GREET Model Development and Life-Cycle Analysis Applications

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Project ID: AN012

Overview

Timeline

- Start: Oct. 2002
- End: not applicable (OFCT program)
- % complete: not applicable

Budget

- Total project funding from DOE: $4.1M through FY11
- Funding received in FY10: $650K
- Funding for FY11: $579K

Barriers to Address

- Evaluate energy and emission benefits of H_2 FC technologies
- Overcome inconsistent data, assumptions, and guidelines
- Develop models and tools
- Conduct unplanned studies and analyses

Partners (in-kind)

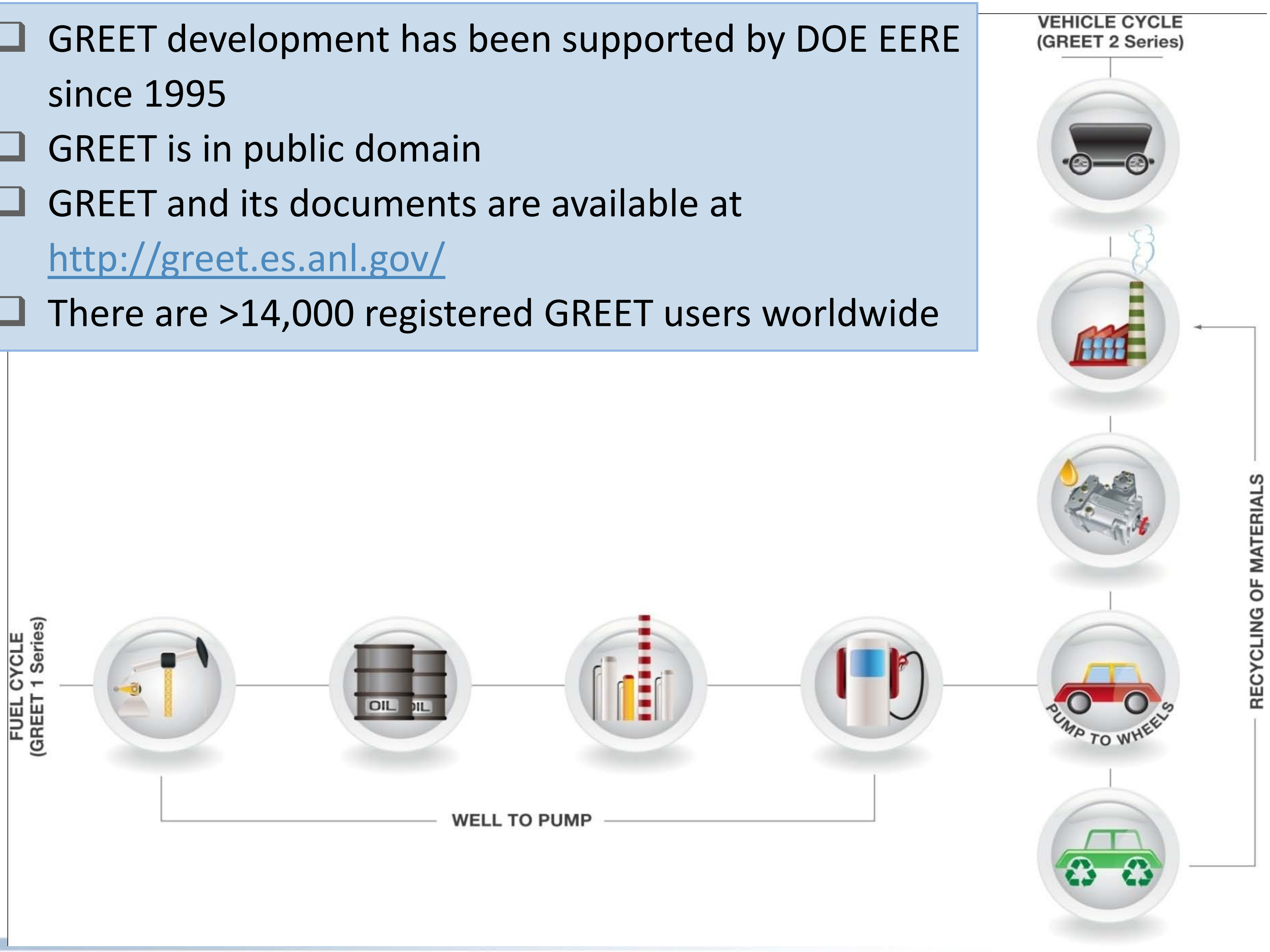
- NREL and other national labs
- Industry stakeholders

Objectives and Relevance

- Develop and update the GREET model for consistently assessing energy and emission benefits of H_2 fuel cell vehicles (FCVs) and other fuel cell (FC) systems
- Conduct fuel-cycle analysis of
  - H_2 FCVs with various hydrogen production pathways
  - Early market FC systems
- Conduct vehicle-cycle analysis of manufacturing H_2 FCVs
- Provide life-cycle analysis (LCA) results for DOE's Office of Fuel Cell Technologies (OFCT) activities such as the H_2 Posture Plan and the Multi-Year Program Plan (MYPP)
- Support and interact with stakeholders to address energy and environmental benefits of H_2 and FC systems

The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model

- GREET development has been supported by DOE EERE since 1995
- GREET is in public domain
- GREET and its documents are available at http://greet.es.anl.gov/
- There are >14,000 registered GREET users worldwide



