Life Cycle Analysis (LCA) of BEV and H_2 FCEV with the GREET® Model

Amgad Elgowainy, Jarod Kelly, Qiang Dai, Pingping Sun and Xinyu Liu

Systems Assessment Center
Energy Systems Division
Argonne National Laboratory

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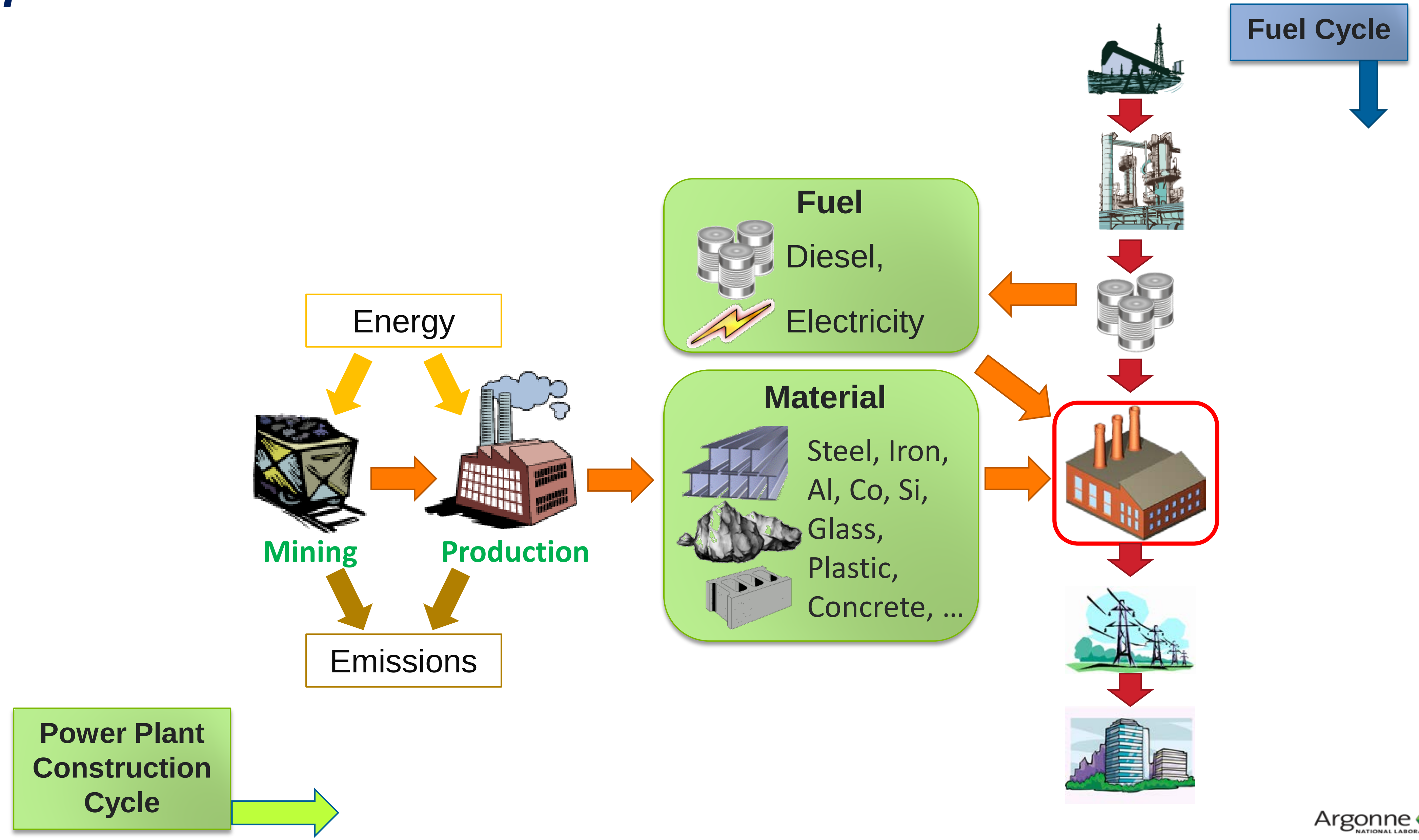
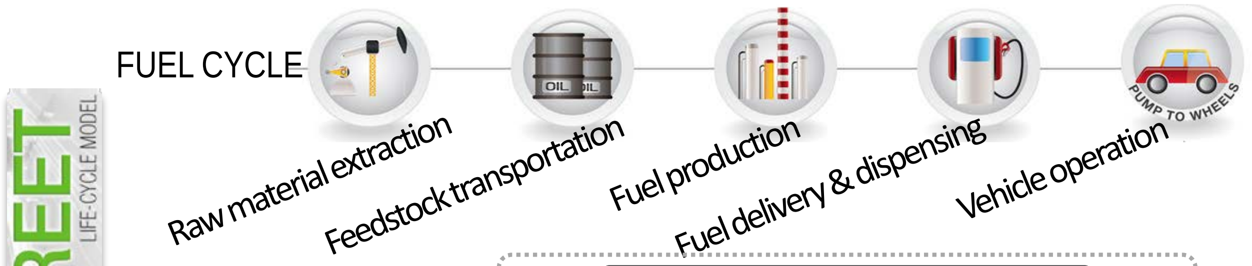
GREET LCA of power sector covers fuel cycle and construction of power plants



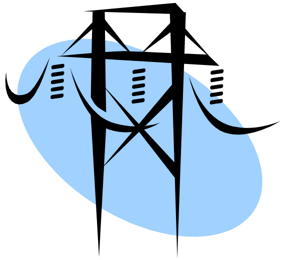
Evaluating PEVs on a WTW basis

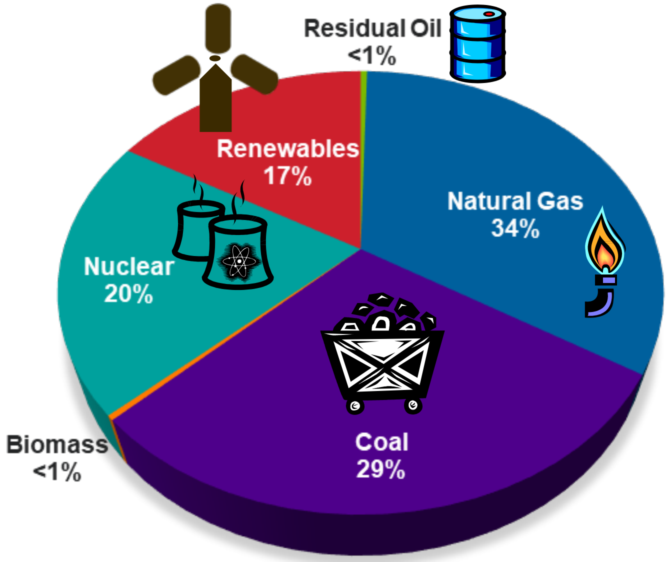


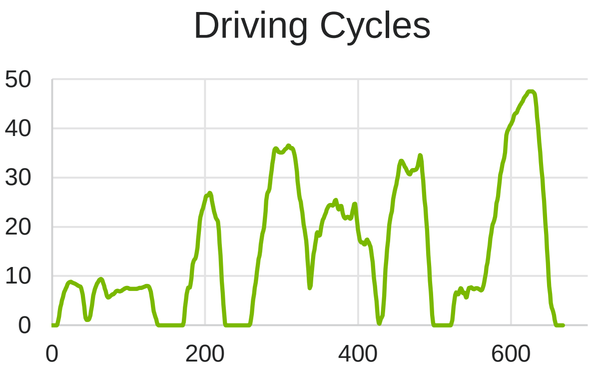
LDV and MHDVs

Fuel economy	Air emissions
o Autonomie	o EPA MOVES

Well-to-Wheels (WTW) Analysis







AUTONOMIE

Provide FE for various driving cycles

Fleet DNA

Idle for MHDVs

Composite FE for ICEV, BEV

BEV/ICEV FE ratio

GREET LIFE-CYCLE MODEL

MOVES Motor Vehicle Emission Simulator

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Electricity generation pathways in GREET

