Life-Cycle Analysis of Vehicle and Fuel Systems with the GREET Model

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Overview: Life-Cycle Analysis (LCA) at Argonne

Timeline

- Start: Oct. 2009
- End: not applicable (FCT program)
- % complete: not applicable

Budget

- Funding received in FY11: $379K
- Funding for FY12: $425K

Barriers to Address

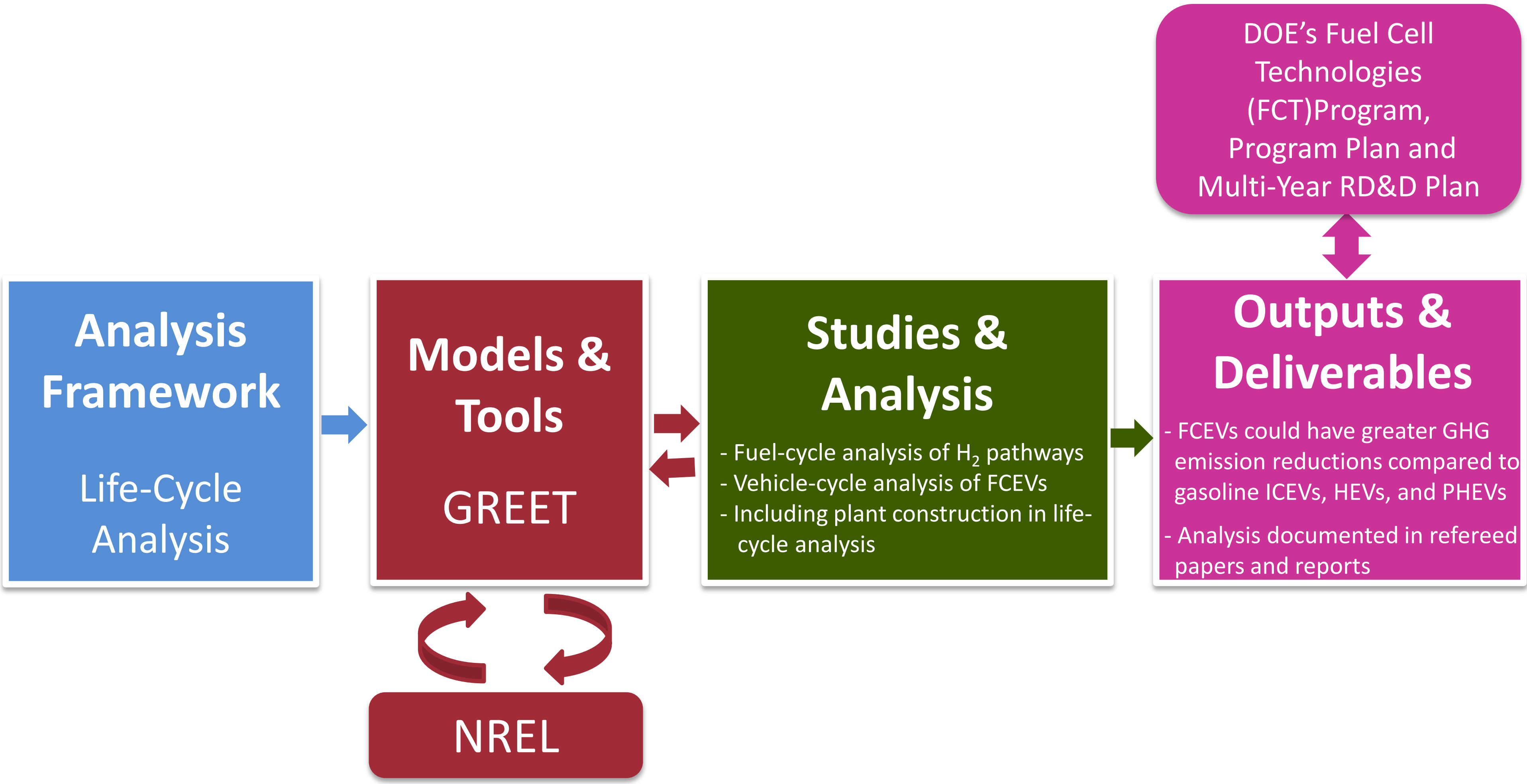
- Evaluate energy and emission benefits of H_2 FC technologies
- Overcome inconsistent data, assumptions, and guidelines
- Develop models and tools
- Conduct unplanned studies and analyses

