Considerations of Alternative Energy Sources in LCA of Passenger Cars

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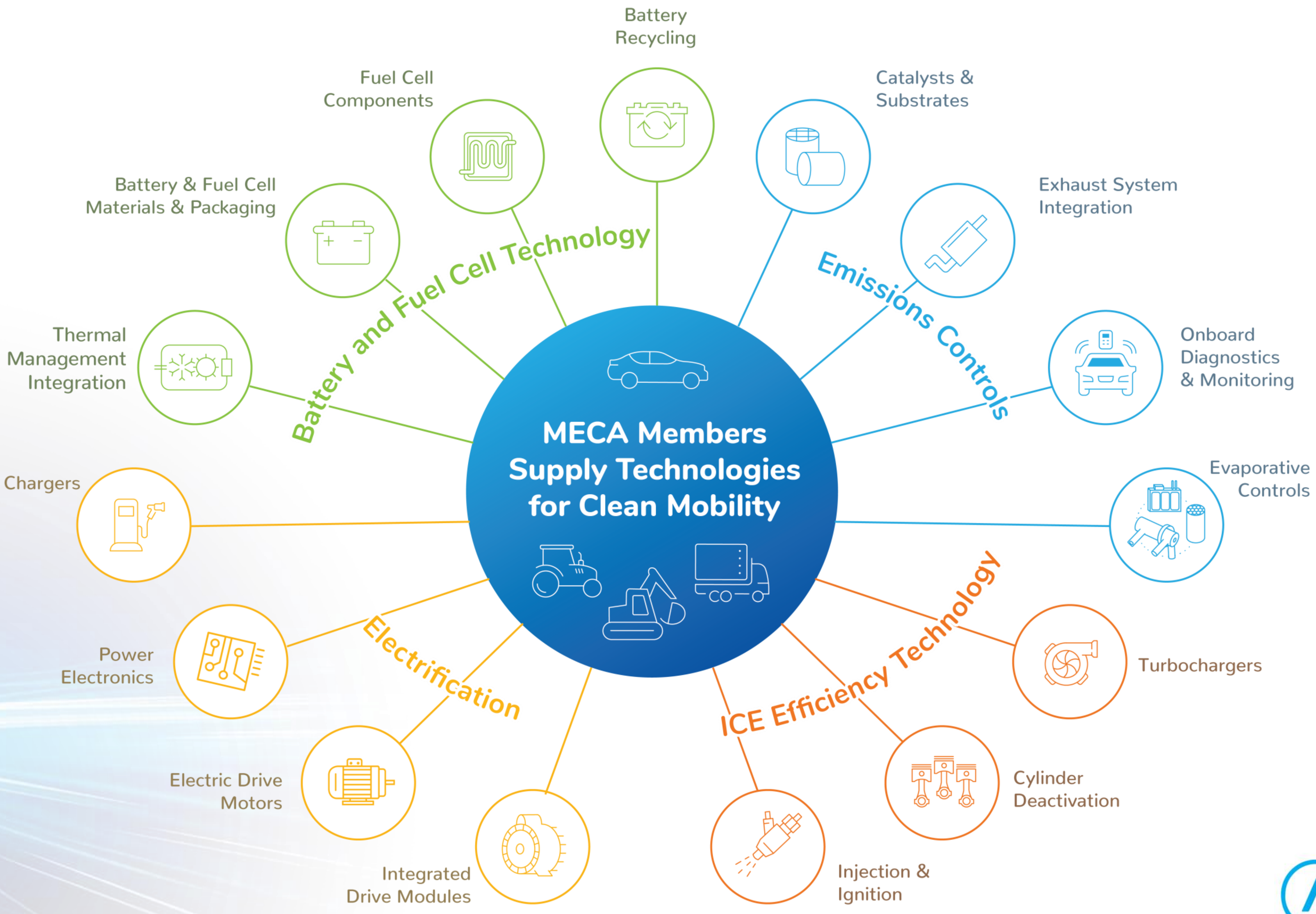

