

GREET Model Development and Life-Cycle Analysis Applications

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The 2011 DOE Fuel Cell Technologies Program and Vehicle Technologies Program
Annual Merit Review and Peer Evaluation Meeting

Arlington, VA, May 10, 2011

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 H₂ 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

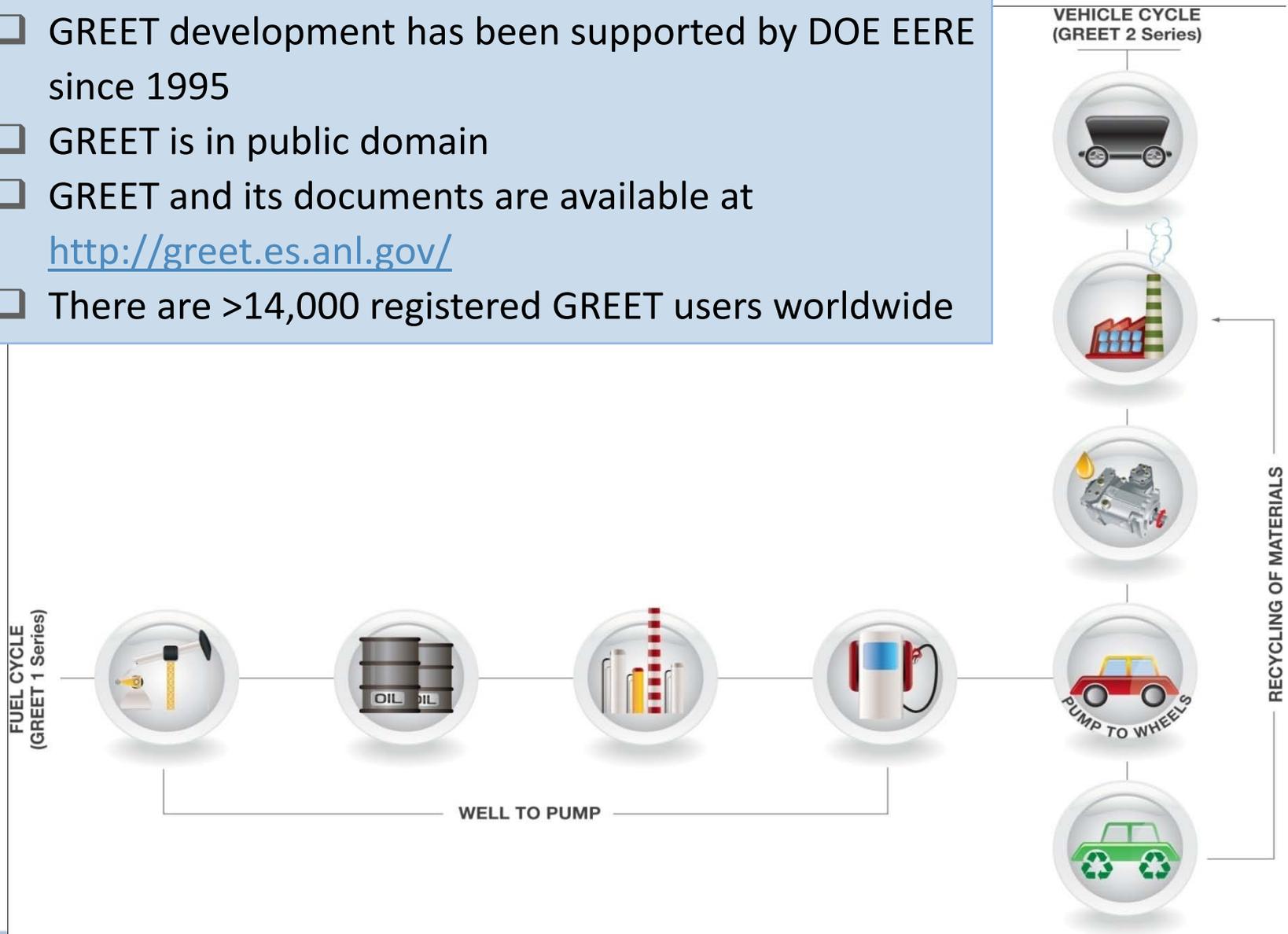


Objectives and Relevance

- ❑ Develop and update the GREET model for consistently assessing energy and emission benefits of H₂ fuel cell vehicles (FCVs) and other fuel cell (FC) systems
- ❑ Conduct fuel-cycle analysis of
 - H₂ FCVs with various hydrogen production pathways
 - Early market FC systems
- ❑ Conduct vehicle-cycle analysis of manufacturing H₂ FCVs
- ❑ Provide life-cycle analysis (LCA) results for DOE's Office of Fuel Cell Technologies (OFCT) activities such as the H₂ Posture Plan and the Multi-Year Program Plan (MYPP)
- ❑ Support and interact with stakeholders to address energy and environmental benefits of H₂ and FC systems