1. Coal: Steam Boiler and IGCC
Coal mining & cleaning
Coal transportation
Power generation

2. Natural Gas: Steam Boiler, Gas Turbine, and NGCC
NG recovery & processing
NG transportation
Power generation

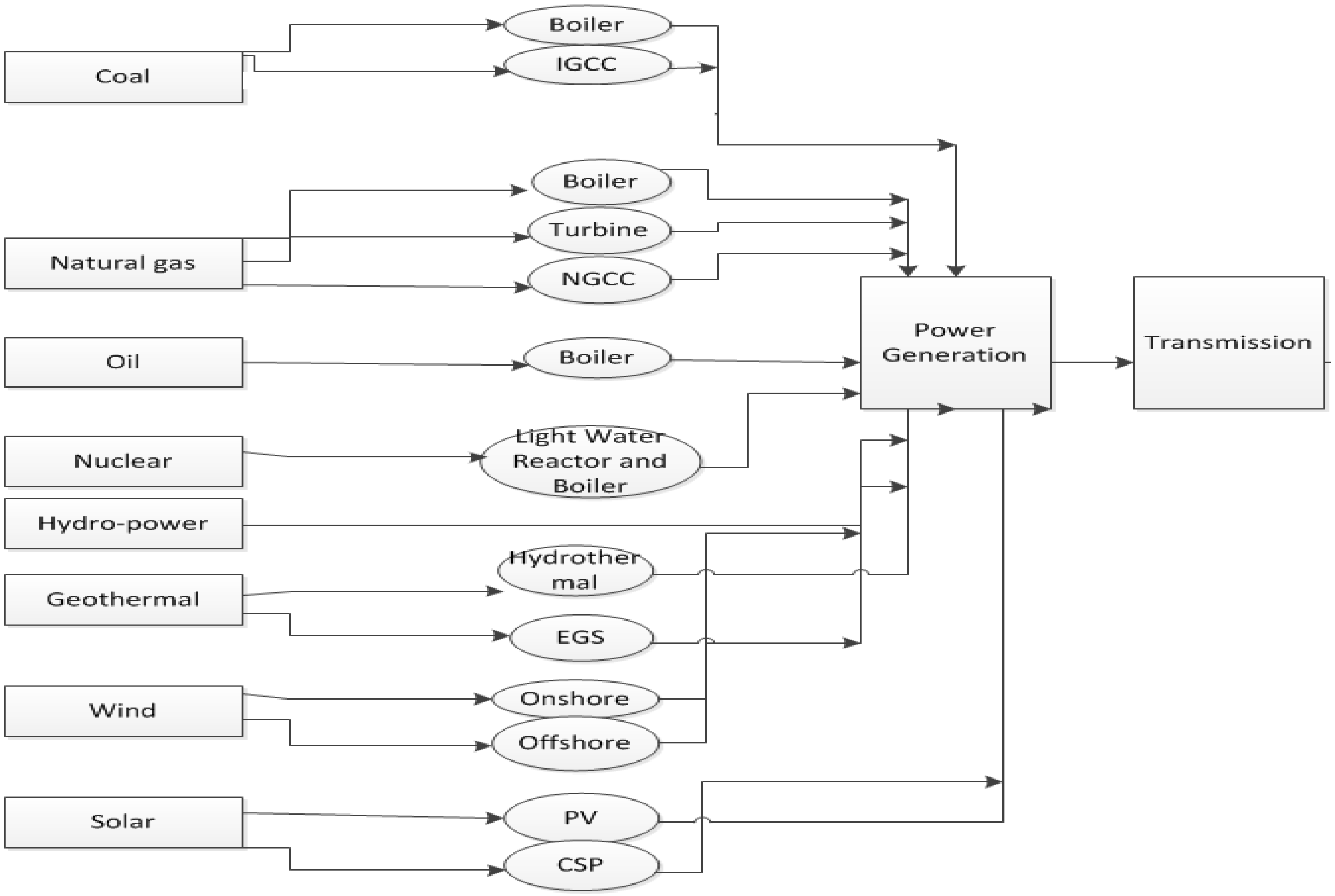
3. Nuclear: light water reactor
Uranium mining
Yellowcake conversion
Enrichment
Fuel rod fabrication
Power generation

5. Biomass: Steam Boiler
Biomass farming & harvesting
Biomass transportation
Power generation

4. Oil: Steam Boiler
Oil recovery & transportation
Refining
Residual fuel oil transportation
Power generation

Renewables
- **6. Hydro-Power**
- **7. Wind Turbine**
- **8. Solar PV and CSP**
- **9. Geothermal**

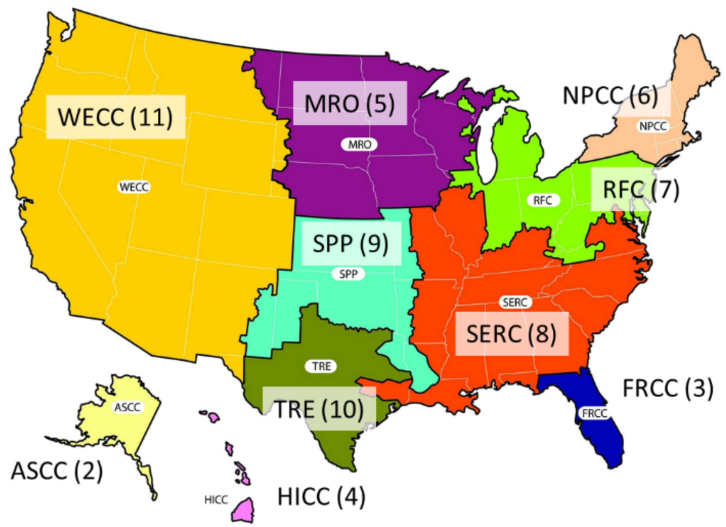
GREET models electricity generation mix at national, state and utility region levels



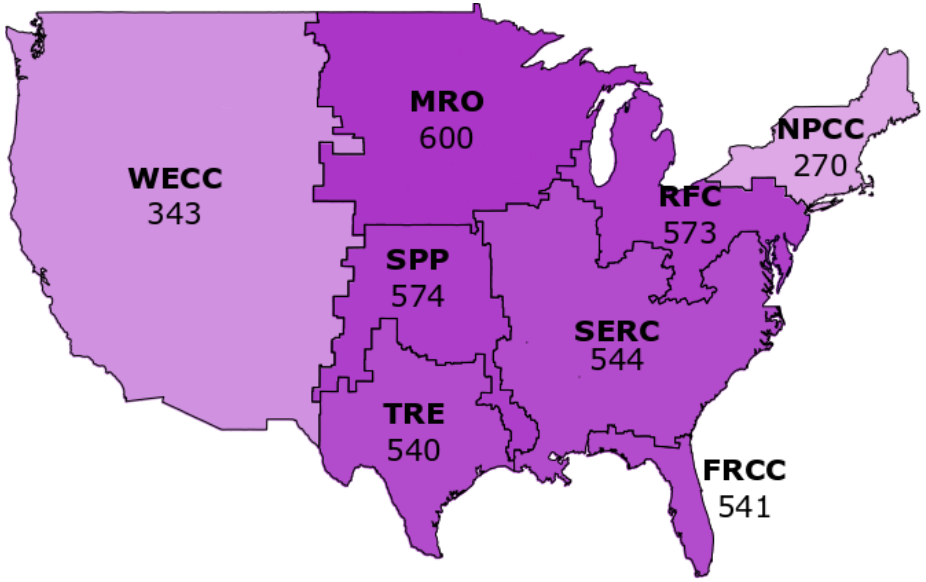
[Recently added]():
- CCS
- CHP

Data and methods

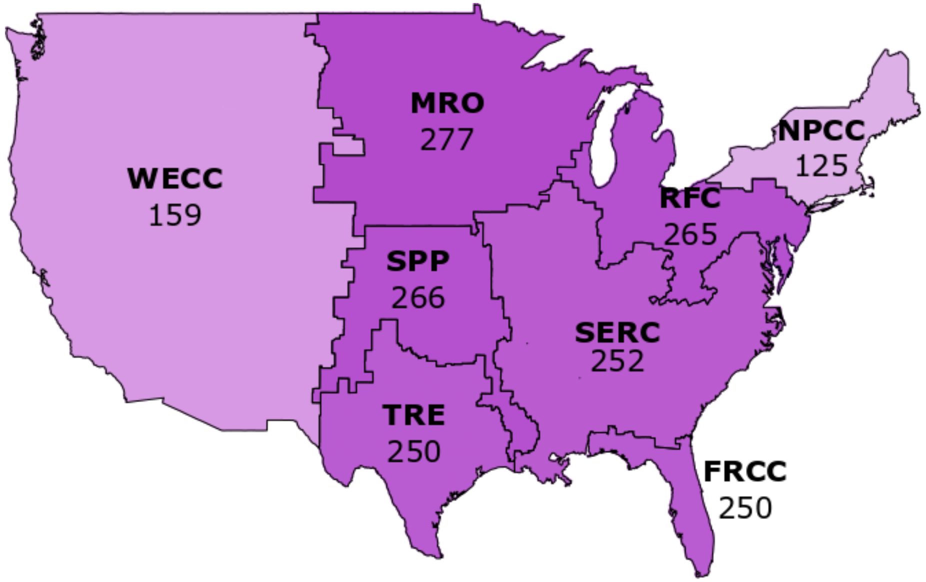
- **Thermal efficiencies**
  - EIA's electric generating unit-level performance data (EIA Form 923 and 860 data)
- **GHG emission factors**
  - CH_4 and N_2O emissions are estimated by multiplying the fuel specific heat input in mmBtu by appropriate EFs from Table C-2 of EPA's Final Mandatory Reporting of Greenhouse Gases Rule (EPA, 2009)
  - CO_2 emissions calculated from fuel carbon intensity and fuel consumption
  - e-grid and EPA models for criteria air pollutants
  - EIA and USGS for water consumption
- **Electricity generation mixes**
  - Regional and national
  - EIA's Annual Energy Outlook



