GREET WTW Analysis of Fuel-Cell Vehicles with Different Hydrogen Production Pathways

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AN-7

Overview

Timeline

- Project start date: Oct. 2002
- Project end date: continuous
- Percent complete: Not applicable

Barriers of Systems Analysis Addressed

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

Budget

- Total project funding by DOE: $1.2 million through FY07
- Funding received in FY06: $200k
- Funding for FY07: $450k

Partners

- H2A team
- PSAT team
- NREL

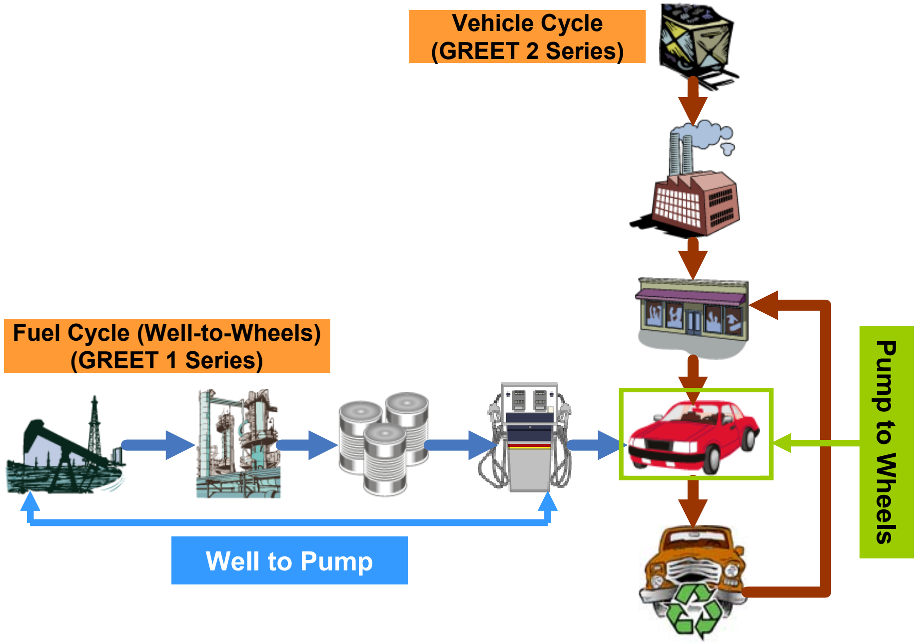
Objectives

- Expand and update the GREET model for hydrogen production pathways and for FCV improvements
- Conduct well-to-wheels (WTW) analysis of hydrogen FCVs with various hydrogen production pathways
- Provide WTW results for OFCHIT efforts on the Hydrogen Posture Plan and the MYPP
- Engage in discussions and dissimilation of energy and environmental benefits of hydrogen FCVs

Approach

- **Obtain data for hydrogen production pathways**
  - Open literature
  - H2A simulation results
  - Process engineering simulations with models such as ASPEN
  - Contact with hydrogen producers
- **Obtain data for hydrogen FCVs**
  - Open literature
  - PSAT simulations
  - Data of available FCV models
- **Expand and update the GREET model**
- **Conduct WTW simulations with GREET**
- **Analyze and present WTW results**

Argonne Has Been Developing The GREET Model Since 1995



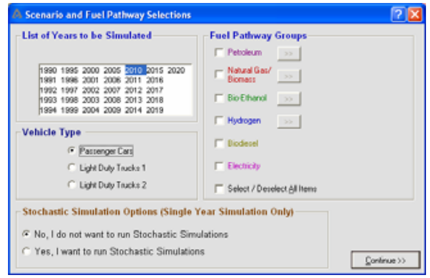
Key GREET features

- **Emissions of greenhouse gases**
  - ✓ CO_2, CH_4, and N_2O
- **Emissions of six criteria pollutants**
  - ✓ Total and urban separately
  - ✓ VOC, CO, NO_x, SO_x, PM_{10} and $PM_{2.5}$
- **Energy use**
  - ✓ All energy sources
  - ✓ Fossil fuels (petroleum, NG and coal)
  - ✓ Petroleum
  - ✓ Coal
  - ✓ NG

- **GREET and its documents are available at http://www.transportation.anl.gov/software/GREET/index.html**
- **At present, there are over 3,500 registered GREET users from**
  - ✓Auto industry, energy industry, governments, universities, etc.
  - ✓North America, Europe, and Asia
- **The most recent GREET1.7 and GREET2.7 models were released in Feb. 2007**

GREET1.7 Has Developed New Simulation Features

- **An improved Graphic User Interface (GUI) program makes GREET user-friendly**



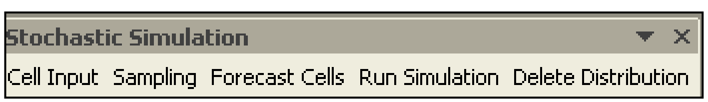
- **GREET1.7 can simulate a target year or multiple years between 1990 and 2020**
  - Previous versions were based on two snap-shot simulations: near term vs. long term
  - Technology advancement over time is established with time-series look-up tables

0.069	
0.069	
5-year period	LDGV: NOx
1990	1.285
1995	0.656
2000	0.300
2005	0.141
2010	0.069
2015	0.069
2020	0.069

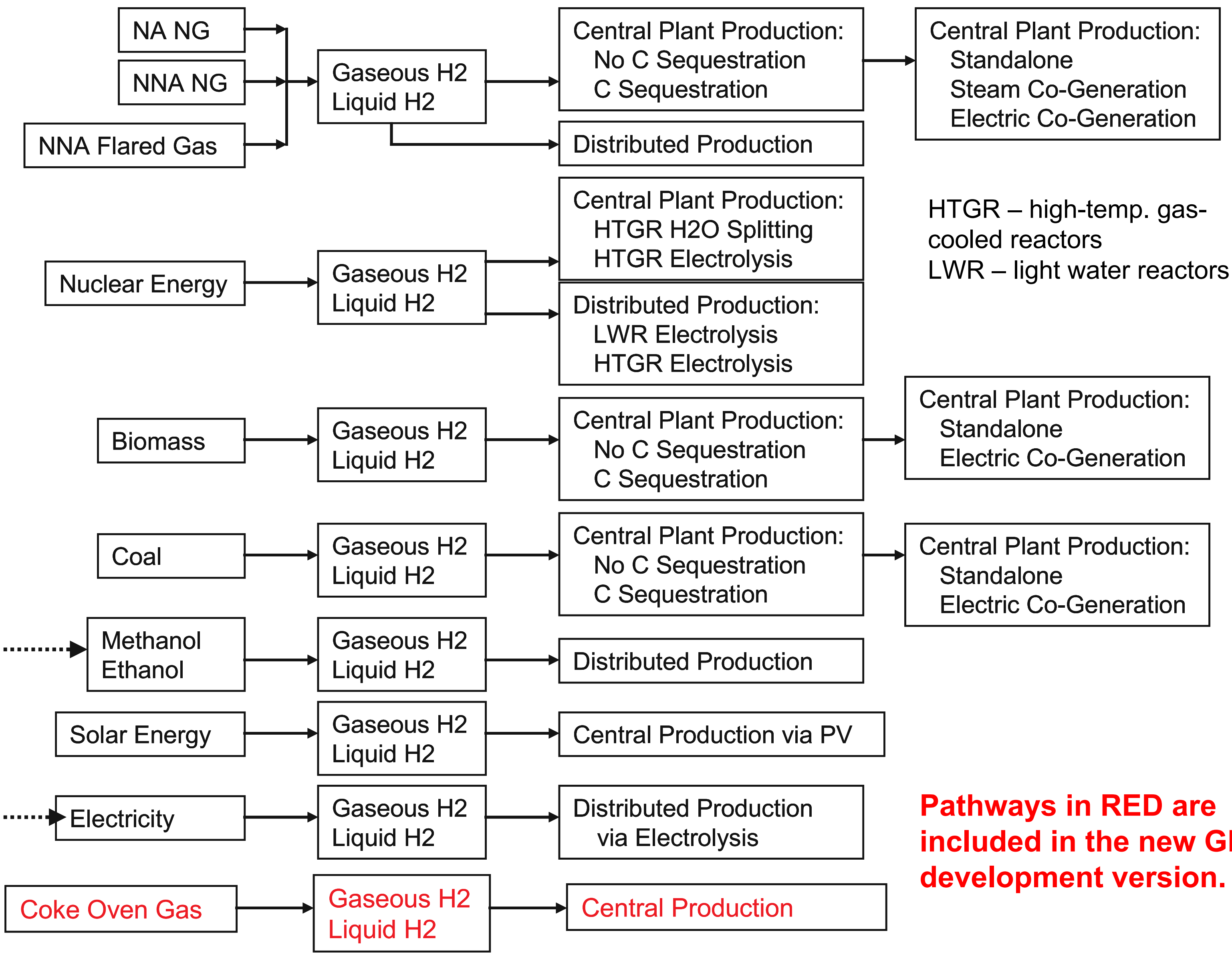
71.50%	
71.50%	
5-year period	G.H2 Production Efficiency (Central, NA-NG, no export)
1990	68.0%
1995	69.0%
2000	71.0%
2005	71.5%
2010	71.5%
2015	72.0%
2020	73.0%