The **GREET** (**G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation) 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 H₂ and FC systems
 - Maintain openness and transparency of LCAs
- ❑ Obtain data for H₂ production pathways
 - Open literature and results from other researchers
 - Simulation results with models such as H2A and ASPEN Plus®
 - H₂ 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 H₂
 - Plug-in hybrid electric vehicles (PHEVs, including FC PHEVs)
 - Updated fuel economy for FCVs

□ Vehicle-cycle analysis of FCVs

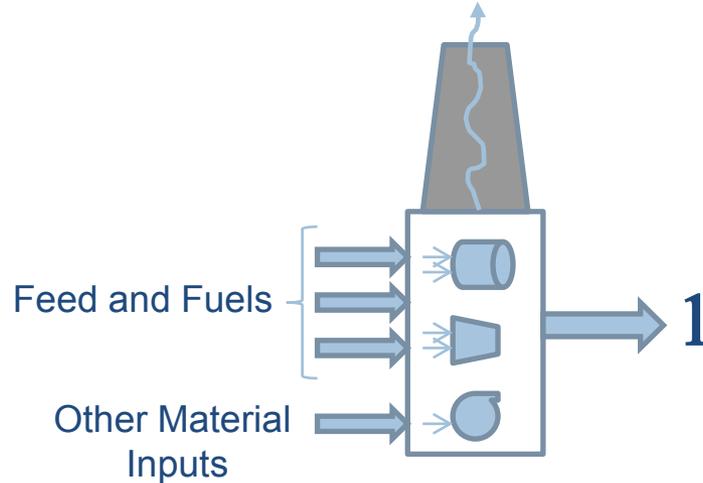
□ LCA of landfill gas (LFG) to H₂ pathway

- FCVs: NG-to-H₂ vs. LFG-to-H₂
- FC systems for
 - Combined H₂, 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

The screenshot displays the GREET software interface with several key components highlighted by red annotations:

- Basic Parameters:** A red box on the left highlights the 'Simulation Year Selection' (set to 2010), 'Stochastic Option' (Disable), and 'Electric Mile Range' (set to 20).
- Pathway Selection:** A red arrow points to a table of fuel pathways. The table lists various fuels and their shares.
- Process Info:** A red arrow points to the 'Emissions Results' and 'Energy Results' sections at the bottom left.
- Feedstock Info:** A red arrow points to a detailed 'Feed' information box for 'Natural Gas as intermediate fuel From FG mix'.
- Pathways Selection:** A red arrow on the right points to the 'Pathways' table in the main simulation area.

Pathways	Share
Gasoline	
Diesel	
Methanol	
Liquefied Petroleum Gas	
Liquefied Natural Gas	
Dimethyl Ether	
Gaseous Hydrogen	
Electricity	
Compressed Natural Gas	

Pathways	Share
Gasoline	
Diesel	
Methanol	
From NG	
Feed : Natural Gas	
NNA Natural Ga...	33.333 %

Parameter	Value
Share	100.000 %
Total energy	57613.169btu/mmBtu
VOC	0.645g/mmBtu
CO	5.305g/mmBtu
NOx	17.073g/mmBtu
PM10	0.337g/mmBtu
PM2.5	0.316g/mmBtu
SOx	0.090g/mmBtu
CH4	110.979g/mmBtu
N2O	0.068g/mmBtu
CO2	3122.582g/mmBtu

Category	Value
Total Energy + Credits	481481.481
Total Energy	481481.481
Losses	0.000

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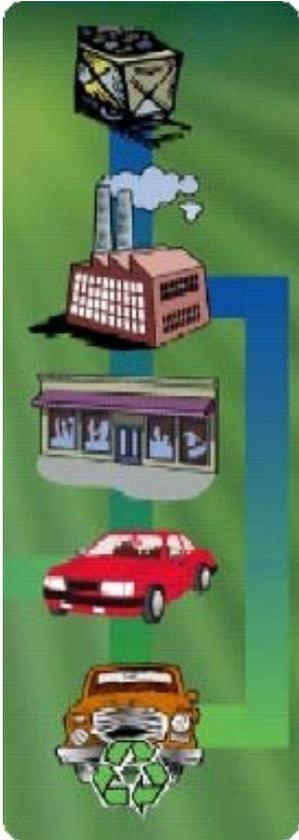
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GREET Provides a Tool for Vehicle-Cycle Analysis of Vehicle Manufacturing

