Potential Energy and Greenhouse Gas Emission Effects of Hydrogen Production from Coke Oven Gas In U.S. Steel Mills

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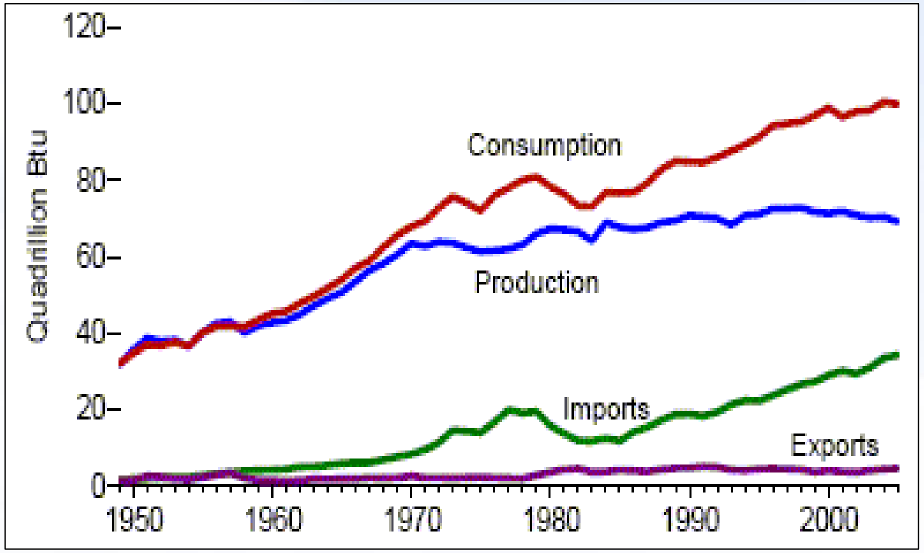
Outline

- **Problem**
  - U.S. Energy Overview
    - Overall
    - Oil Dependence
    - Greenhouse Gas Emissions
- **Solutions**
  - Advanced Energy Initiative
    - Background
    - Fueling Vehicles
  - Hydrogen Supply through Indigenous Sources
    - Pathway Examined: Recovery of Hydrogen from the Coal-to-Coke process
    - Results of Analyses
- **Closing**

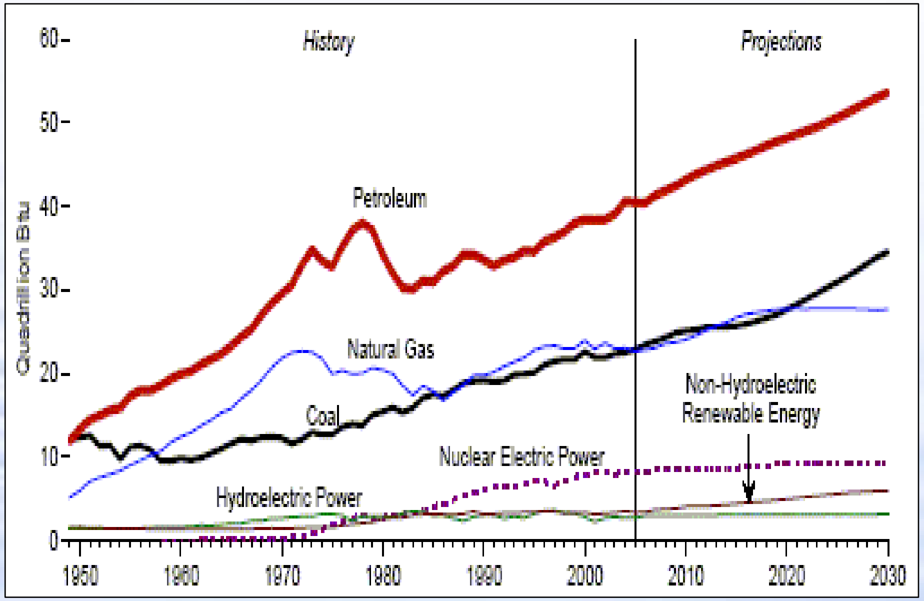
U.S. Energy Overview

- U.S. not self-sufficient in energy – consumption outpaced domestic production after late 1950s
- Imports continue to increase (oil accounts for ~90% of net U.S. energy imports)
- Projections show:
  - ⇨ Reliance on fossils (petroleum, natural gas, coal)
  - ⇨ Modest expansion in renewables
  - ⇨ Not much change in nuclear