Impact of electricity mix (2019): WTW GHG emissions of light-duty BEVs



Unit: grams g_CO_{2e}/kWh



Unit: g_CO_{2e}/mile

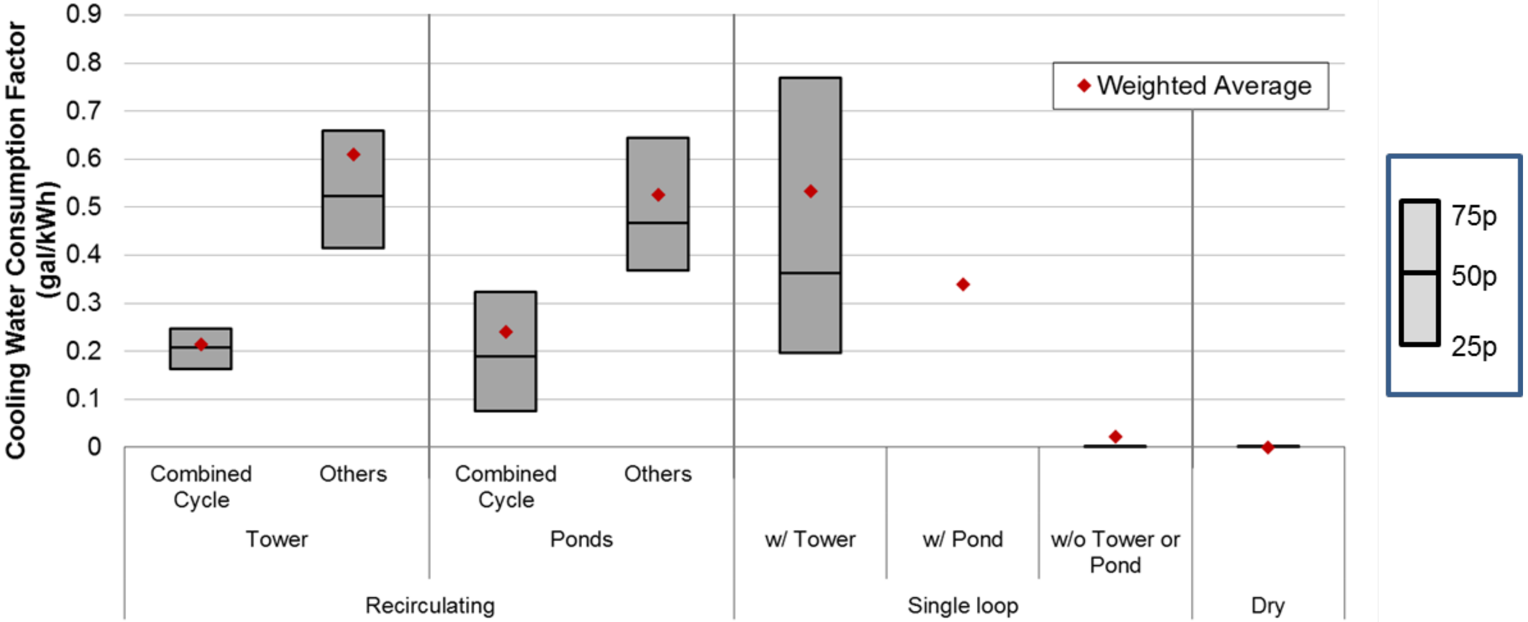
2019 U.S. electricity generation mix

483 g_CO_{2e}/kWhe at the plug

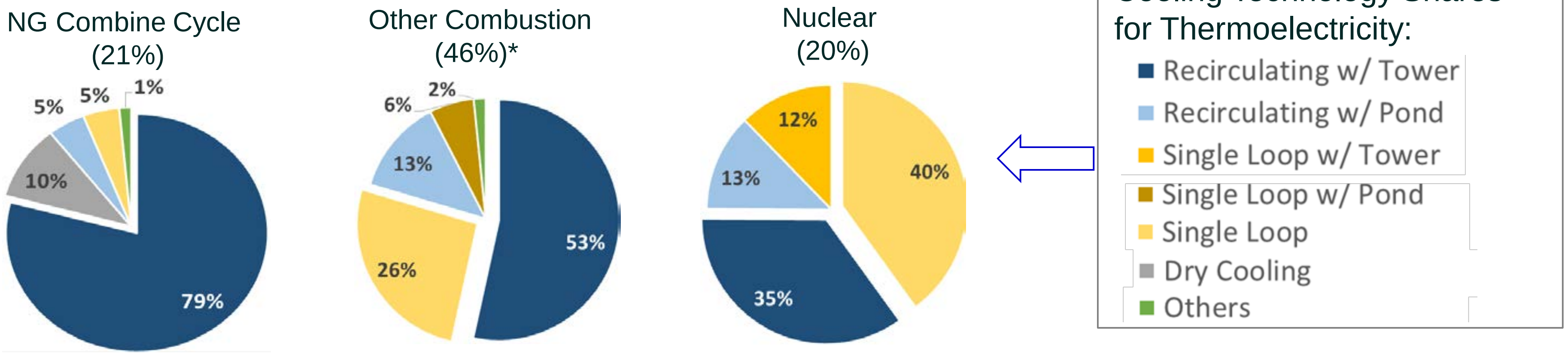
2019 electricity generation mix:

	MRO Mix	NPCC Mix	U.S. Mix
Natural gas	10.3%	42.0%	33.5%
Coal	47.7%	2.7%	29.0%
Nuclear power	10.6%	32.6%	20.3%

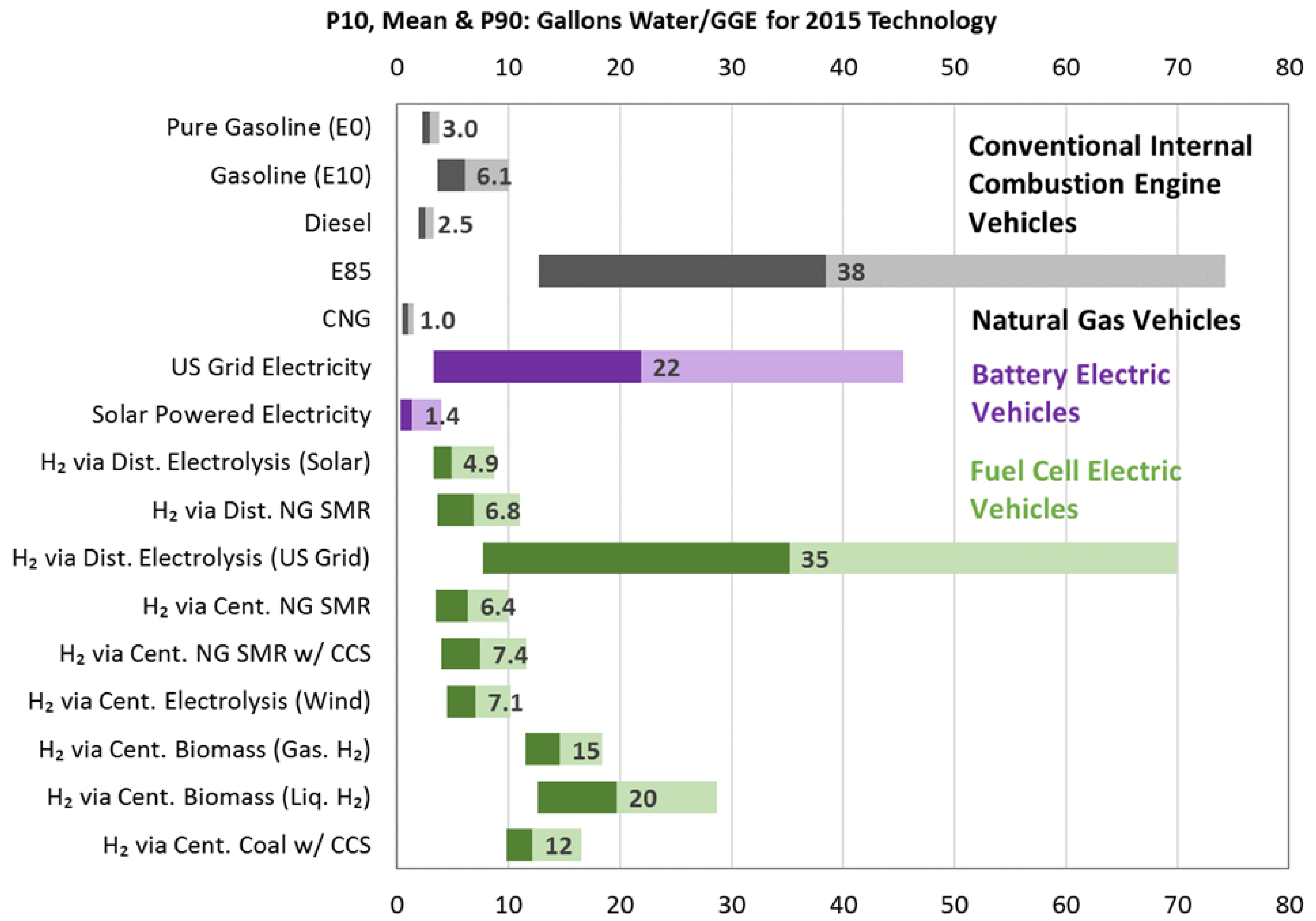
Water consumption by electricity generation and cooling technologies



