Plug-in Electric and Hydrogen Fuel Cell Electric Vehicles

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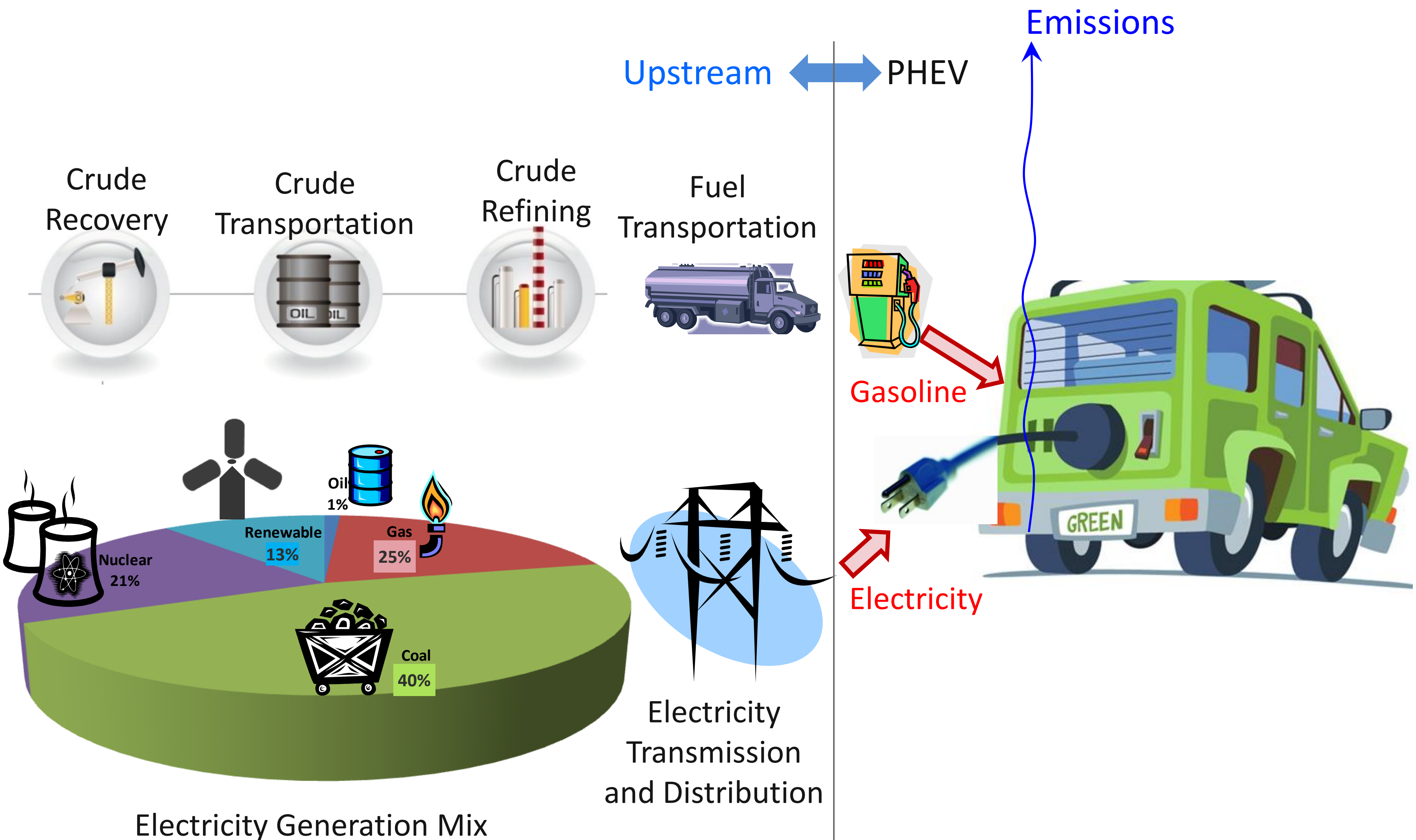
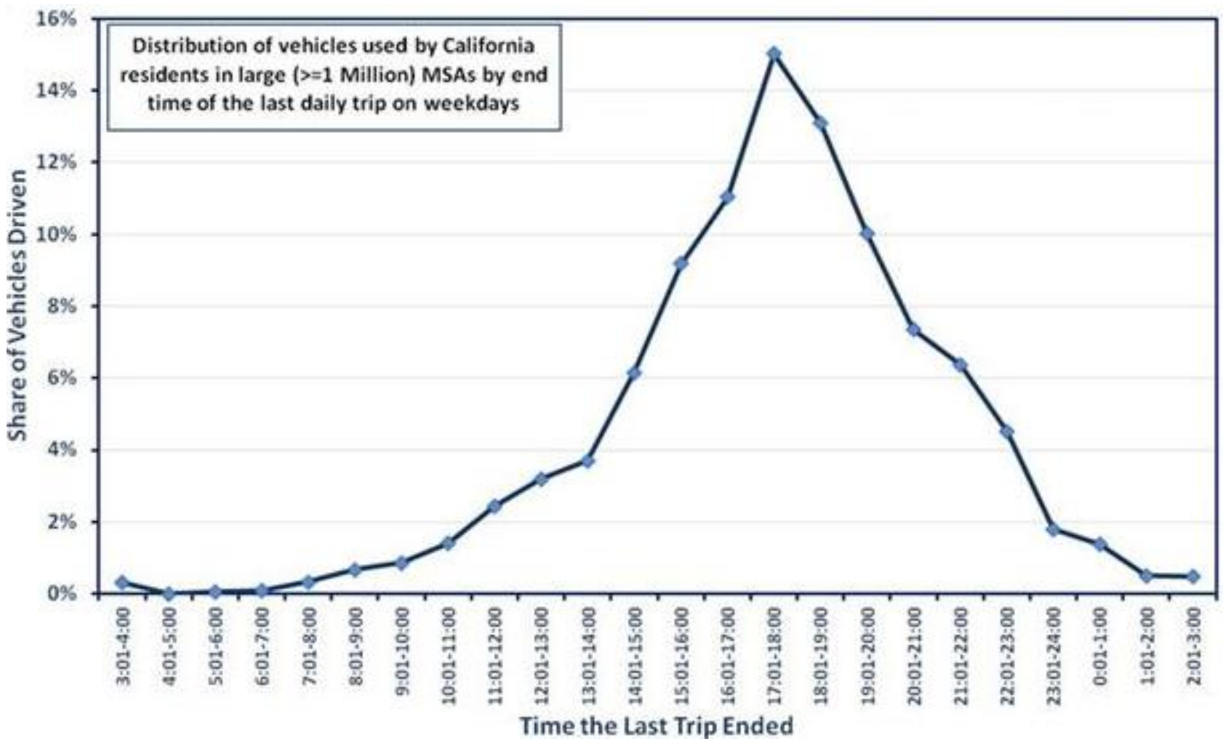
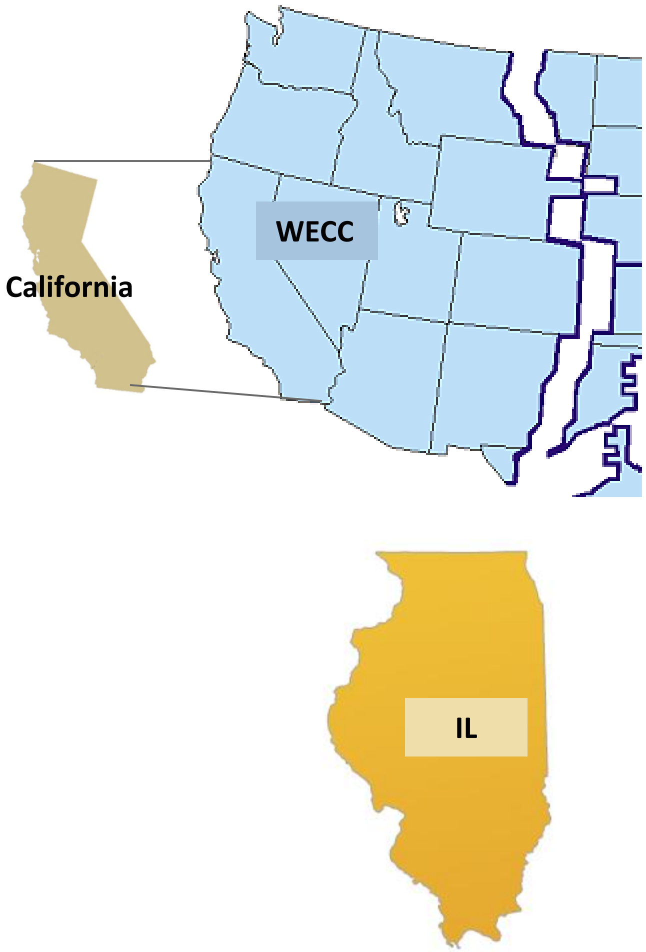
Plug-in vehicles