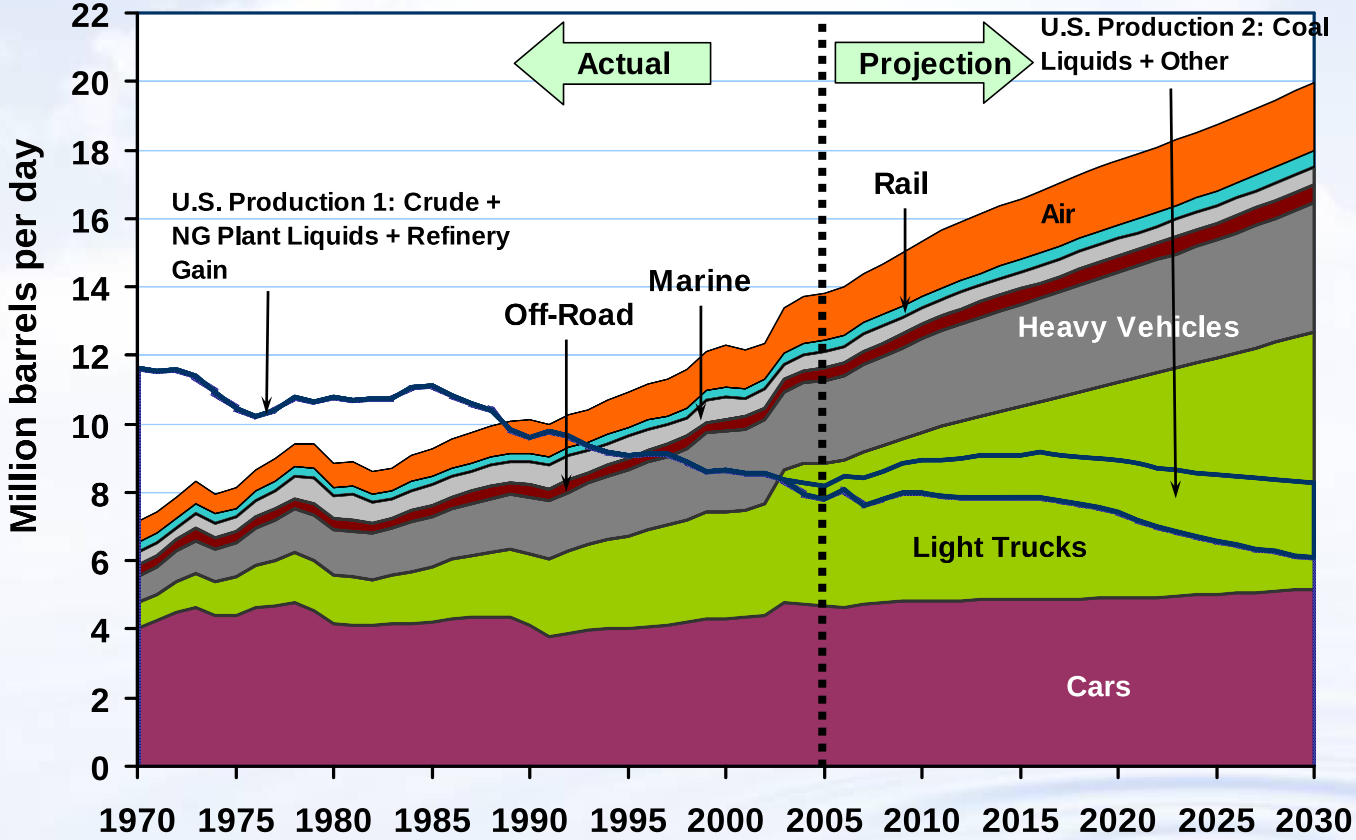
Energy Consumption Overview



Energy Consumption History and Outlook



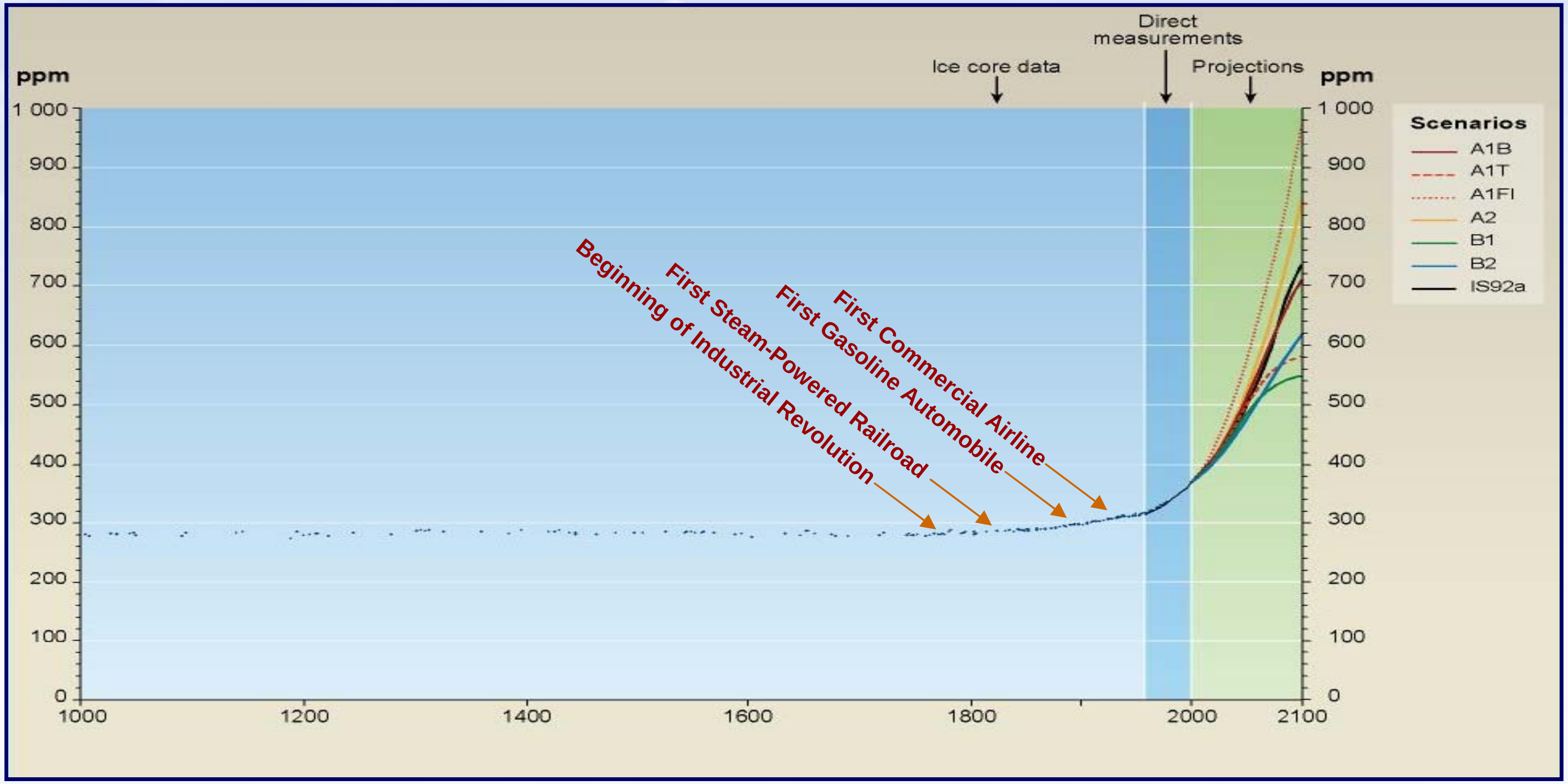
Transportation Energy Use
U.S. Transportation Oil Gap



- Heavy reliance on oil
- Transportation is largest consuming sector of petroleum (67% of total U.S. consumption)
- Domestic oil production able to supply demand prior to 1990s
- Gap between domestic production and demand continues to grow
- We import 60% of our oil today – projected to go up to 68% by 2025 if we continue business as usual

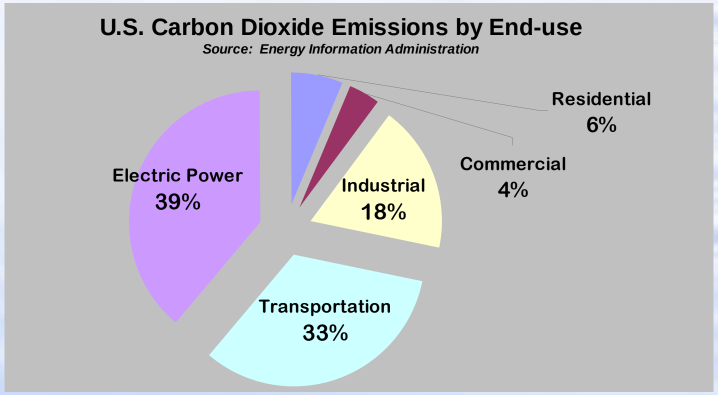
Note: Domestic production includes crude oil, natural gas plant liquids, refinery gain, and other inputs. This is consistent with AER Table 5.1. Source: Transportation Energy Data Book: Edition 24, ORNL-6973, and EIA Annual Energy Outlook 2006, February, 2006.

Carbon Dioxide

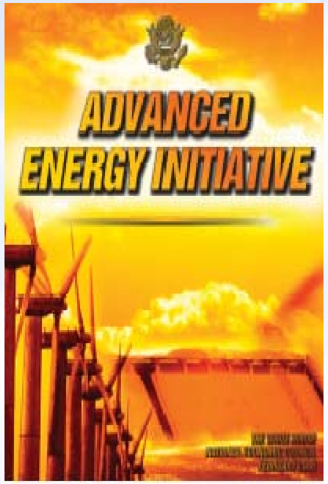


Sources: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.