Partners/Collaborators

- NREL
- Industry stakeholders

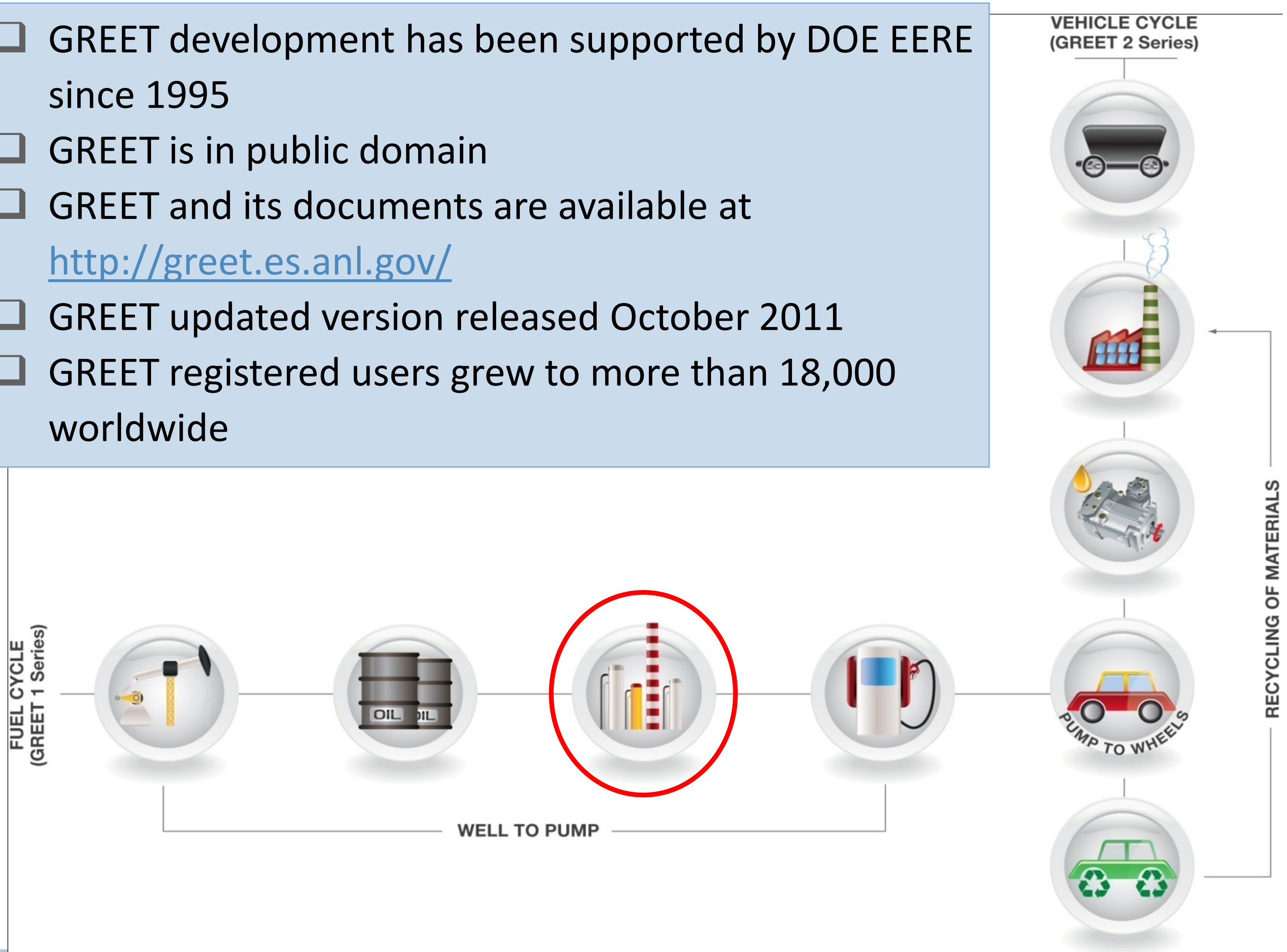
LCA of Energy and Emission Effects of H_2 Fuel Cell Systems with GREET:

A Consistent Platform To Compare Different Vehicle and Fuel 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/
- GREET updated version released October 2011
- GREET registered users grew to more than 18,000 worldwide



Approach, Data Sources, and General Assumptions

- 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

- Data Sources
  - 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
  - Data for FCEVs and other FC systems
    - Open literature and results from other researchers
    - Simulation results from models such as Autonomie and H2A
    - Demonstration programs of available FCEV models and FC systems
    - Auto makers and FC system producers

- General Assumptions
  - Baseline technologies and energy systems: EIA AEO projections, EPA eGrid for electric systems, etc.
  - Both baseline technologies and new technologies continue to advance over time
  - Regulations already adopted by agencies are taken into account

Key Milestones

- Fuel-cycle analysis of renewable H_2 pathways
  - Renewable natural gas (RNG)-to-H_2
  - RNG vs. conventional/shale gas-to-H_2
- Vehicle-cycle analysis of fuel-cell electric vehicles (FCEVs), battery electric vehicles (BEVs) and baseline vehicles
- Addition of plant construction to LCAs
  - Petroleum refineries
  - H_2 SMR plants
  - Electric power plants
- Development of GREET.net platform to improve GREET usability and functionality

