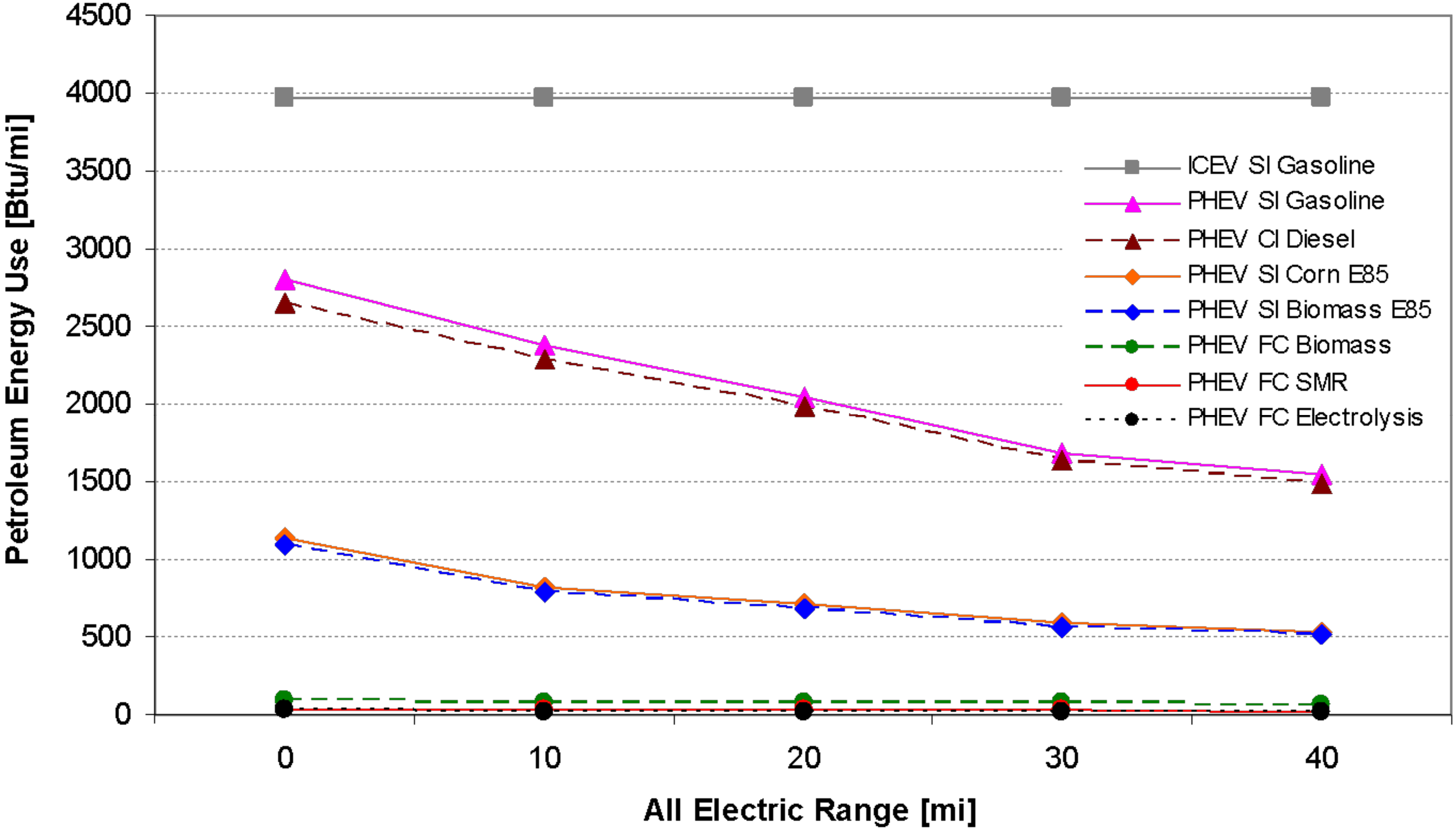
Argonne Began A WTW Analysis of Plug-in Hybrid Electric Vehicles (PHEVs) in Summer 2008