Thermoelectricity makes up 87% of U.S. total power generation (for 2015)



WTW water consumption for various fuels, including electricity for BEVs



Low/high band: sensitivity to uncertainties associated with fuel pathway parameters

https://www.hydrogen.energy.gov/pdfs/17005_water_consumption_ldv_fuels.pdf

(DOE EERE June 23 2017, Record 17005)

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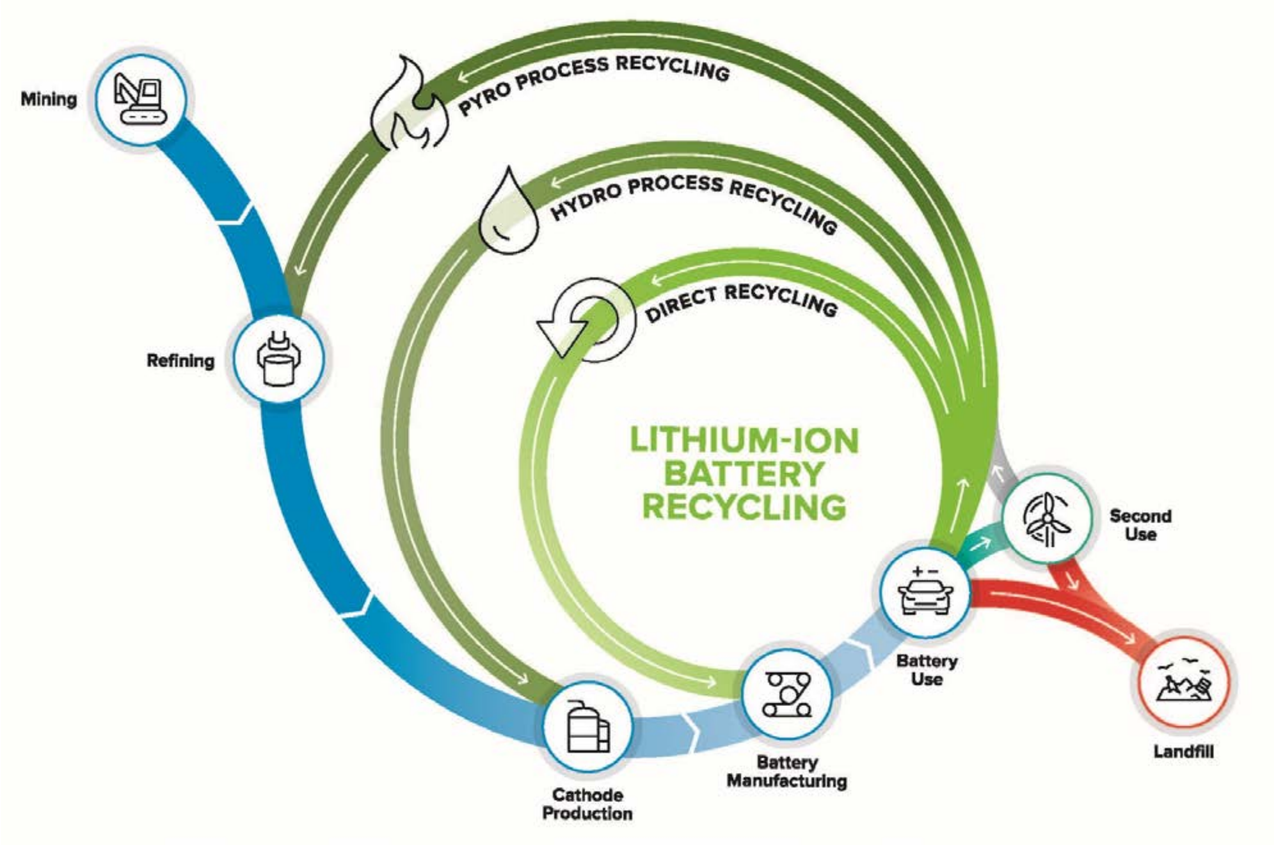
Battery recycling: closed-loop model is needed

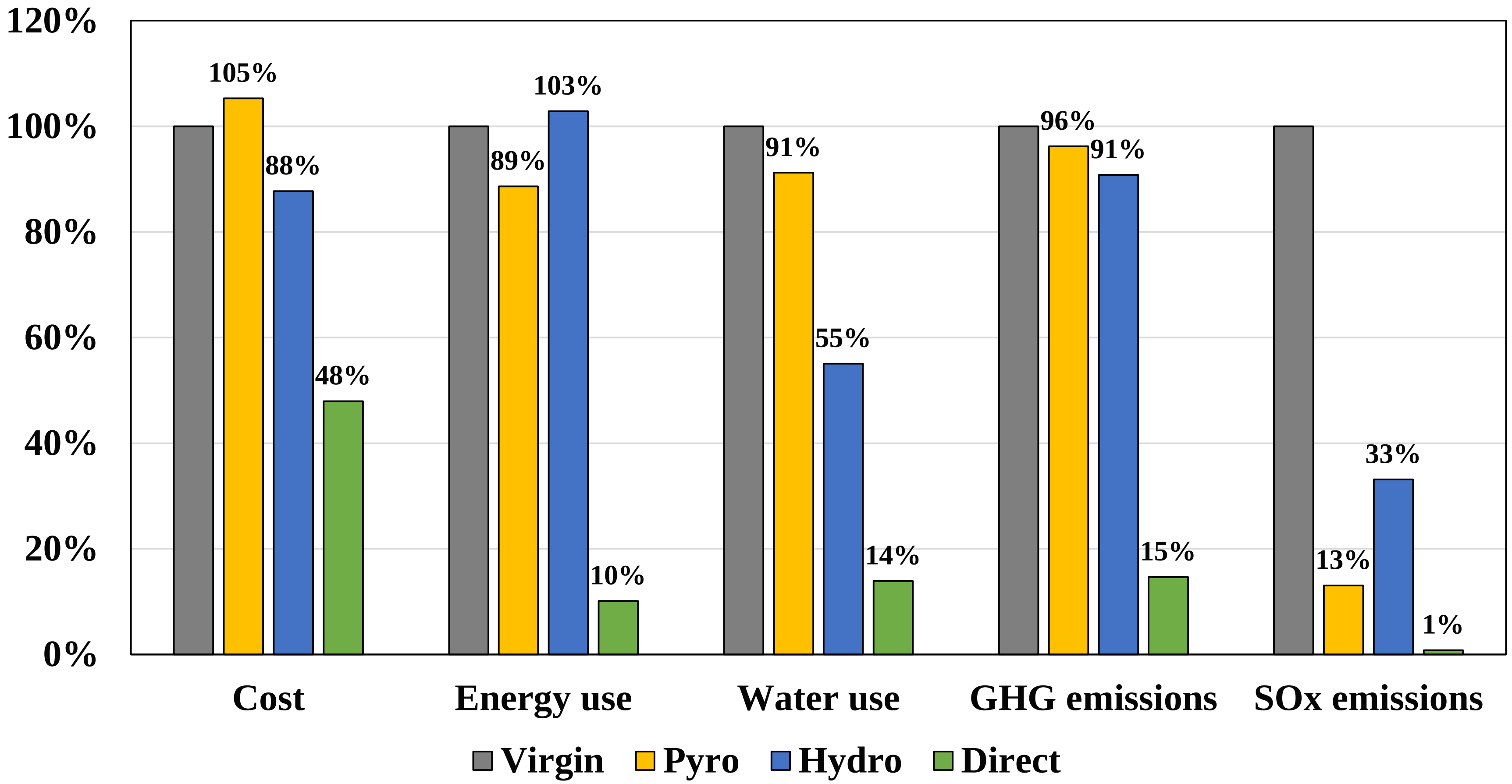
Modeling Framework of Argonne's EverBatt Battery Recycling Model