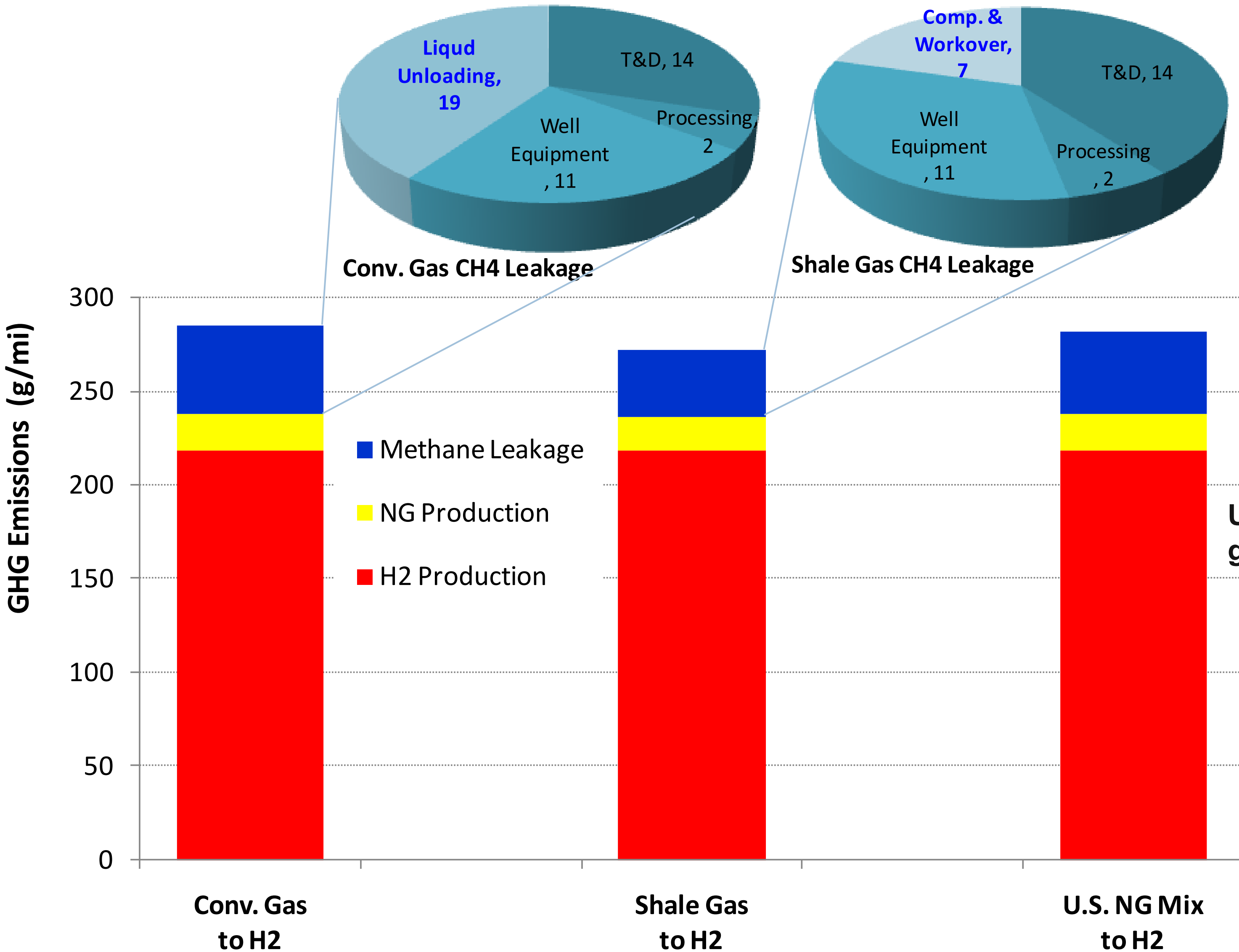
GREET Added Shale Gas (SG) Pathway and Updated Methane Emissions of Natural Gas (NG) Pathways

Well Infrastructure → NG Recovery → NG Processing → NG Transmission and Distribution → Hydrogen Reforming → Hydrogen Compression → Vehicle Operation

- NG recovery includes conventional and shale gas recovery
- Key parameters affecting LCA results
  - Share of shale gas in the U.S. NG mix (23% in 2010)
  - Methane emissions (CH_4: volumetric % of NG produced)
  - NG recovery/processing and H_2 production/compression efficiency
- Significant uncertainty in methane emissions
  - Large uncertainty in estimated ultimate recovery
  - Methane losses during recovery and transmission
- SMR H_2 production pathways were expanded and updated

Methane emissions (volumetric % of NG produced)	Conv. Gas	Shale Gas
Well completion and workover	0.003%	0.46%
Liquid unloading	1.2%	N/A
Well equipment	0.73%	0.73%
NG processing	0.15%	0.15%
NG transmission and distribution	0.83%	0.83%

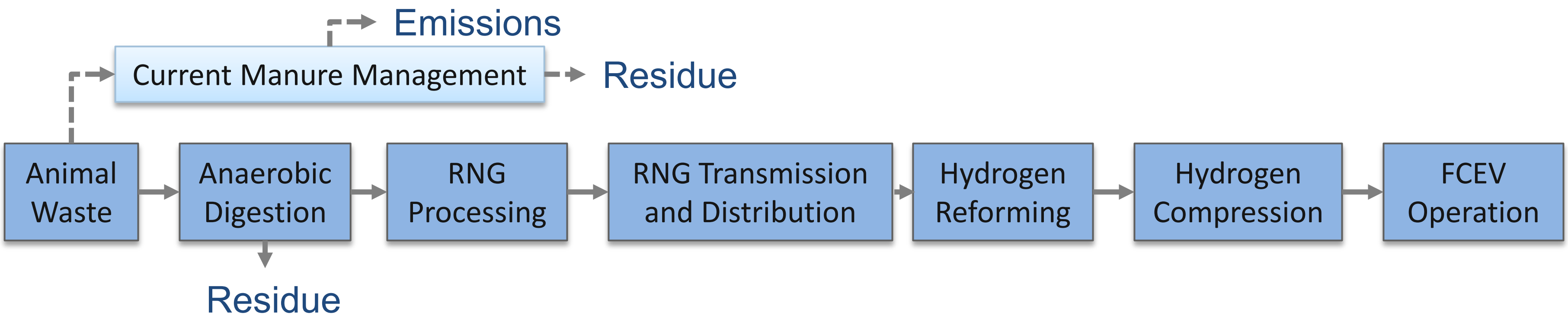
CH_4 Leakage Is a Major GHG Emissions Source for Production of H_2 from NG and Shale gas: FCEV GHG Emissions with SMR H_2



