GREET Development and Applications for Life-Cycle Analysis of Vehicle/Fuel Systems

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Project ID: van002

Project Overview

Timeline

- Start: Oct. 1993
- End: not applicable (ongoing annual allocation
- % complete: 70% (for FY13)

Budget (all from DOE)

- Total funding since the beginning: $5.6 M

- Funding for FY12: $400K
- Funding for FY13: $400K

Barriers to Address

- Indicators and methodology for evaluating environmental sustainability
- Evaluate energy and emission benefits of vehicle/fuel systems
- Overcome inconsistent data, assumptions, and guidelines
- Develop models and tools
- Conduct unplanned studies and analyses

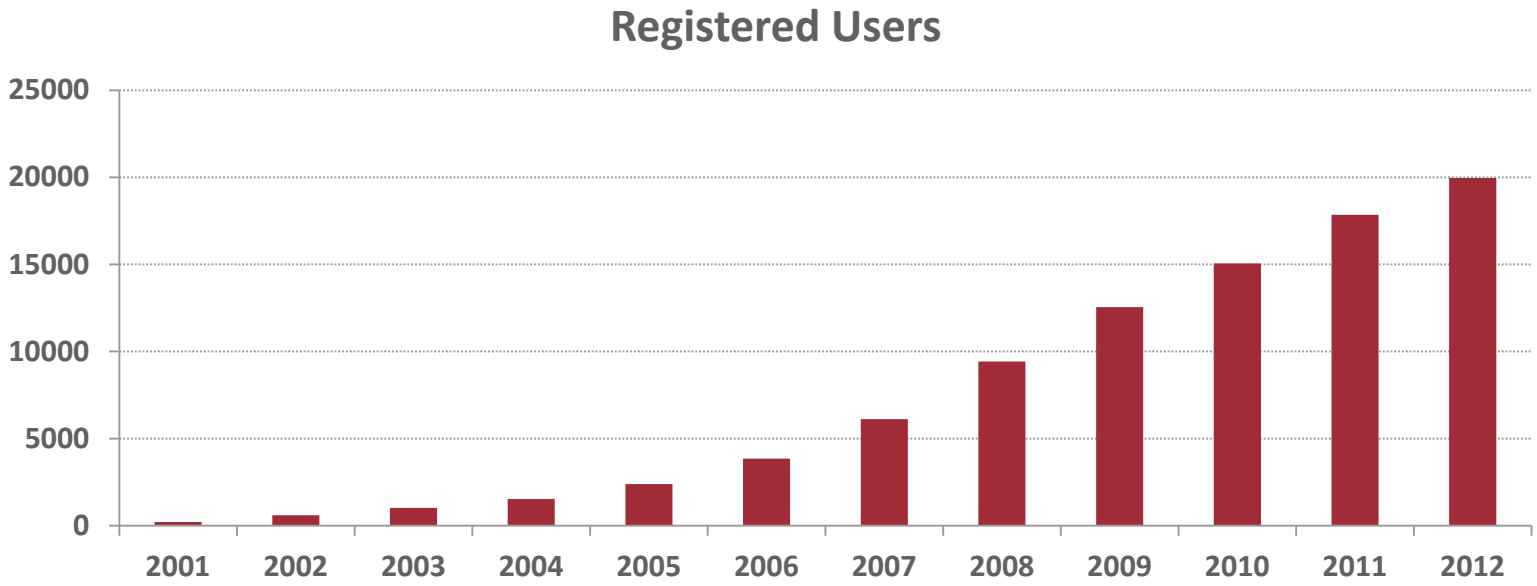
Partners/Collaborators

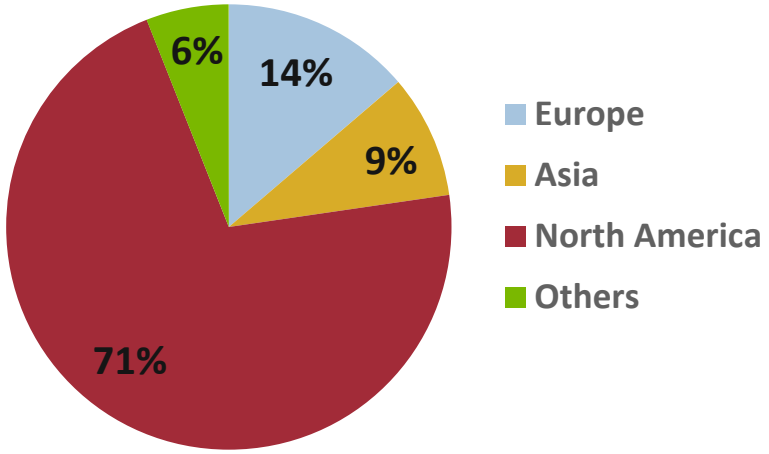
- Other research teams funded by VTP
- Other federal/state agencies
- Industry stakeholders

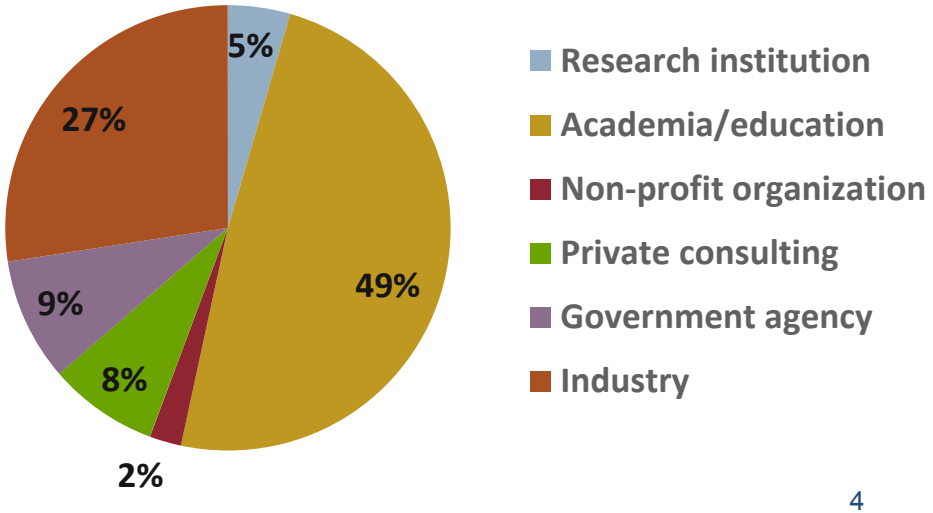
The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model Evaluates Alternative Vehicle/Fuel Systems