U.S. mix: Average					
	1.7%	20.6%	50.2%	17.7%	9.8%
5-year period	Residual Oil	Natural Gas	Coal	Nuclear	Others
1990	4.2%	12.3%	52.5%	19.0%	12.0%
1995	2.2%	14.8%	51.0%	20.1%	11.9%
2000	2.9%	15.8%	51.7%	19.8%	9.8%
2005	1.7%	18.4%	50.3%	19.4%	10.2%
2010	1.7%	20.6%	50.2%	17.7%	9.8%
2015	2.5%	22.7%	48.6%	16.6%	9.6%
2020	1.9%	24.2%	49.2%	15.4%	9.3%

- **New stochastic simulation codes were developed within GREET to address uncertainties**



Hydrogen Production Pathways in GREET

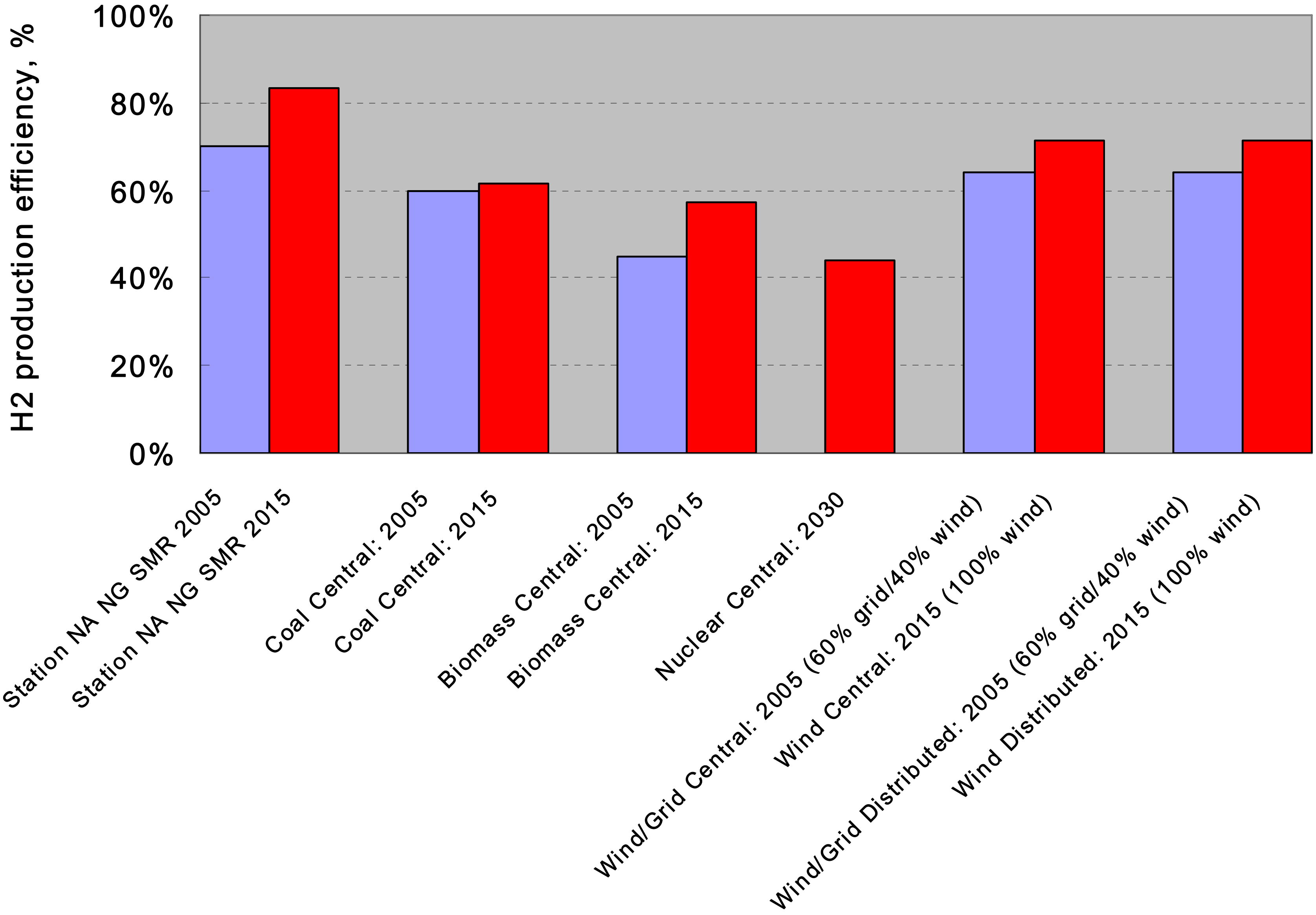


Pathways in RED are included in the new GREET development version.