T&D= Transportation and distribution

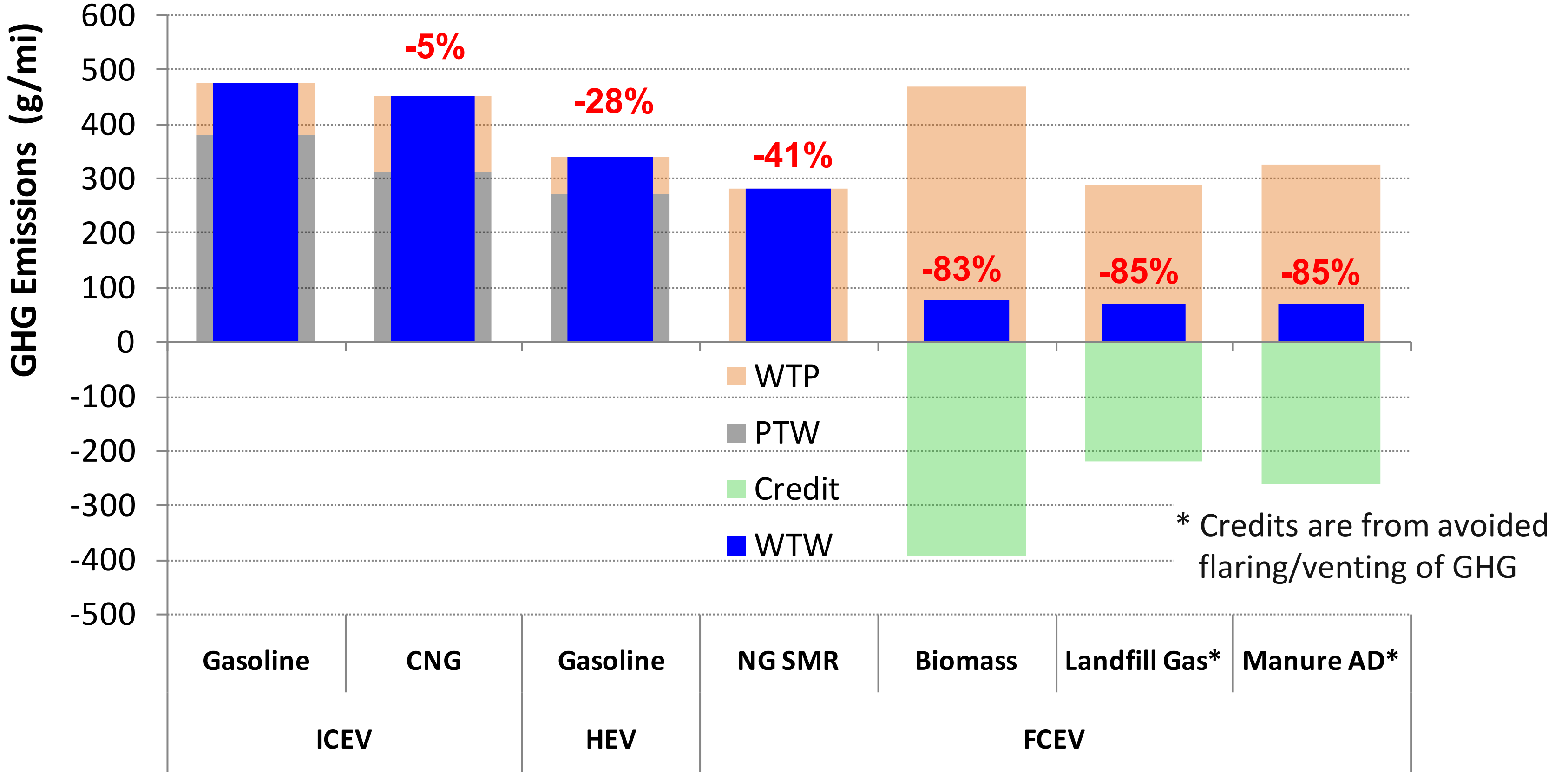
U.S. NG mix is 77% conv. gas and 23% shale gas

Argonne Has Examined H_2 from Renewable Natural Gas (RNG) of Anaerobic Digestion of Animal Waste



- Emissions credit from current manure management
  - Potentially significant due to high methane emissions
- Large CH_4 leakage (2% by vol.) during anaerobic digestion and RNG processing
- Transportation and fertilizer displacement effects of AD residue are included
- Key parameters affecting LCA results
  - Anaerobic digestion process assumptions such as methane yield
  - Current manure management (practice, weather, etc.)
  - RNG processing and H_2 production/compression efficiency