- GREET development has been supported by DOE EERE since 1993 (with VTP as the sole early sponsor)
- GREET is in public domain
- GREET and its documents are available at http://greet.es.anl.gov/
- GREET latest public release was made December 2012

There Are More Than 20,000 Registered GREET Users Worldwide



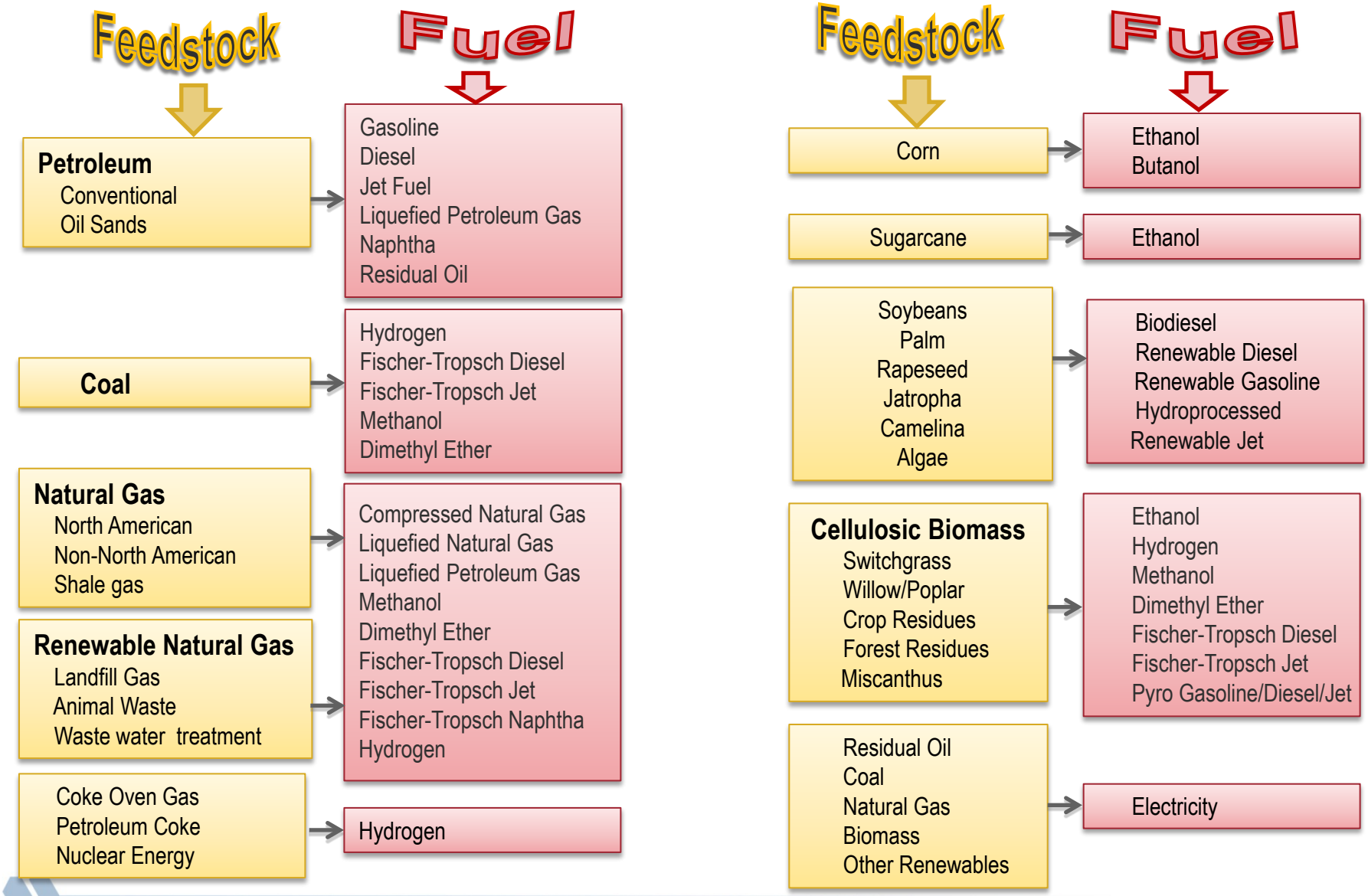




Relevance

- **Provide a consistent platform for comparing energy use and emissions of vehicle/fuel systems:**
  - ✓ Include fuel cycle (a.k.a well-to-wheels or WTW), and vehicle manufacturing cycle (a.k.a. vehicle cycle) for a complete life-cycle analysis (LCA)
  - ✓ Establish a baseline of life-cycle energy use and emissions for baseline fuels and vehicle technologies
  - ✓ Evaluate energy and emissions of new fuel production pathways and advanced vehicle technologies
  - ✓ Identify major contributors to LCA energy use and emission results
- **Assist VTP:**
  - ✓ Evaluate the energy and emission impacts of deploying new fuels and advanced vehicle technologies
  - ✓ Identify R&D priorities to reduce energy and emission footprints of vehicle/fuel systems
- **Support existing DOE-sponsored tools:**
  - ✓ Collaborate with other model developers and lab partners
  - ✓ Collaborate with industry for input and review
- **Assist fuel producers/providers and regulatory agencies to evaluate fuel and vehicle technologies with respect to greenhouse gas (GHG) metrics**

GREET Includes More Than 100 Fuel Production Pathways from Various Energy Feedstock Sources



GREET Examines More Than 85 Vehicle/Fuel Systems

Conventional Spark-Ignition Engine Vehicles
- Gasoline
- Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
- Gaseous and liquid hydrogen
- Methanol and ethanol
- Renewable gasoline
- Pyrolysis-based gasoline

Spark-Ignition, Direct-Injection Engine Vehicles
- Gasoline
- Methanol and ethanol