Approach

- Build LCA modeling capacity with the GREET model
  - Continue to expand and update GREET to serve the community
  - Address emerging LCA issues related to H_2 and FC systems
  - Maintain openness and transparency of LCAs
- Obtain data for H_2 production pathways
  - Open literature and results from other researchers
  - Simulation results with models such as H2A and ASPEN Plus®
  - H_2 producers and technology developers
- Obtain data for FCVs and other FC systems
  - Open literature and results from other researchers
  - Simulation results from models such as Autonomie and H2A
  - Demonstration programs of available FCV models and FC systems
  - Auto makers and FC system producers

Key Milestones

- GREET model development
  - New GREET programming platform
  - The new GREET version (GREET1.8d, released in Aug. 2010) include:
    - Landfill gas to H_2
    - Plug-in hybrid electric vehicles (PHEVs, including FC PHEVs)
    - Updated fuel economy for FCVs
- Vehicle-cycle analysis of FCVs
- LCA of landfill gas (LFG) to H_2 pathway
  - FCVs: NG-to-H_2 vs. LFG-to-H_2
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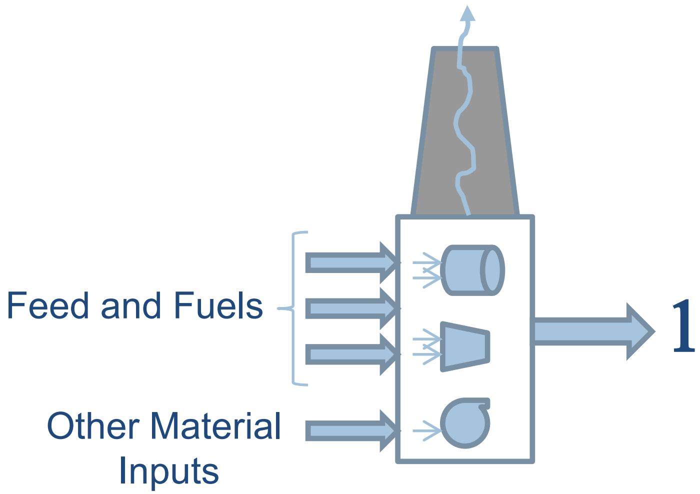
    - Combined H_2, heat, and Power (CHHP) systems
    - Combined heat and power (CHP) systems
    - NG vs. LFG
- LCA of plug-in hybrid electric vehicles (PHEVs)
  - Phase 2 report completed in June 2010
  - Phase 3 study is under way

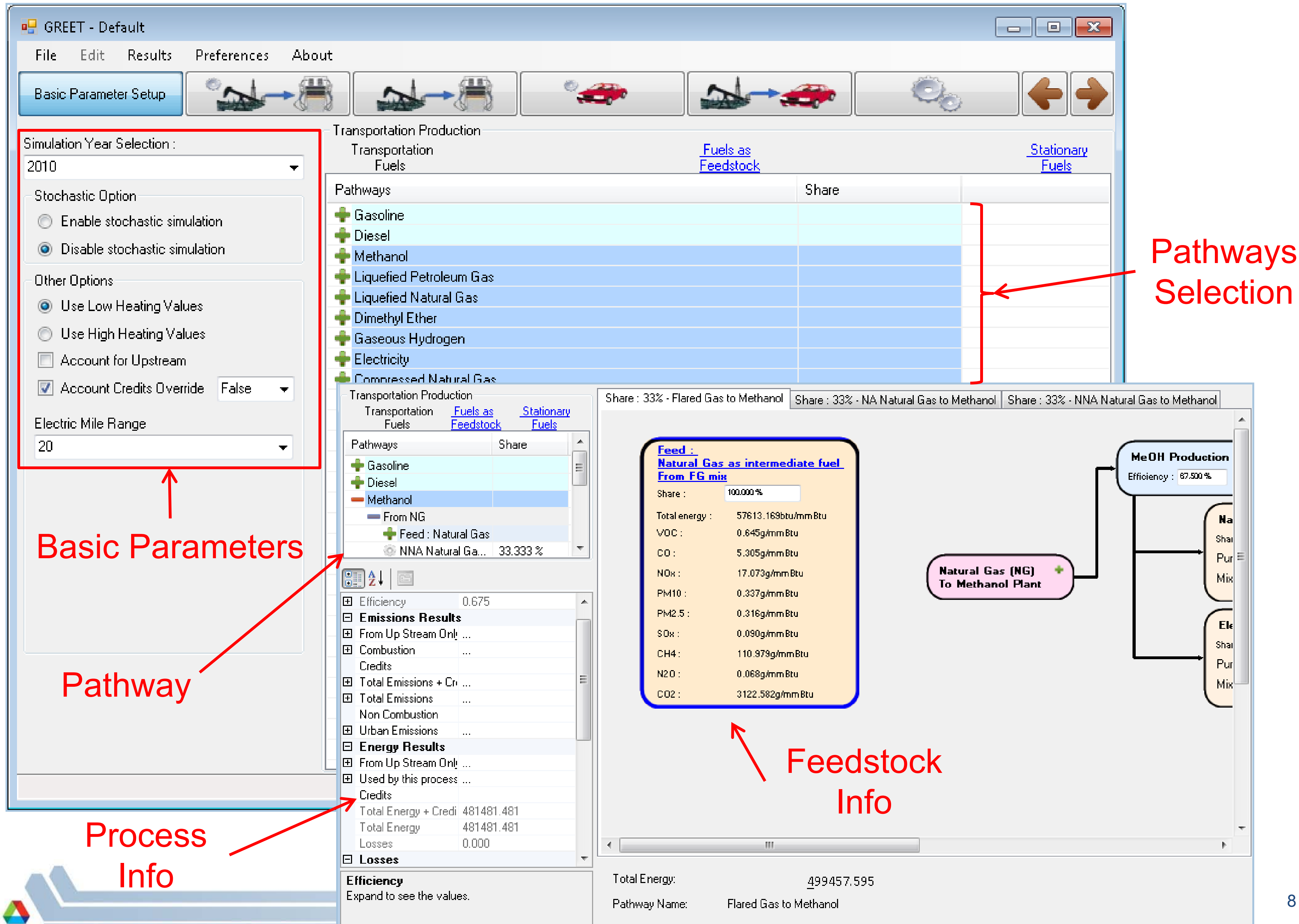
The New GREET Architecture Provides a Platform for Easier LCA Simulation and Analysis