Two Major Efforts Were Conducted for WTW Analysis of Hydrogen FCVs

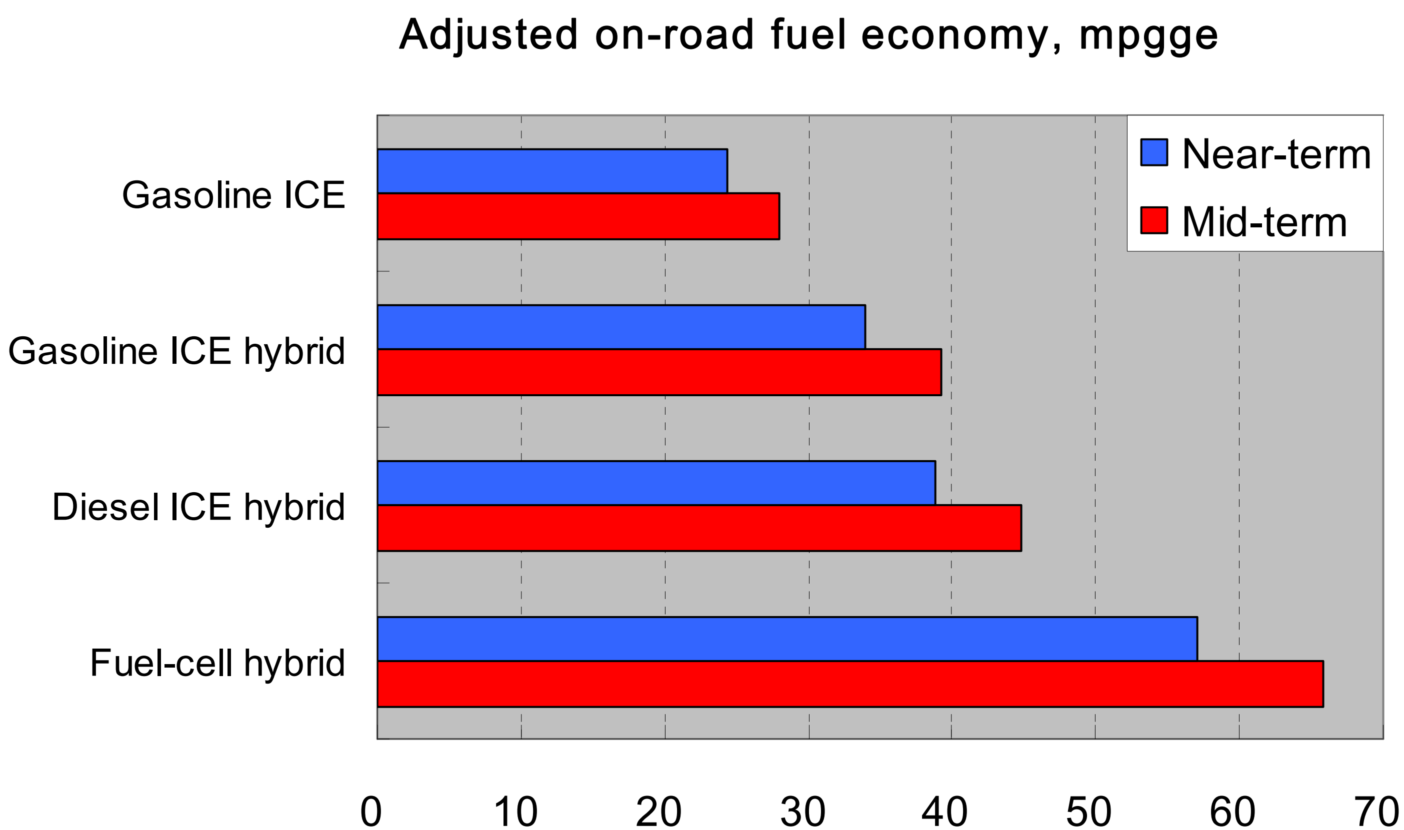
- **WTW analysis of energy use and greenhouse emissions for the following selected H2 production pathways for DOE's Hydrogen Posture Plan**
  - ✓ ***Distributed production of GH2 from North American natural gas (NA NG) via steam methane reforming (SMR) (2005 and 2015)***
  - ✓ ***Central production of GH2 from cellulosic biomass via gasification (2005 and 2015)***
  - ✓ ***Central production of GH2 from coal via gasification with CO2 sequestration (2005 and 2015)***
  - ✓ ***Distributed production of GH2 from wind/grid electricity via electrolysis (2005 and 2015)***
  - ✓ ***Central production of GH2 from wind/grid electricity via electrolysis (2005 and 2015)***
  - ✓ ***Central production of GH2 from nuclear via thermo-chemical water cracking (2030)***
- **Potential energy and greenhouse gas emissions effects of hydrogen production from coke oven gas in U.S. steel mills**

Mass and Energy Balance Data for Hydrogen Production Are from H2A Simulations by NREL

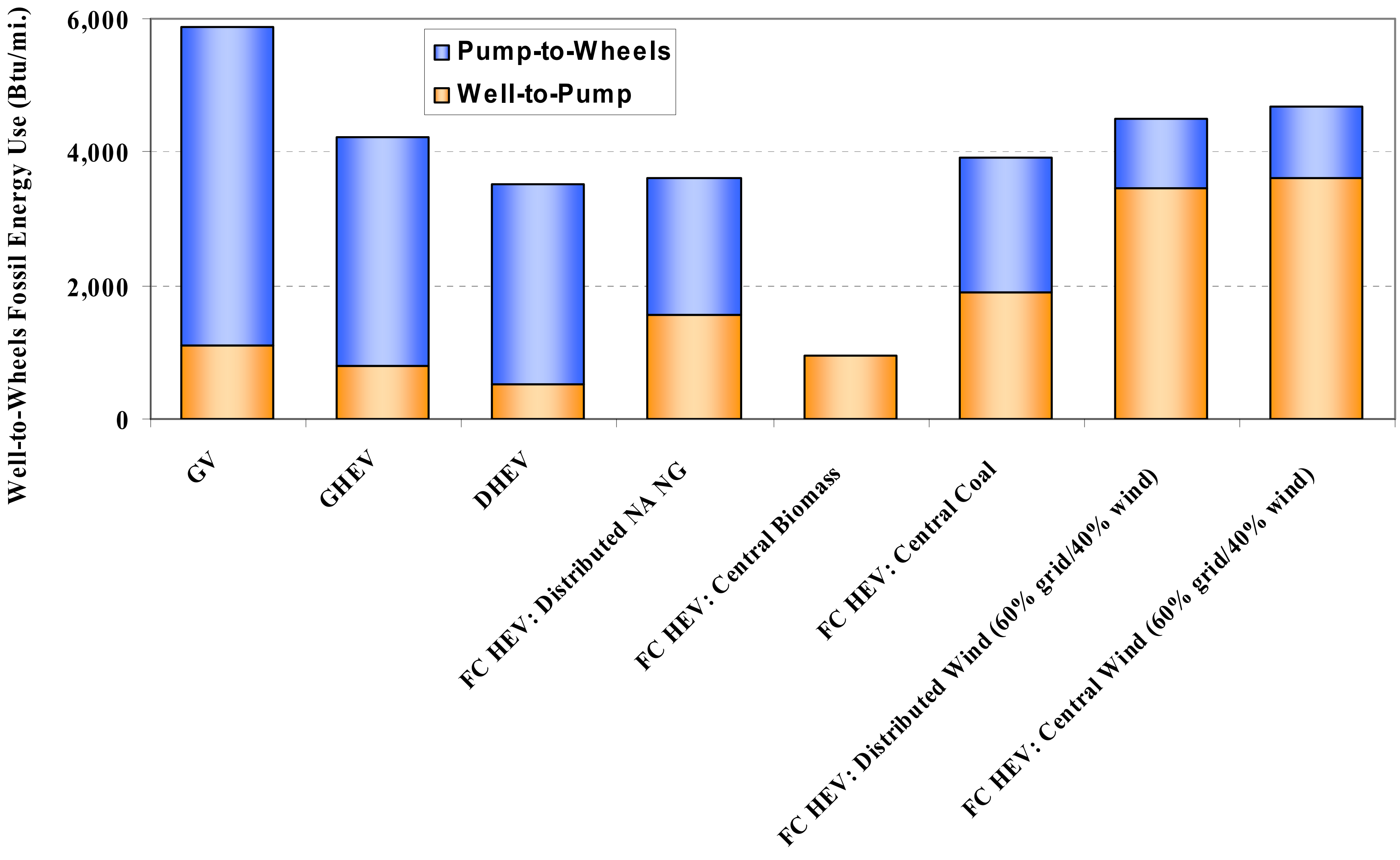


Fuel Economy of Vehicle Technologies Was Simulated with The PSAT Model by Argonne