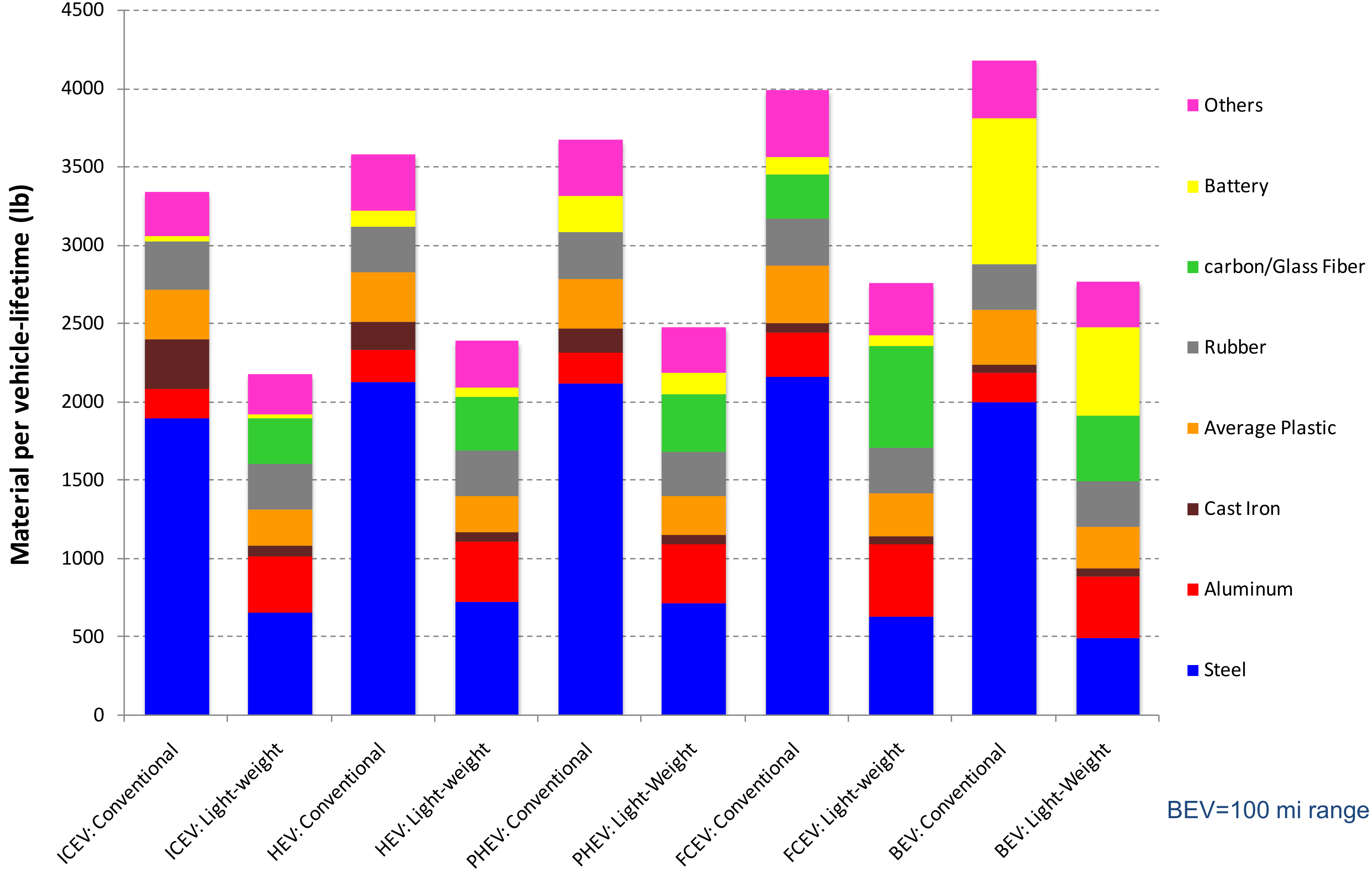
FCEVs with Fossil and Renewable H_2 Pathways Show 41% and 83-85% GHG Reduction Relative to Gasoline ICEVs



	Gasoline Refining	NG Processing	SMR to H2	Biomass to H2	Landfill Gas to H2	Manure AD Biogas to H2
Production Efficiency	91%	97%	72%	51%	61%	61%