A "process" is the smallest building block in a fuel pathway

- Materials database for feed, fuels, and others
  - Properties: heating values, density, …
  - Pathways for material production are built internally
- Emission factor database
- Stationary process database
  - Energy efficiency
  - Process shares
  - Material inputs
- Transportation logistic database
  - Transportation modes and shares
  - Transportation distances
- Vehicles database
  - Fuel economy
  - Tailpipe emissions
  - Operation parameters (those for PHEVs)

New Platform Enhances Accessibility, Expandability, and Transparency



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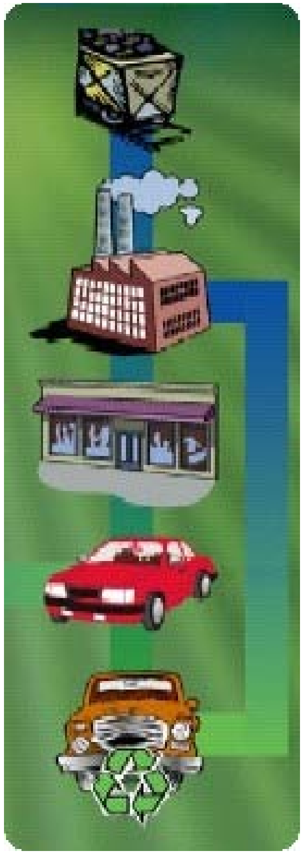
GREET Provides a Tool for Vehicle-Cycle Analysis of Vehicle Manufacturing