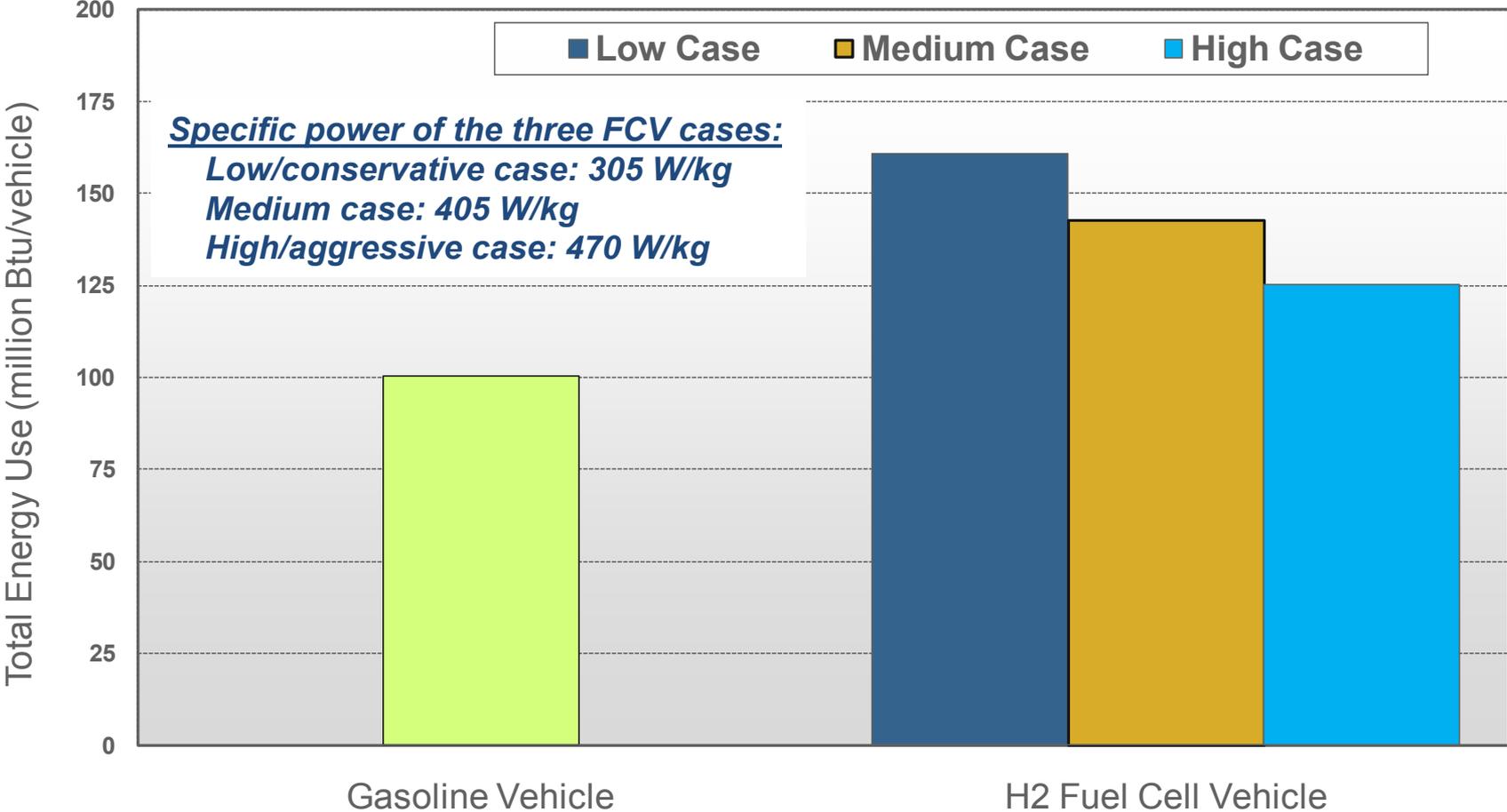


- Raw material recovery
- Material processing and fabrication
- Vehicle component production
- Vehicle assembly
- Vehicle disposal and recycling