SUPPLYING CLEAN MOBILITY

The End of the ICE Age has Been Forecasted for over a Decade

Is the problem the powertrain, or the fuel? Life Cycle Analysis holds the key

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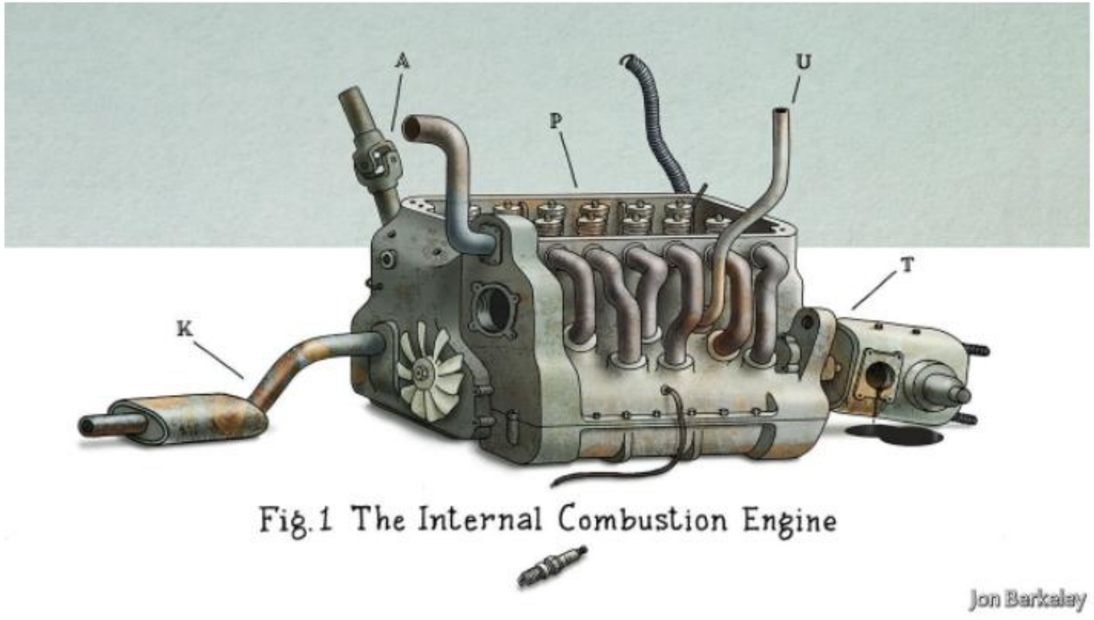
Electric cars

The death of the internal combustion engine

It had a good run. But the end is in sight for the machine that changed the world



Outline

- Introduction to Life Cycle Analysis
- The impact of the energy source that powers vehicles
- MECA's LCA tool
- A case study at alternate solutions to our climate goals

What is Life Cycle Analysis?

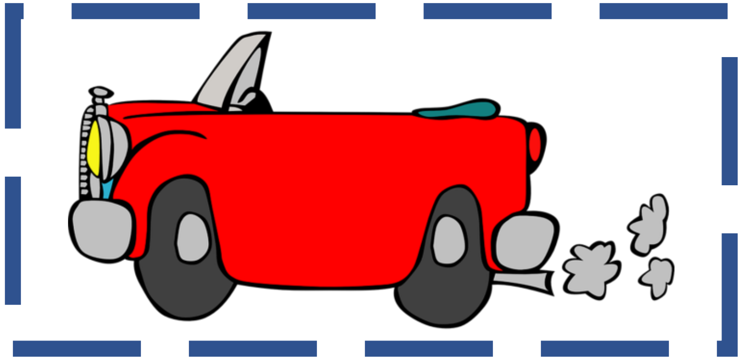
LCA is a method used to evaluate the environmental impact of a product through its life cycle encompassing raw material extraction and processing, manufacturing, distribution, use, recycling, and final disposal.