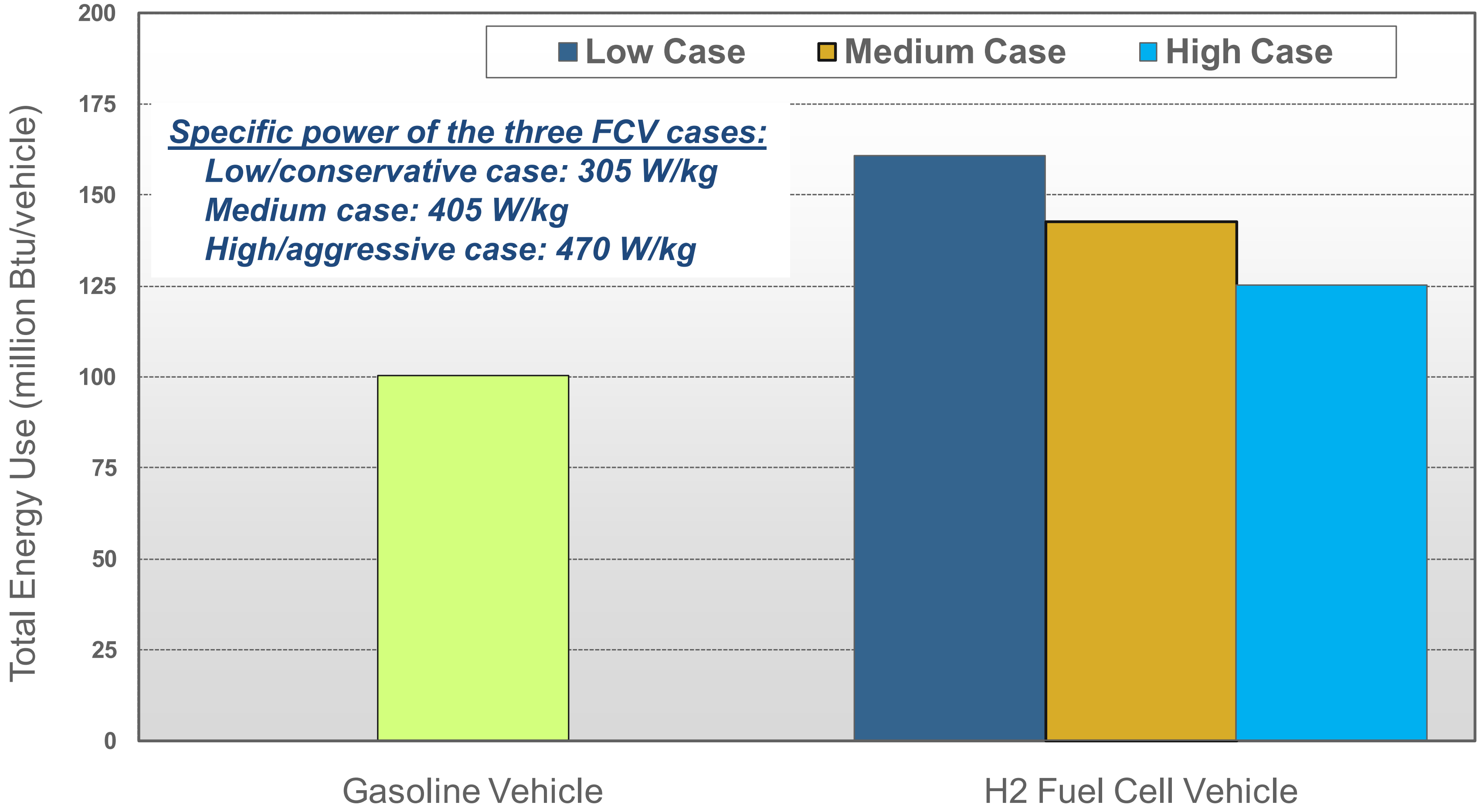


- Raw material recovery
- Material processing and fabrication
- Vehicle component production
- Vehicle assembly
- Vehicle disposal and recycling

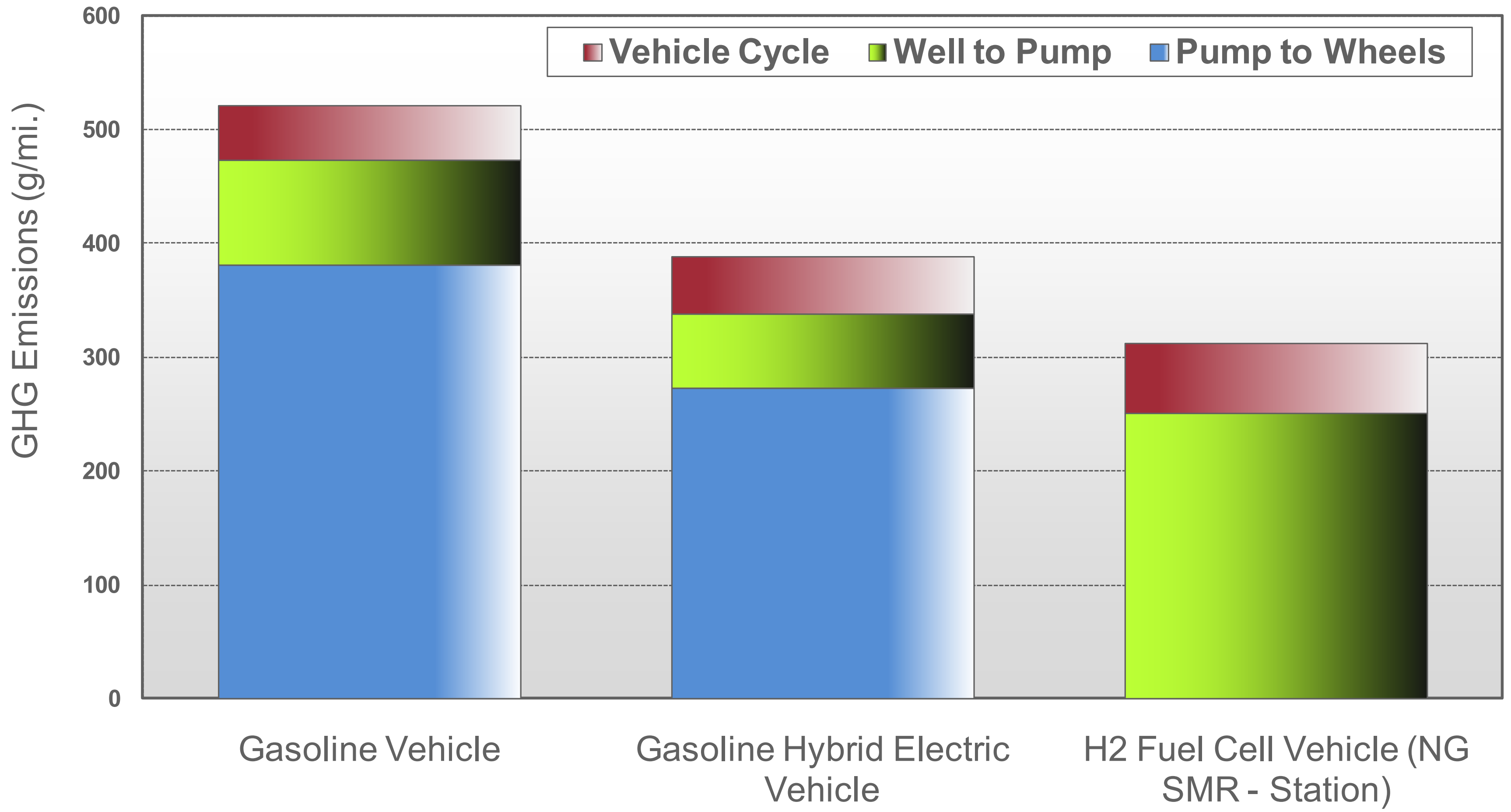
FCV Vehicle-Cycle Results Are Influenced by The Allocation Method for Platinum Production