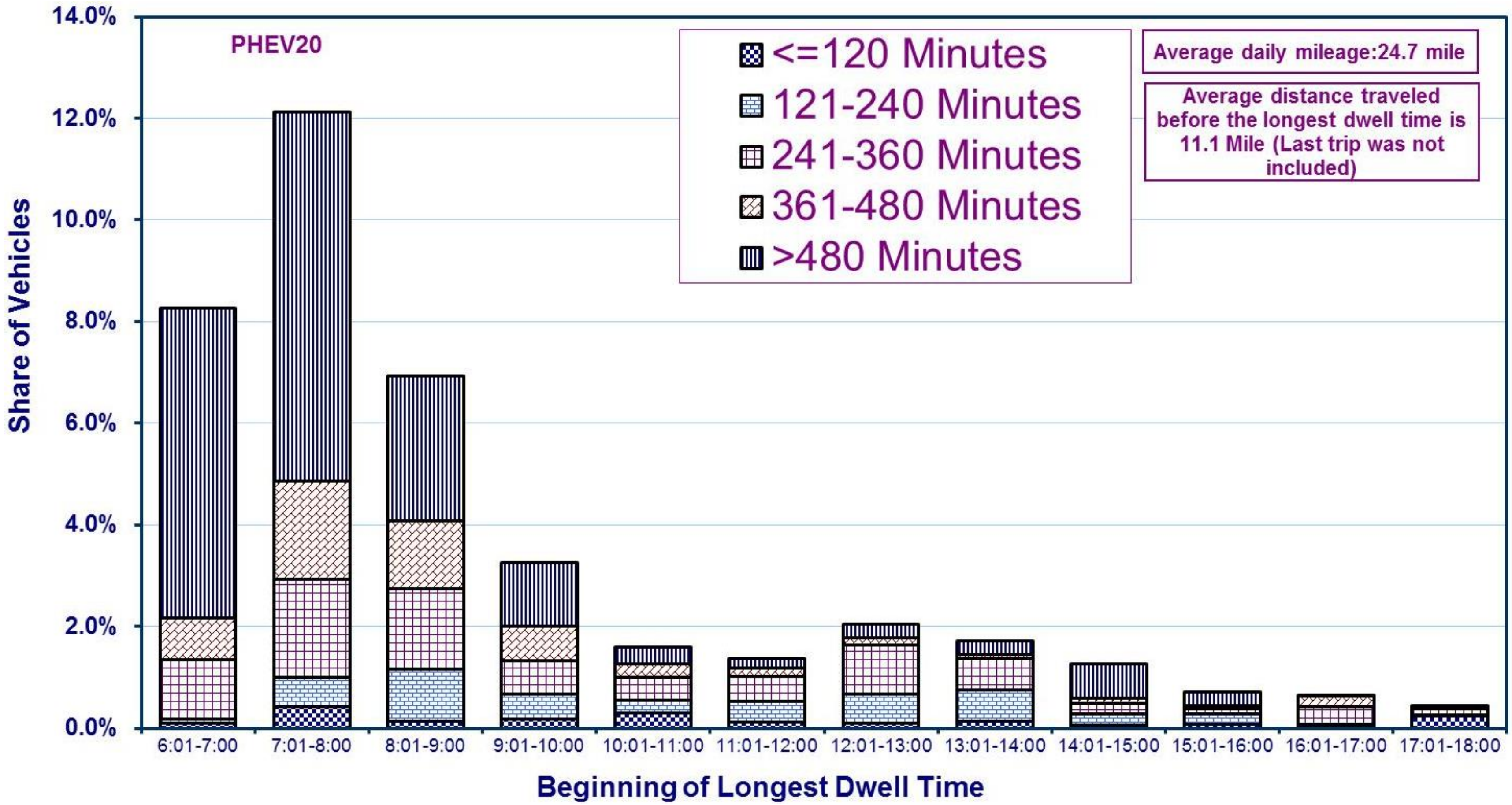


ANL examined three charging choices based on travel behavior in two distinct utility regions in the U.S. → WECC and IL