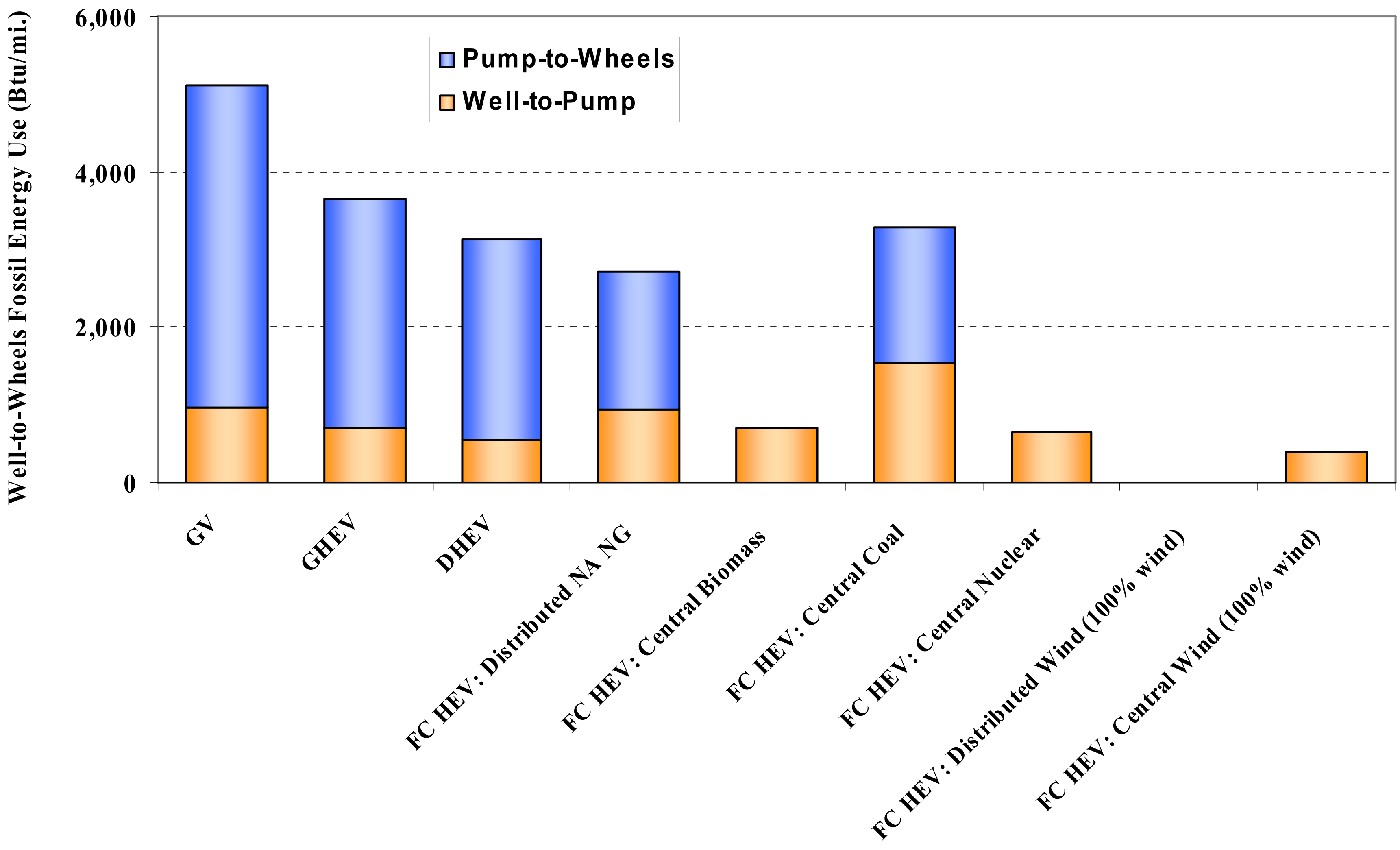
- **PSAT was used to estimate vehicle fuel economy for a typical mid-size passenger car platform**
- **PSAT results were adjusted to reflect on-road MPG**



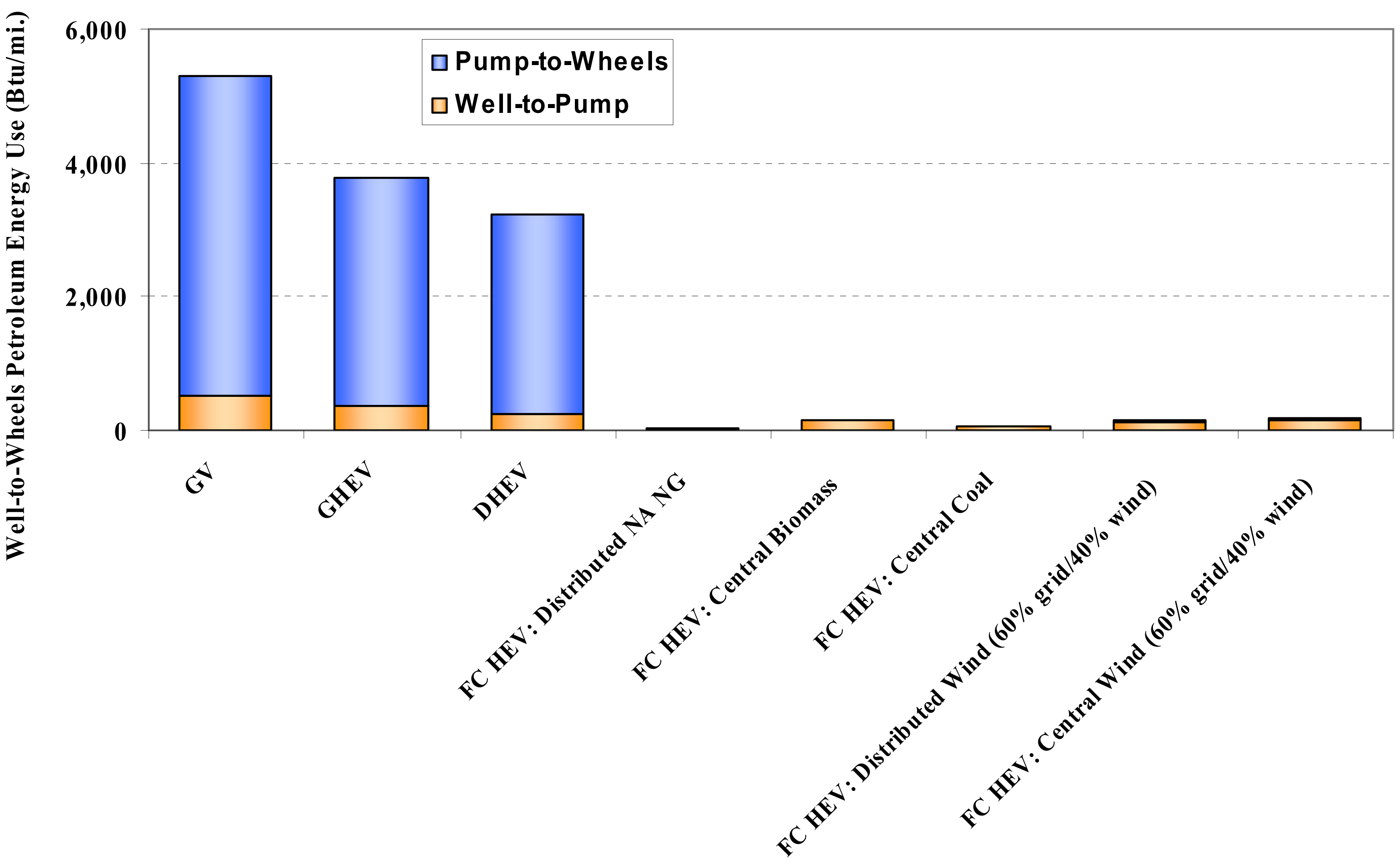
Well-to-Wheels Results: Fossil Energy Use (Near Term)



Well-to-Wheels Results: Fossil Energy Use (Mid Term)



Well-to-Wheels Results: Petroleum Energy Use (Near Term)