Compression-Ignition, Direct-Injection Engine Vehicles
- Diesel
- Fischer-Tropsch diesel
- Dimethyl ether
- Biodiesel
- Renewable diesel
- Pyrolysis-based diesel

Fuel Cell Vehicles
- On-board hydrogen storage
  - Gaseous and liquid hydrogen
- On-board hydrocarbon reforming to hydrogen

Battery-Powered Electric Vehicles
- Various electricity generation sources

Hybrid Electric Vehicles (HEVs)
- Spark-ignition engines:
  - Petroleum and renewable gasoline
  - Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
  - Gaseous and liquid hydrogen
  - Methanol and ethanol
- Compression-ignition engines
  - Petroleum and renewable diesel
  - Fischer-Tropsch diesel
  - Dimethyl ether
  - Biodiesel

Plug-in Hybrid Electric Vehicles (PHEVs)
- Spark-ignition engines:
  - Petroleum and renewable gasoline
  - Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
  - Gaseous and liquid hydrogen
  - Methanol and ethanol
- Compression-ignition engines
  - Petroleum and renewable diesel
  - Fischer-Tropsch diesel
  - Dimethyl ether
  - Biodiesel
- Fuel cell
  - Gaseous and liquid hydrogen from various sources

Approach, Data Sources, and General Assumptions

- **Approach: build LCA modeling capacity with the GREET model**
  - Build a consistent LCA platform with reliable, widely accepted methods/protocols
  - Address emerging LCA issues related to vehicle/fuel systems
  - Maintain openness and transparency of LCAs with availability of GREET
- **Data Sources:**
  - Data for fuel production pathways
    - Open literature and results from other researchers
    - Simulation results with models such as ASPEN Plus
    - Fuel producers and technology developers
  - Data for vehicle systems
    - Open literature and results from other researchers
    - Simulation results from models such as Autonomie
    - Auto makers and system components producers
- **General Assumptions:**
  - Baseline technologies and energy systems: EIA AEO projections, EPA eGrid for electric systems, etc.
  - Evolution of both baseline technologies and new technologies over time
  - Consideration of effects of regulations already adopted by agencies

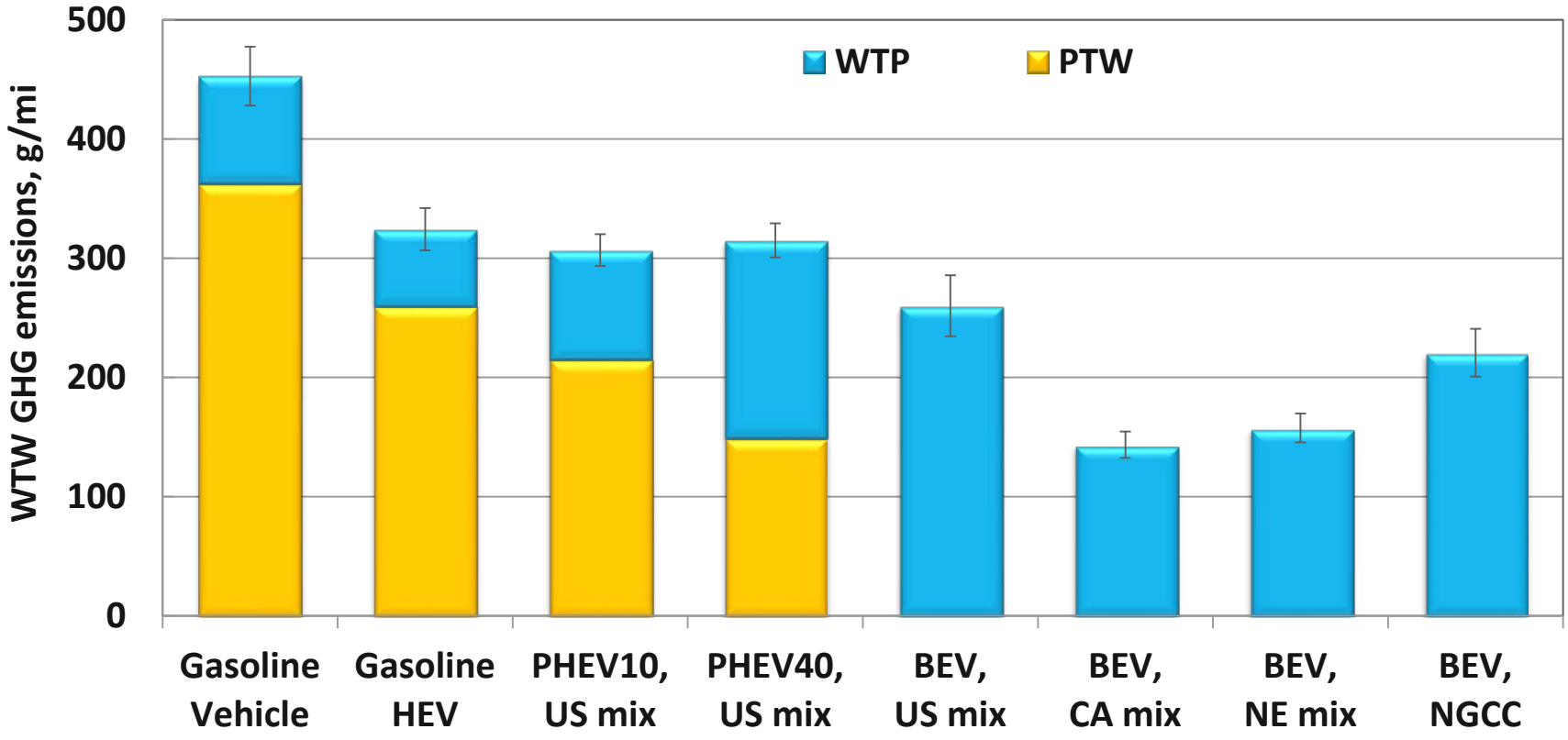
Key Milestones

- Update fuel-cycle (WTW) simulations of baseline fuels
  - Update electricity sector and plug-in electric vehicles performance
  - Update petroleum recovery and refining parameters for baseline gasoline and diesel fuels
- Update vehicle-cycle analysis of conventional and advanced vehicle propulsion systems
  - Incorporate new vehicle designs and new propulsion systems for meeting new regulatory requirements such as CAFE standards
  - Update vehicle materials energy and carbon intensities
  - Update vehicle manufacturing energy and carbon intensities
- Evaluate contribution of construction of fuel production/distribution infrastructure to LCA results
  - Oil rigs and petroleum refineries
  - Natural gas well drilling and processing plants
- Develop GREET in a new platform to improve GREET usability and functionality