- Platinum, one of the platinum group metals (PGM), is mined together with gold, copper, nickel, and other metals
- South Africa-estimated energy use value (77.2 mm Btu/ton) for PGM is used in GREET for now, which is consistent with other values from Europe
- However, energy and emissions of PGM mining are influenced greatly by allocation method: a North American example
  - Weight-based allocation
    - Shares: 1% PMG, ,1% gold, 40% copper, and 59% nickel
    - Platinum would account for **<0.02%** of vehicle-cycle energy use of FCVs
  - Market value-based allocation
    - Shares: 93% PMG, 2% gold, 1% copper, and 4% nickel
    - Platinum accounts for **~10%** of vehicle-cycle energy use of FCVs

Fuel-Cell Stack Specific Power Affects Vehicle-Cycle Energy Use of a FCV



When Combining Fuel Cycle and Vehicle Cycle Results, FCVs Show Energy and Emission Benefits



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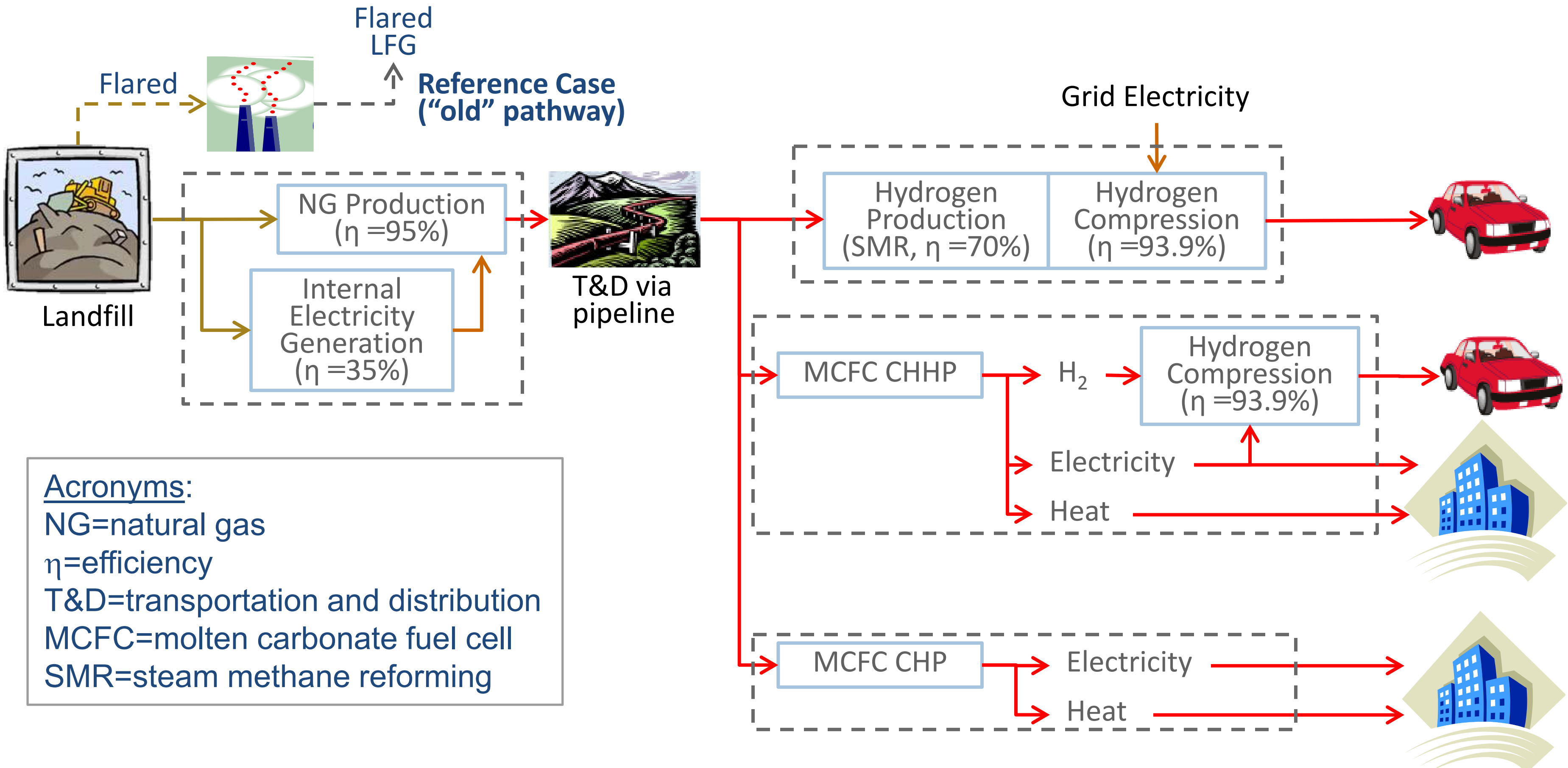
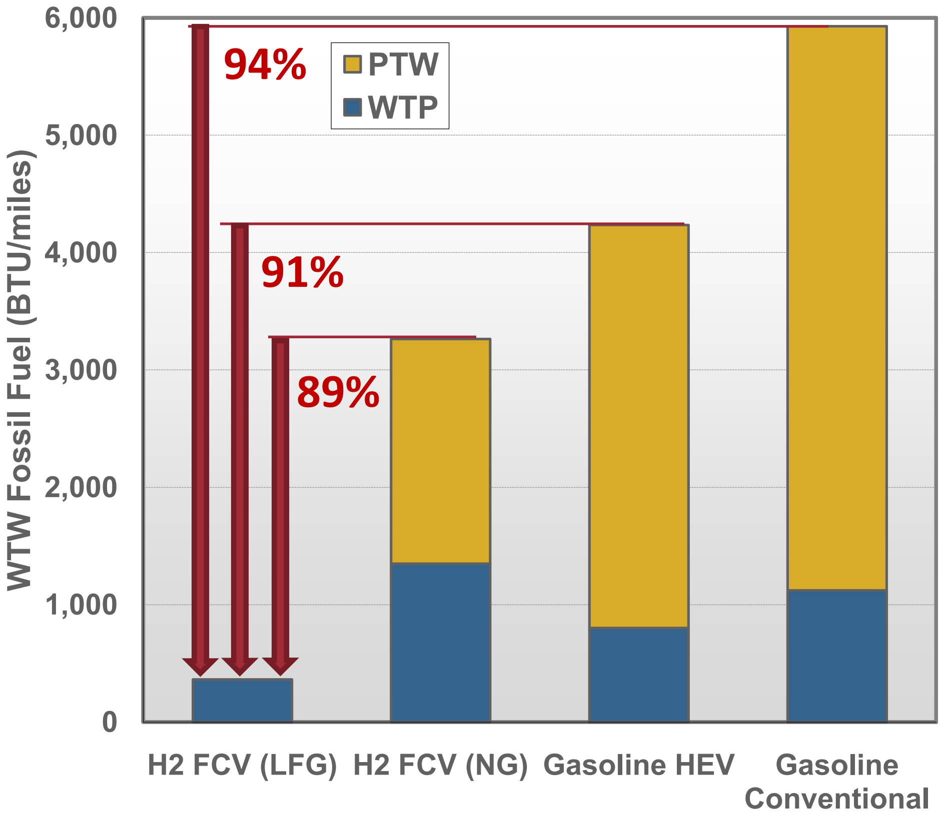
GREET Simulates LFG-to-H_2 Pathway for FCVs and LFG-Powered CHHP and CHP