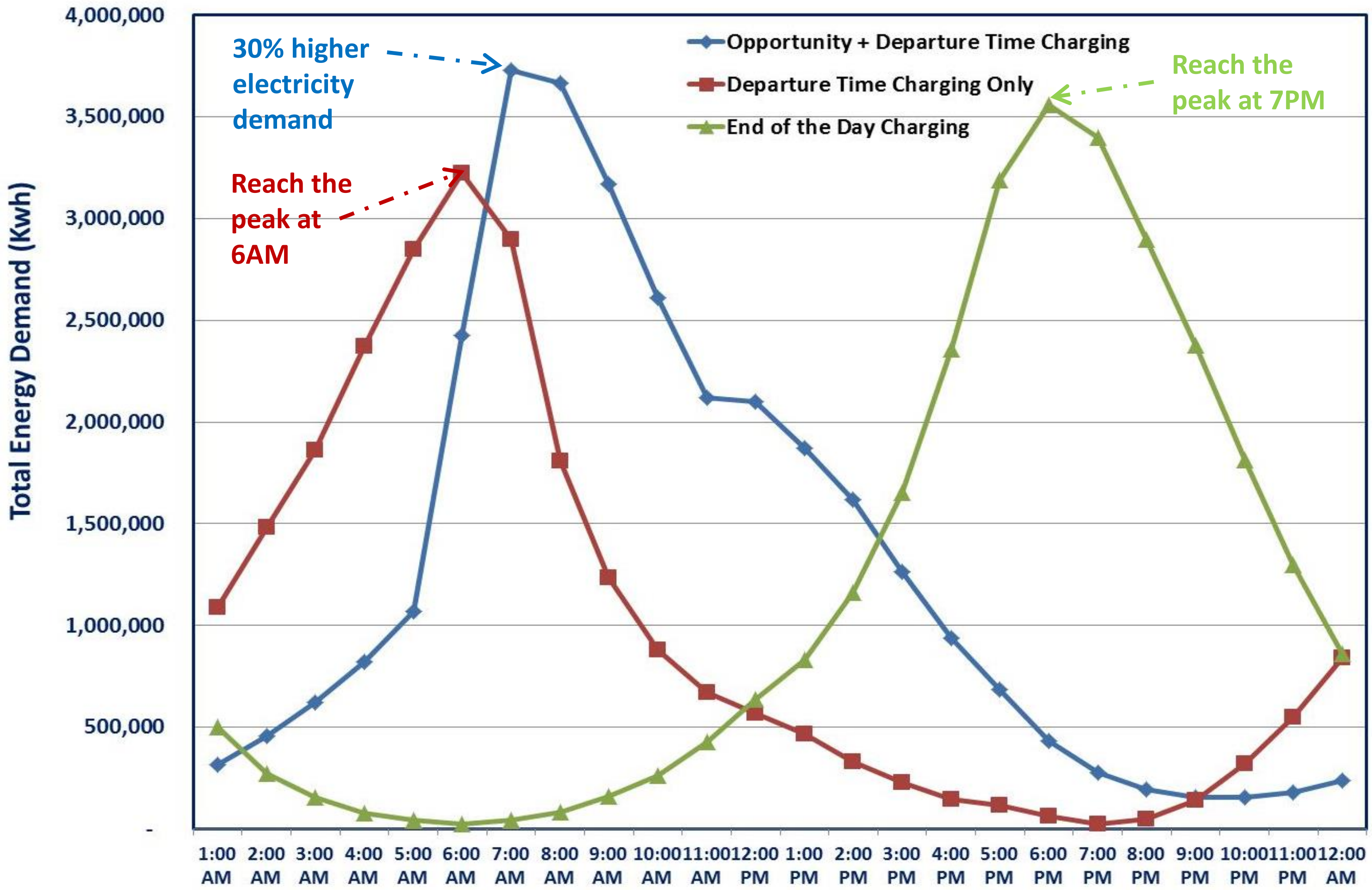




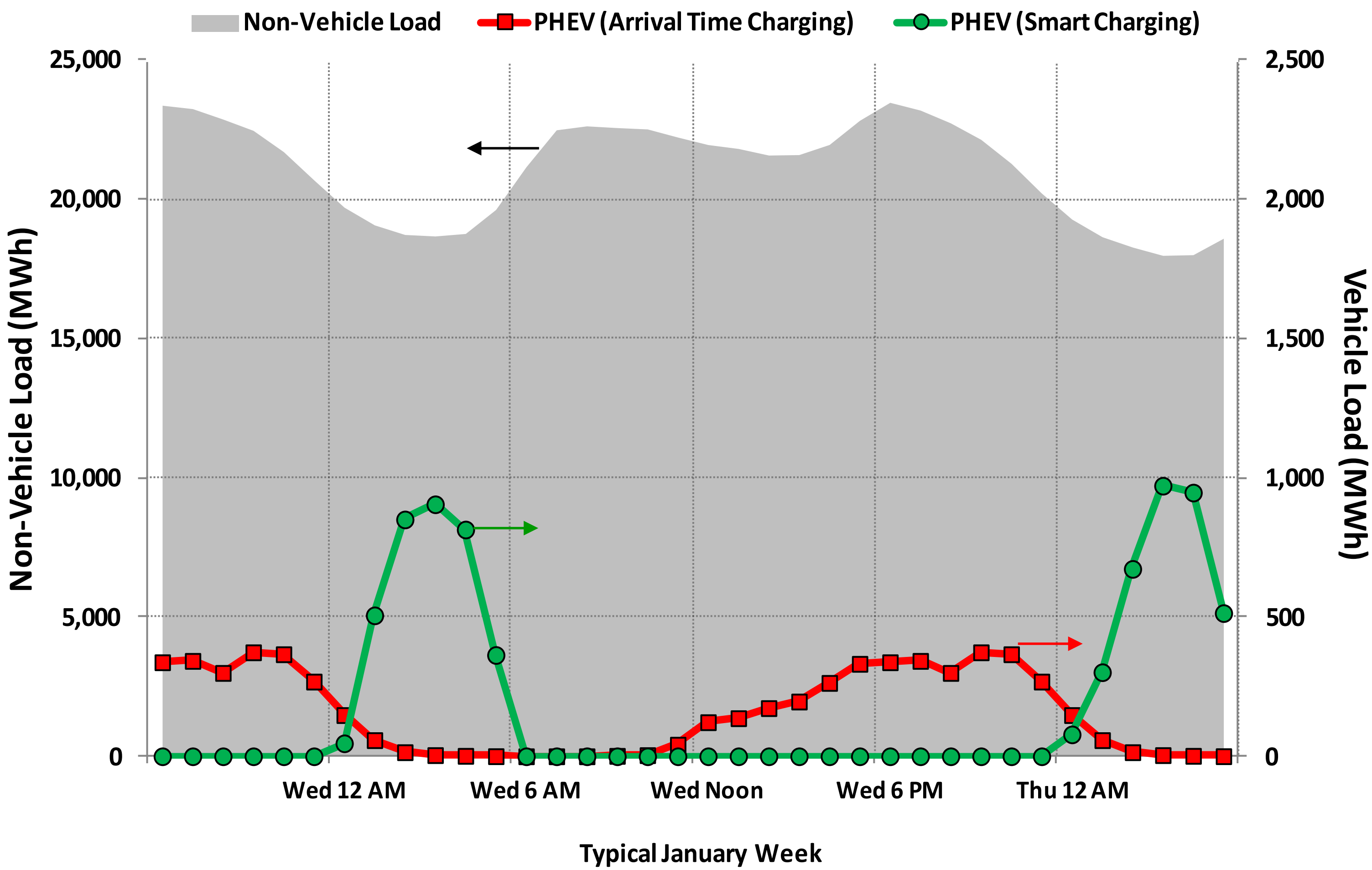
Long dwell time during the day offers another charging opportunity at work and at home (figure shown for vehicles driven to work)



PHEVs load profile can vary considerably with charging scenario (figure shown for U.S. WECC service area)

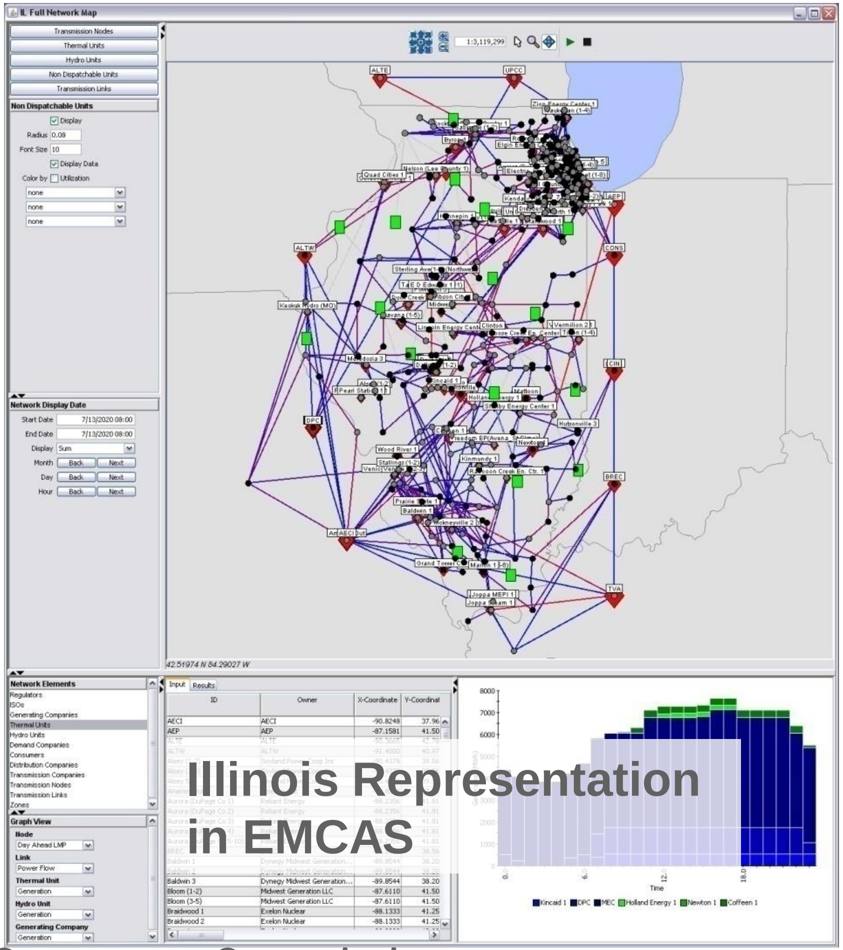


PHEVs Load is Relatively Small Even at 10% Penetration in the LDV FLEET (Figure Shown for IL in 2030)