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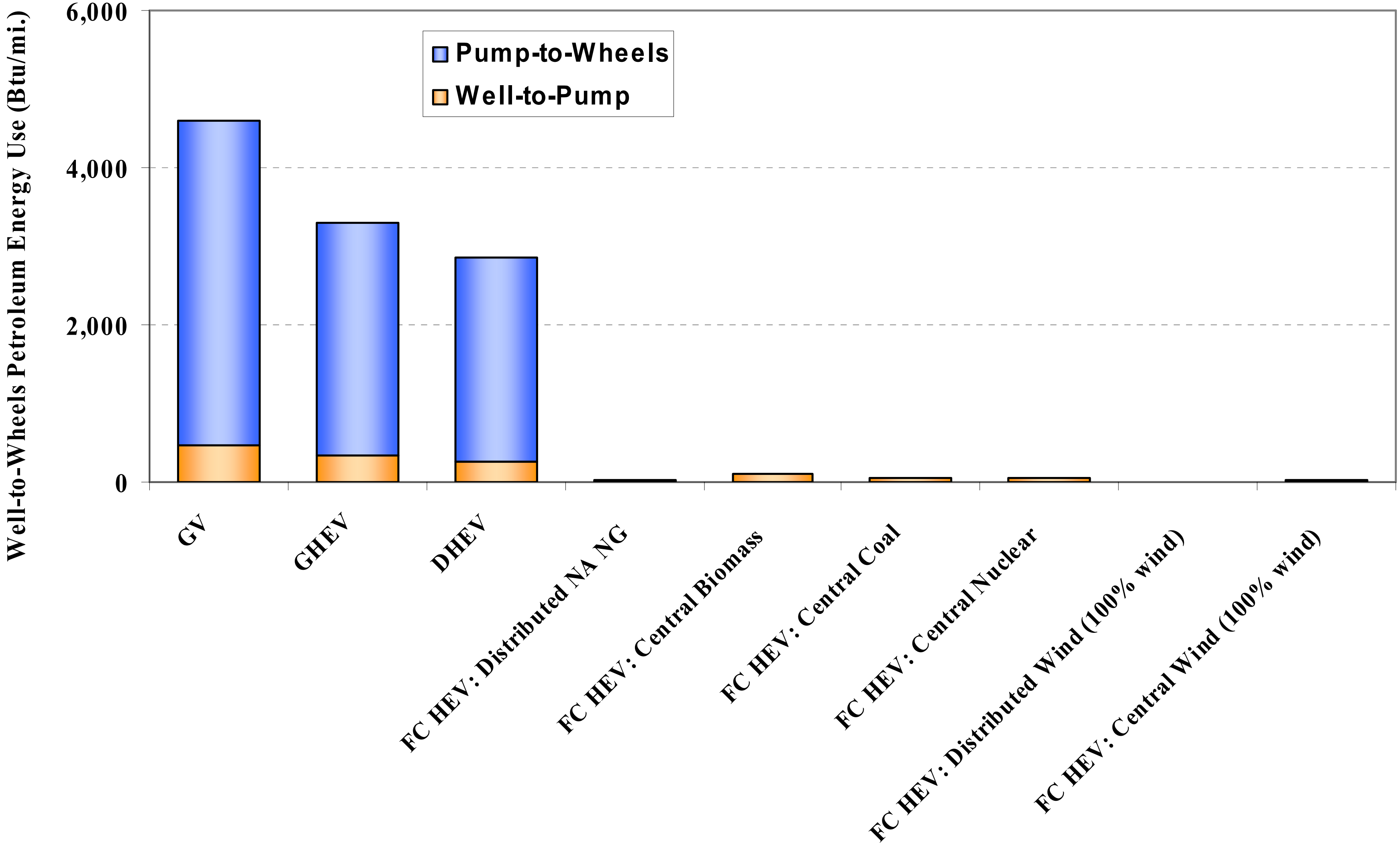
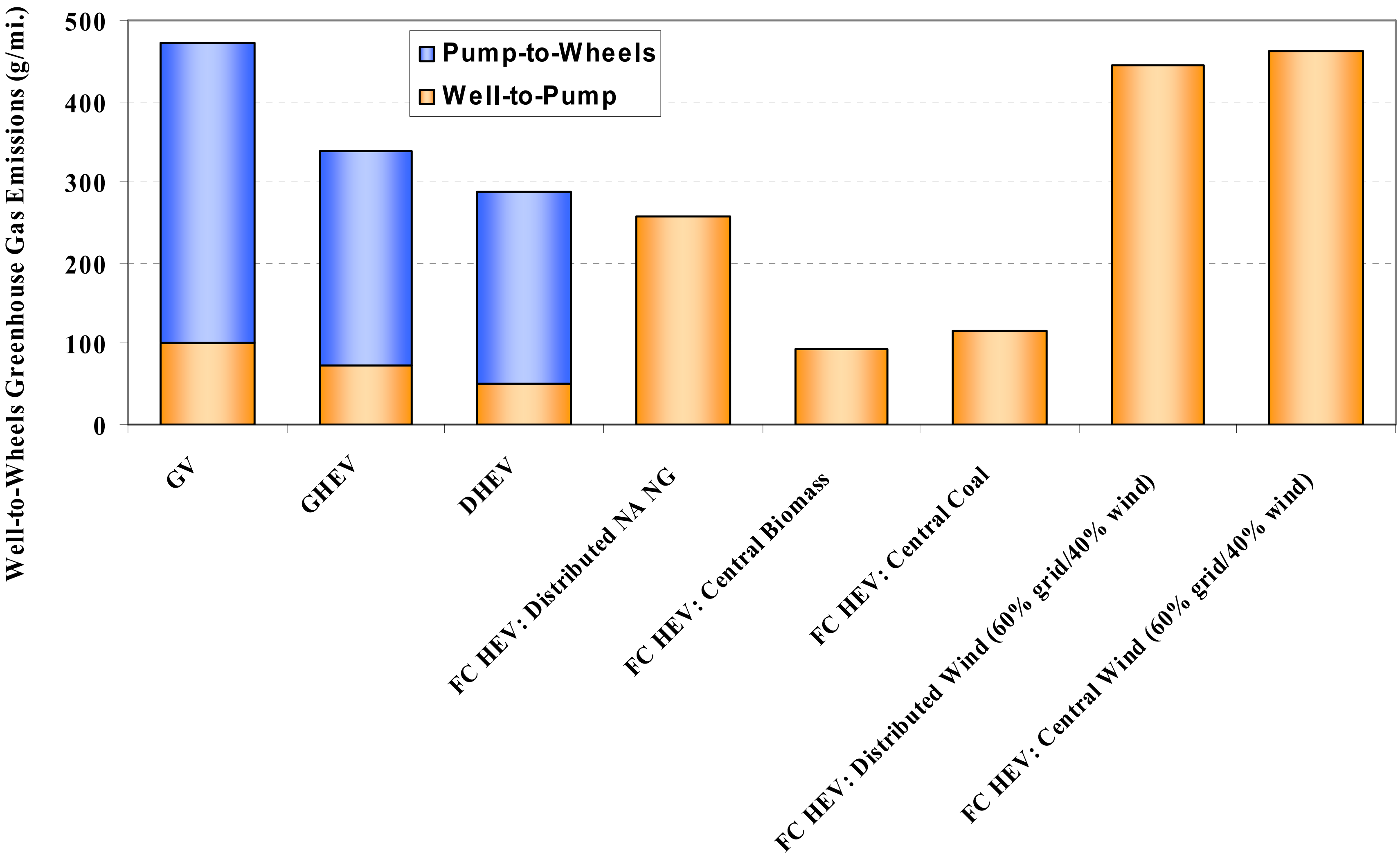
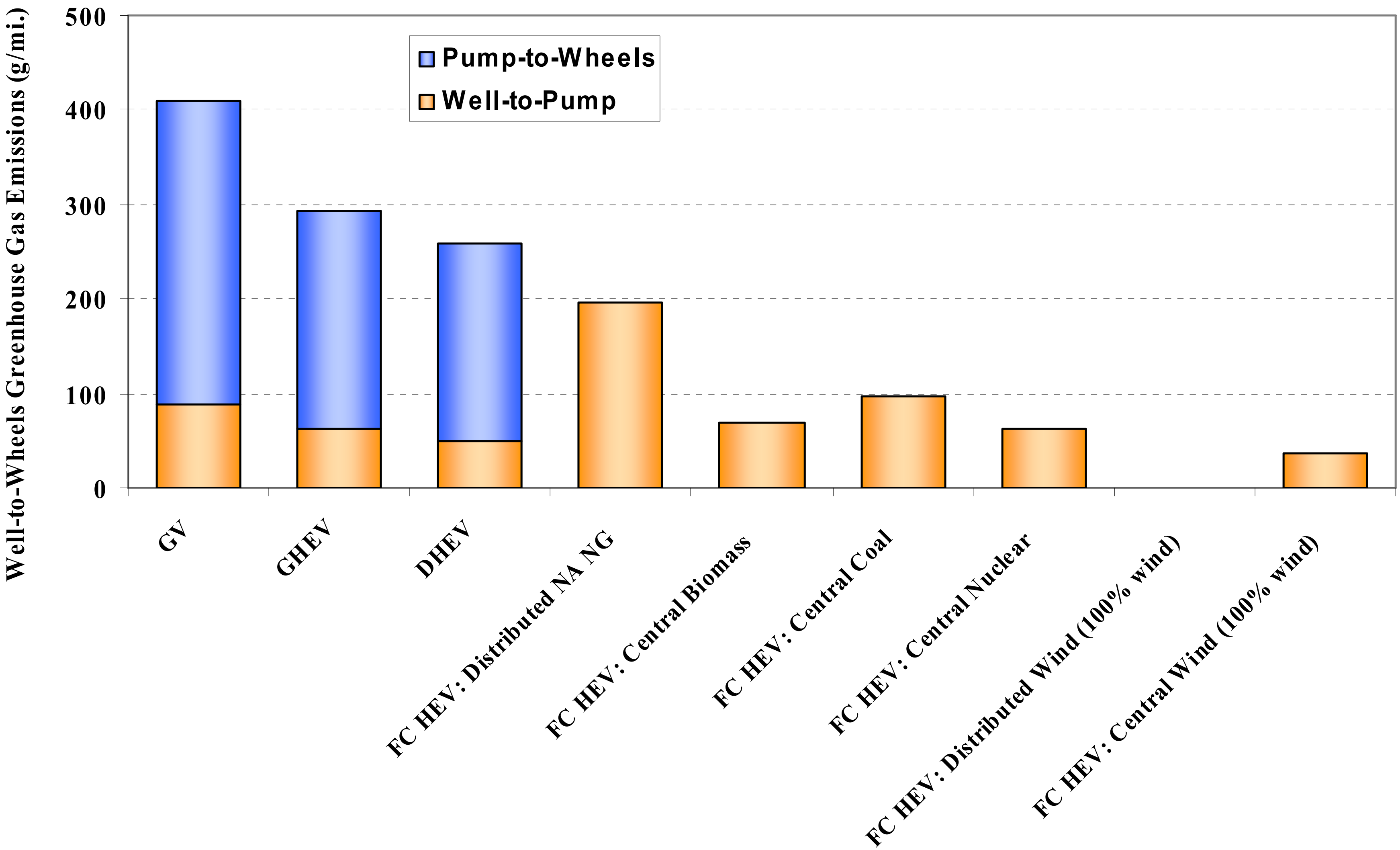