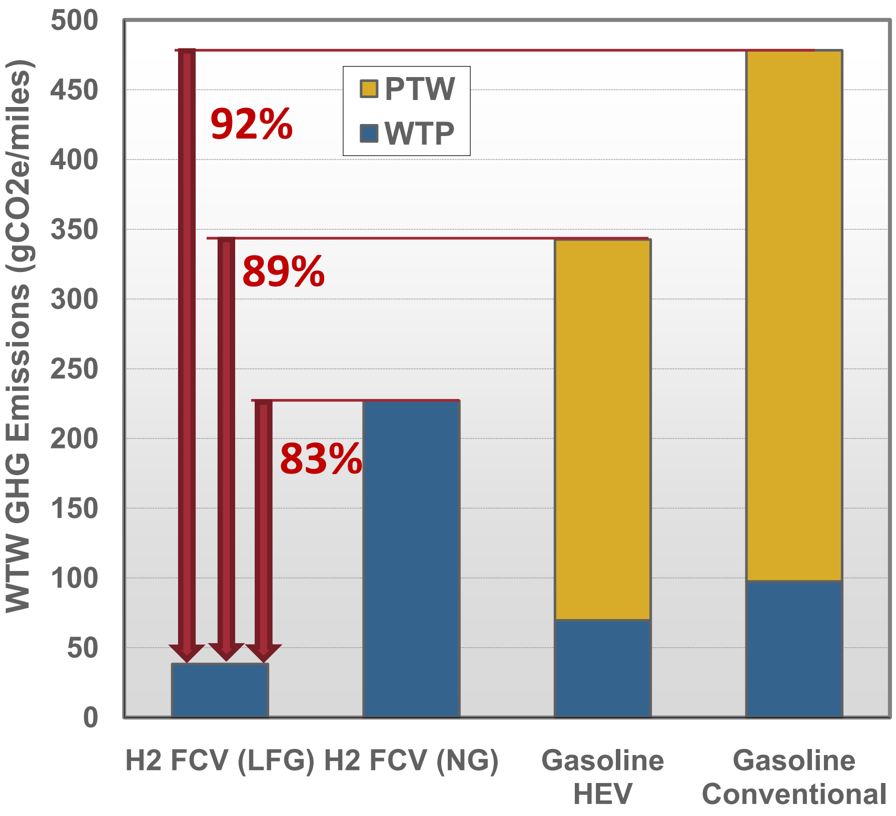


<u>Acronyms</u>:
NG=natural gas
η=efficiency
T&D=transportation and distribution
MCFC=molten carbonate fuel cell
SMR=steam methane reforming

- Pipeline-quality of methane from LFG is produced
- Energy and emission credits from avoided LFG flaring are accounted for

FCVs with H2 from LFG Achieve Large GHG Emissions Reduction Relative to FCVs with H2 from NG and gasoline ICEVs