Expanded and Updated Electricity Sector in GREET

- Expanded modeling of electricity generation by including regional characterization
  - Generation by NERC regions
  - Generation for each U.S. state
- Completed updates include:
  - Air pollutant emissions factors for each electric generator type
  - Shares of electricity generation by fuel type and prime mover technology
  - Electric generation efficiencies
  - Electric transmission losses
  - Properties of energy resources for power plants
  - Probability distribution functions for efficiencies, emission factors and fuel properties to address uncertainties
- Significant findings include increased share of NGCC and reduced transmission losses

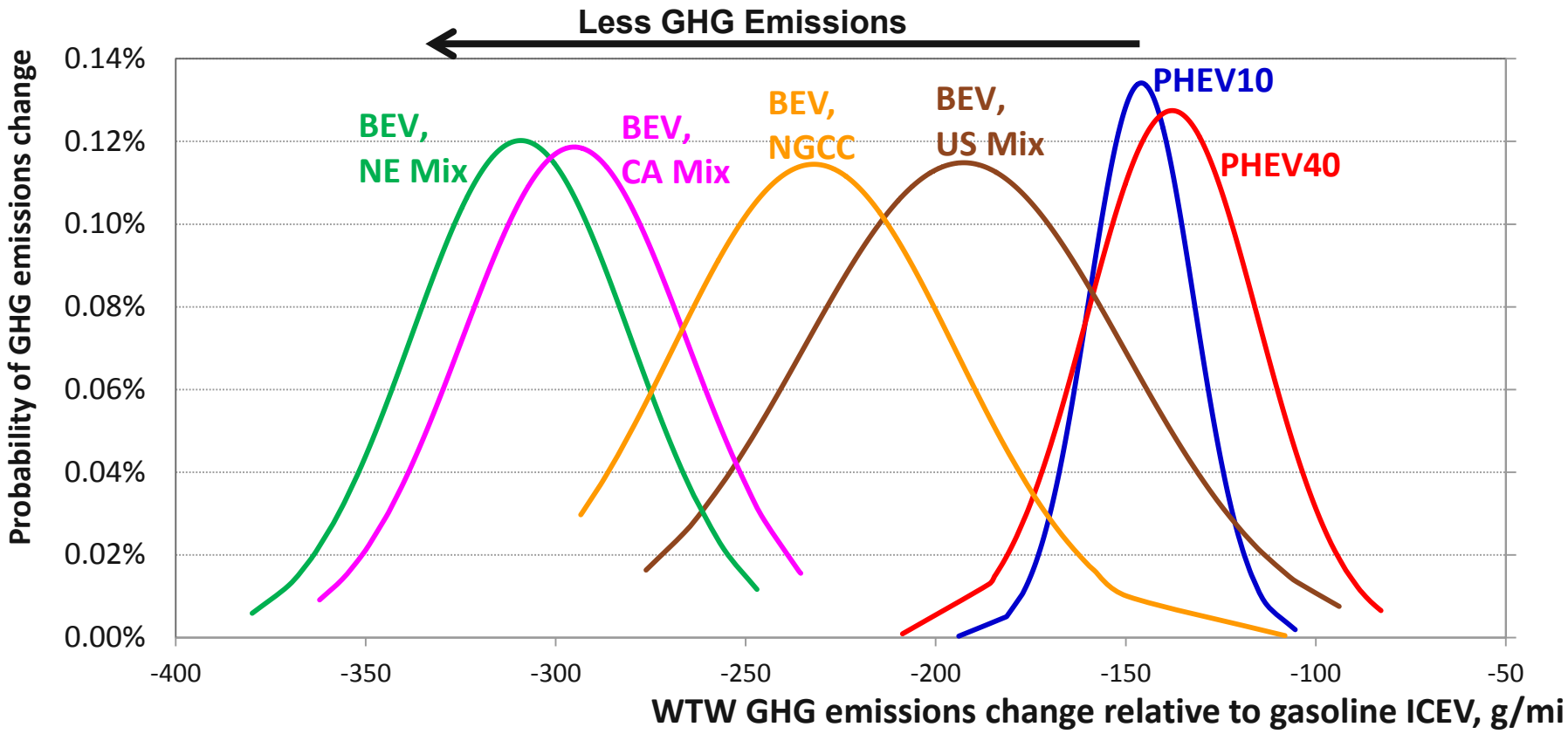
Plug-in Vehicles Provide Varying GHG Emissions Reductions Depending on the Electric Generation Mix for Recharging



	Gasoline Vehicle	Gasoline HEV	PHEV10, US mix	PHEV40, US mix	BEV, US mix	BEV, CA mix	BEV, NE mix	BEV, NGCC
MPGGE:	24.8	34.7	48.3 CD* 36.6 CS	83.4 CD* 27.6 CS	84.4*	84.4*	84.4*	84.4*