Well-to-Wheels Results: Greenhouse Gas Emissions (Near Term)

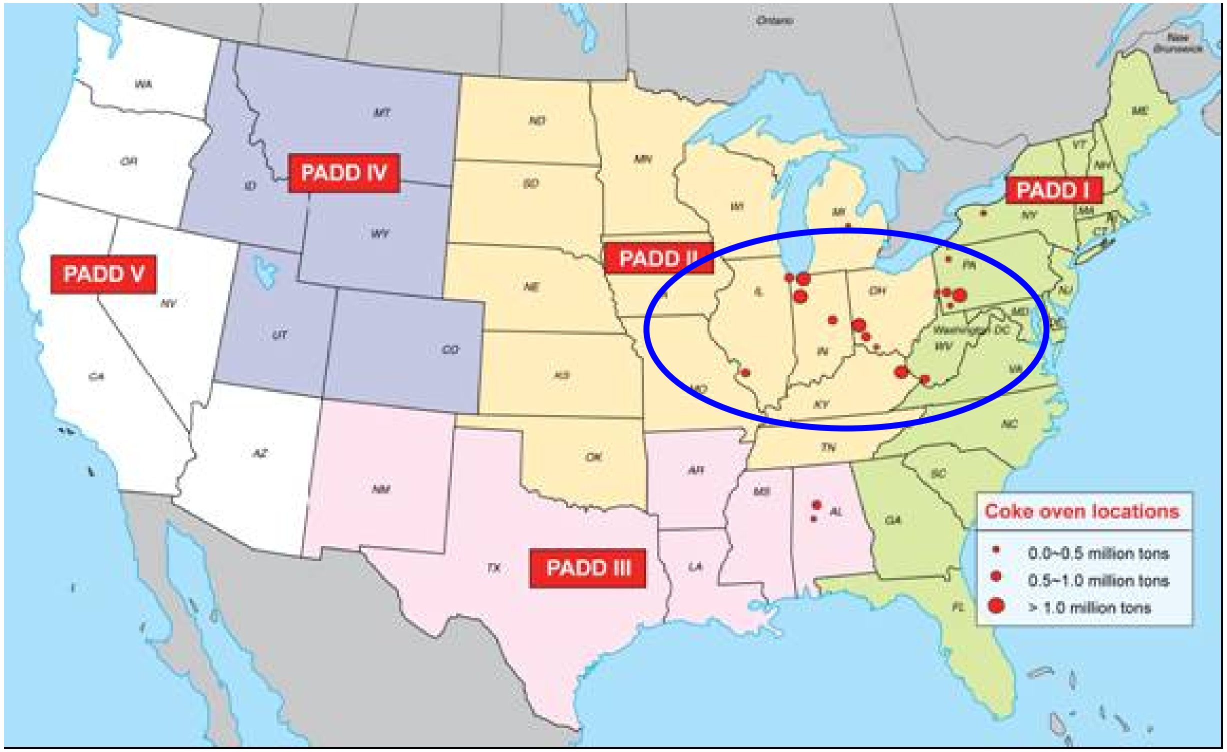


Well-to-Wheels Results: Greenhouse Gas Emissions (Mid Term)