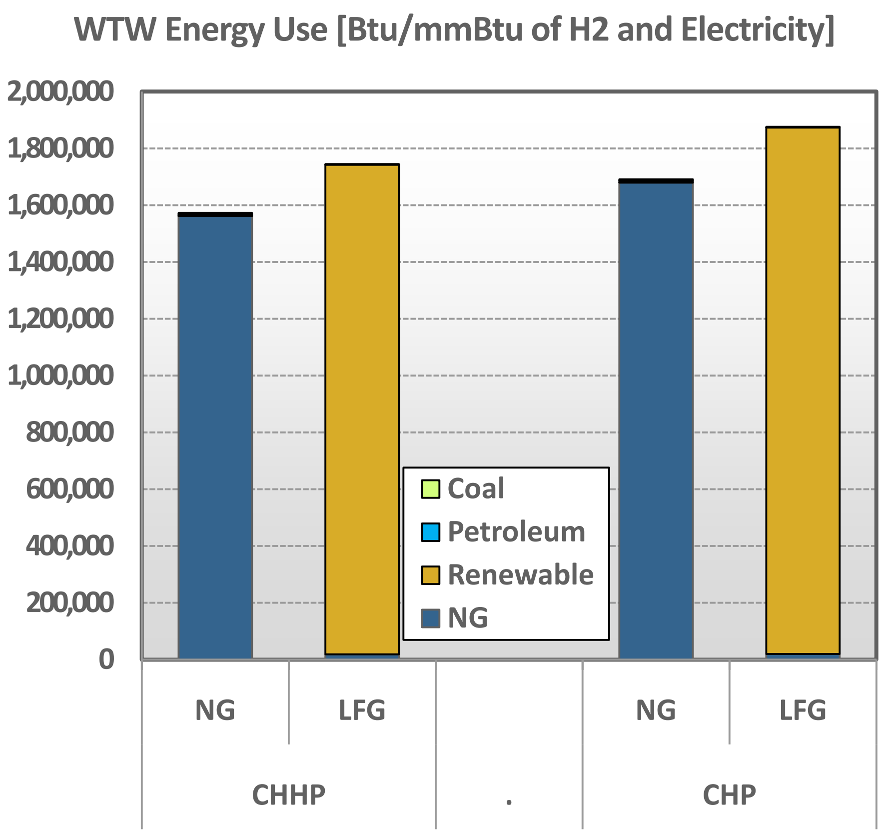
Fuel Economy values (miles per gasoline gallon equivalent):

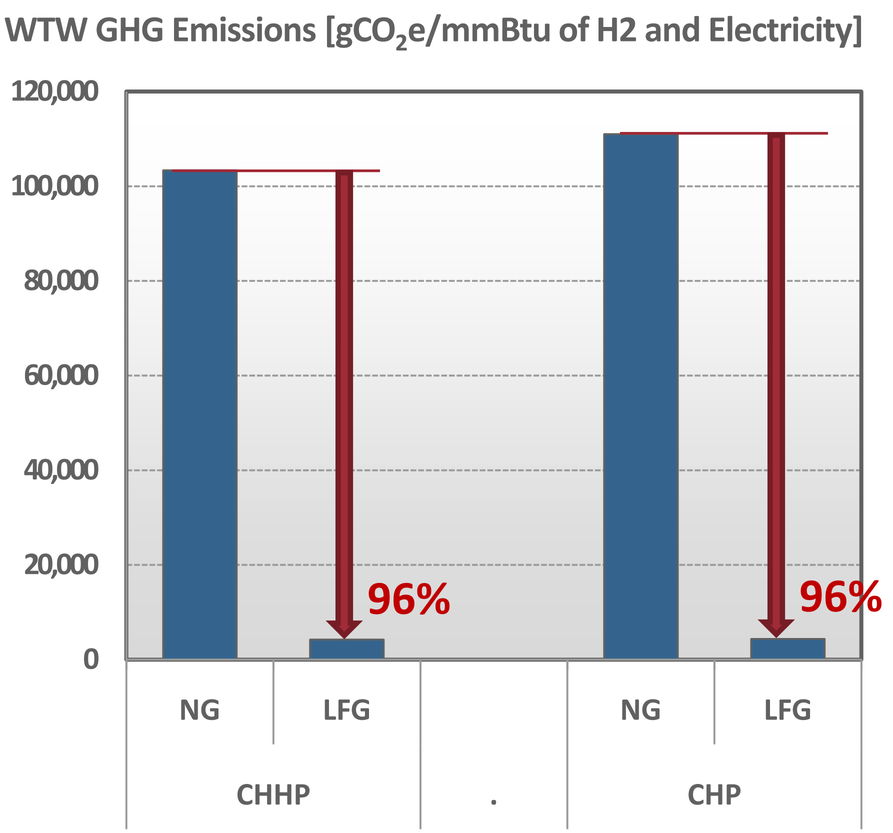
H_2 FCV – 60 mpgge

Gasoline hybrid electric vehicle (HEV) – 32.8 mpgge

Gasoline conventional vehicle – 23.4 mpgge

LFG For CHP and CHHP Fuel Cells Achieve Large GHG Emissions Reduction Relative to NG-Powered Fuel Cells





Note: the displacement approach was used to deal with byproduct heat.