- To examine relative energy and emission merits of PHEVs; the vehicle types addressed are:
  - ➢ Conventional international 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

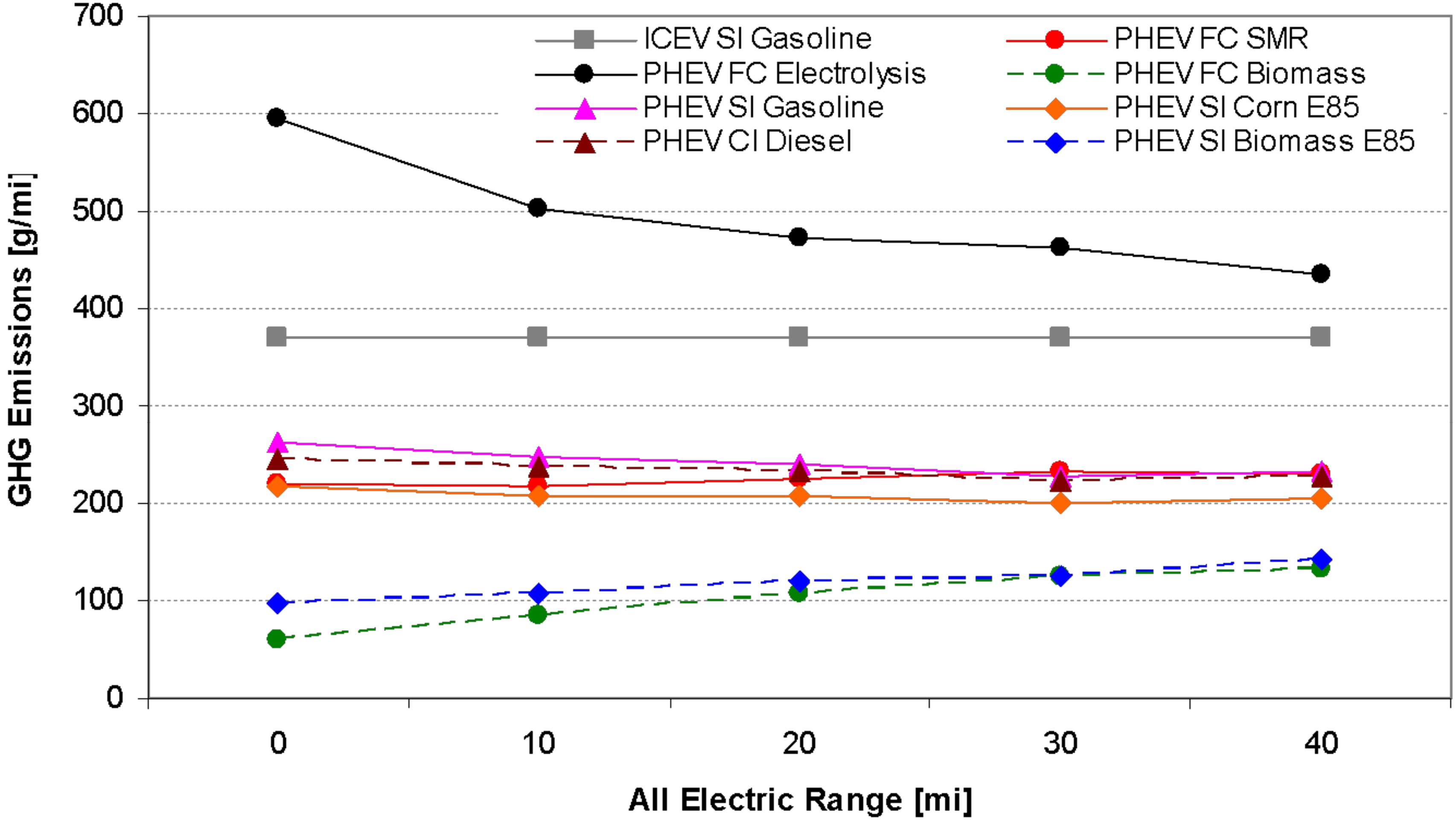
A Few Key Issues Have Been Addressed in the PHEV WTW Analysis