- Benchmark recycling against virgin production to provide a holistic picture of the benefits and trade-offs of battery recycling.
- EverBatt produces results for energy, emissions, water, and costs of battery recycling and remanufacturing
- EverBatt relies on GREET for energy and environmental modeling and BatPac for cost modeling

Comparison of 1kg virgin NMC111 powder against that from recycled materials

EverBatt quantifies cost and energy/environmental impacts of battery recycling

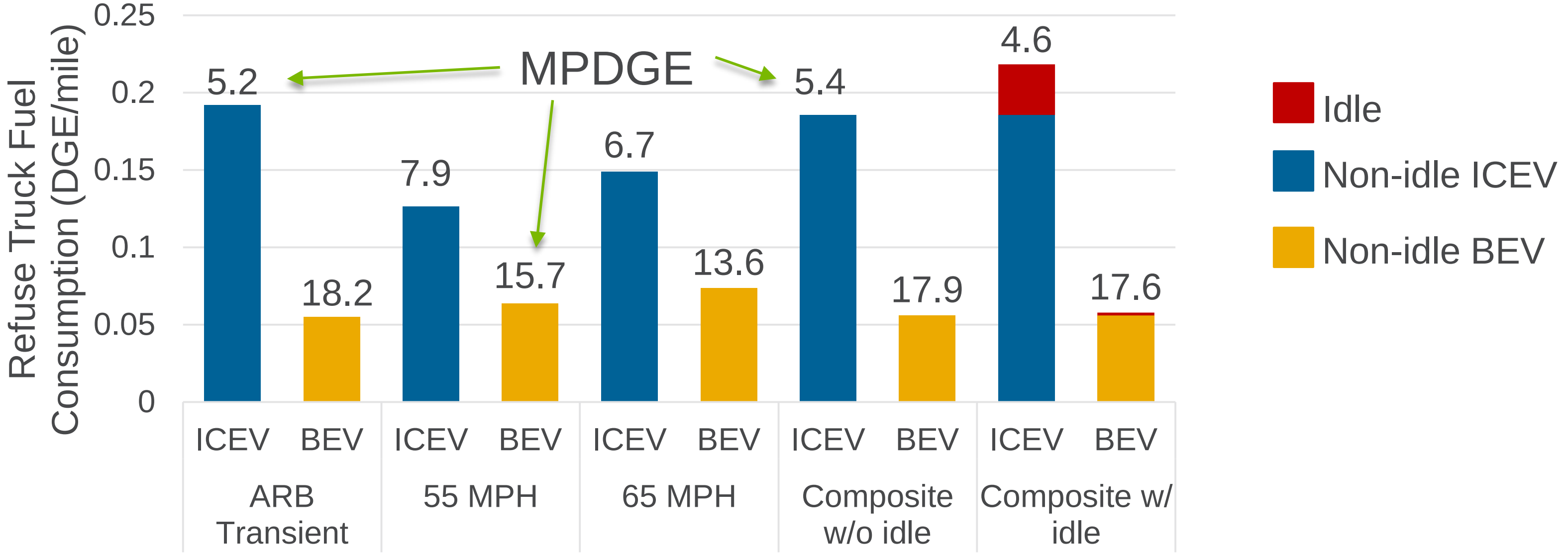


EverBatt results assuming 10,000 t/yr recycling plant in the U.S. Recycling processes are generic in nature and do not reflect specific companies.

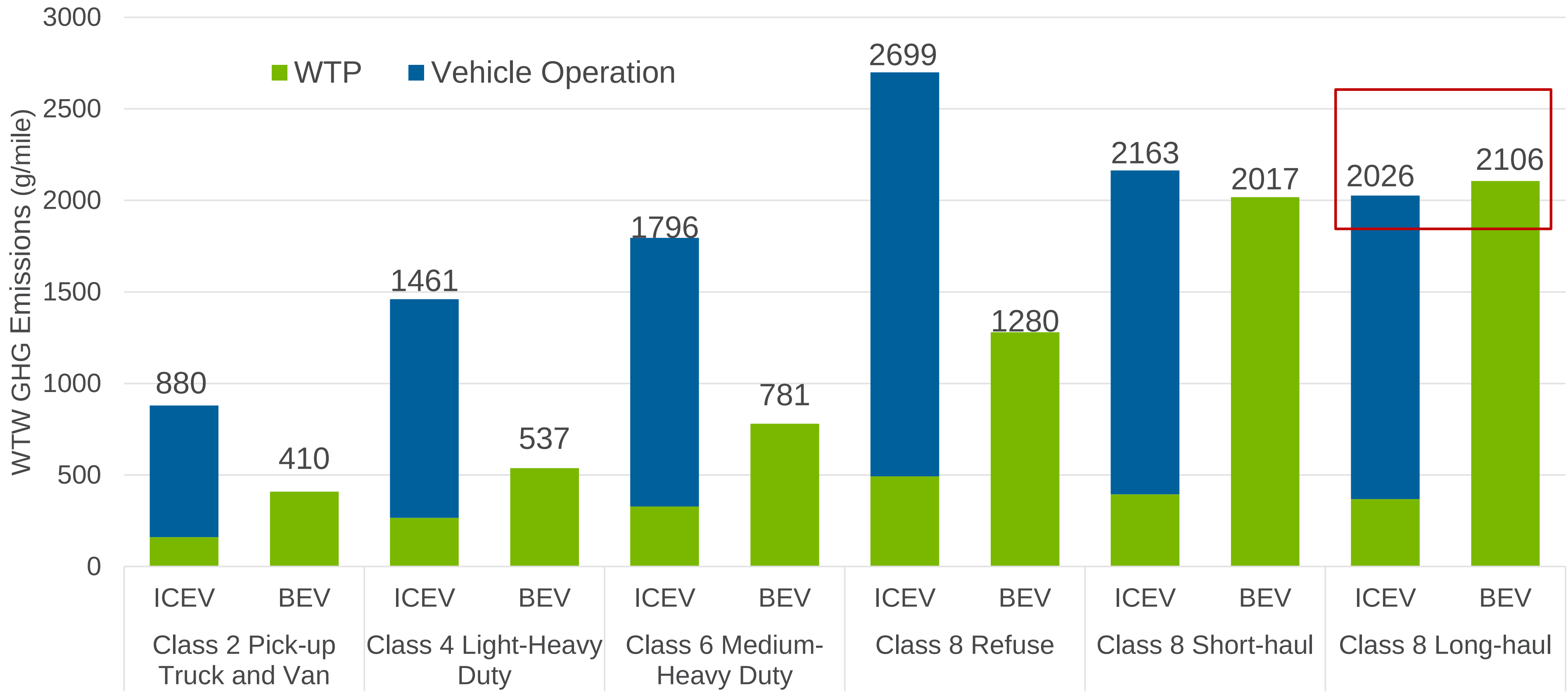
GREET 2019 was expanded with plug-in battery electric MHDVs

- fuel economy on various duty cycles is key for WTW analysis

Class	Type	Weighting Factors (%)			BEV FE (MPDGE)	FE Ratio
		ARB Cycle	55 MPH Cycle	65 MPH Cycle	Composite	BEV/ICEV
8	Long-haul combination	5	9	86	10.7	172%
	Short-haul combination	19	17	64	11.2	193%
	Refuse	90	10	0	17.6	379%
6	Medium heavy-duty vocational	92	8	0	28.9	413%
4	Light heavy-duty vocational	92	8	0	42.0	488%
2	Pick-up Trucks and Vans	54	29	17	55.1	385%