	Gasoline ICEV	Gasoline HEV	CNG	H_2 FCEV
Fuel Economy (mpgge)	23	33	22	54

Material Composition of Vehicle Weight Impact Vehicle Cycle Analysis

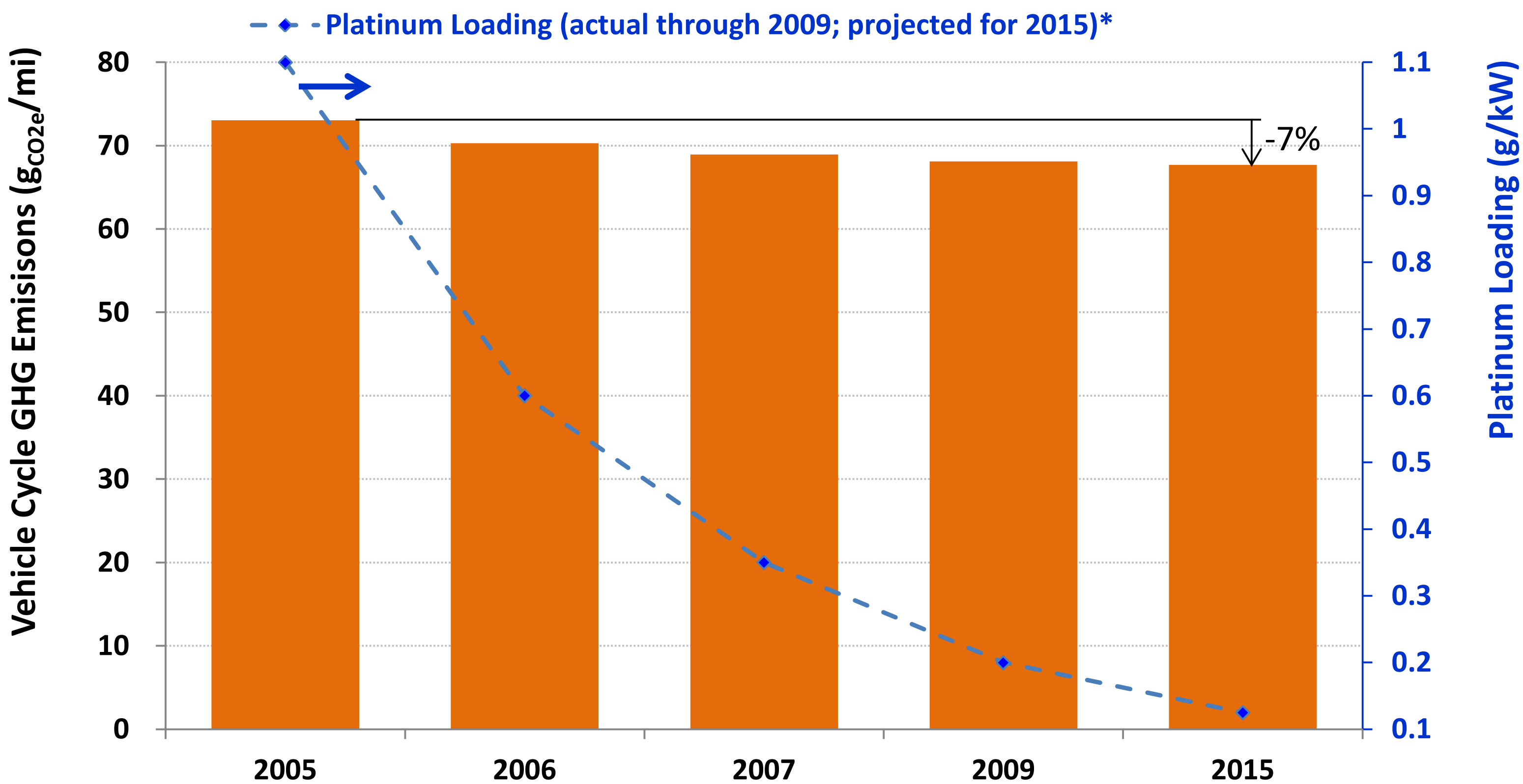


BEV=100 mi range

- Both conventional and light-weighting vehicle material options are included in GREET vehicle-cycle analysis.
- Material composition among vehicle propulsion technologies varies considerably

Besides Cost Benefits, Platinum Loading Reduction for FC Stacks by FCTP R&D Efforts Cuts FCEV Vehicle-Cycle GHG Emissions by 7%

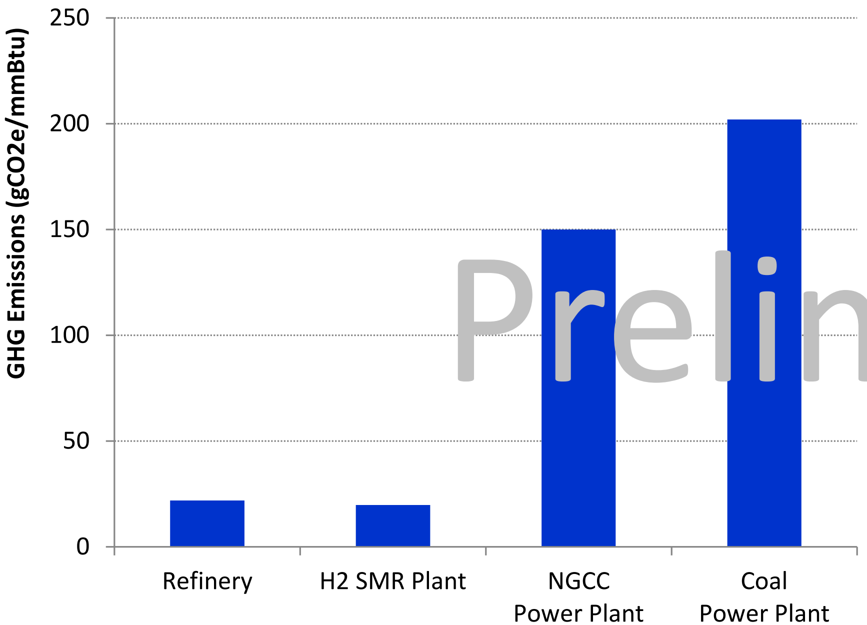
- Each gram of platinum contribute to 12 kg of life-cycle GHG emissions
- Platinum loading for FCEV dropped from 1.1 g/kW to < 0.2 g/kW*
- For 70 kW FC stack , total platinum loading dropped from 77 g to < 14 g
- When amortized over the lifetime of FCEV (150,000 mi), platinum life-cycle contribution to vehicle-cycle GHG emissions dropped from 6 g/mi to < 1 g/mi, resulting in 7% reduction of FCEV vehicle-cycle emissions