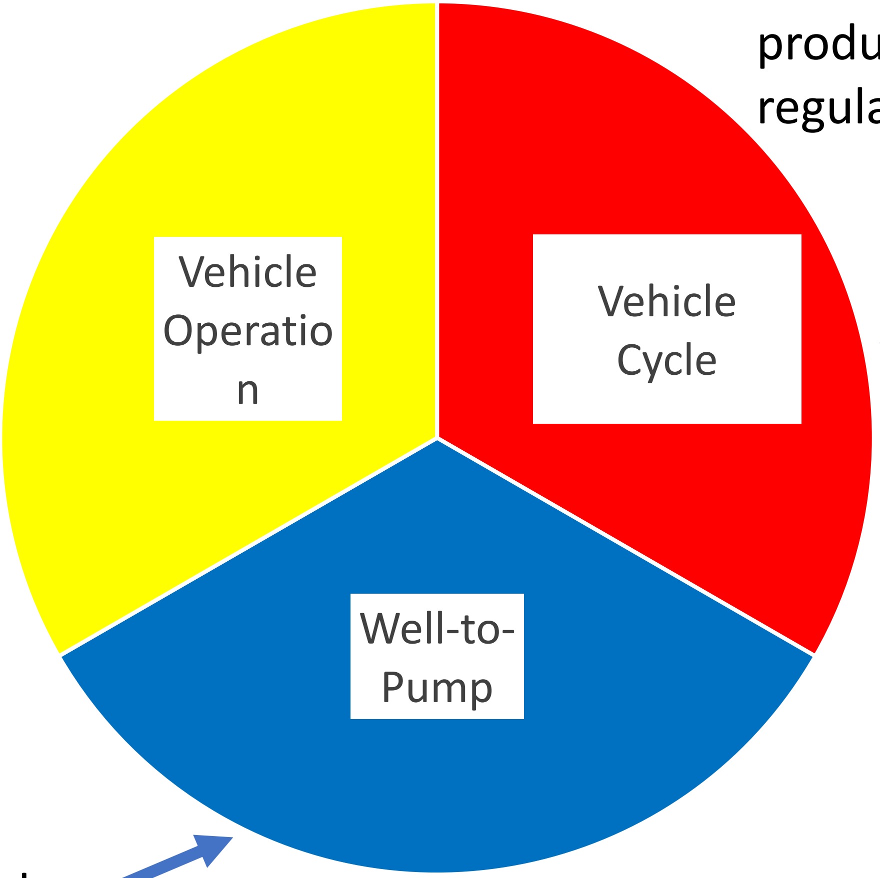
Source: Ilgin and Gupta, "Environmentally conscious manufacturing and product recovery (ECMPRO): A review of the state of the art," Journal of Environmental Management, January 2010

The Challenge: Vehicle Regulations Focus on the Tailpipe, LCA adds Upstream

Emissions from vehicle production is not regulated, but coming

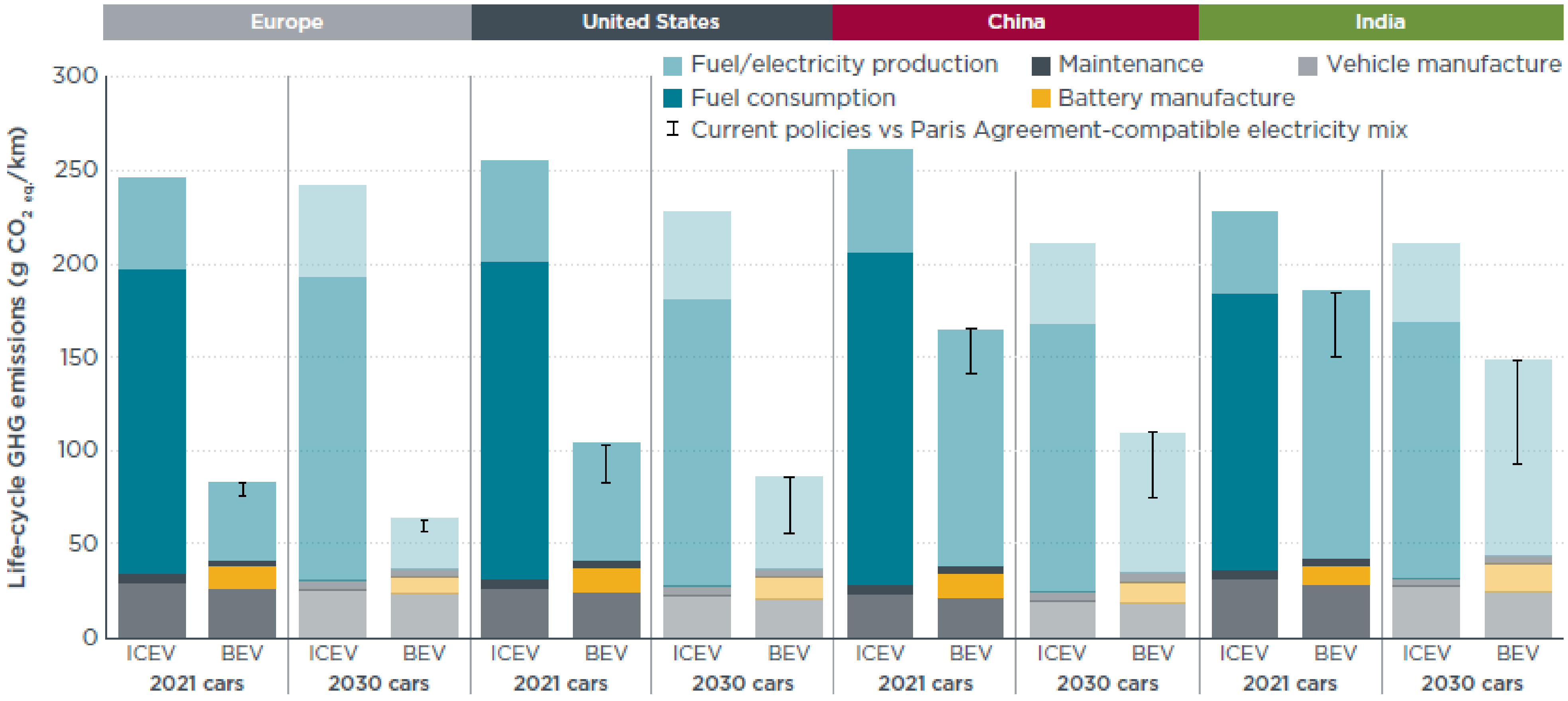
Vehicle standards focus on tailpipe pollution and GHG emission standards