Sources of Carbon Dioxide



Advanced Energy Initiative (AEI)
Background

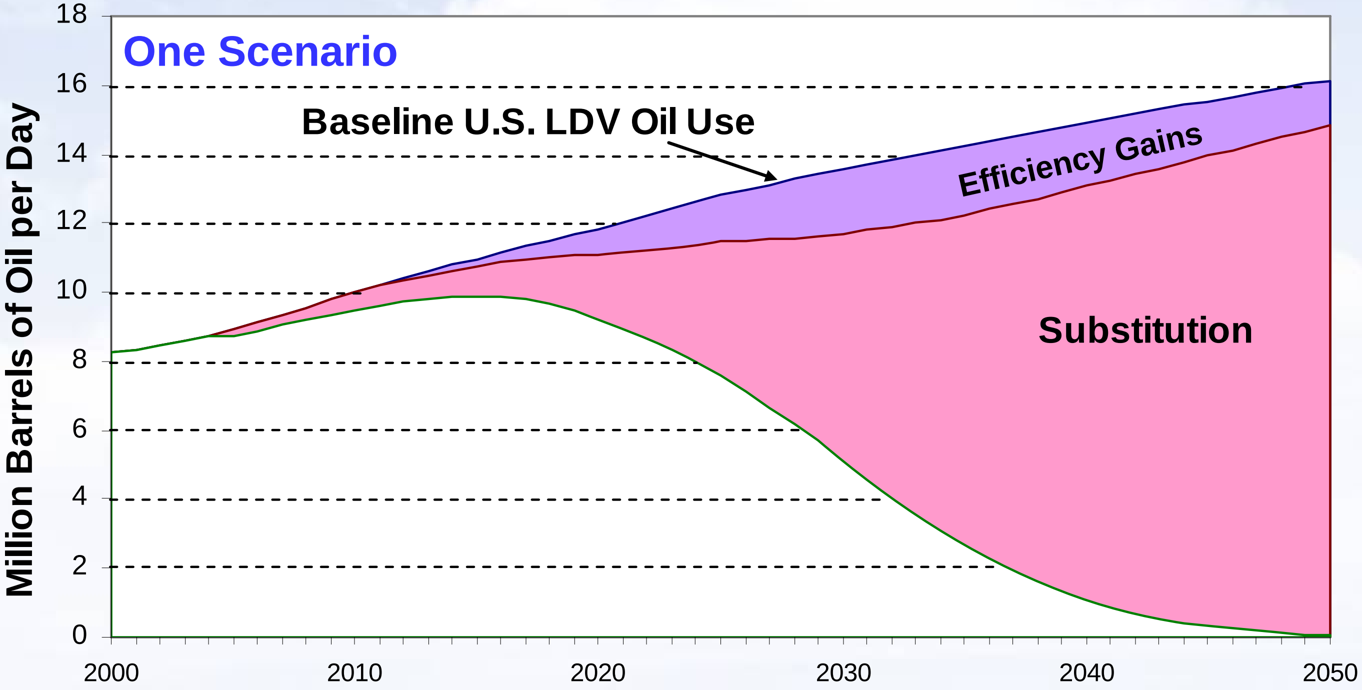


- Announced by the President in his 2006 State of the Union Address
- Reduce dependence on foreign sources of energy by accelerating development of advanced technologies
- Provides 22% increase in funding for clean energy research at DOE
- Covers both the electricity and transportation sectors

Hydrogen Fuel Initiative

- **In his 2003 State of the Union address, President Bush announced a $1.2 billion Hydrogen Fuel Initiative to develop technology for commercially viable hydrogen-powered fuel cells, which would power cars, trucks, homes, and businesses with no pollution or greenhouse gases.**
- **Through private-sector partnerships, the Initiative and related FreedomCAR programs will make it practical and cost-effective for Americans to use clean, hydrogen fuel cell vehicles by 2020.**
- **Through the President's program, the cost of a hydrogen fuel cell has been cut by more than 50% in just four years.**

Removing Light Duty Vehicles from the Oil Demand Equation through Technology Innovation



- **Petroleum-based HEVs**
- **Lighter weight vehicles**

- **Ethanol-Blends ICEVs/HEVs**
- **Plug-in HEVs**
- **H2 FCV HEVs**

- DOE Role: Balanced Research Portfolio to Overcome Technical and Economic Barriers

Petroleum-based HEVs
- Hybrid component cost

Lighter Weight Vehicles
- Materials/Manufacturing cost

Ethanol-based ICEVs/HEVs
- Cellulosic feedstock cost

Plug-In Hybrids
- High energy batteries
- Hybrid component cost

H2 FCV /HEVs
- Fuel cell cost
- Hydrogen fuel cost
- Hydrogen storage

- Markets will determine technology choice(s)

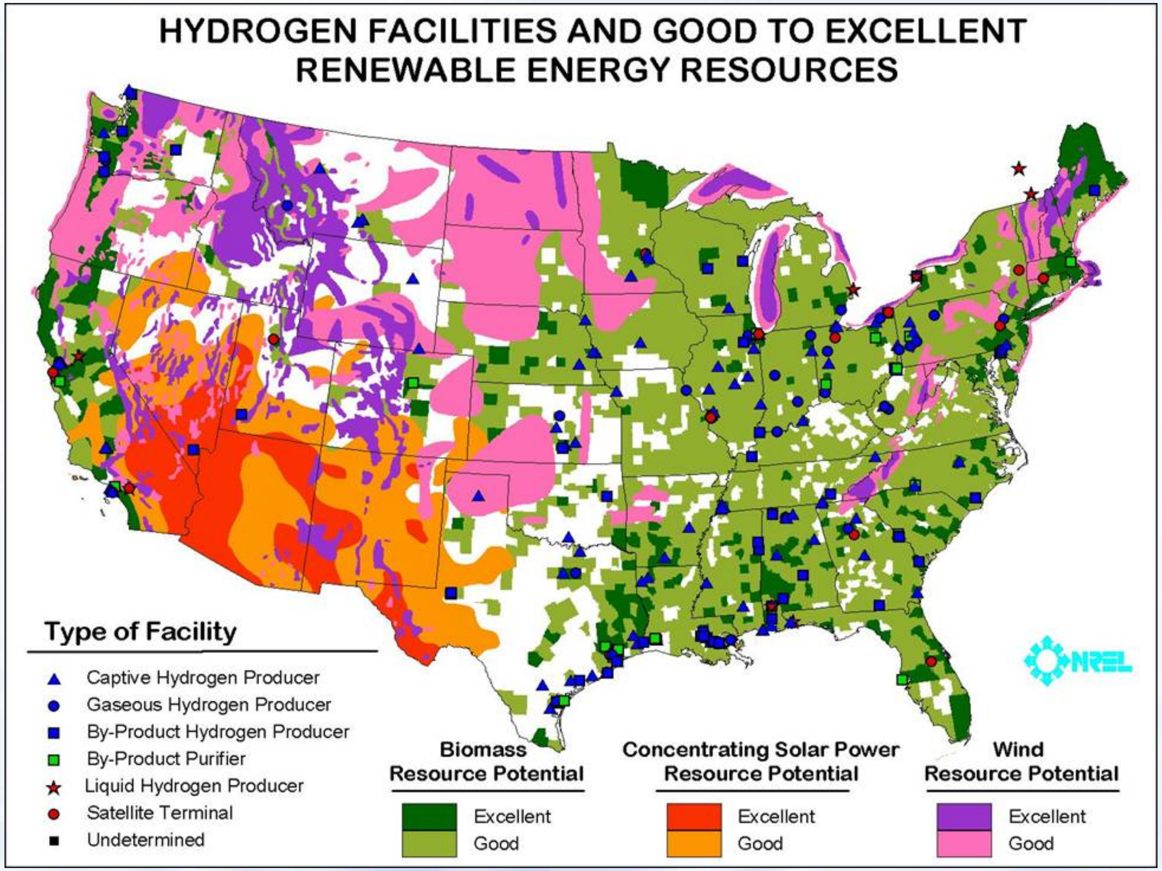
Legend:
ICEV: Internal Combustion Engine Vehicle
HEV: Hybrid Electric Vehicle
FCV: Fuel Cell Vehicle
LDV: Light Duty Vehicle

Why a Hydrogen Future?