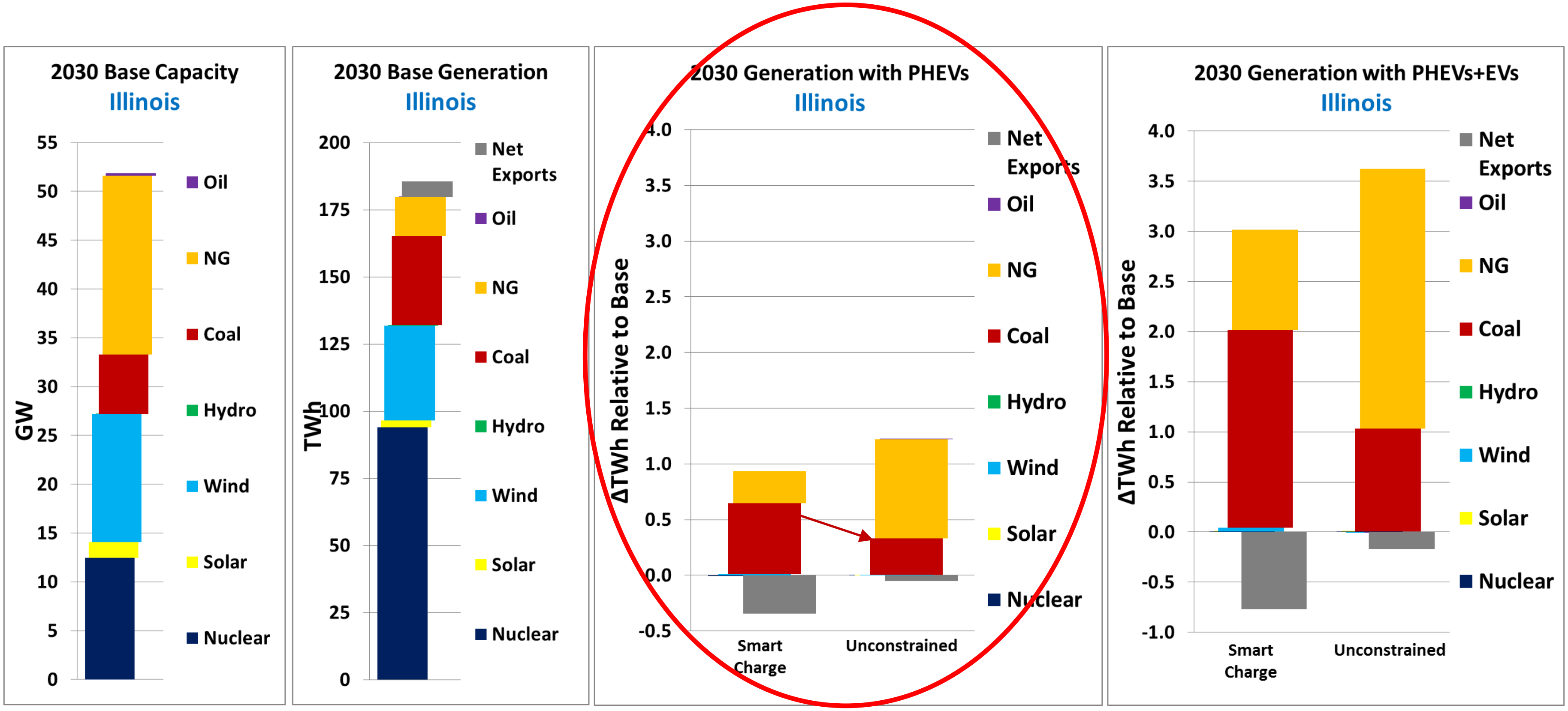
State of Illinois – Modeling Approach and Data Sources

- Modeled state of Illinois in detail; buses in adjacent states were aggregated.
- Agent-based modeling structure simulated operation of the electricity market – EMCAS.
- Transmission modeled at bus/line level (1900 buses and 2500 lines).
- Load profiles developed from FERC* data and published utility hourly data; projected to 2020 using Energy Information Administration (EIA) data.
- Virtually no hydropower.
- Non-dispatchable renewable generation (wind) determined from hourly wind speed and electric generation profile data from NREL web site.
- Thermal power plants simulated at the unit level; unit characteristics derived from EIA data; supplemented with data from NERC and Illinois Commerce Commission.



*Federal Energy Regulatory Commission

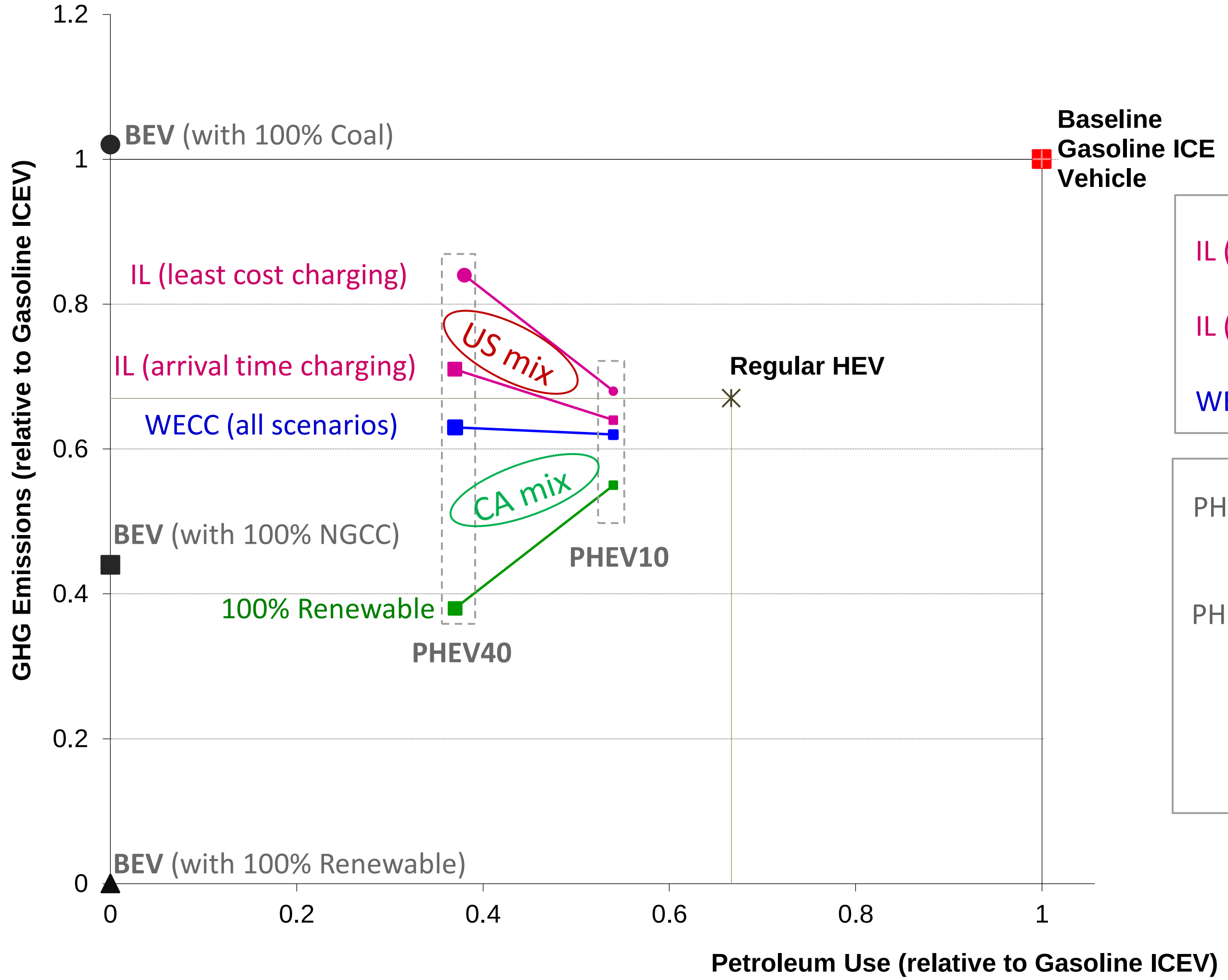
Marginal generation mix for charging varies significantly with charging scenario in IL(figure shown for IL in 2030)