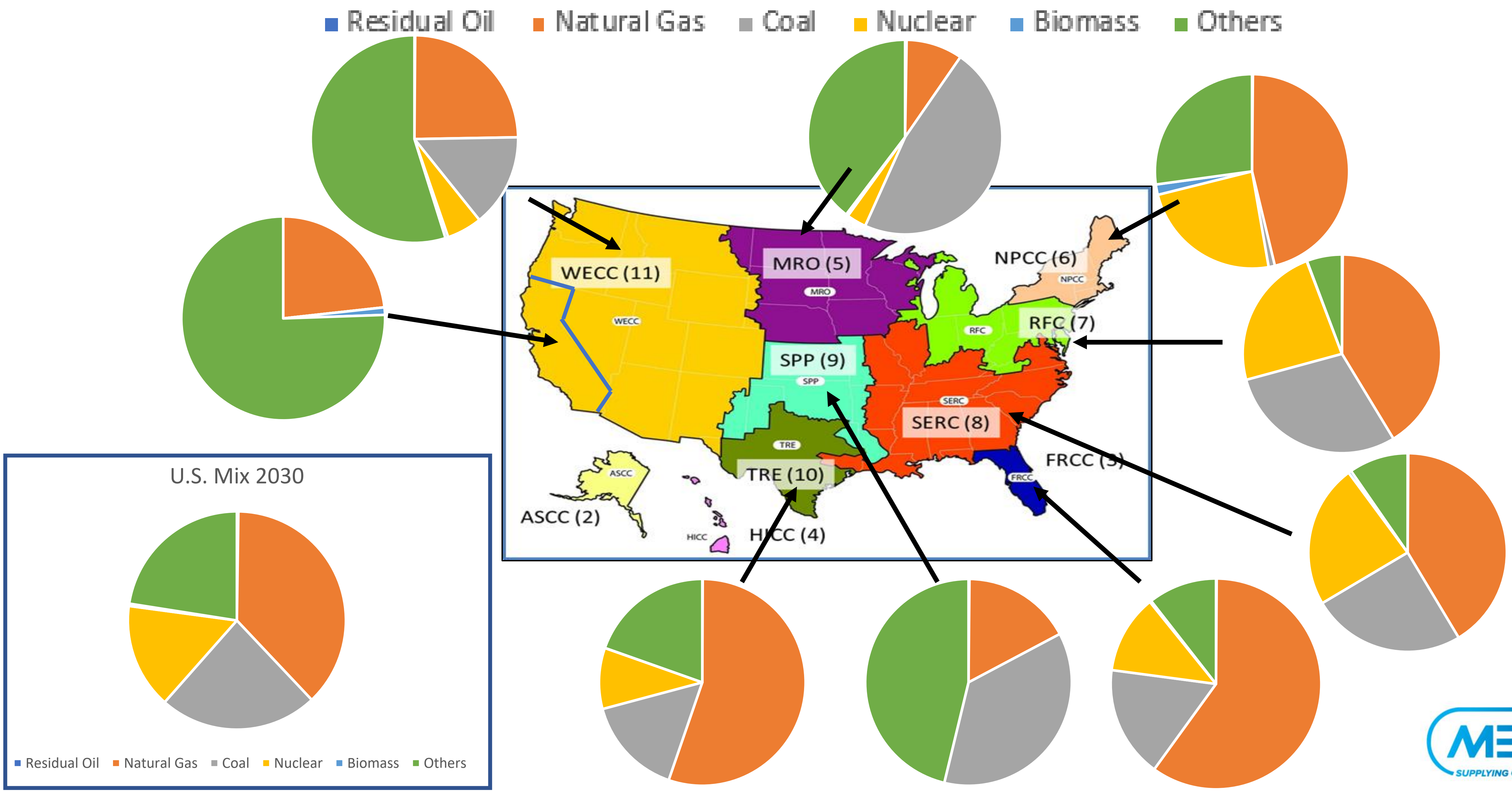
Low Carbon Fuel Standards regulate upstream fuel and energy production