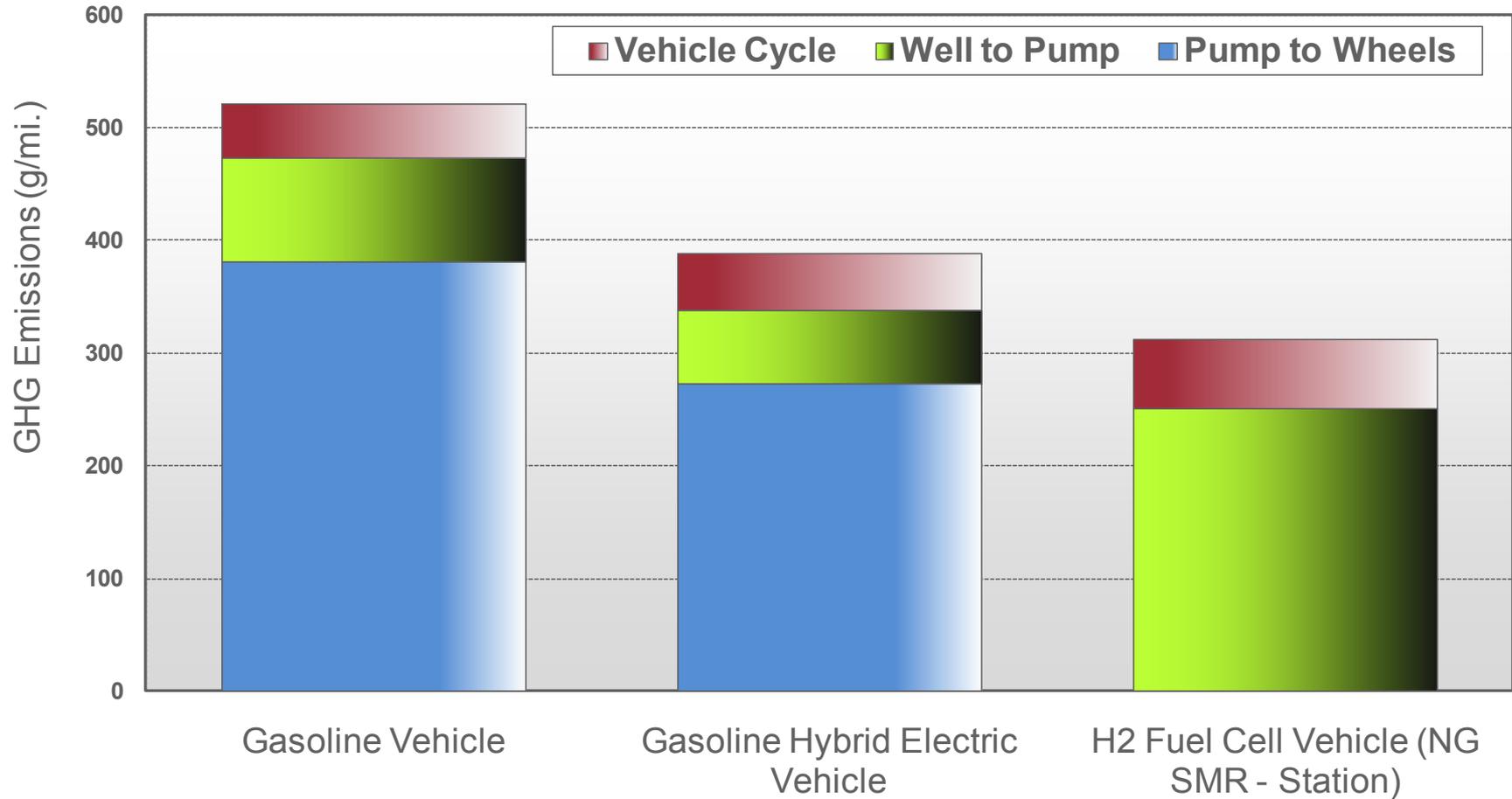
FCV Vehicle-Cycle Results Are Influenced by The Allocation Method for Platinum Production