- 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



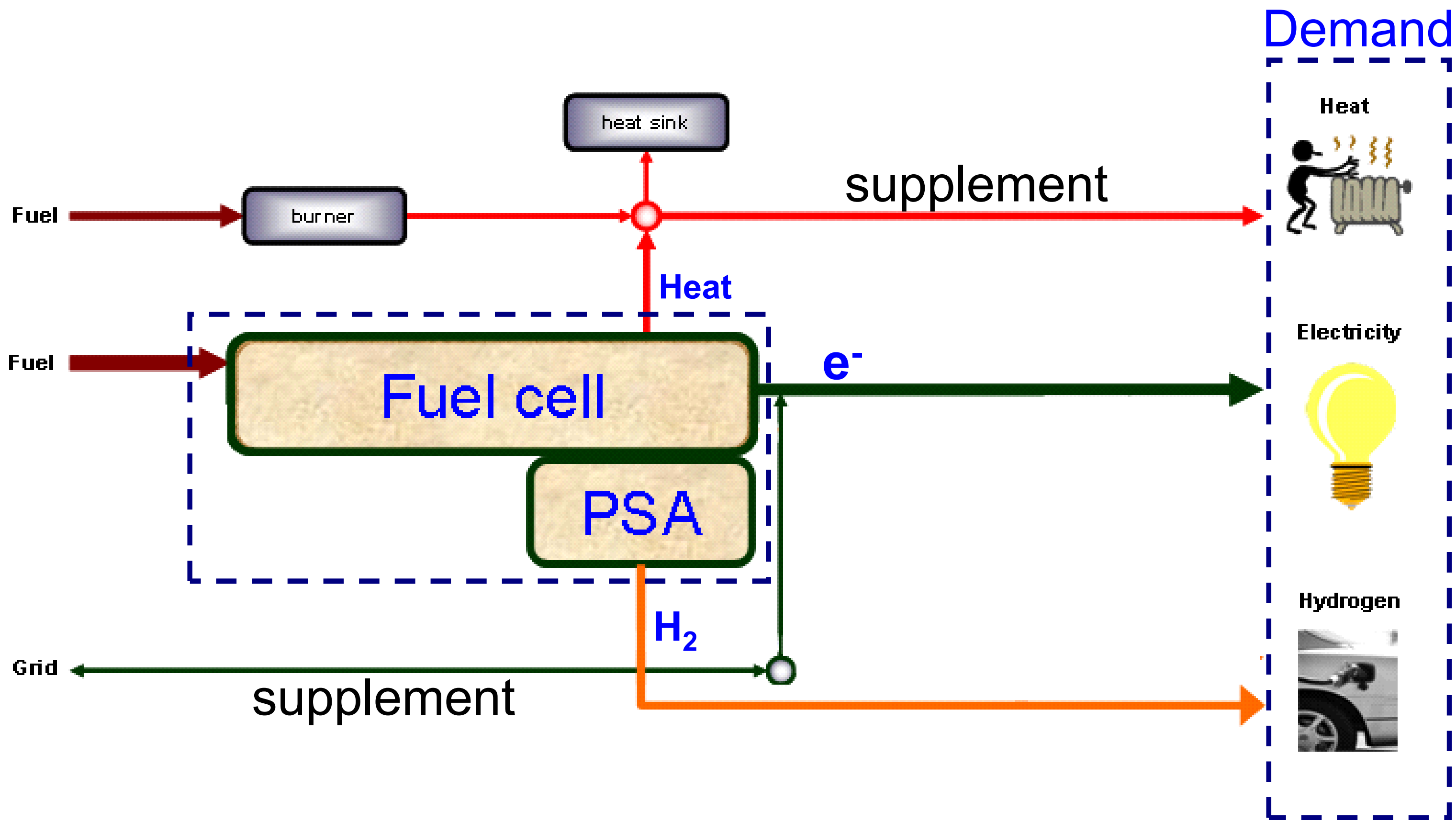
WTW GHG Emissions of PHEV Options Vary Among Fuel Options (US Mix for PHEV Recharge)