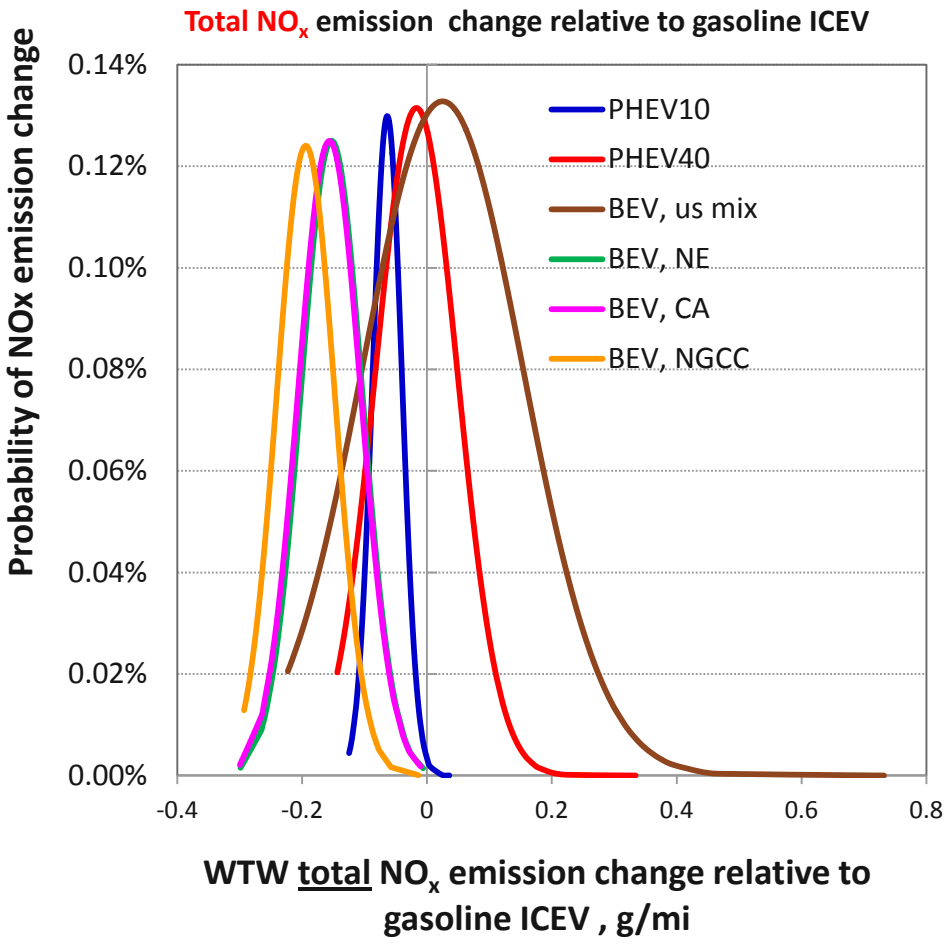
*Including charging losses (assumed 85% charging efficiency)

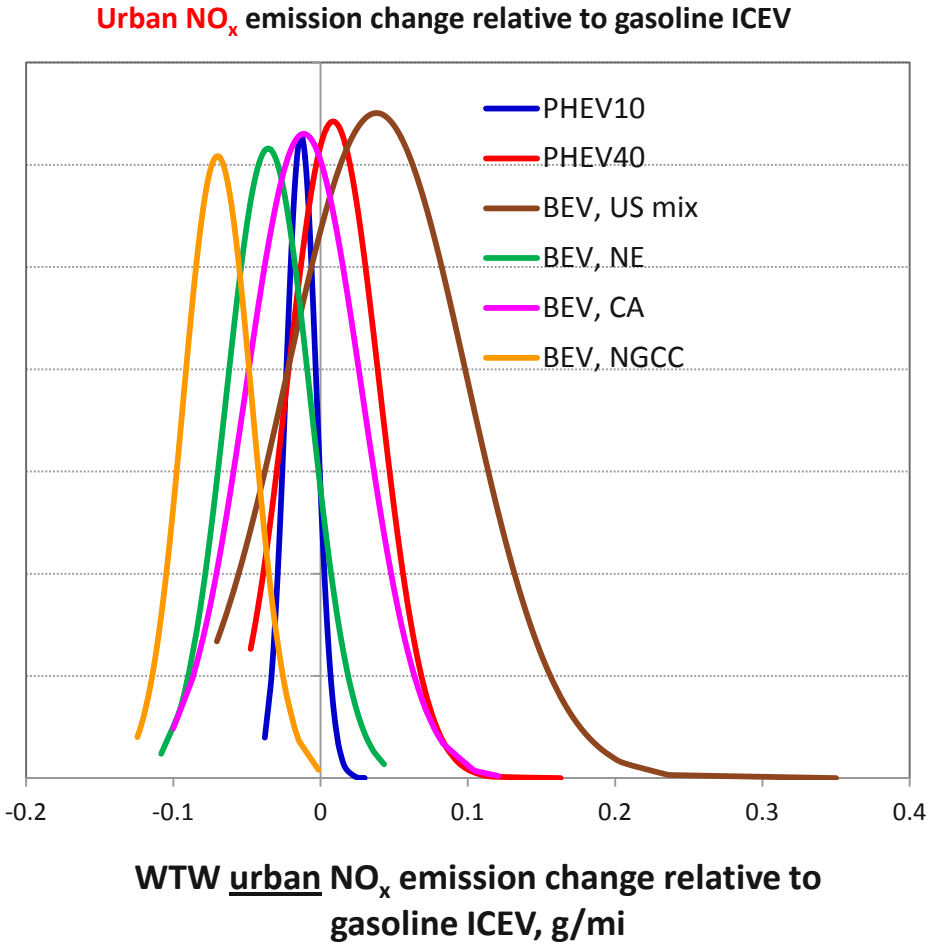
Plug-in Vehicles With Various Configurations Provide Varying GHG Emissions Reduction Potentials



- ✓ Gasoline ICEV has average GHG emissions of 450 g/mi
- ✓ Variation of power plant efficiencies and carbon content of coal are the key technical variables impacting the probability distribution of GHG emissions from various mixes

Plug-in Vehicles With Various Configurations Have Varying Air Emissions





- ✓ Gasoline ICEV has average total and urban NOx emissions of 0.29 and 0.09 g/mi, respectively