- ❑ 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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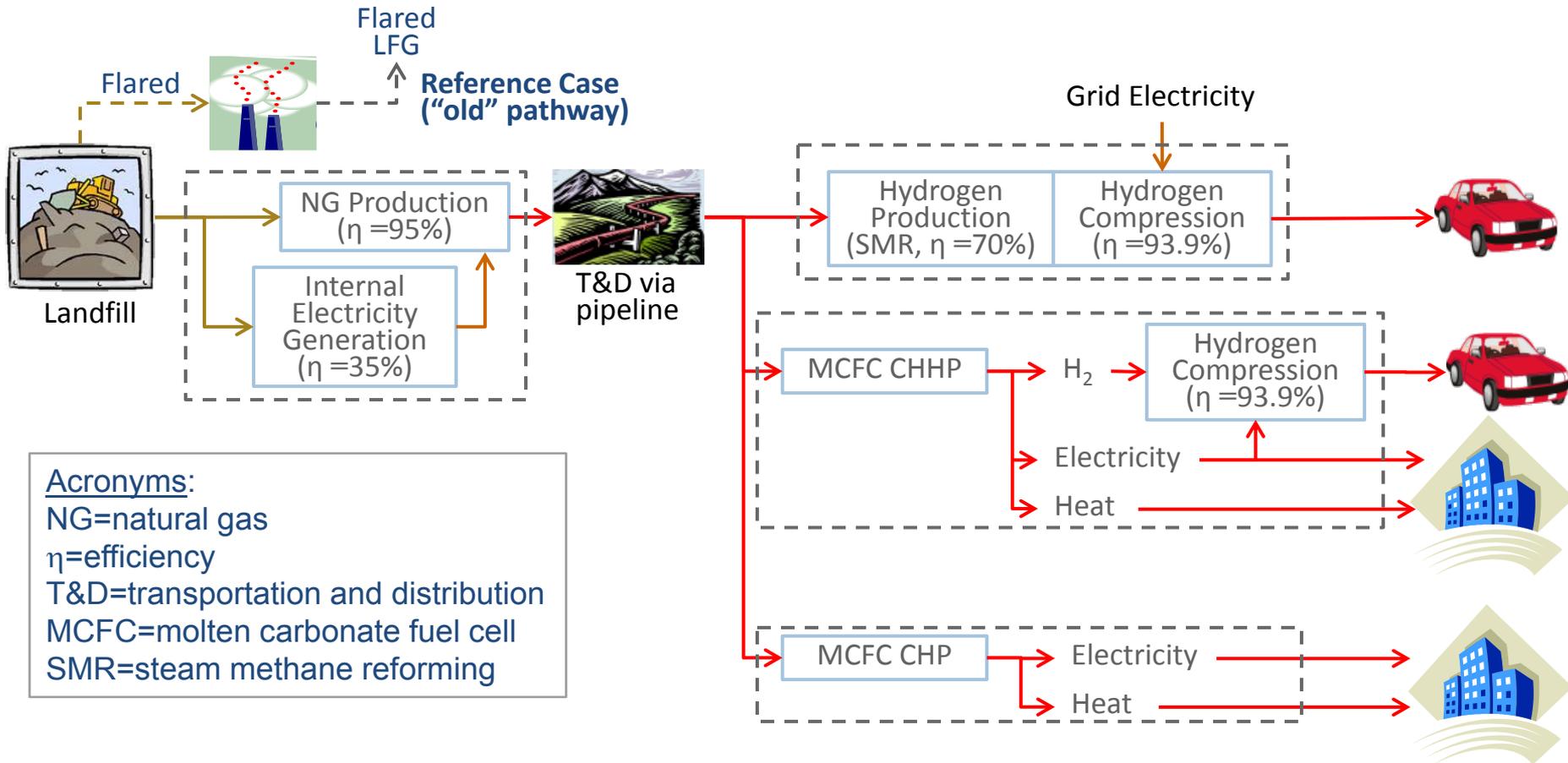
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REET Simulates LFG-to-H₂ Pathway for FCVs and LFG-Powered CHHP and CHP



Acronyms:

NG=natural gas

η=efficiency

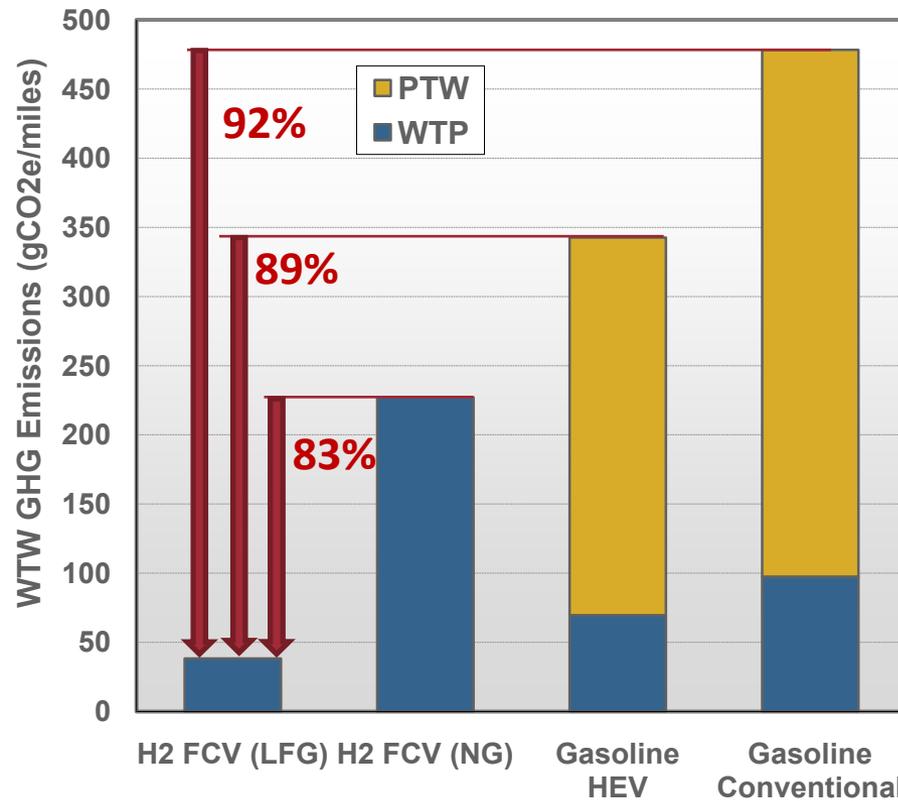
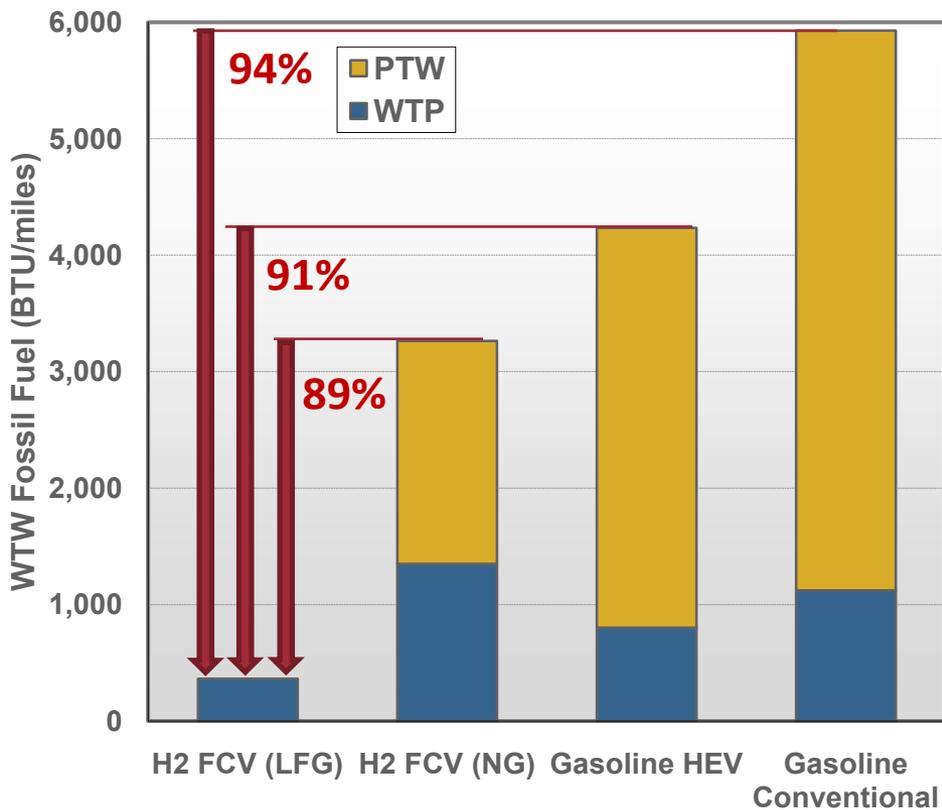
T&D=transportation and distribution

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):