Flexibility

- Hydrogen can be produced from water or from carbon-containing materials (reacting with water)

- Regional variations in traditional energy resources are no longer an issue (every region in the U.S. has some indigenous fossil or renewable resource that can be used to make hydrogen)



(AEI) – Fueling Vehicles

Hydrogen

<u>Production Pathways:</u> Hydrogen can be produced from renewable, nuclear, and fossil energy resources using a variety of process technologies, including:

HYDROGEN PRODUCTION

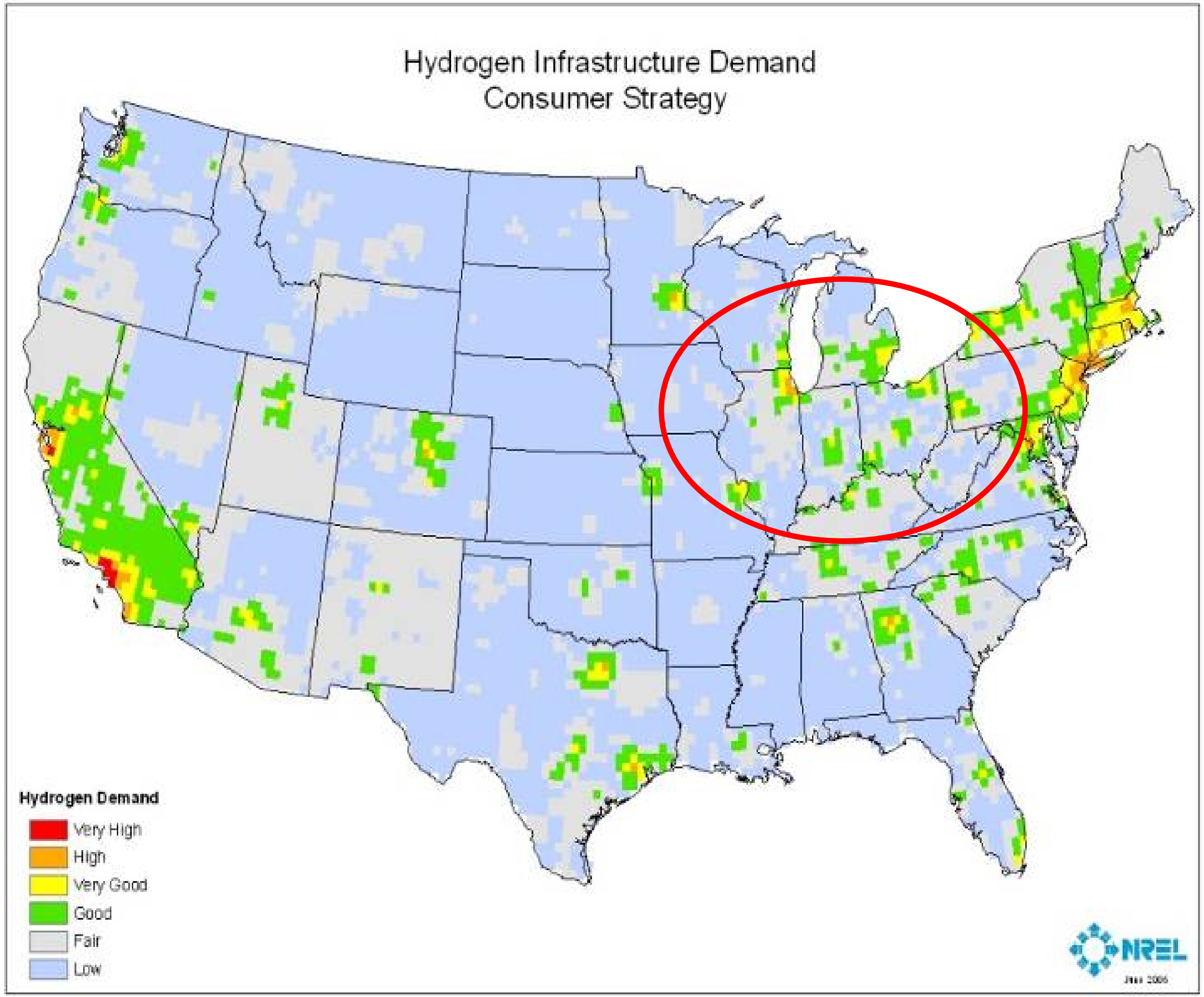
- Renewable electrolysis (using wind, solar, or geothermal energy)
- Biomass and renewable liquids
- High temperature thermochemical
    - Nuclear energy
    - High temperature solar
- Biological and photoelectrochemical technologies
- Coal (with carbon sequestration)
- Natural gas

Quick Fact: **The U.S. hydrogen industry currently produces ~9 million tons of hydrogen a year – that's enough to power about 34 million vehicles.**

Quick Fact: **Today there are about 700 miles of hydrogen pipelines in the U. S. (compared to more than 1 million miles of natural gas pipelines).**