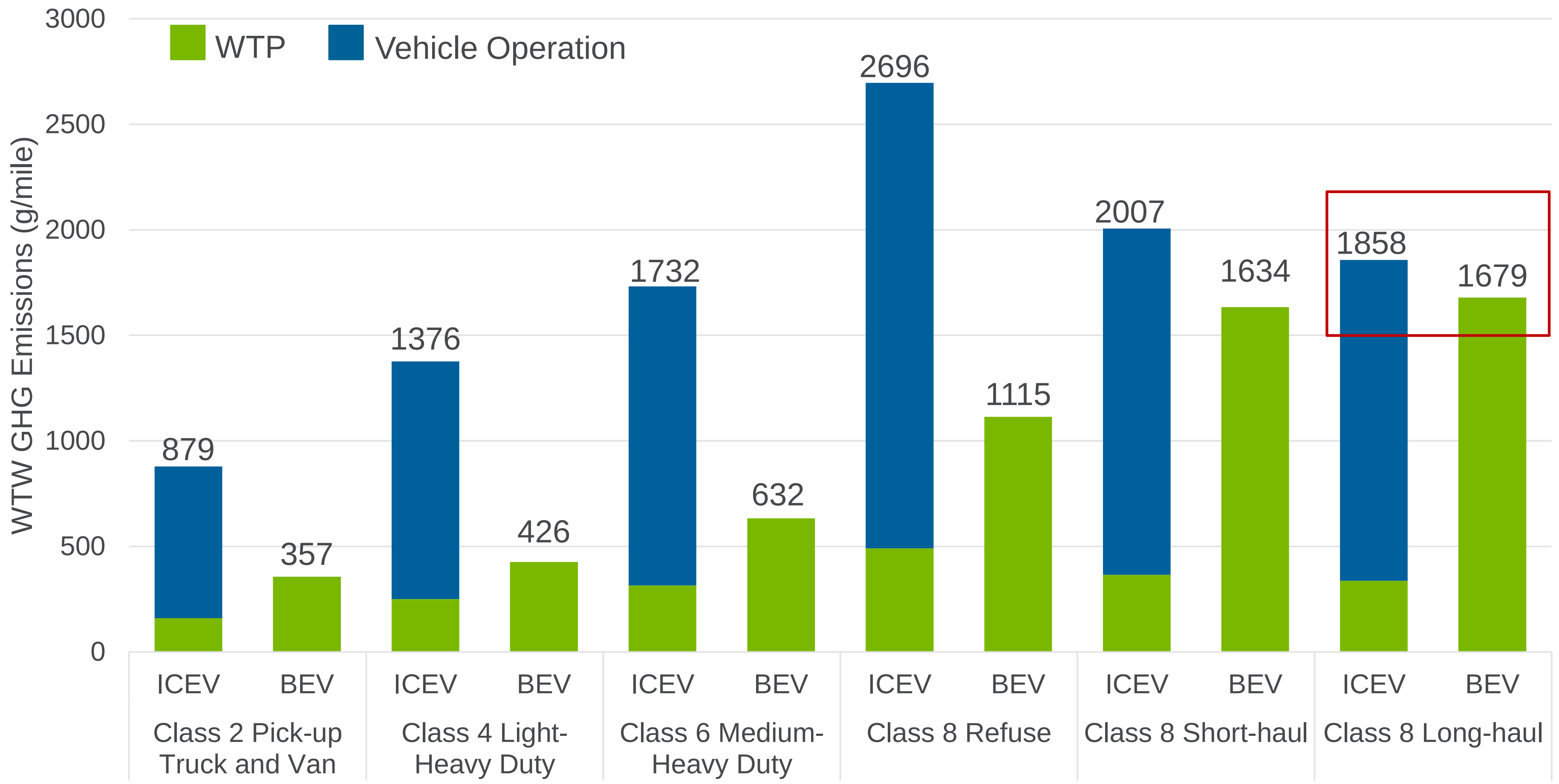


WTW GHG emissions of battery electric MHDVs (2019 U.S. Mix)



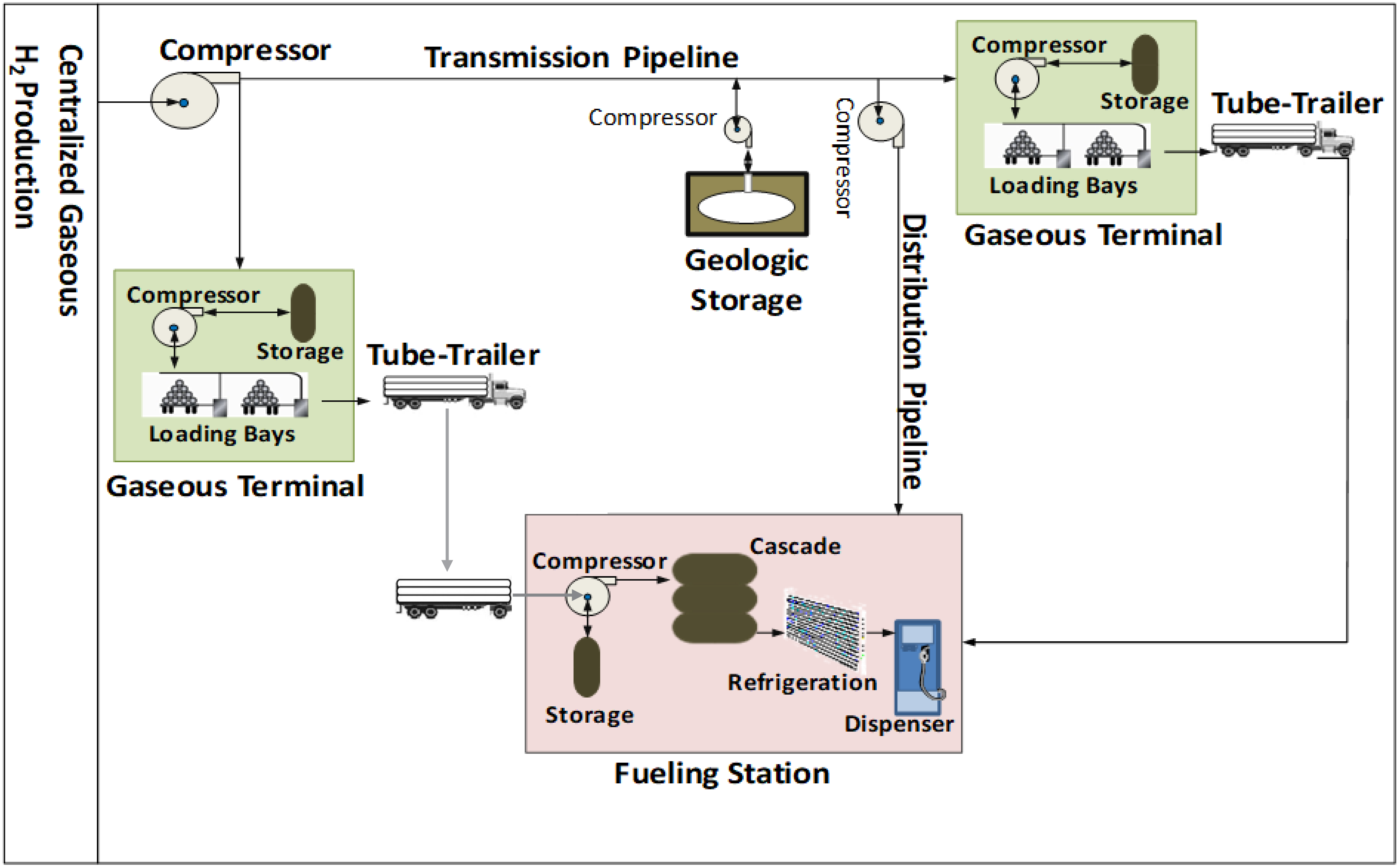
- For BEVs, the fuel consumption, and thus GHG emissions, increase with increasing weight class
- For vocational vehicles, shifting to BEV from ICEV can reduce WTW GHG emissions by 49-63%

WTW GHG emissions of battery electric MHDVs (2030 U.S. Mix)