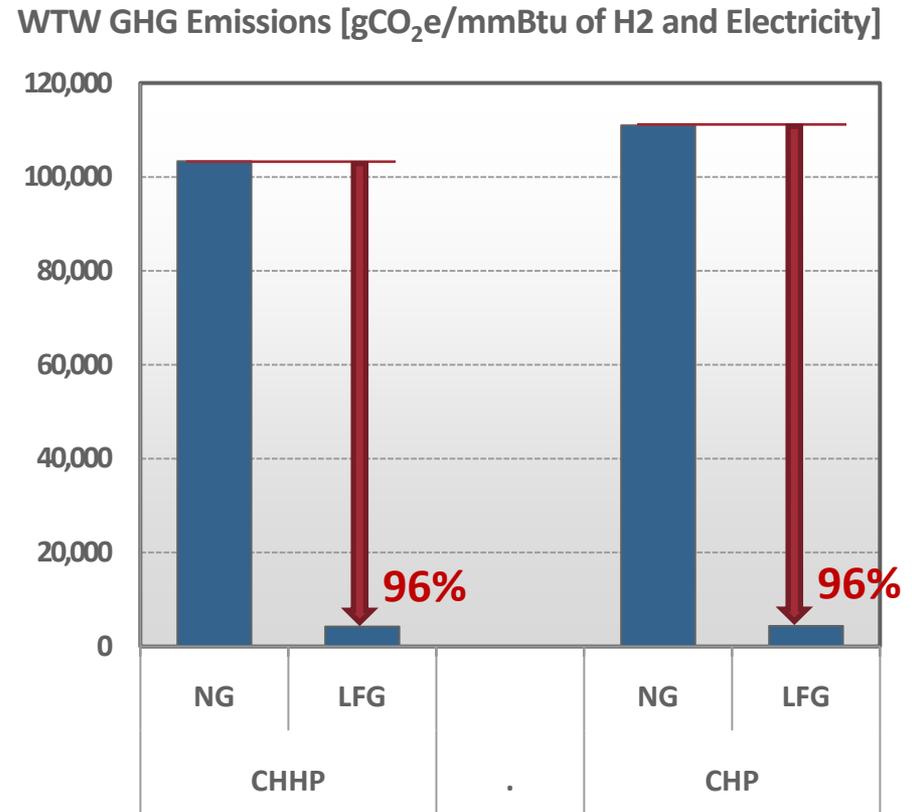
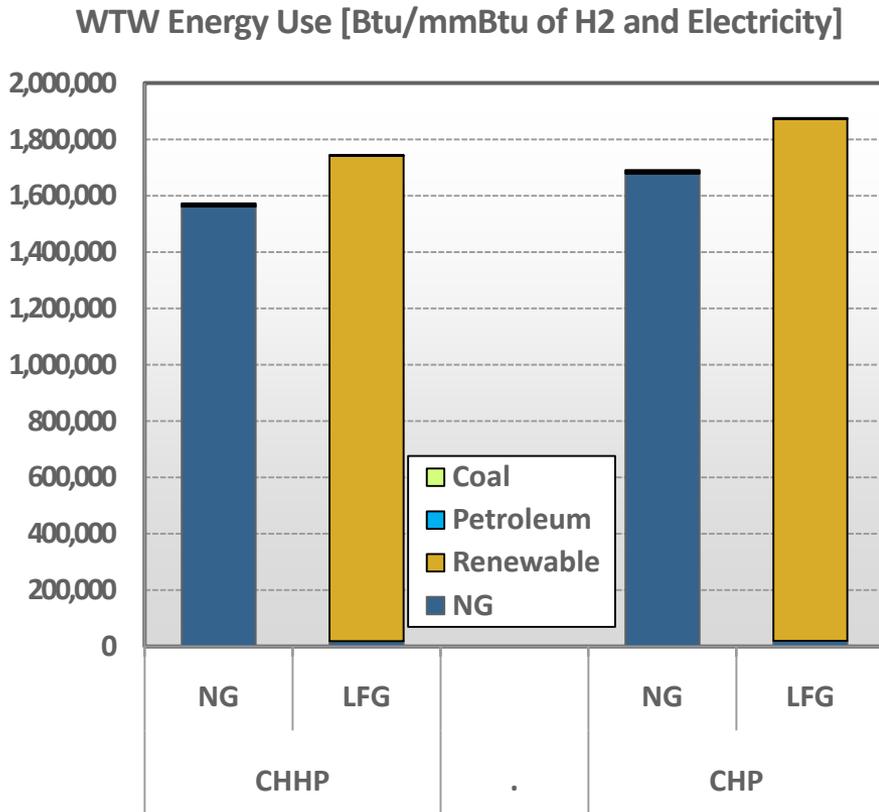
H₂ FCV – 60 mpgge

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:

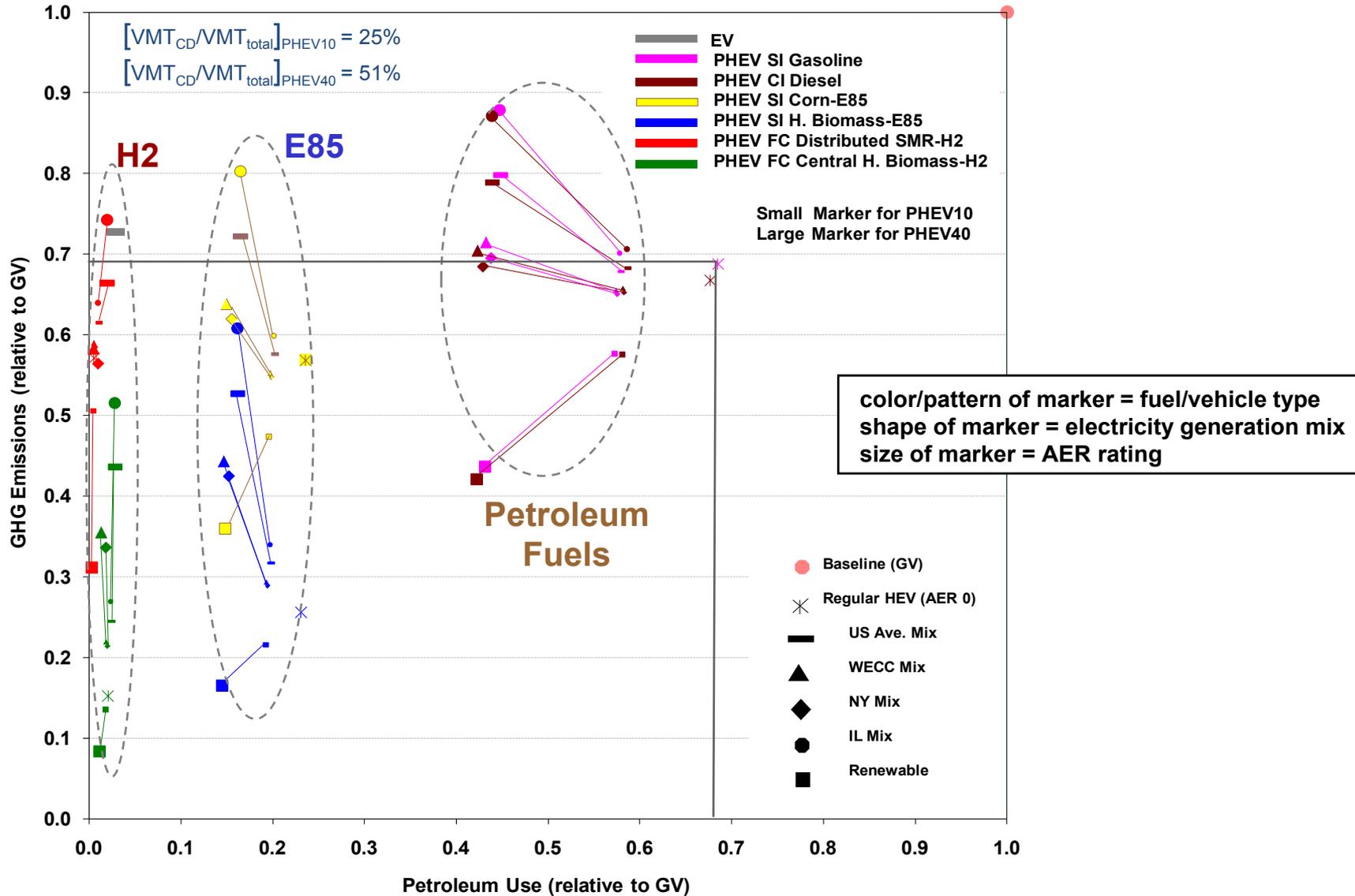
- Conventional internal combustion engine vehicles (ICEVs)
- Regular hybrid electric vehicles (HEVs)
- Plug-in hybrid electric vehicles (PHEVs) with all electric range (AER) of 10-40 miles
- Fuel-cell vehicles (FCVs)
- Electric vehicles (EVs)

❑ 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 H₂ from LFG achieve life-cycle GHG reduction
 - By 83% relative to FCVs with H₂ 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 H₂
 - Wastewater treatment plant biogas to H₂
- ❑ Detailed vehicle-cycle analysis of FCVs