Potential Hydrogen from Coke Oven Gas

Coke Oven Operations in the United States

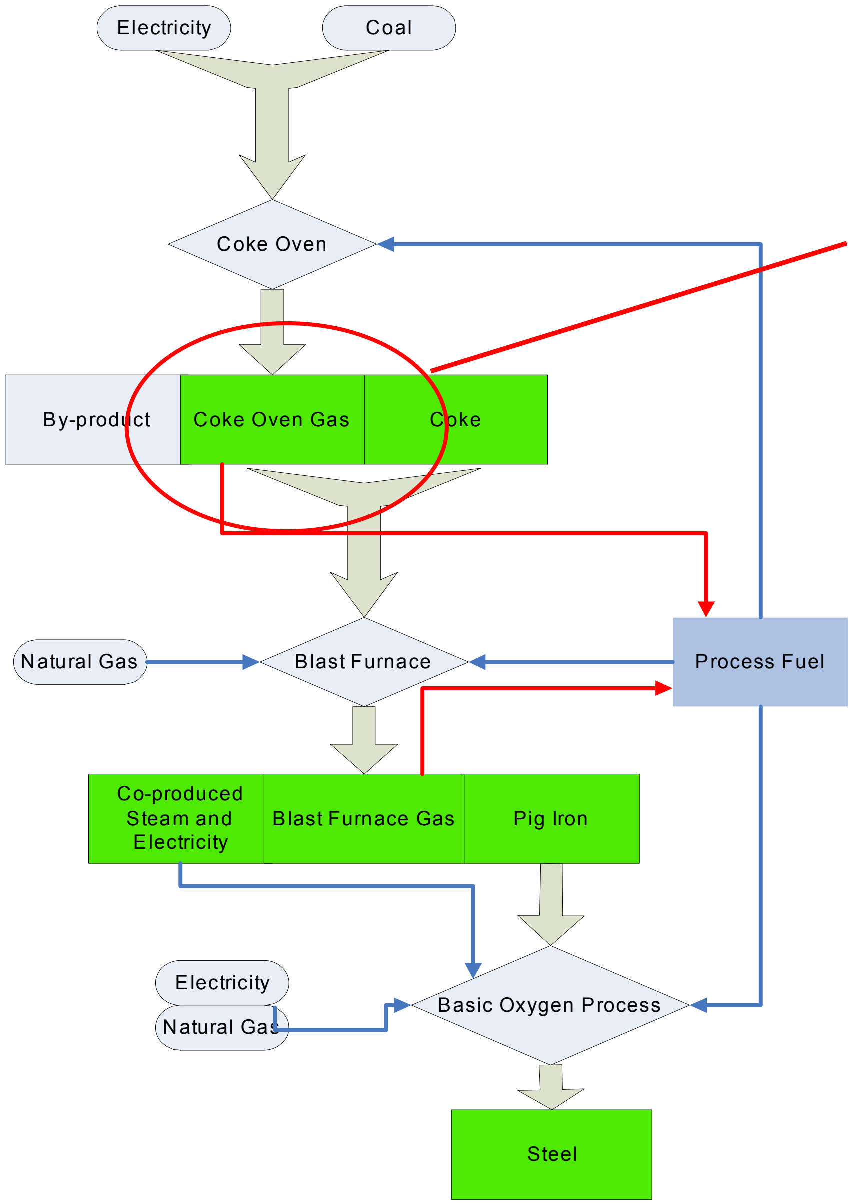


- Hydrogen from coal-to-coke process could fuel ~1 million FCVs/yr.
- Industry demonstrated this method in Japan.

Estimated Annual COG-Based H2 Production by U.S. Regions, metric tons/Year

	2004	2005	Share (Based on 2005 Data)
PADD I	122,259	120,812	33%
PADD II	211,175	208,675	57%
PADD III	37,048	36,610	10%
Total	370,482	366,097	100%

Coal-to-Coke Process Flow Diagram



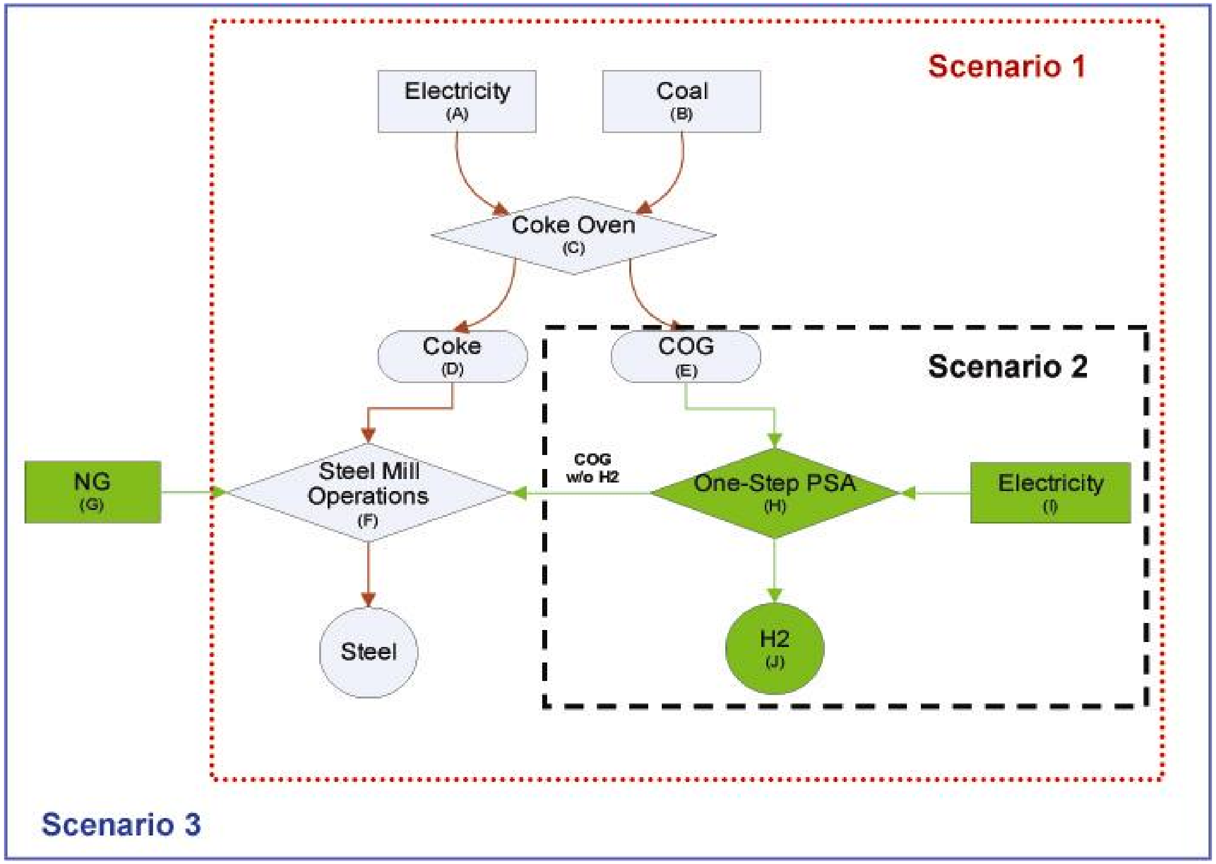
Typical Analysis of Coke Oven Gas

	% by volume
H_2	55
CH_4	25
N_2	10
CO	6
CO_2	3
HC (ethane, propane, etc.)	1
Lower Heating Value (LHV), Btu/standard cubic feet (scf)	443

Source: http://www.energymanagertraining.com/iron_steel/coke_oven_steel.htm

- Producing coke from coal is a traditional process in the steel industry.
- Coke oven gas is a byproduct of the coking process and used as a fuel in other ancillary operations.
- In some cases, excess gas is flared.
- The flow diagram illustrates an integrated steel production facility.

Recovery of Hydrogen from Coke Oven Gas



Scenario 1 (S1):

- Based on relative energy efficiencies of coking process, the PSA system and the delivery systems.
- COG is treated as a co-product.
- Energy use and CO_2 emissions from coking process are allocated between coke and COG.