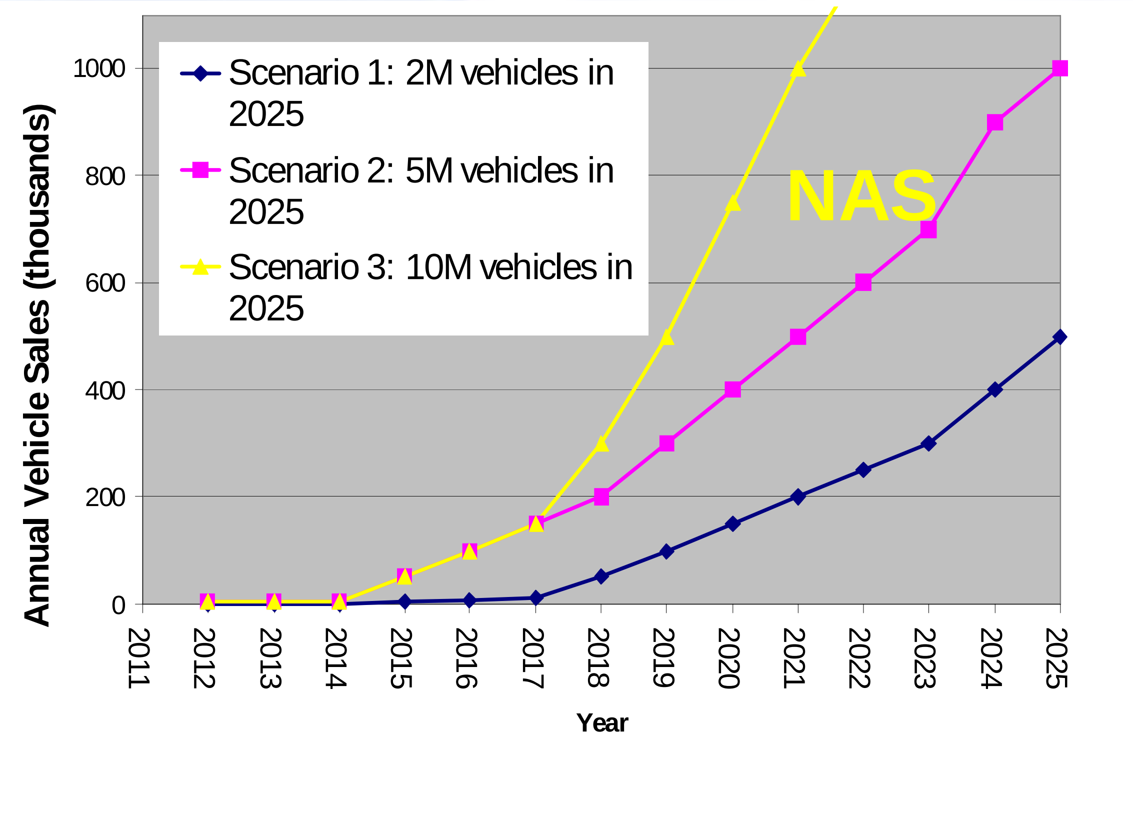
Baseline H2 Demand Results

Early hydrogen demand will be concentrated in major metropolitan cities



- **Hydrogen demand will be dependent on rate of vehicle penetration.**

Transition Requirements for Hydrogen Fuel Cell Vehicles



	Scenario #1	Scenario #2	Scenario #3
No. of vehicles	2 million	5 million	10 million
Hydrogen Demand	0.5 million metric tonnes/yr.	1.25 million metric tonnes/yr	2.5 million metric tonnes/yr

- Vehicle penetration scenarios based on results of Scenario Analysis workshops.

Scenario 1:
- Hundreds to thousands of vehicles per year by 2012 and by 2018 tens of thousands of vehicles per year.
- Leads to a market penetration of 2 million FCVs by 2025.

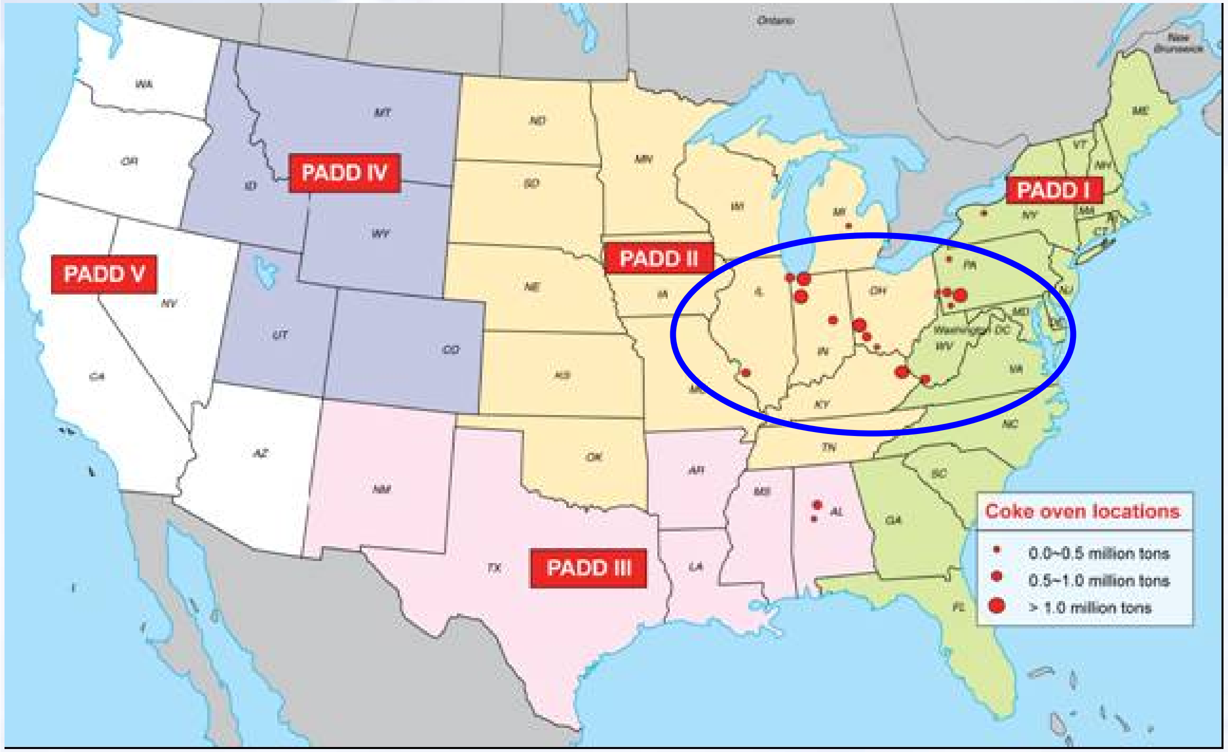
Scenario 2:
- Thousands of vehicles by 2012, tens of thousands by 2015 and by 2018 hundreds of thousands of vehicles per year.
- Leads to a market penetration of 5 million FCVs by 2025

Scenario 3:
- Thousands of vehicles by 2012 and millions of vehicles per year by 2021.
- Leads to a market penetration of 10 million FCVs by 2025

Potential Hydrogen from Coke Oven Gas

Hydrogen can be recovered from the byproduct gas of the traditional coal-to-coke process.