Marginal mix for charging is dominated by NGCC for All considered charging choices (table shown for WECC)

		Alternative Charging Scenarios of PHEVs in WECC (including California)		
Fuel	Technology	**Charging Starts at End of Trip**	**Charging Ends Before Time of Departure**	**Charging Ends Before Time of Departure + Opportunity Charge at Work or Home**
Coal	Utility Boiler / IGCC	0%	0%	0
Natural Gas	**Utility Boiler**	**-0.5%**	**0.2%**	**0.9%**
	Combined Cycle	**96.5%**	**97.2%**	**92.0%**
	Combustion Turbine	**3.5%**	**1.8%**	**6.5%**
Residual Oil	Utility Boiler	0%	0%	0%
Nuclear	Utility Boiler	0%	0%	0%
Biomass	Utility Boiler	0%	0%	0%
Renewable	Hydro/Wind/Solar	0.5%	0.8%	0.6%
Total		100%	100%	100%

*WTW GHG emissions of plug-in vehicles** mainly depend on *electricity generation mix*



IL (least cost charging) → 69% coal

IL (arrival time charging) → 27% coal

WECC (all scenarios) → 99% NG

PHEV10 = 10 mi range,
25% VMT on battery (+ engine)

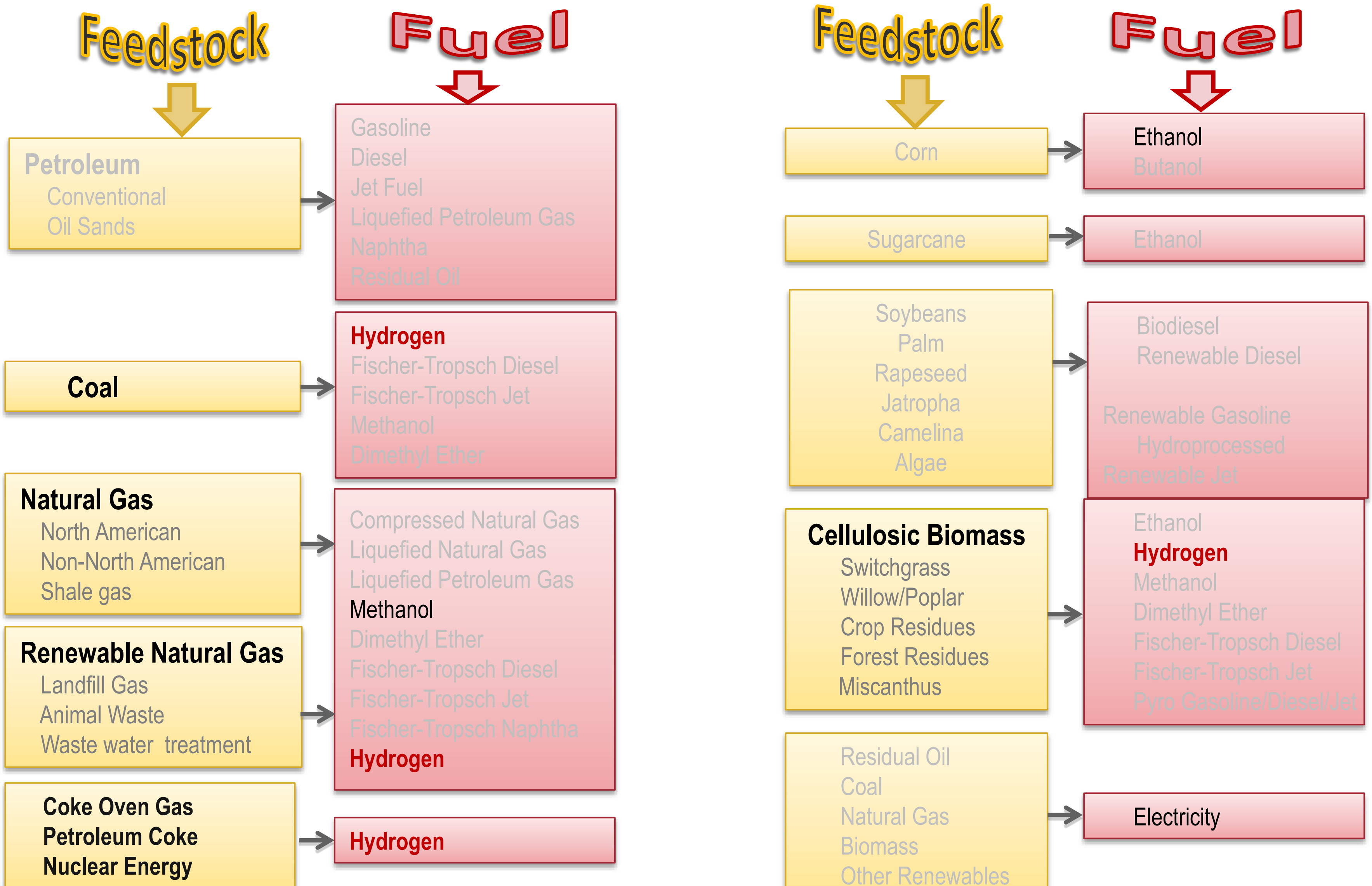
PHEV40 = 40 mi range,
50% VMT on battery alone