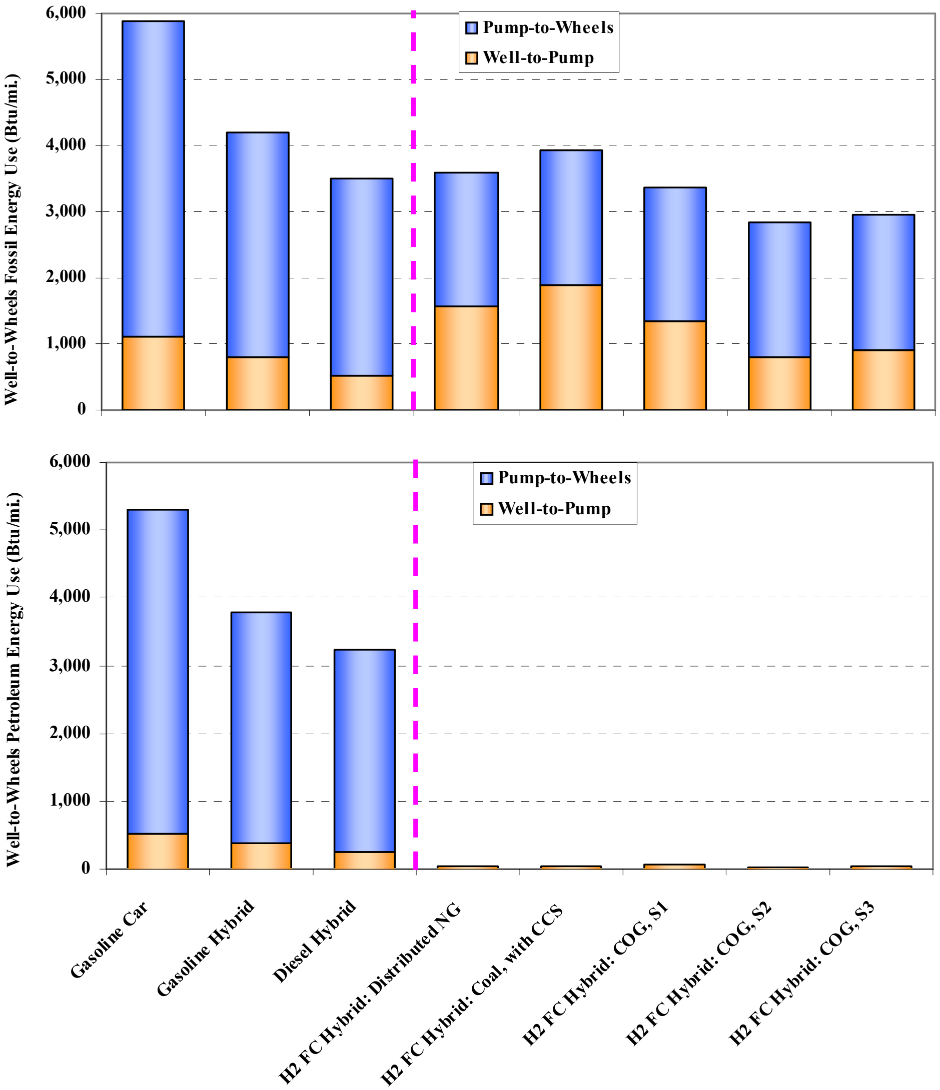
Scenario 2 (S2):

- Based on the energy use of the PSA and delivery systems.
- COG is treated as a byproduct.
- Energy accounting for the COG-to-hydrogen production pathway starts with the energy content of the COG.

Scenario 3 (S3):

- Based on the energy use by the PSA unit and the amount of supplemental natural gas used to makeup for BTU withdrawal from separated hydrogen.

Well-to-Wheels Results of Hydrogen From COG: Fossil and Petroleum Energy Use



Vehicle Fuel Efficiency, mpgge

Gaso. ICE HEV	Gaso. HEV	Diesel HEV	FCV
24	34	39	57

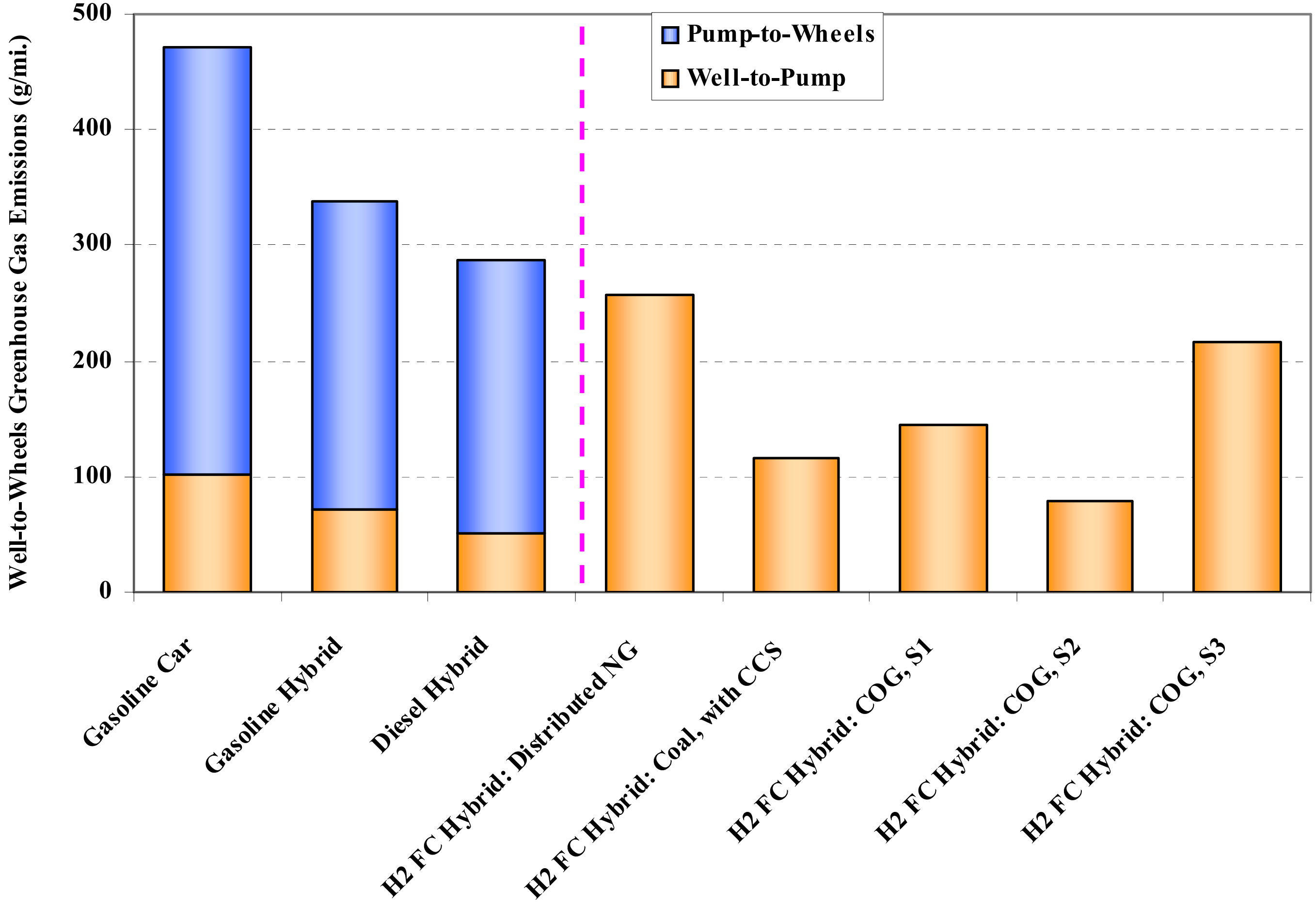
Notes:

- Fuel Efficiencies based on mid size car.
- The fuel efficiencies were determined with the ANL PSAT model.

Notes

- **The distributed reforming cases are based on a capacity of 1,500 kg/day.**
- **The central coal gasification case has carbon sequestration.**
- **The central coal case assume hydrogen at the plant gate is compressed and distributed to the fueling stations by pipeline.**
- **The dispensing pressure for the hydrogen cases is 5,000 psi.**
- **The hydrogen recovered from COG is compressed and distributed to the fueling stations by pipeline.**

Well-to-Wheels Results of Hydrogen from COG: Greenhouse Gas Emissions



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Future Work

- Expand GREET to include two hydrogen delivery options
  - Liquid hydrogen trucks
  - Tube trailer trucks for gaseous hydrogen
- Update existing hydrogen production pathways with H2A results
- Examine fuel economy potential of hydrogen FCVs and other advanced vehicle technologies with PSAT
- Start to examine water requirements of hydrogen production and production of other competing fuels
- Provide assistance to OFCHIT's analysis efforts

Summary

- WTW analysis is an integral part of examining energy and environmental effects of hydrogen FCVs and other vehicle/fuel technologies
- The GREET model has become a standard WTW analysis tool for stakeholders to use
- H2 FCVs generally achieve significant reductions in energy use and GHG emissions
- Hydrogen recovery from coke oven gas provides another hydrogen source in the portfolio of hydrogen production options, especially in the early stages of market transformation