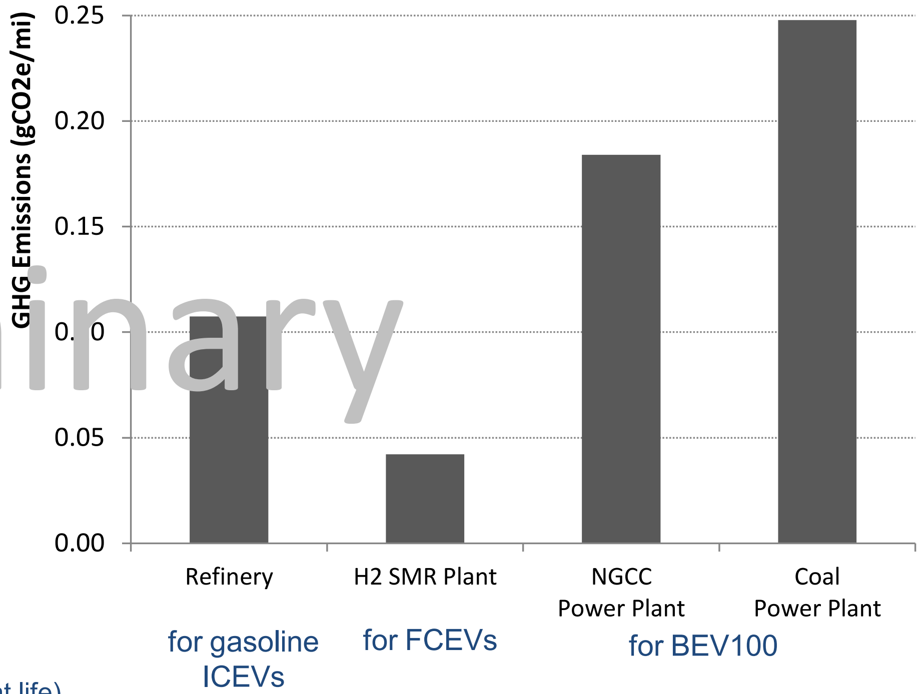


*Source: DOE Hydrogen Program Record (Record # 9018, June 1, 2010)

Amortized GHG Emissions of Plant Construction Vary by Fuel Type

	Petroleum Refinery	H_2 SMR Plant	NGCC Power Plant	Coal Power Plant
Steel (tons)#	34,000	200	74,000	131,000
Stainless Steel (tons)	1,800	80	1,500	2,000
Concrete (tons)	47,000	900	165,000	341,000
Catalyst (tons)*	4,000	-	-	-
Plant size	120,000 BBL/day	18.5 mmSCF/day	650 MW	750 MW