BEV = 100 mi range,
100% VMT on battery

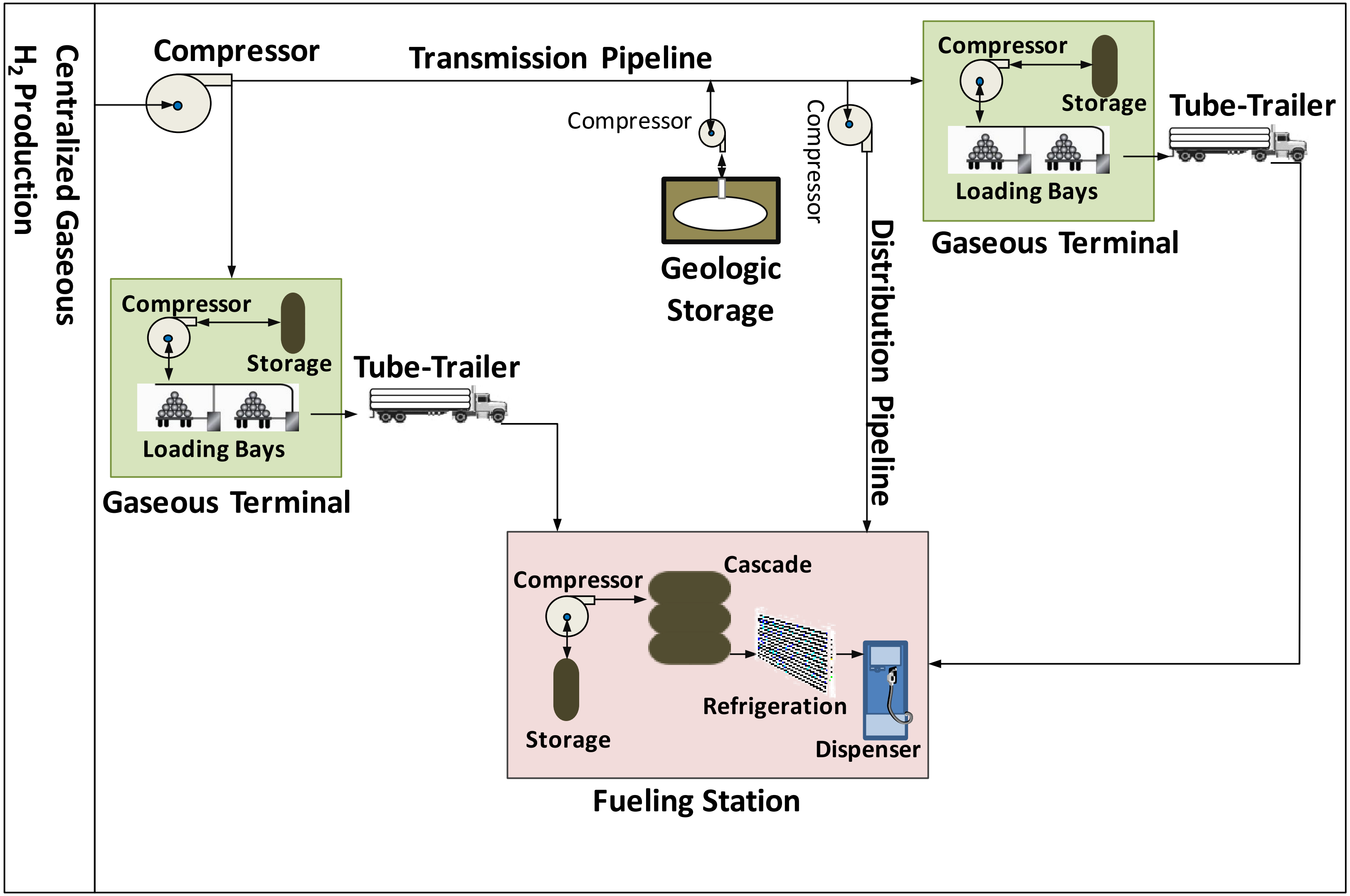
*Marginal mix and fuel economy are based on simulations for 2030

Elgowainy et al. 2012 (TRR)
Elgowainy et al. 2012 (EVS 26)

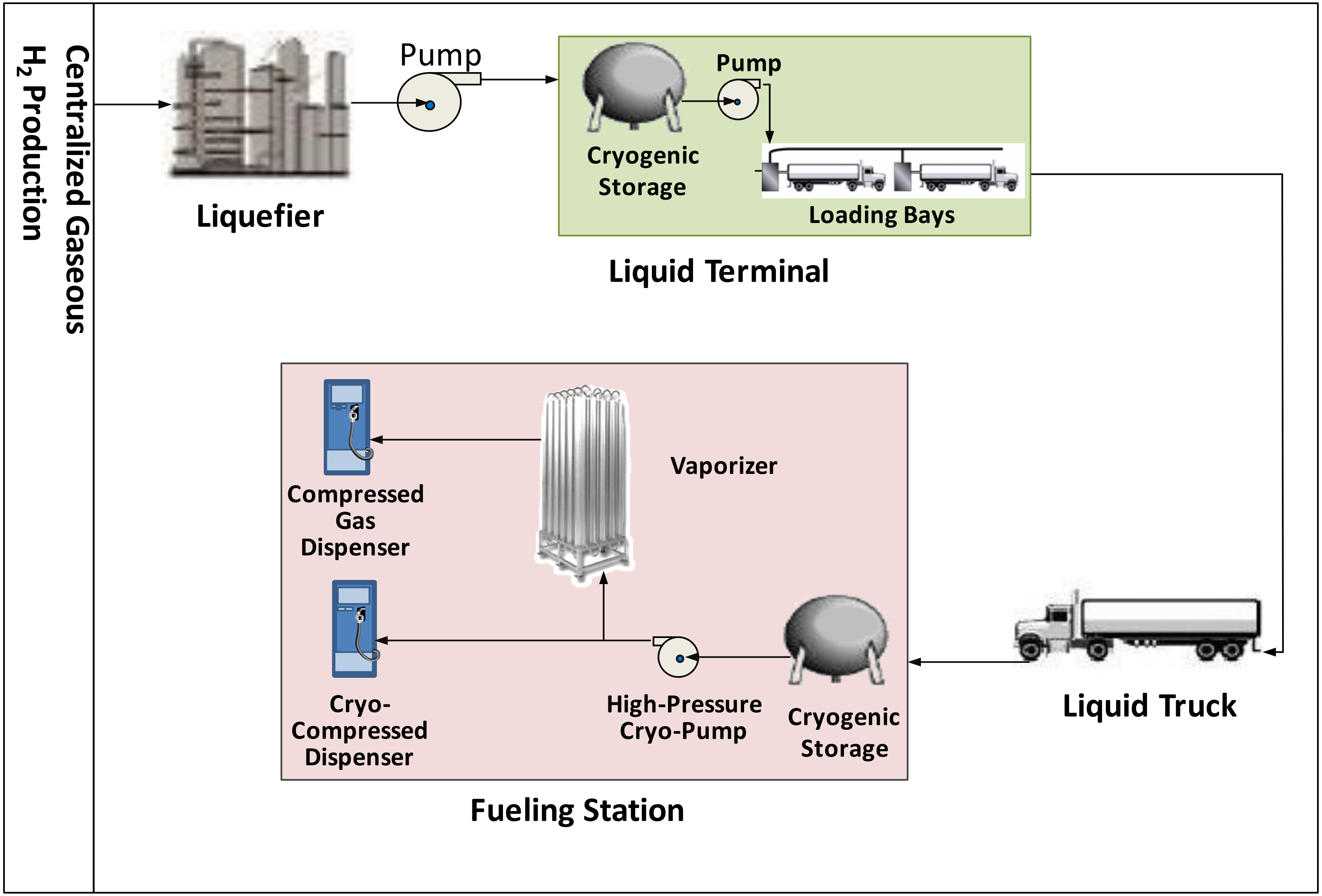
GREET includes more than 20 pathways for central and distributed *hydrogen* production