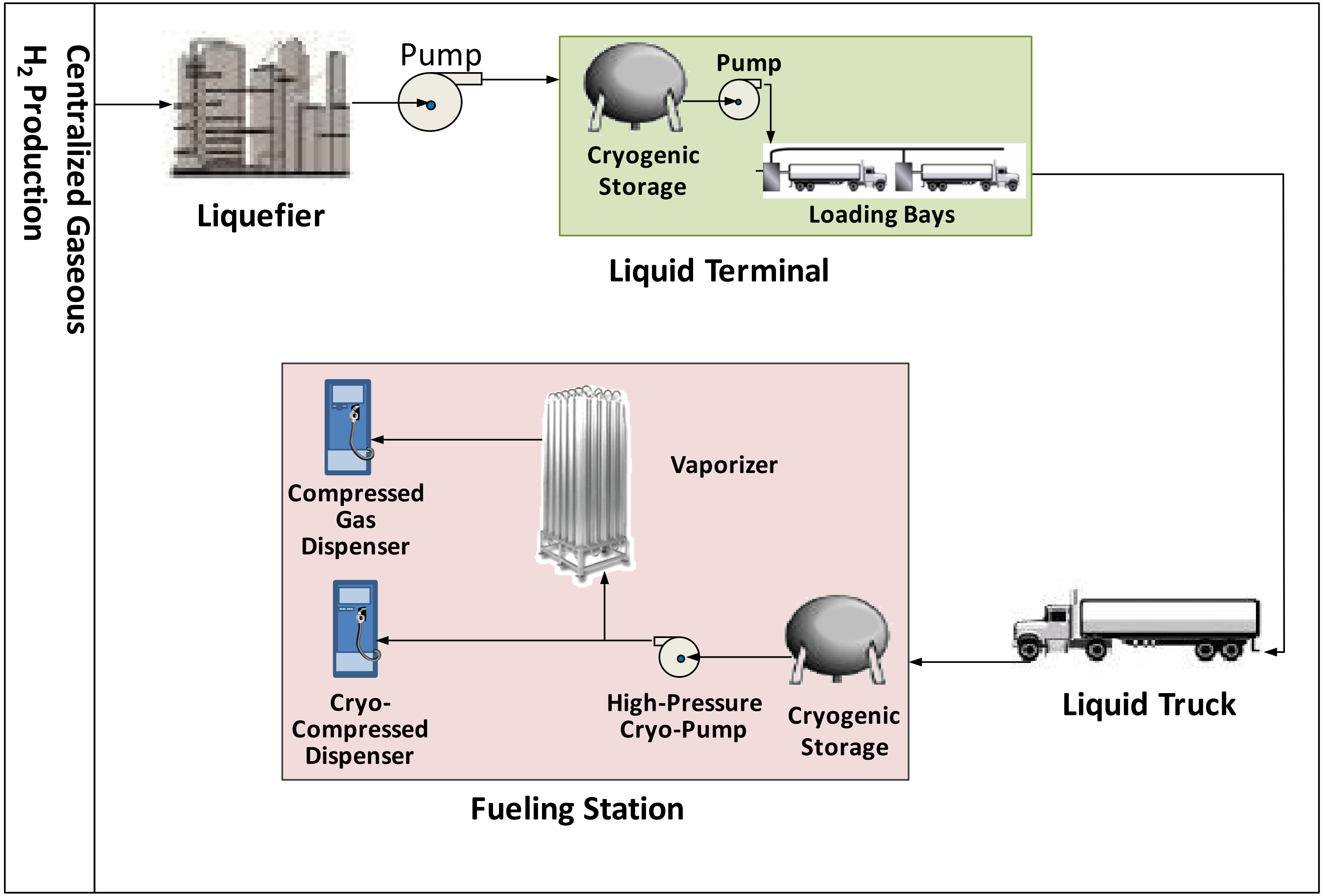


- For Class 8 long-haul, the WTW GHG emissions for BEV are estimated to be less compared to diesel ICEV in 2030