Updated Petroleum Refinery Efficiency

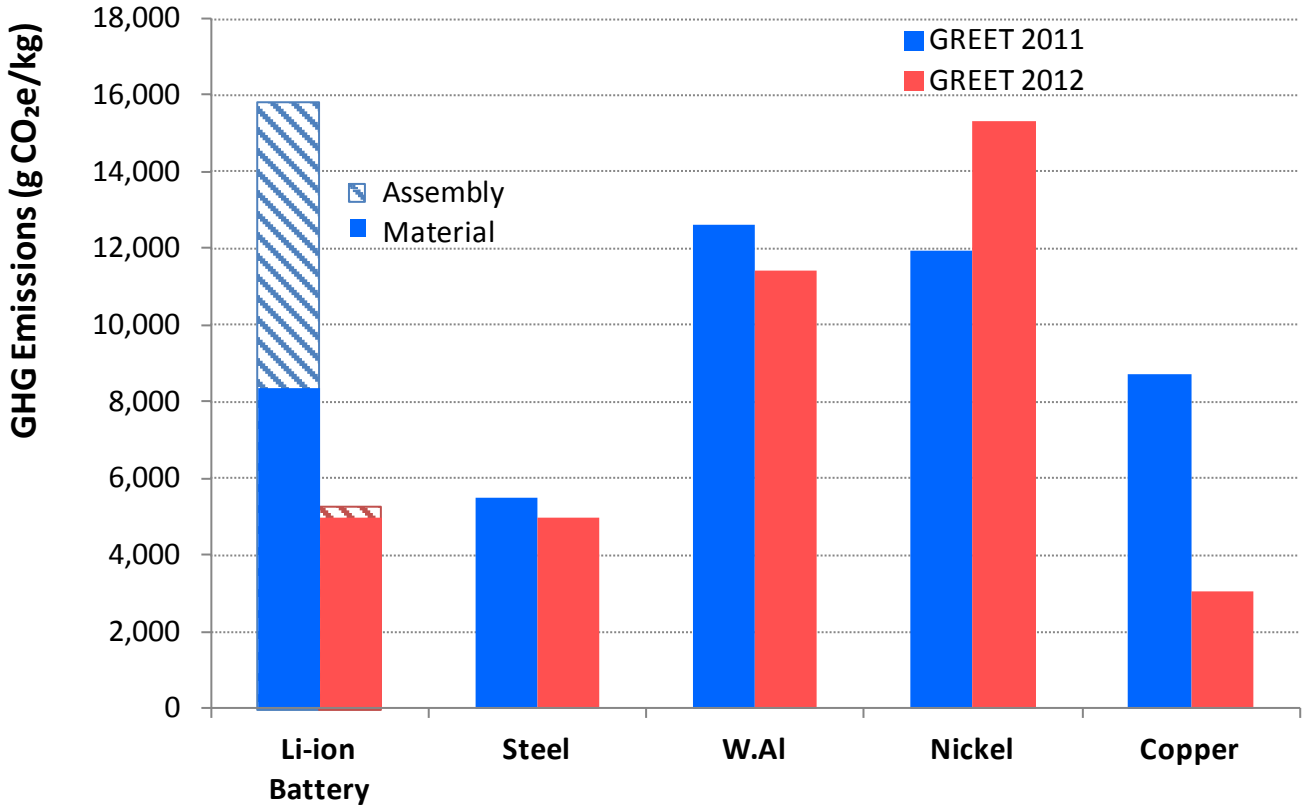
- Petroleum refinery energy efficiencies updated with EIA 2011 survey data on refinery inputs and outputs by PADD:
  - **Inputs**: crude oil, blending components, and process fuel inputs including LPG, DFO, RFO, NG, coal, and purchased electricity and steam
  - **Outputs**: refining products

U.S. Overall Petroleum Refinery Energy Efficiency

	PAD Districts					US
	I	II	III	IV	V	Total
EIA 2011	94.9%	91.2%	90.8%	89.7%	90.8%	91.1%
EIA 2008	94.8%	92.6%	91.9%	90.8%	92.6%	90.6%

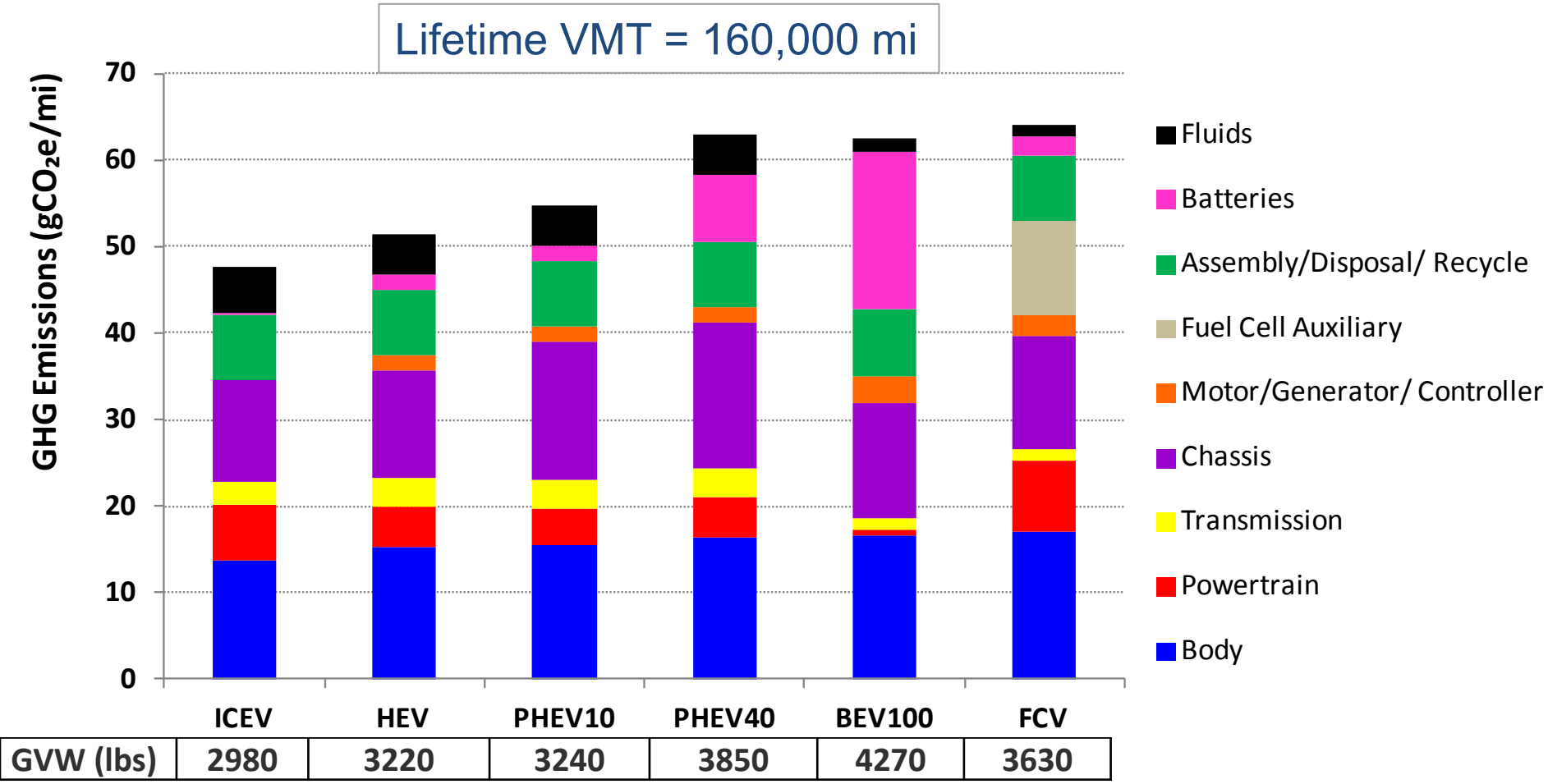
- Argonne is currently conducting in-depth analysis of product-specific refining efficiencies covering gasoline, diesel, jet fuel, LPG, etc.