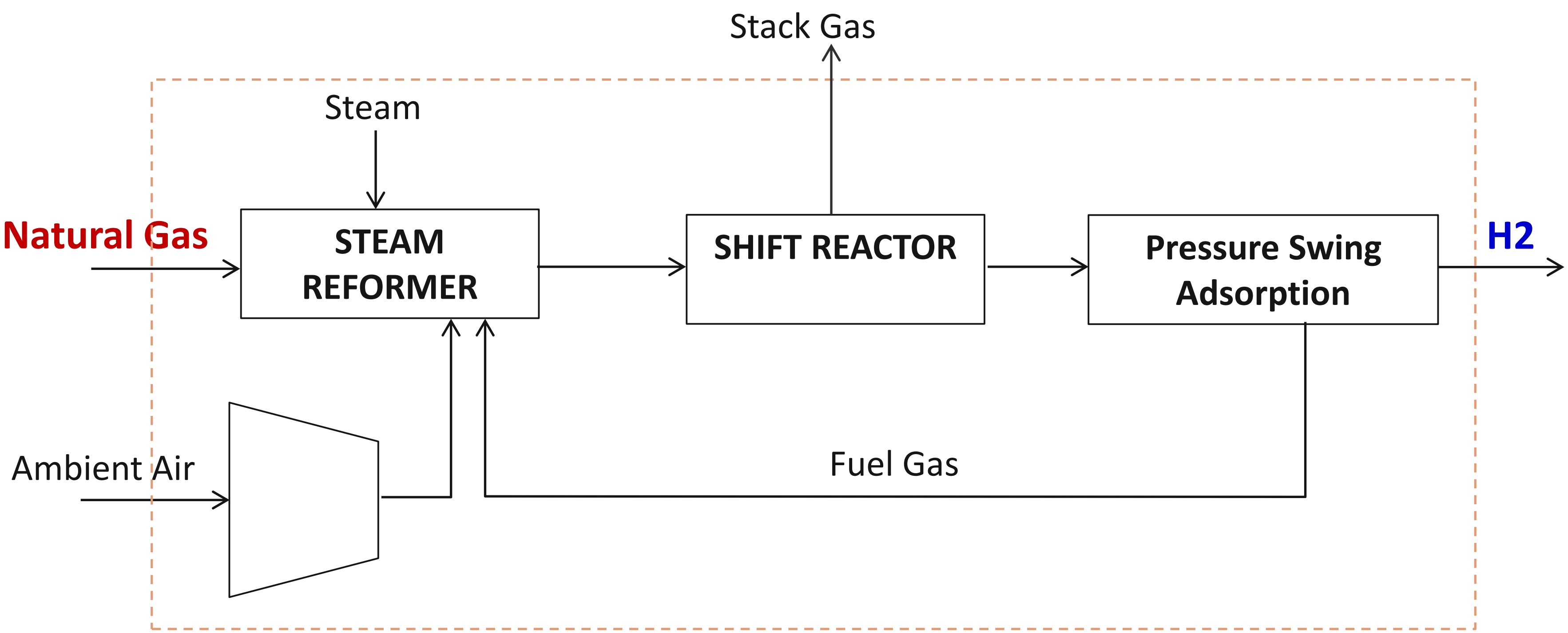
Fuel production and delivery pathways for compressed gaseous hydrogen



Fuel production and delivery pathways for cryo-compressed hydrogen



Hydrogen production today is mainly from SMR, but other low-carbon pathways exist today



At 72% NG to H2 energy efficiency

→ $12\ kg_{CO2e}/kg_{H2}$

Actual North America liquefaction plants GHG emissions are different from US average mix

Liquefaction GHG emissions today may be much less (~40% less) than based on US average mix

Region	GHG Emissions (g_{CO2e}/kWhe)	GHG Emissions (kg_{CO2e}/kg_{H2})*	Liquefaction Capacity (ton/day)
California	380	4.5	30
Louisiana	610	7.4	70
Indiana	1070	12.8	30
New York	330	4.0 or 0**	40
Alabama	580	7.0	30
Ontario	130	1.6	30
Quebec	20	0.20	27
Total			257
Weighted average		**5.7 or 5.0****	
If US mix	670	**8.0**	

*Assuming liquefaction energy of 12 kWhe/kg_H2

** Plant in NY uses hydro power

GHG emissions of H2 compression are based on US average mix

Compression process	Pressure lift (bar)	Compression Energy ($kWhe/kg_{H2}$)	GHG Emissions (kg_{CO2e}/kg_{H2})*
Pipeline compression	20 → 70	0.6	**0.40**
350 bar dispensing	20 → 440	3	**2.0**
700 bar dispensing	20 → 900	4	**2.7**
-40°C pre-cooling	---	0.25	**0.17**
CcH2 station	2 → 350	0.3	**0.20**

*Assuming US average generation mix

GHG emissions of LH2 truck delivery is smaller than tube-trailer delivery due to higher payload

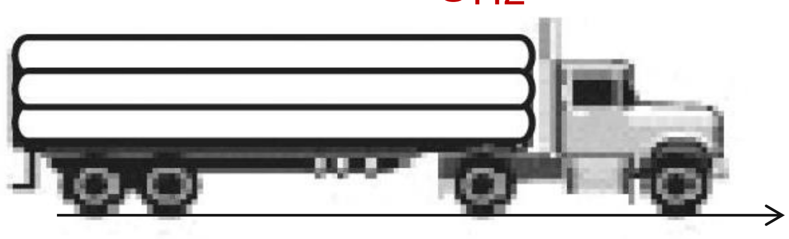
4000 kg_{H2}

0.1 kg_{CO2e}/kg_{H2}

100 km (60 mi)

250 bar, 550 kg_{H2}

0.7 kg_{CO2e}/kg_{H2}



100 km (60 mi)

Fuel cycle GHG emissions of MOF-5, LH2 and compressed GH2 pathways

kg_{CO2e}/kg_{H2}

Pathway	Production	Transport	Compression/ liquefaction	Total
GH2 Pathway (350 bar)	12	0.7	2.0	**14.7**
GH2 Pathway (700 bar)	12	0.7	2.9	**15.6**
LH2 Pathway (CcH2)	12	0.1	5.2 **or** **8.2‡**	**17.3 or** **20.3‡**
MOF-5 Pathway	12	0.7	5.4	**18.1**

‡ Assuming US mix for H2 liquefaction

Onboard storage represents 3-5% of total LCA GHG emissions of compressed GH2, LH2 and MOF-5 pathways – Accomplishment