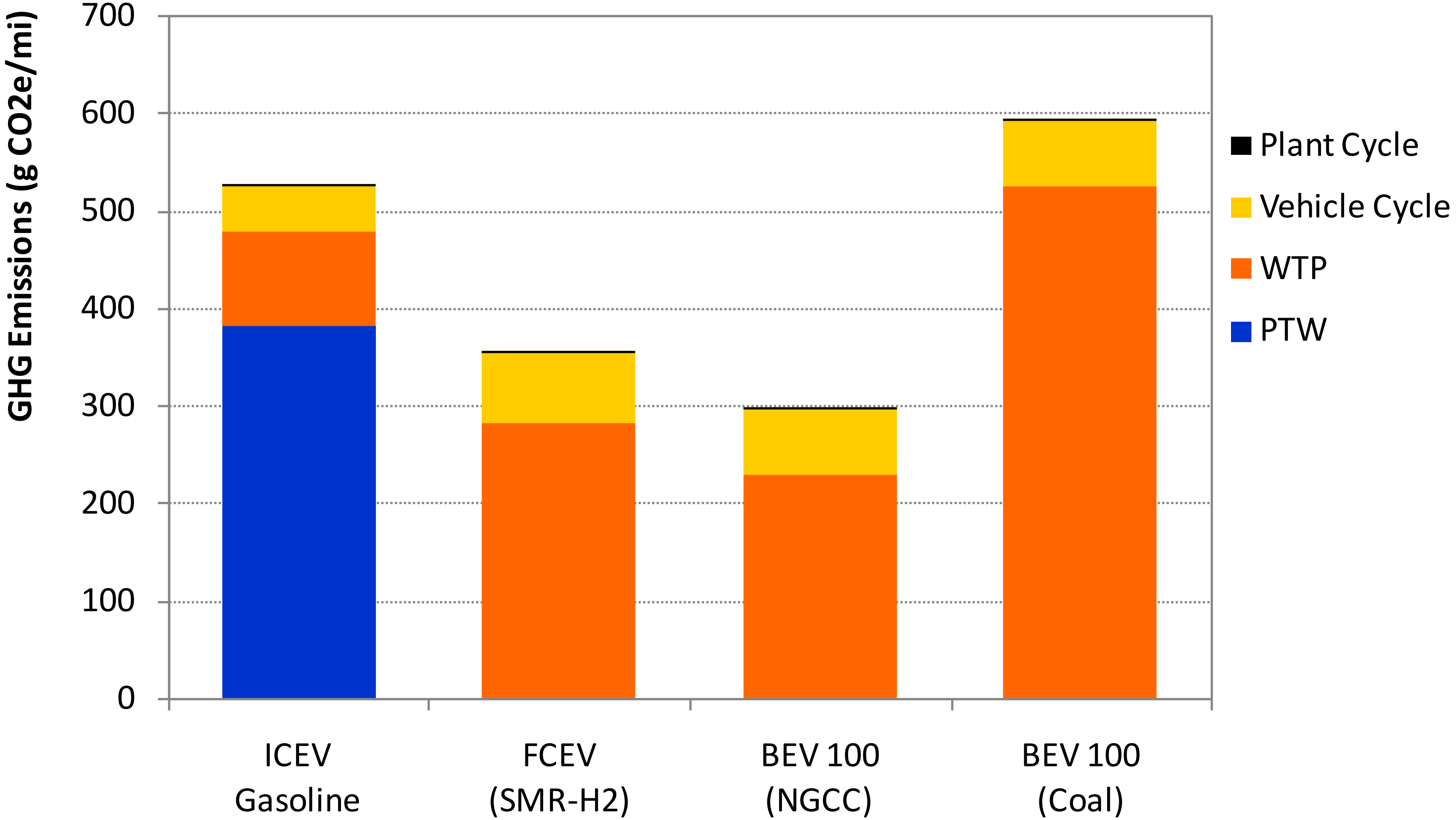


A plant lifetime of 35 years was assumed for all plants

#Assuming 10 years of rotary equipment life (3.5 replacements per plant life)

*Assuming 10 years of catalyst life (3.5 replacements per plant life)

Overall, Emissions from Plant Construction Are Negligible Compared to Fuel- and Vehicle-Cycle Emissions



	Gasoline ICEV	H_2 FCEV	BEV 100
Fuel Economy (mpgge)	23	54	80*

*from wall outlet (assuming 85% charging efficiency)

Alpha Version of GREET.net Has Been Under Testing by Selected Users

- GREET.net provides a platform for faster development of new fuel/vehicle pathways, and easier LCA simulation and analysis
- GREET.net was released in Feb. 2012 to selected users for alpha testing
- A beta version is scheduled for release in July 2012
- Final release is scheduled by end of FY12

Summary of GREET LCA Results

- CH_4 leakage is a major GHG emissions source for production of H_2 from NG and shale gas
- FCEVs with fossil and renewable H_2 production pathways could have significant GHG reductions relative to gasoline ICEV
  - By 41% when H_2 is produced from fossil NG/SG
  - By 83-85% when H_2 is produced from RNG or biomass
- FCEV vehicle-cycle GHG emissions are reduced by 7% with platinum loading reduction
- Emissions of plant construction are negligible compared to fuel- and vehicle-cycle emissions

Future Work

- Finalize incorporation of hydrogen and petroleum refinery plant construction into GREET
- New H_2 production pathways such as biogas from waste water to H_2
- Expand characterization of the electric power sector in GREET to include generation by utility regions and sub-regions, fuels and technology types, stationary and tri-generation fuel cells, and CHP generators
- Release and provide support for first version of GREET.net by the end of FY12
- Continue to provide LCA technical support to DOE FCT program and industry stakeholders

Acronyms

- AEO: Annual Energy Outlook
- AD: Anaerobic Digestion
- ANL: Argonne National Laboratory
- BEV: Battery Electric Vehicle
- BBL: Barrel
- DOE: Department of Energy
- EERE: Energy Efficiency and Renewable Energy
- eGRID: Emissions & Generation Resource Integrated Database
- EIA: Energy Information Administration
- EPA: Environmental Protection Agency
- FC: Fuel Cell
- FCEV: Fuel Cell Electric Vehicle
- FCT: Fuel Cell Technology
- GHG: Greenhouse Gases
- GREET: Greenhouse gases, Emissions, and Energy use in Transportation
- H2A: Hydrogen Analysis
- HEV: Hybrid Electric Vehicle
- ICEV: Internal Combustion Engine Vehicle
- LCA: Life Cycle Analysis
- LFG: Landfill Gas
- NG: Natural Gas
- NGCC: Natural Gas Combined Cycle
- NREL: National Renewable Energy Laboratory
- PHEV: Plug-in Hybrid Electric Vehicle
- RNG: Renewable Natural Gas
- SCF: Standard Cubic Feet
- SMR: Steam Methane Reforming
- T&D: Transportation and Distribution