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

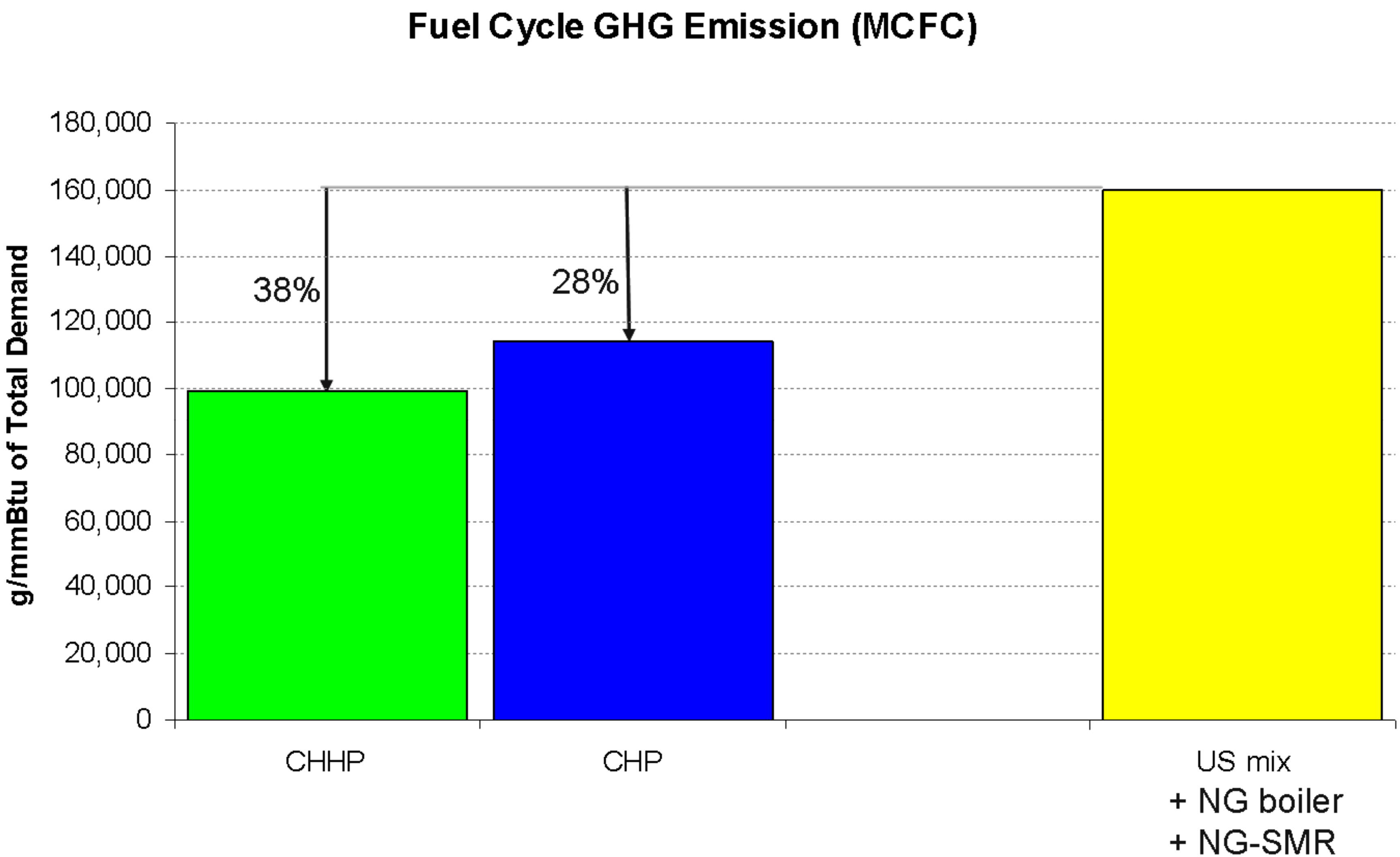


Reference: Darlene Steward (NREL)