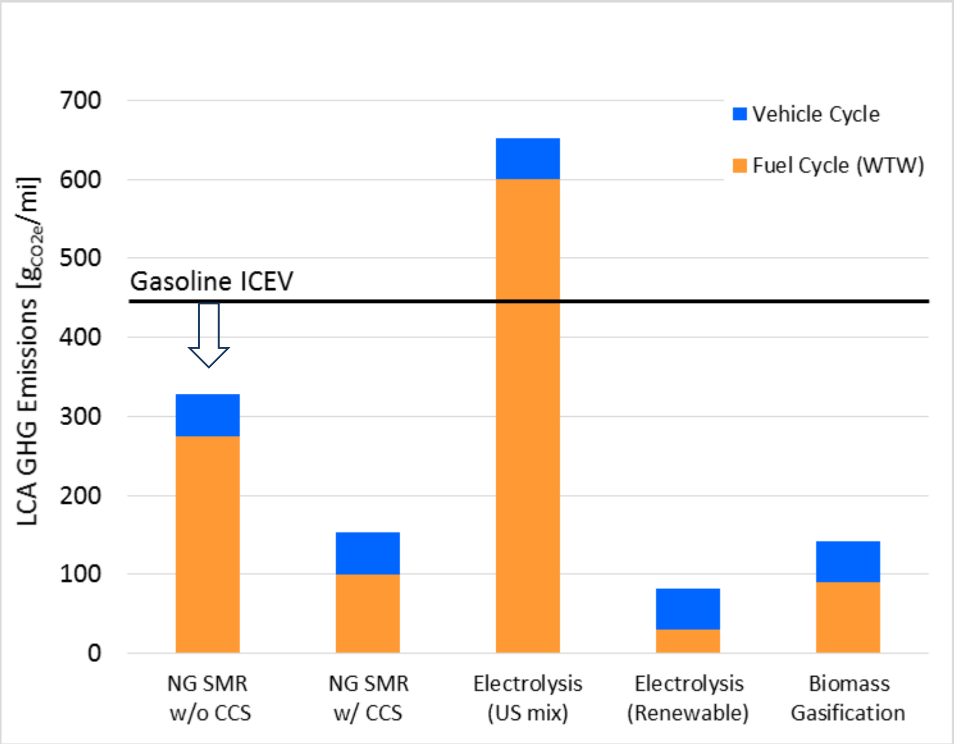
g_{CO2e}/mi*

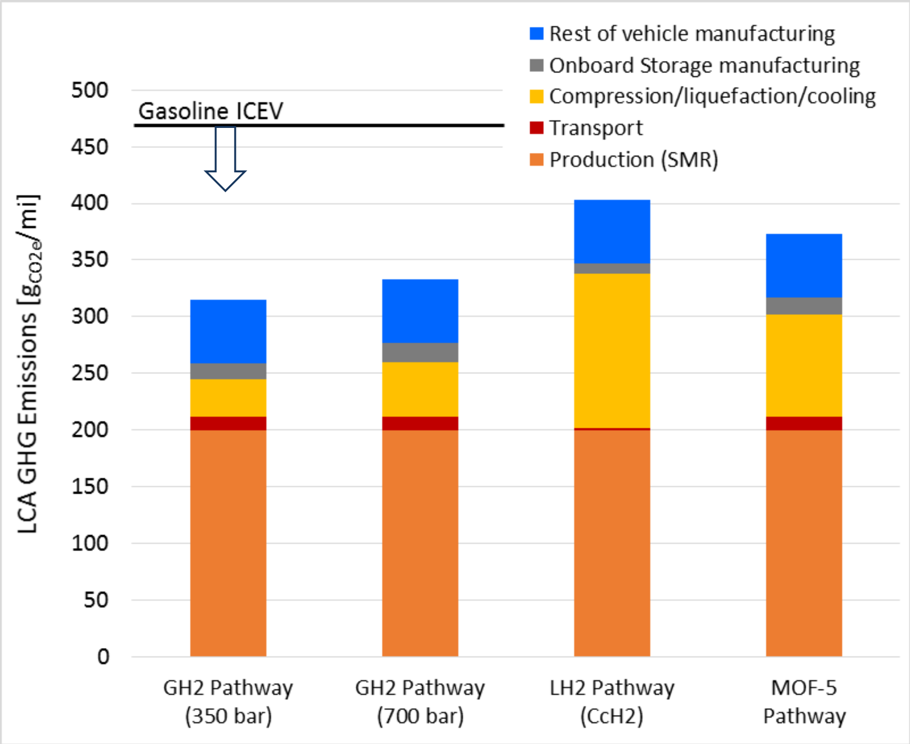
Pathway	Onboard Storage	Balance of Vehicle Cycle	Fuel Cycle (WTW)	Total
GH2 Pathway (350 bar)	14	56	245	**315**
GH2 Pathway (700 bar)	17	56	257	**330**
LH2 Pathway (CcH2)	9	56	288	**350** or **400‡**
MOF-5 pathway	15	56	302	**373**

*Assuming 60 mi/kg_{H2} fuel economy for FCEVs, and 160,000 lifetime VMT

‡ Assuming US mix for H2 liquefaction

GHG emissions reduction potential depends on H2 production and packaging for delivery and onboard storage



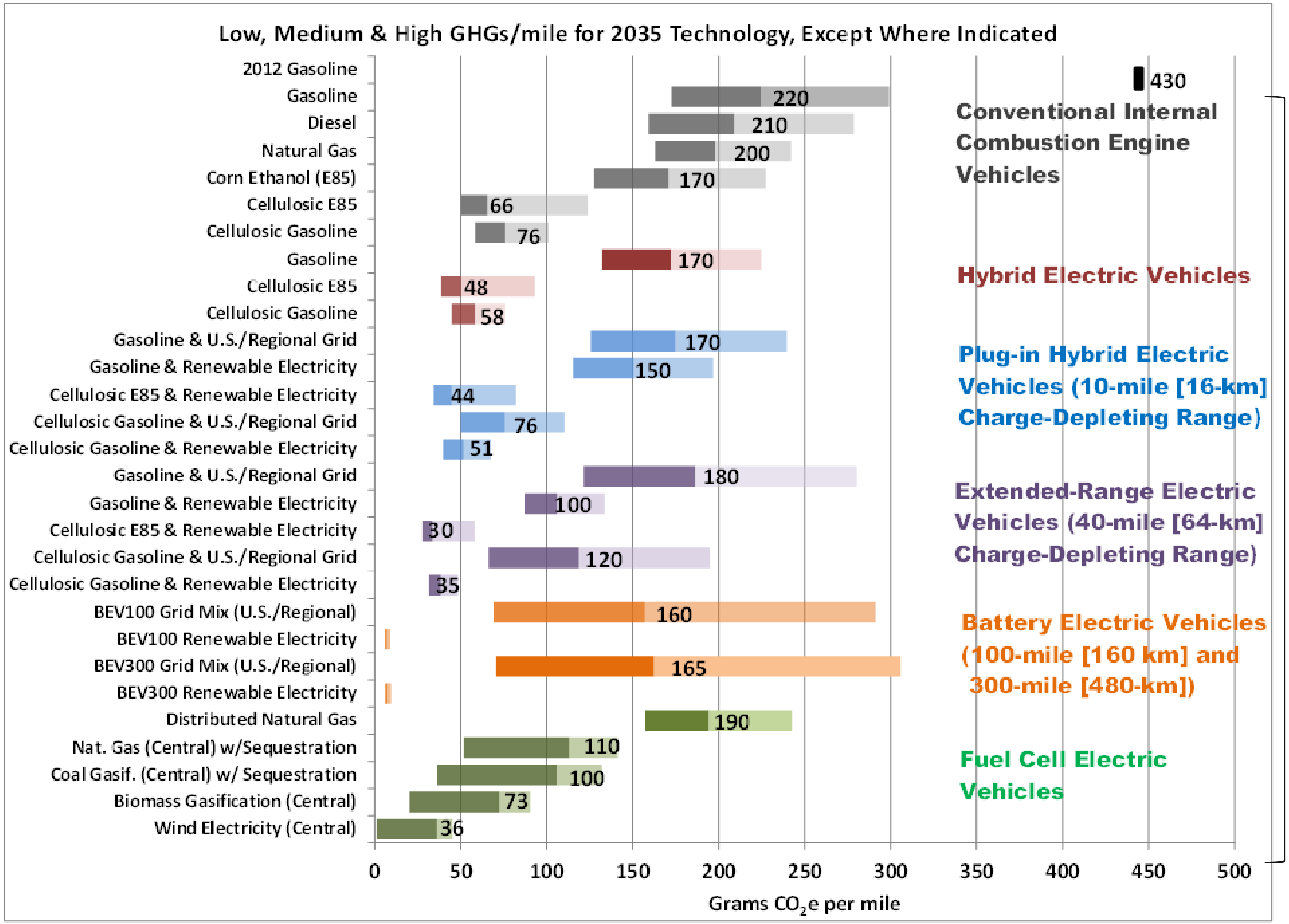


Assuming gaseous delivery via pipelines and 700 bar onboard storage

Acronyms

GH2 = gaseous hydrogen	CcH2 = cryocompressed	SMR = steam methane reforming	CCS = carbon capture and storage
LH2 = liquid hydrogen	MOF = metal-organic framework	ICEV = internal combustion engine vehicle	

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 2013, Record 13005)

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

Acknowledgment

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Questions?