GHG Emissions Intensities for Key Vehicle Materials/Components Are Updated



- Battery manufacturing contribution to GHG emissions was reduced:
  - ➢ Recent ANL study updated previous battery material assumptions where nickel was used as a surrogate cathode material.
- Copper production in recent studies showed lower energy requirement than previous estimates (for excavation, concentration, and the smelting/refining processes).

Vehicle Cycle GHG Emissions Vary Among Vehicle Propulsion Technologies



GVW (lbs)	2980	3220	3240	3850	4270	3630

Impacts of Significant Steel Use for Petroleum Infrastructure on GHG Emissions Per Mile Are Small

	Steel Use (lb)	Daily Throughput	Lifetime	Steel Use per Unit of Lifetime Throughput	GHG Emissions [g_{CO2e}/mi]
Vehicle	1,895	N/A	160,000 mi	5.4 g/mi	19
Oil Wells (1200 count)	$2.5x10^9$	120,000 BBL/day	30 years	1000 g/BBL*	2.4**, ¥
Refinery	$7x10^7$	120,000 BBL/day	30 years	28 g/BBL*	0.07**, ¥
Keystone Pipeline (2400 mi)	$2.5x10^9$	590,000 BBL/Day	30 years	200 g/BBL*	0.5**, ¥

* Assuming 85% annual capacity factor

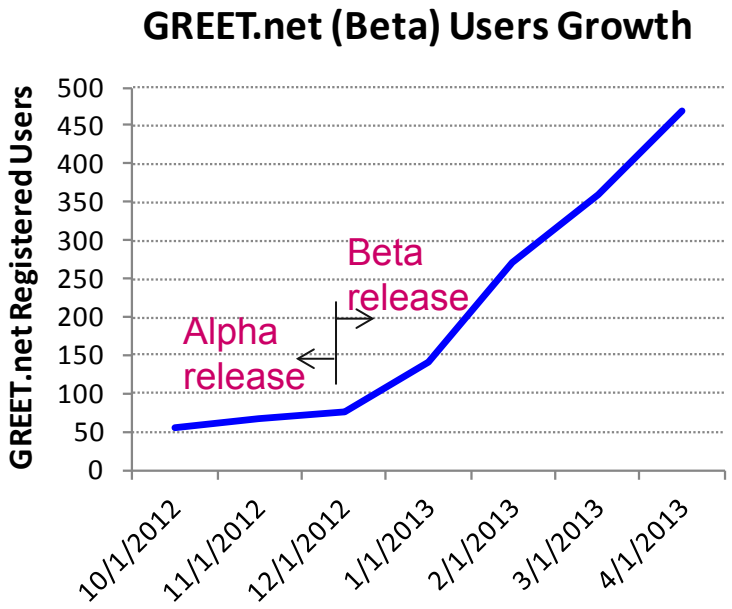
** Assuming 24.8 mpg for baseline gasoline ICEV

¥ Combined steel for infrastructure build up ~only 0.5% of the 450 g_{CO2e}/mi WTW GHG emissions

Implemented a GREET Vision in a New Platform

- To build a common platform for GREET LCA that is
  - ✓ adaptable to a broad range of applications
  - ✓ expandable to include new pathways and expanded boundaries
  - ✓ transparent to enhance usability and build credibility

- New version of GREET.net was released
  - ✓ Alpha release to limited users (Oct. 2012)
  - ✓ Beta release to all users (Dec. 2012)
  - ✓ > 450 registered users in 4 months
  - ✓ Positive feedback and strong interest from users