Coke Oven operations in the United States

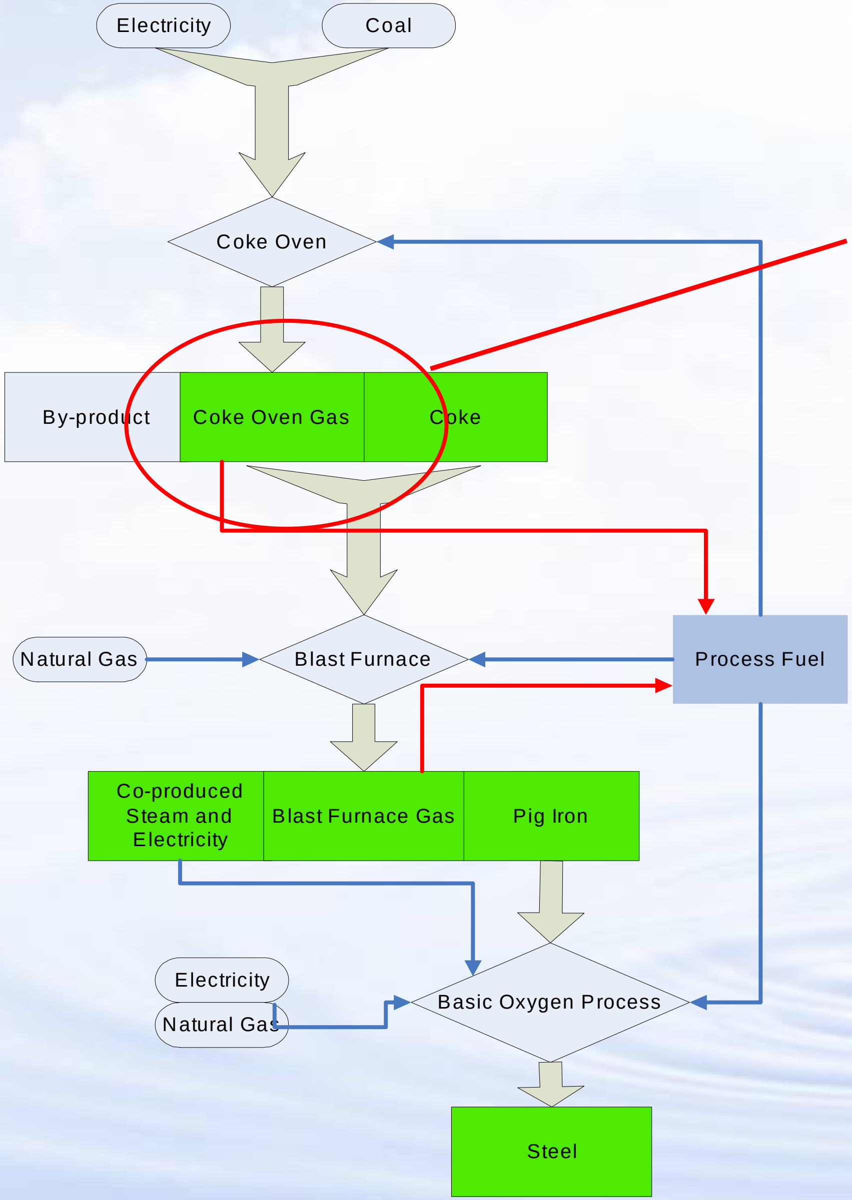


- Hydrogen from coal-to-coke process could fuel ~1 million FCVs/yr.
- Industry demonstrated this method in Japan.

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



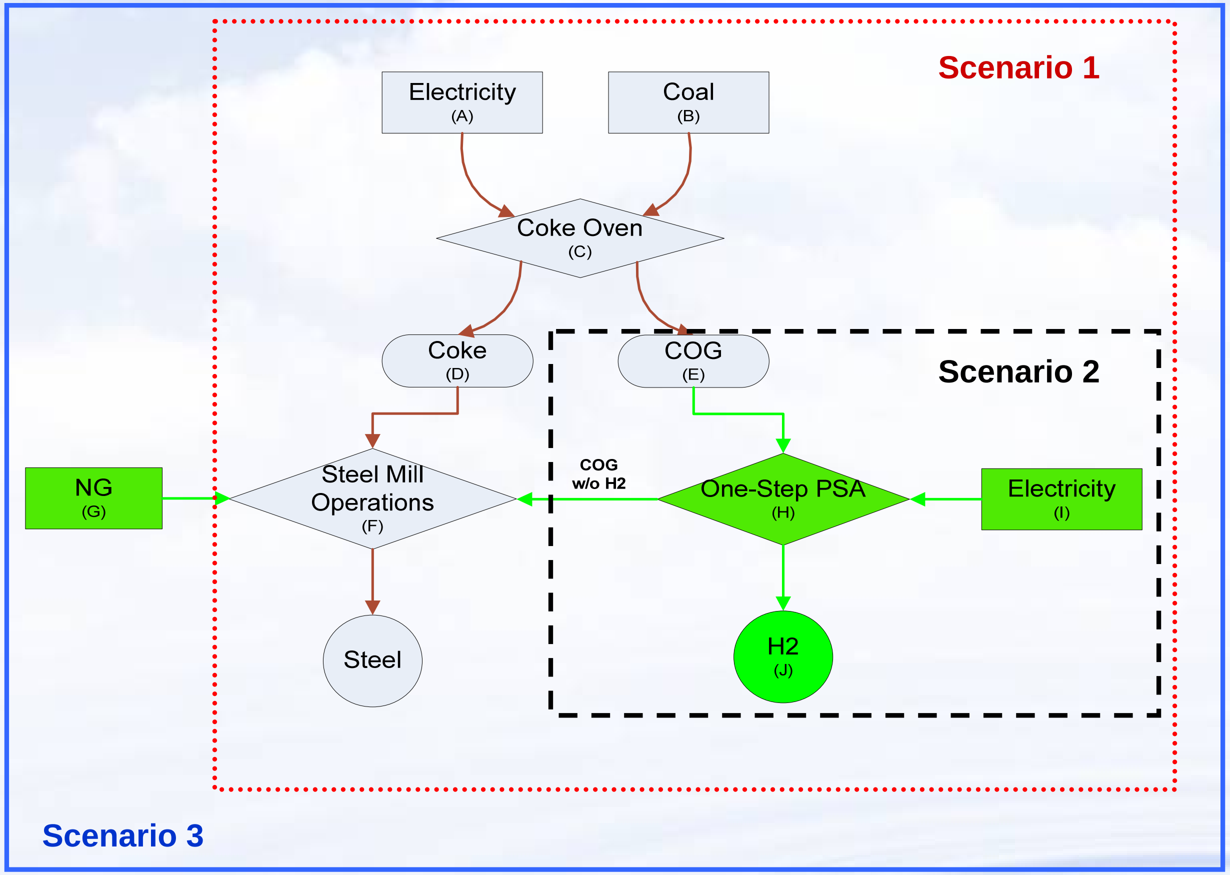
Typical Analysis of Coke Oven Gas

	% 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):

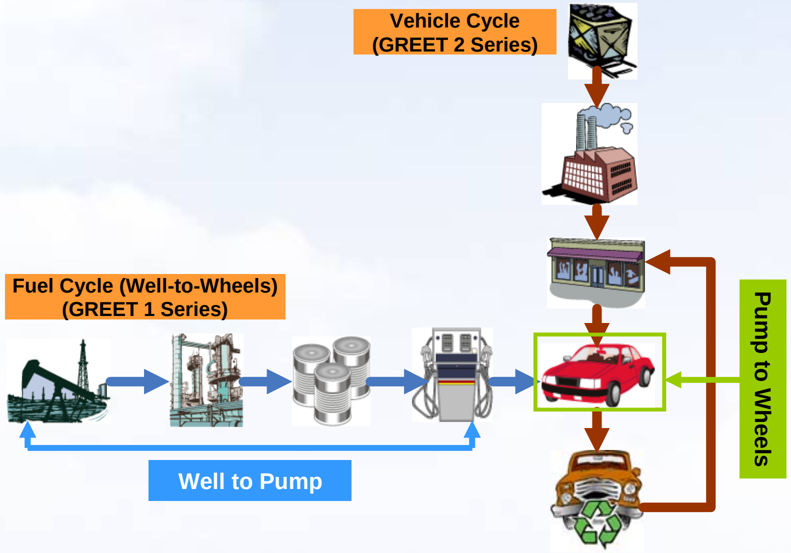
- Based on the energy use by the PSA unit and the amount of supplemental natural gas used to makeup for BTU withdrawal from separated hydrogen.