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



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

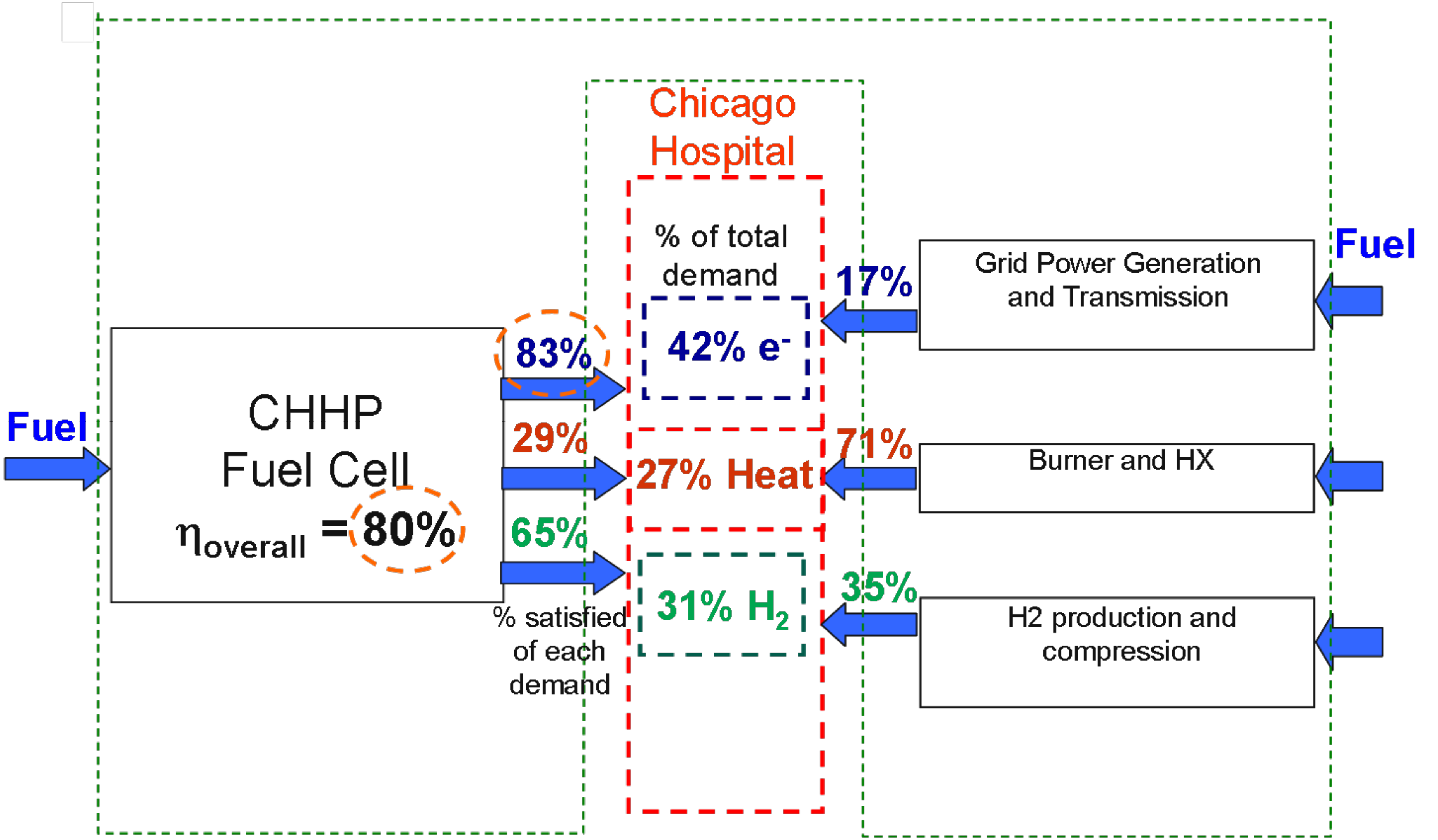
- Add new hydrogen production options
  - Biogas/landfill gas to hydrogen
- Continue the PHEV WTW analysis
  - Modeling of electric utility dispatches to serve PHEVs
- Complete fuel-cycle analysis of FC CHHP systems
- Expand GREET for new hydrogen production pathways and for FC early market applications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