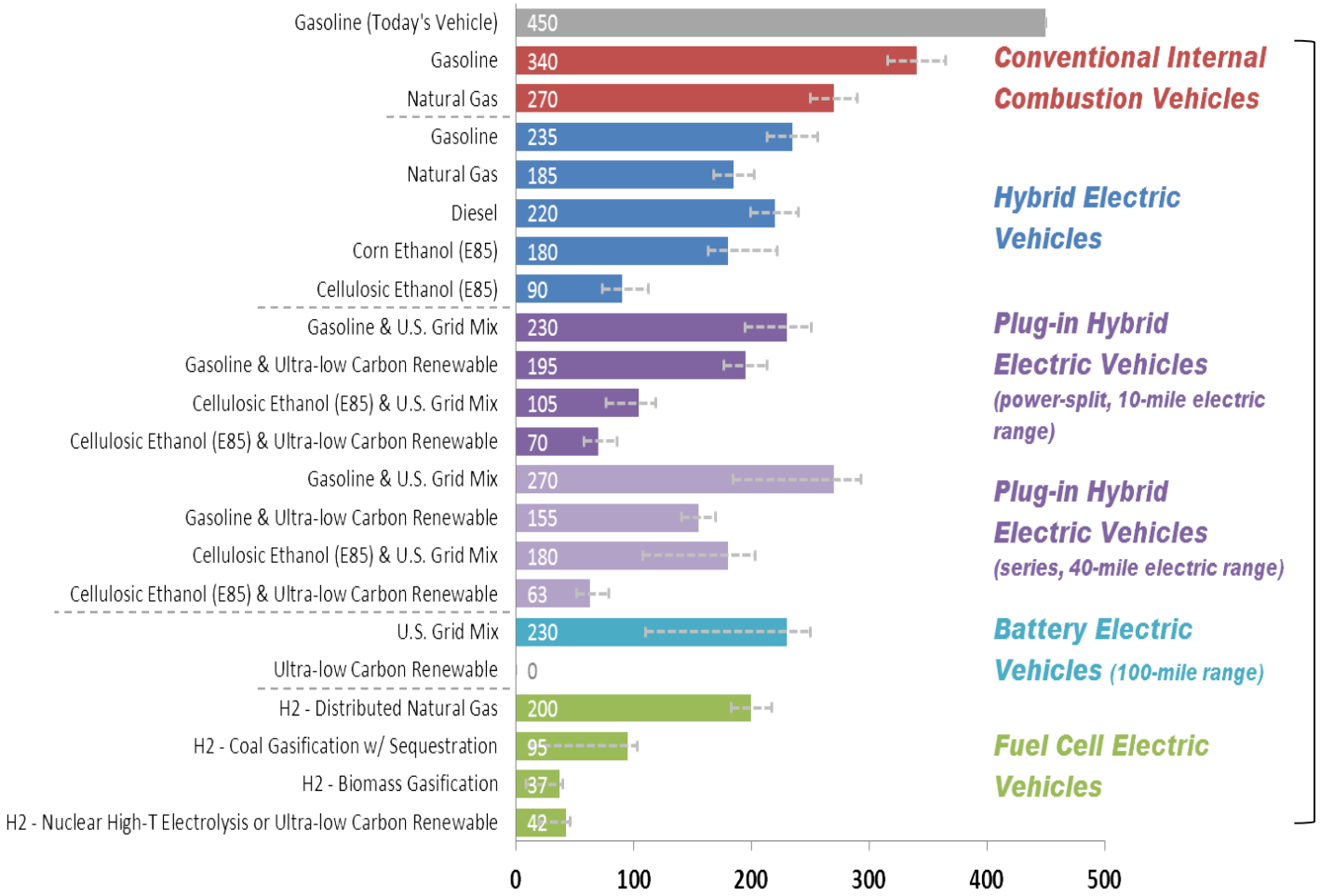
ARGONNE'S GREET.net beta

TAKING LIFE CYCLE ANALYSIS TO THE NEXT LEVEL

http://greet.es.anl.gov/greet/

- **Build complex pathways within minutes**
  Drag and drop predefined processes to assemble a pathway
- **Add your own data**
  Create new resources, processes, technologies using simple graphical editors
- **Navigate through the model**
  Use the well to pump explorer to reveal the details of each pathway
- **Analyze results**
  Examine detailled results at different levels within the pathway
- **Share your project**
  Save all your data into an easy to share data file
- **Adaptable unit system**
  Enables users to change the representation of any result or data using their prefered units
- **Free and maintained**
  Tools and data are provided at no charge and can be updated automatically

GREET Application: WTW GHG Results of a Mid-Size Car (g/mile)



For projected state of technologies in 2035

Low/high band: sensitivity to uncertainties associated with projection of fuel economy and fuel pathways (DOE EERE 2010, Record 10001)

- A new EERE WTW Record is under development with GREET_2012
- A GREET WTW results file with most recent GREET version is available at GREET website (http://greet.es.anl.gov/results)

Summary

- Electricity sector in GREET has been expanded and updated
- GHG emissions of plug-in electric vehicles with various configurations have been updated
- GHG emissions intensities for key vehicle materials/components have been updated
- Vehicle cycle GHG emissions have been updated for advanced vehicle technologies
- GHG emissions of infrastructure build up for petroleum and natural gas production/distribution have been evaluated
- GREET in a new platform has been developed and (beta) released
- Argonne will continue to update and upgrade GREET to serve DOE and the community

Future Work

- Update petroleum refinery efficiencies by crude type, refinery complexity and product slate
- Investigate materials for vehicle lightweighting to meet future CAFE standards
- Investigate LCA of water consumption for petroleum fuels and electric vehicles and add water consumption into GREET
- Incorporate short-lived GHGs such as black carbon into GREET

Acronyms

- AEO: Annual Energy Outlook
- ANL: Argonne National Laboratory
- BEV: Battery Electric Vehicle
- BBL: Barrels
- CA: California
- CAFE: Corporate Average Fuel Economy
- CD: Charge Depletion operation
- CS: Charge Sustaining operation
- DFO: Distillate Fuel Oil
- DOE: Department of Energy
- EERE: Energy Efficiency and Renewable Energy
- eGRID: Emissions & Generation Resource Integrated Database
- EIA: Energy Information Administration
- EPA: Environmental Protection Agency
- FCV: Fuel Cell Vehicle
- GHG: Greenhouse Gases
- GREET: Greenhouse gases, Emissions, and Energy use in Transportation
- HEV: Hybrid Electric Vehicle
- ICEV: Internal Combustion Engine Vehicle
- LCA: Life Cycle Analysis
- LPG: Liquefied Petroleum Gas
- Mi: Mile
- MPGGE: Miles Per Gallon of Gasoline Equivalent
- NE: North Eastern United State
- NERC: North American Electric Reliability Corporation
- NG: Natural Gas
- NGCC: Natural Gas Combined Cycle
- NOx: Nitrogen Oxides
- PADD: Petroleum Administration for Defense Districts
- PHEV10: Plug-in Hybrid Electric Vehicle with 10 miles range on urban driving cycle
- PTW: Pump-To-Wheels
- RFO: Residual Fuel Oil
- VTP: Vehicle Technologies Program
- W. Al: Wrought Aluminum
- WTP: Well-To-Pump
- WTW: Well-To-Wheels