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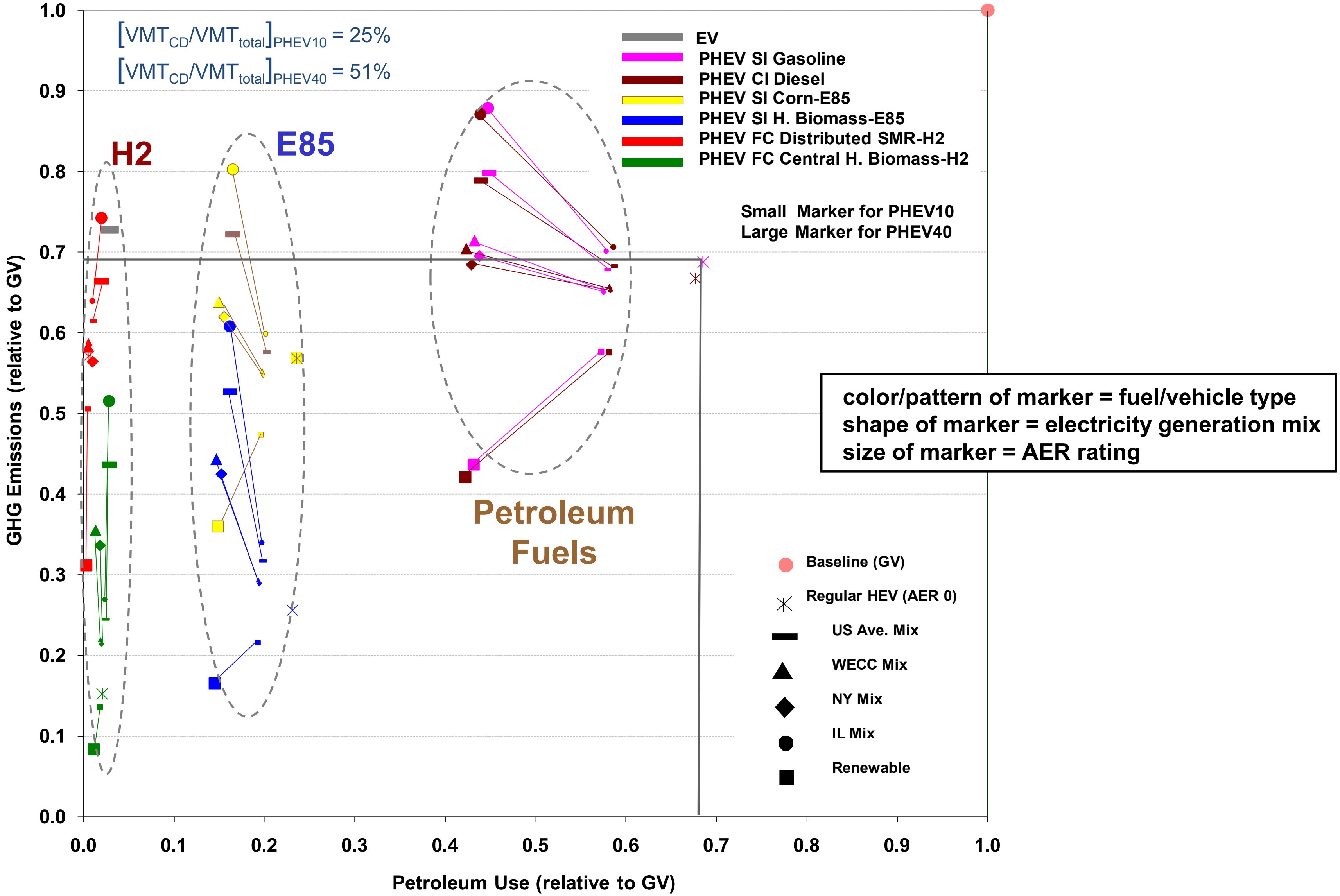
PHEV LCA Analysis Includes Alternative Vehicle/Fuel Options

- Vehicle types:
  - Conventional international combustion engine vehicles (ICEVs)
  - Regular hybrid electric vehicles (HEVs)
  - Plug-in hybrid electric vehicles (PHEVs) with all electric range (AER) of 10-40 miles
  - Fuel-cell vehicles (FCVs)
  - Electric vehicles (EVs)
- Fuel options:
  - Petroleum fuels
    - ✓ Gasoline and diesel (from a mix of conventional crude and oil sands)
  - Ethanol (used in E85 blend with gasoline)
    - ✓ Corn and cellulosic biomass feedstock sources
  - Hydrogen
    - ✓ Natural gas and biomass feedstock sources
  - Electricity
    - ✓ Marginal generation mix for PHEV recharging in four regions (Western US, New England, New York, and IL)

PHEVs Require Large Share of Renewable Feedstock Sources To Achieve Significant GHG Emissions



Summary of GREET LCA Results

- On the vehicle-cycle basis, FCVs require more energy to make than ICEVs do, but FCVs reduce energy and emissions on the basis of both the vehicle and fuel cycle
- FCVs with H_2 from LFG achieve life-cycle GHG reduction
  - By 83% relative to FCVs with H_2 from NG
  - By 92% relative to gasoline ICEVs
- CHHP and CHP FC systems with LFG achieve 96% GHG reduction relative to those with NG
- Gasoline PHEVs require a large share of non-fossil electricity for battery recharging to achieve significant reduction in GHG emissions

Future Work

- Release of a beta version of GREET in the new programming platform
- Documentation of criteria pollutant emissions of CHP and CHHP
- New H2 production pathways such as
  - Animal waste biogas to H_2
  - Wastewater treatment plant biogas to H_2
- Detailed vehicle-cycle analysis of FCVs