Well-to-Wheels Analyses (Transportation)

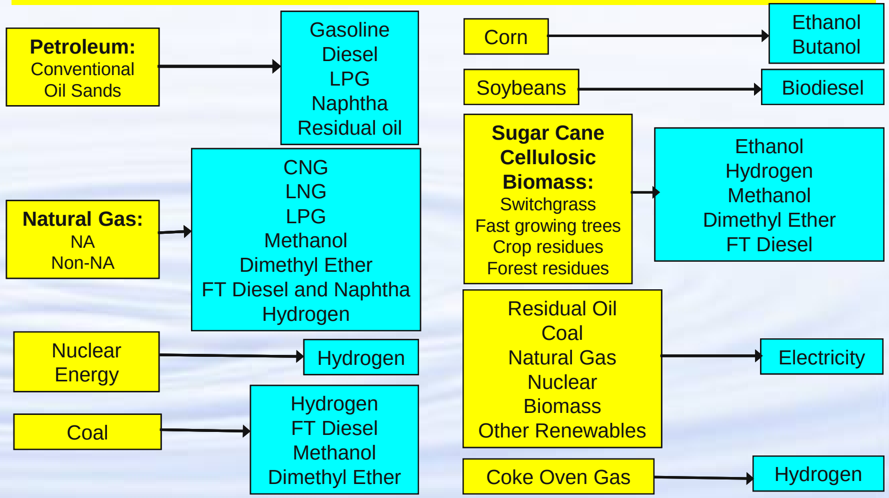
Tools Available – GREET Model

GREET: Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

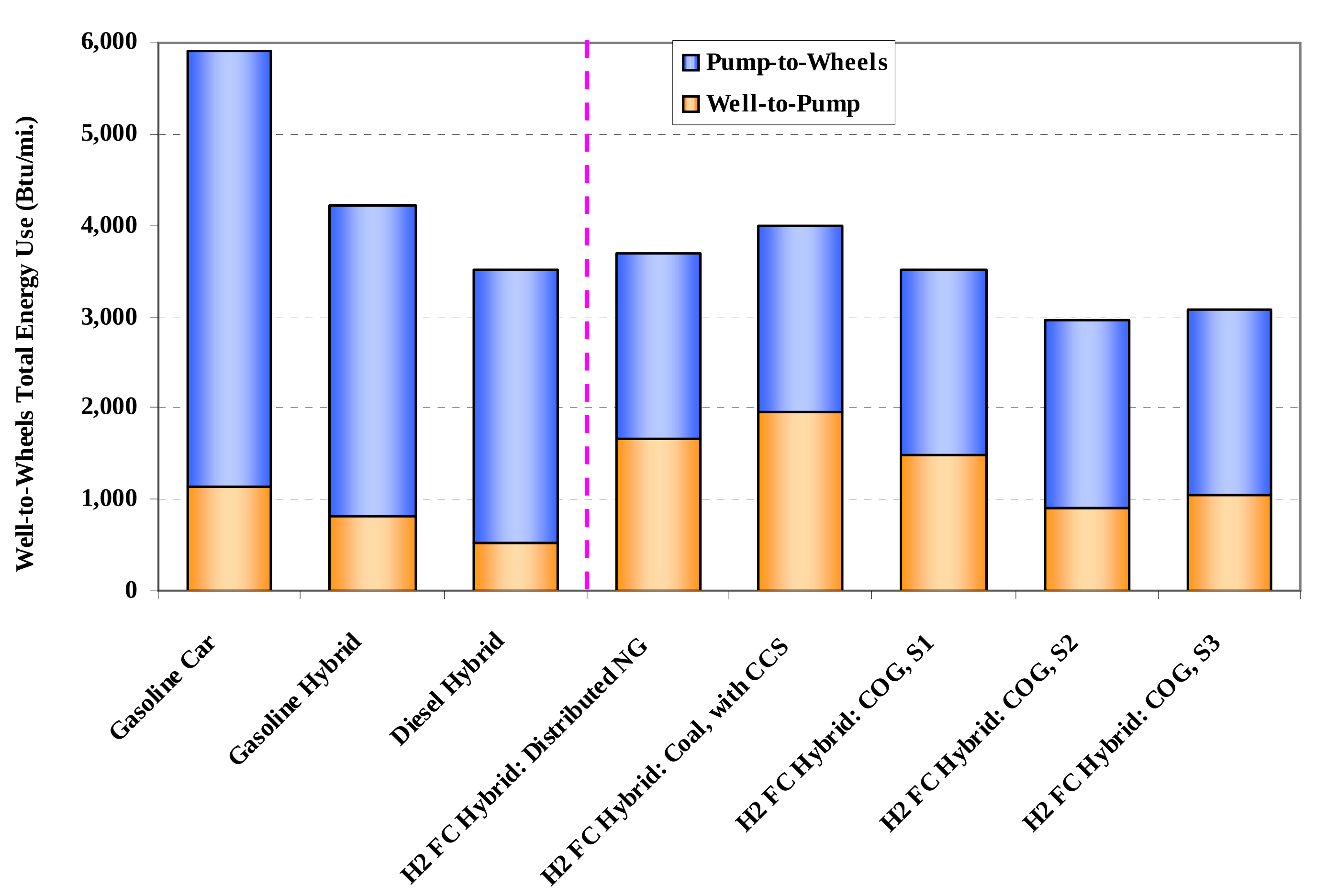
- Multi-dimensional spreadsheet model developed by Argonne National Lab with support from DOE
- Public information
- Well-to-wheels fuel cycle
- Vehicle cycle through materials recovery and vehicle disposal
- For given vehicle and fuel system, model determines:
  - Consumption of energy by type
  - Emissions of CO_2-equivalent GHGs (mainly CO_2, CH_4, & N_2O)
  - Emissions of 6 criteria pollutants: NO_x, SO_x, PM10, PM2.5, CO & VOCs



GREET has more than 100 fuel production pathways



Well-to-Wheels Analysis
Total Energy Use



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.