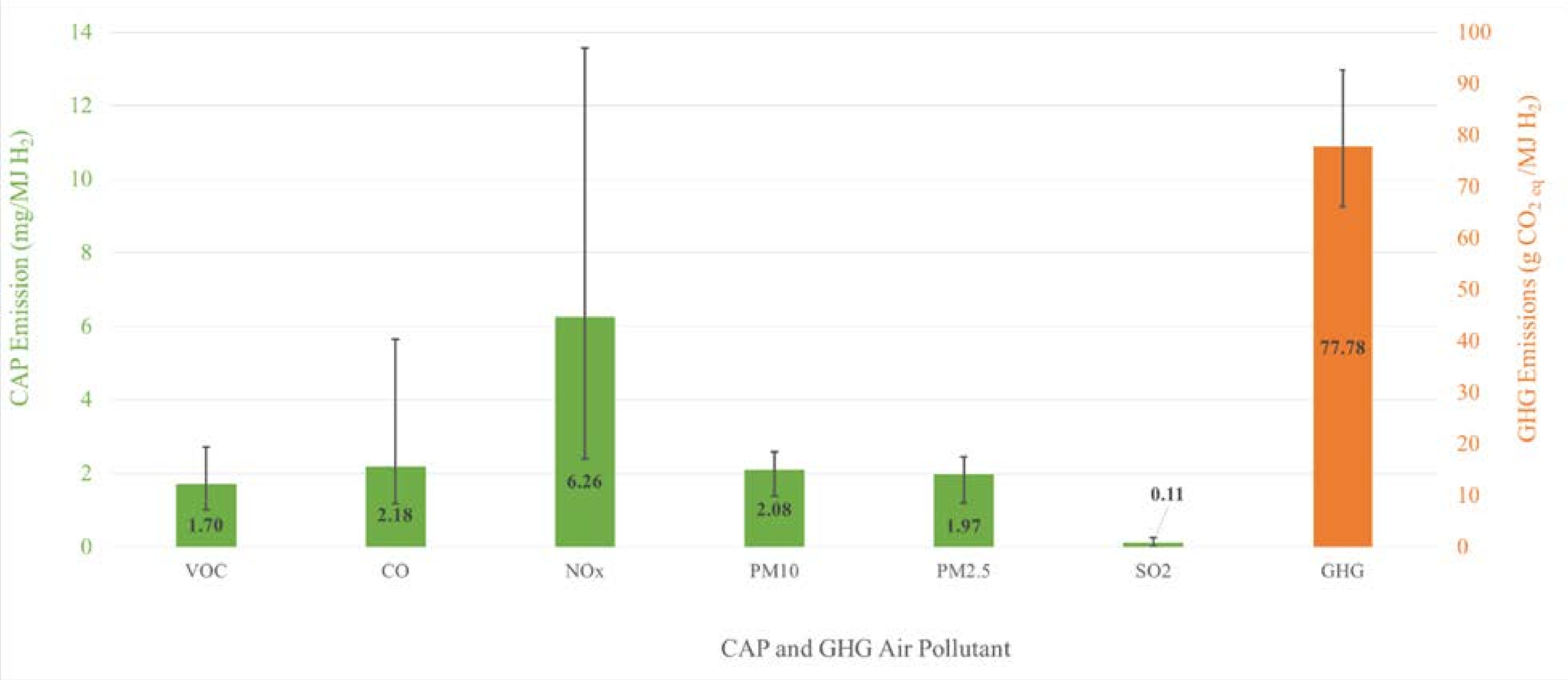
Gaseous hydrogen pathways



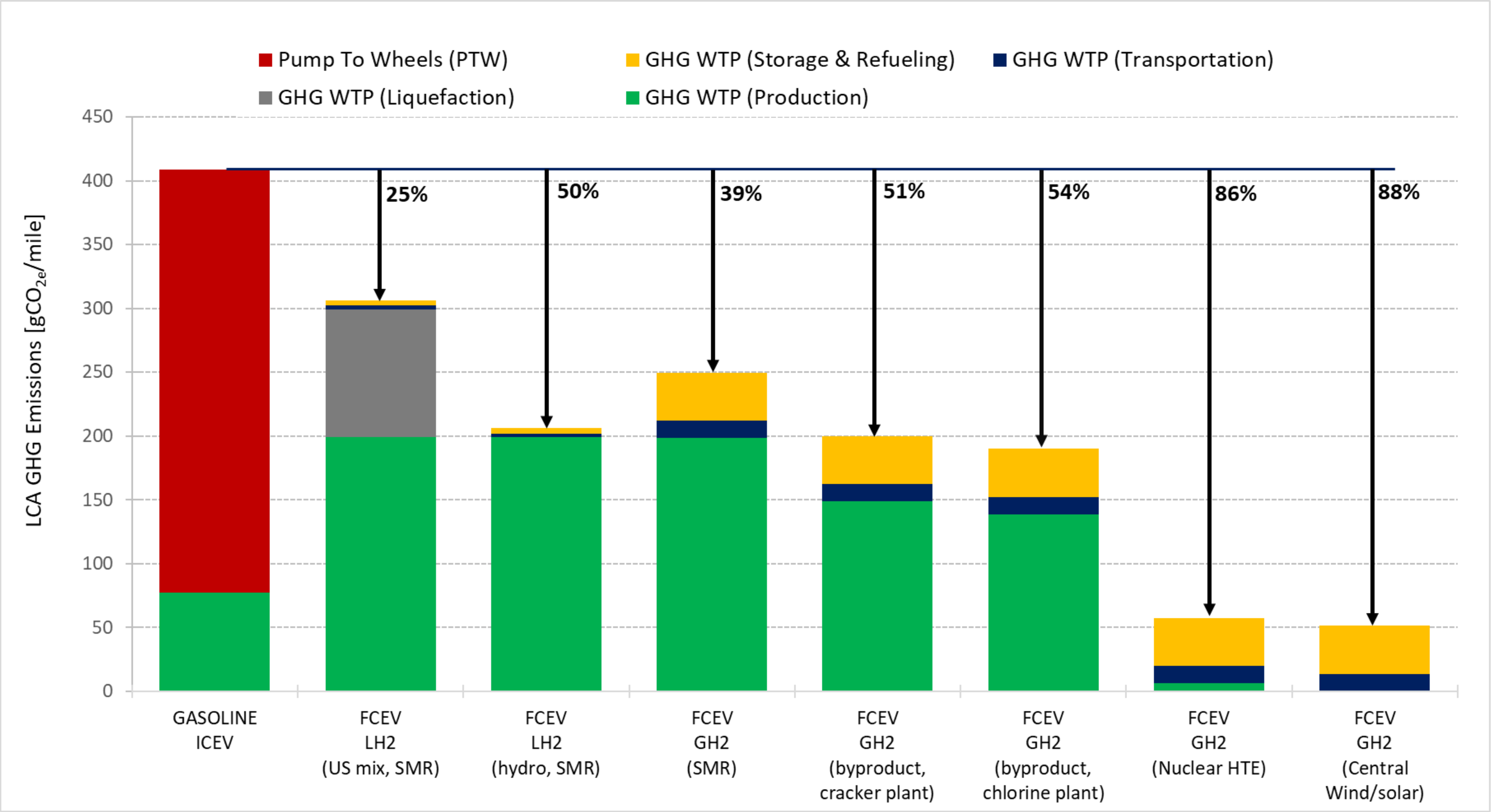
Liquid hydrogen pathways



Updated SMR emission factors in GREET 2019



Renewable sources are key for sustainable H_2 production



Assuming 26 mpg for gasoline ICEV and 55 mpgge for H_2 FCEV

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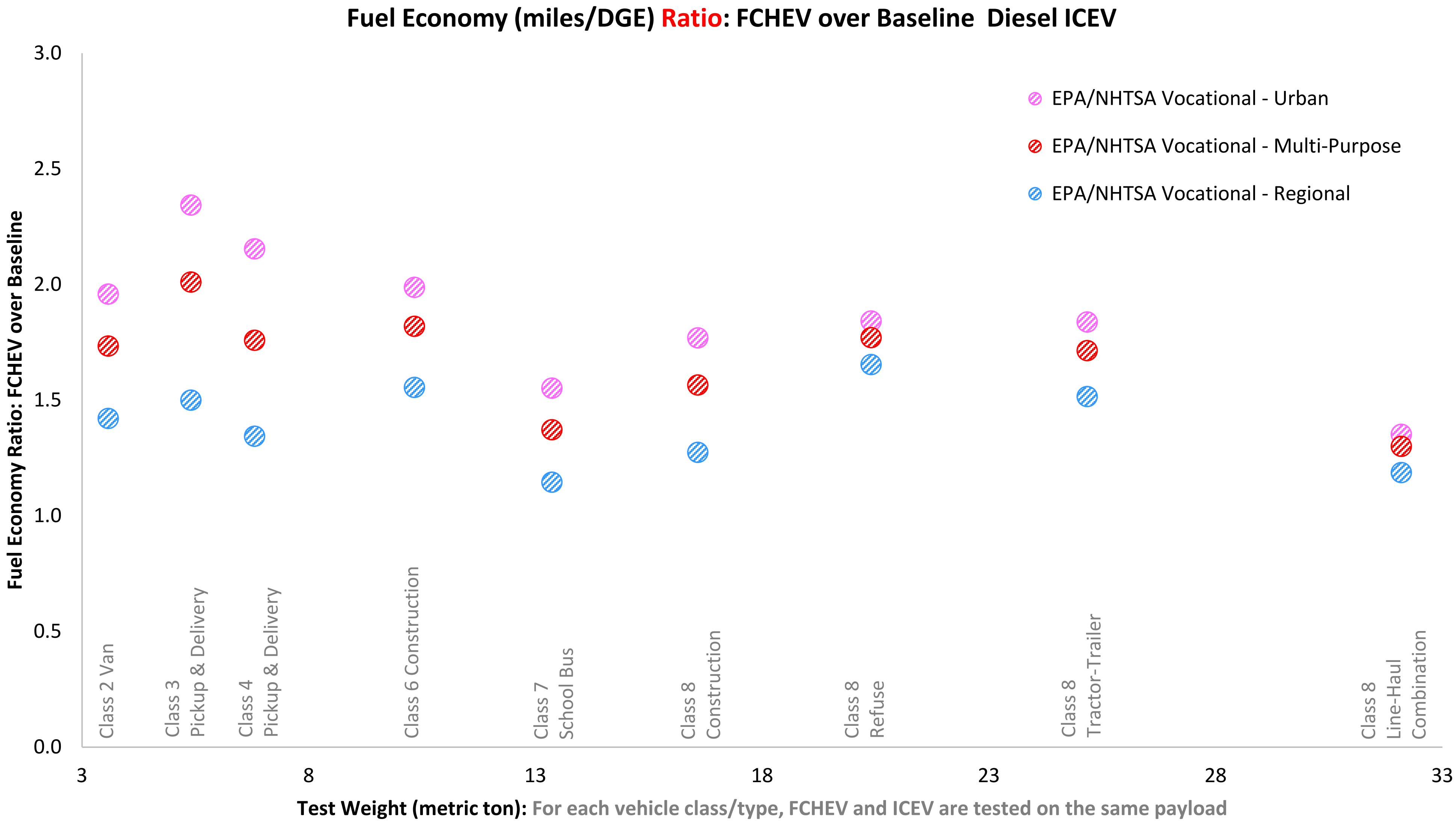
Fuel cell MHD vehicles achieve better fuel economy than diesel



FE ratio relative to diesel is ~1.7 (1.2 – 2.3) → Vary with vocations & duty cycles

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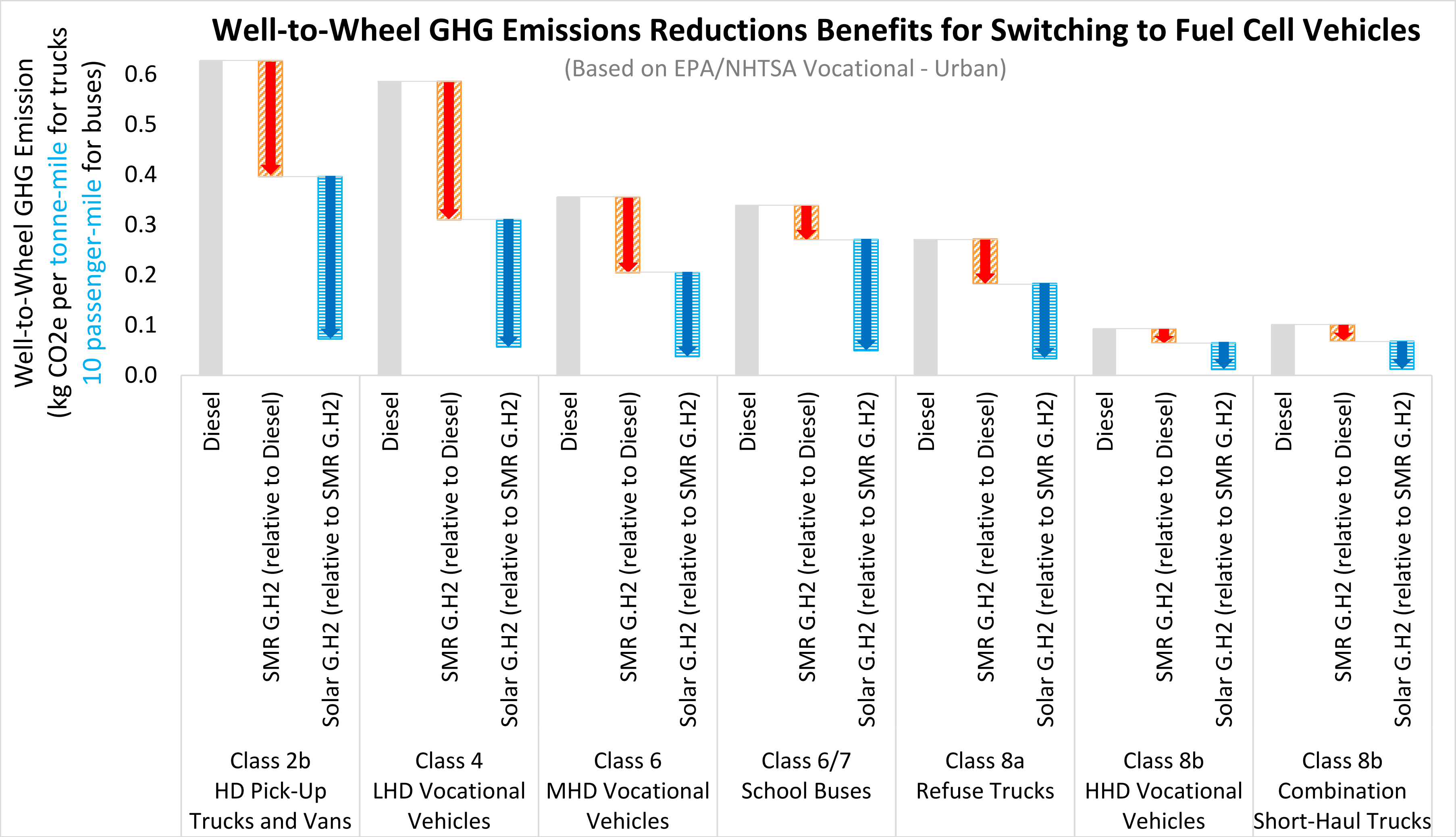
GHG emissions reductions for different MHD fuel cell vehicle types and vocations



Compared to diesel counterparts, medium- and heavy-duty (MHD) hydrogen fuel cell vehicles create less GHG emissions across classes

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aelgowainy@anl.gov

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http://greet.es.anl.gov

for:

- ***GREET models***
- ***GREET documents***
- ***LCA publications***
- ***GREET-based tools and calculators***

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