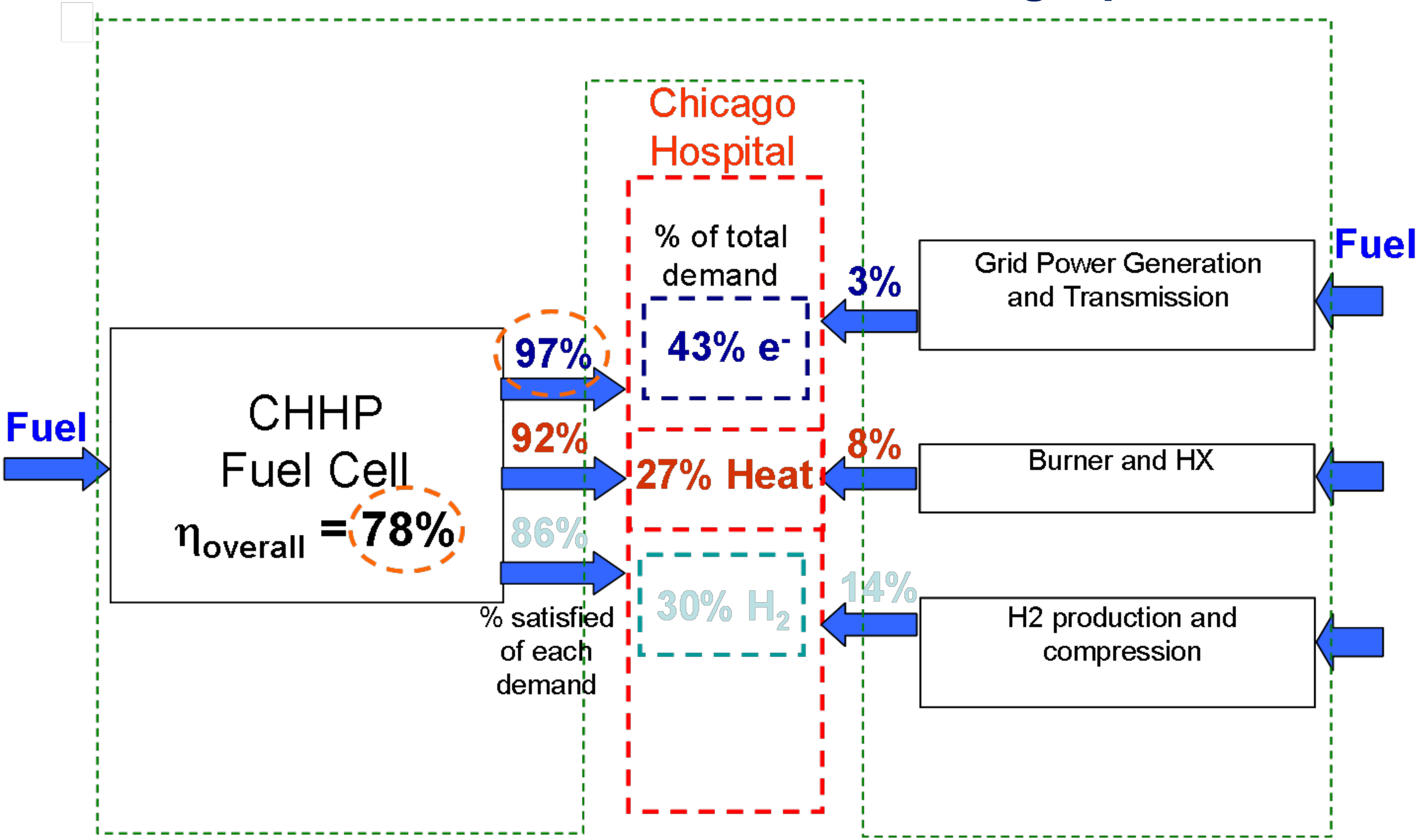
Backup Slides

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