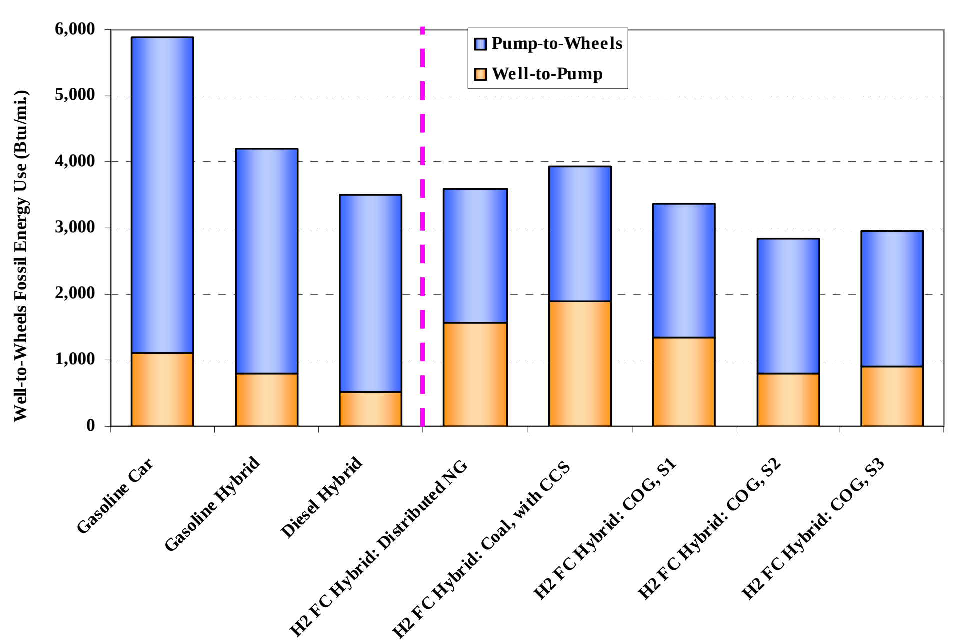
Vehicle Fuel Efficiency, mpgge

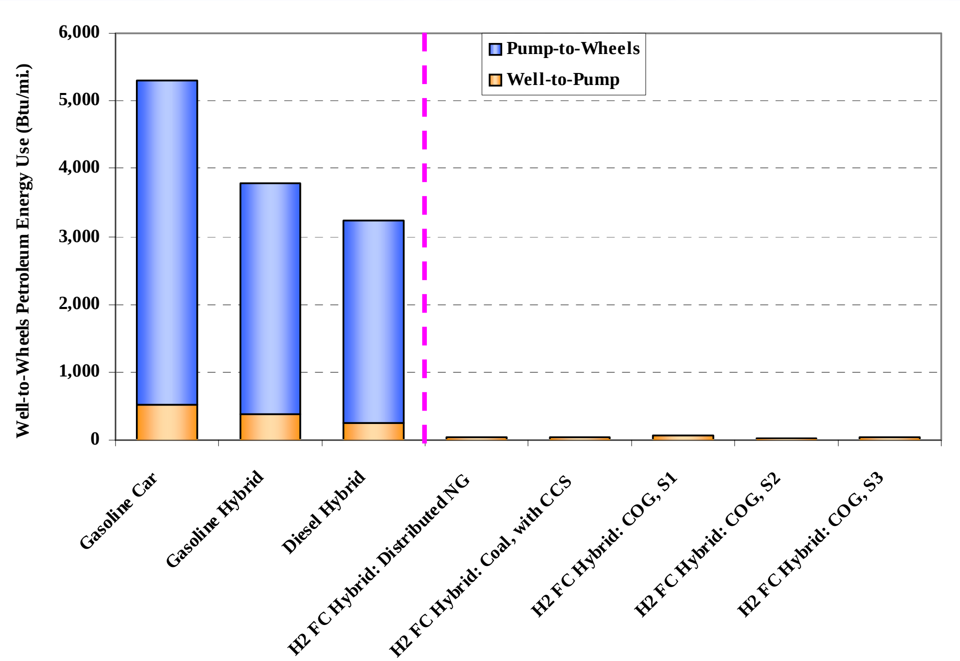
Gaso. ICE	Gaso. HEV	Diesel HEV	FCV HEV
24	34	39	57

Notes:

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

Well-to-Wheels Analysis





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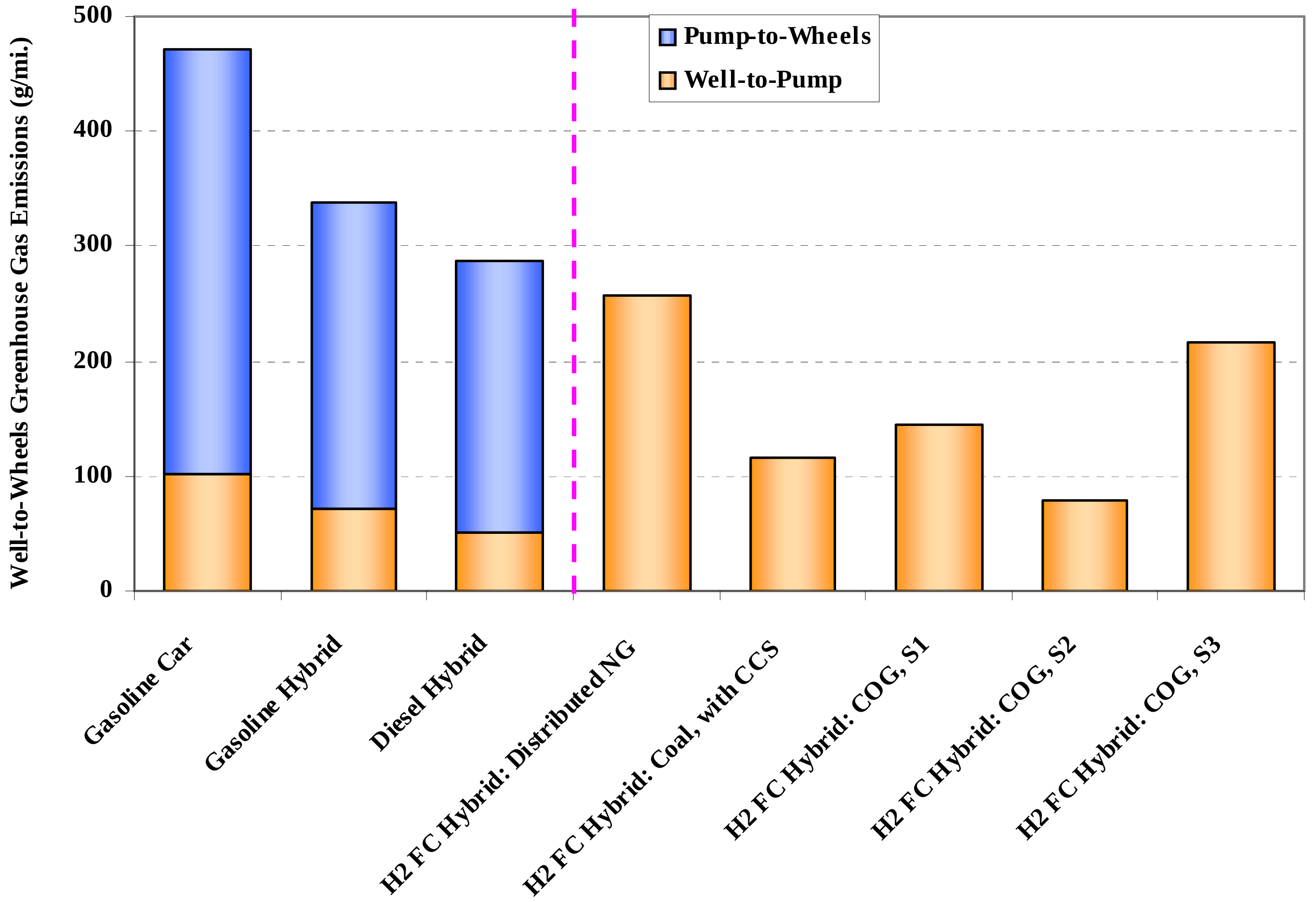
Well-to-Wheels Analysis
Greenhouse Gas Emissions



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Take Away

- Hydrogen recovery from indigenous domestic sources compares favorably with the other hydrogen production technologies being considered.

- 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.

- Hydrogen supply from indigenous sources such as coke oven gas can help reduce greenhouse gas emissions and petroleum dependency when used for FCV vehicles.

Photo:Shell Hydrogen

Shell hydrogen and gasoline station, WA DC

BP LAX refueling station

Thank you!

Note:

A copy of the paper associated with this presentation is available through the conference proceedings.