LCA Studies: ICCT

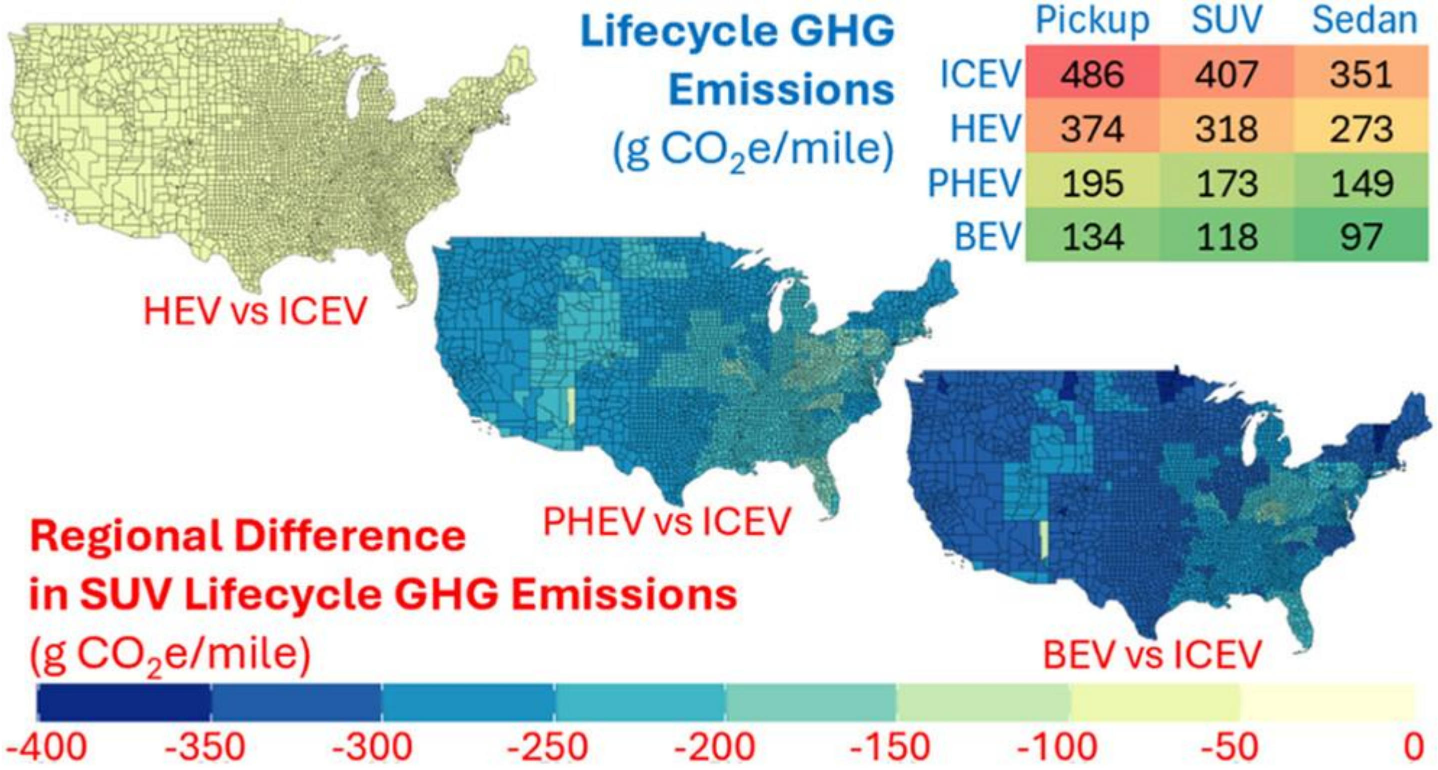


Source: "A Global Comparison of the Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars," Georg Bieker, July 2021.

U.S. Electricity Mixes Included in GREET for 2030



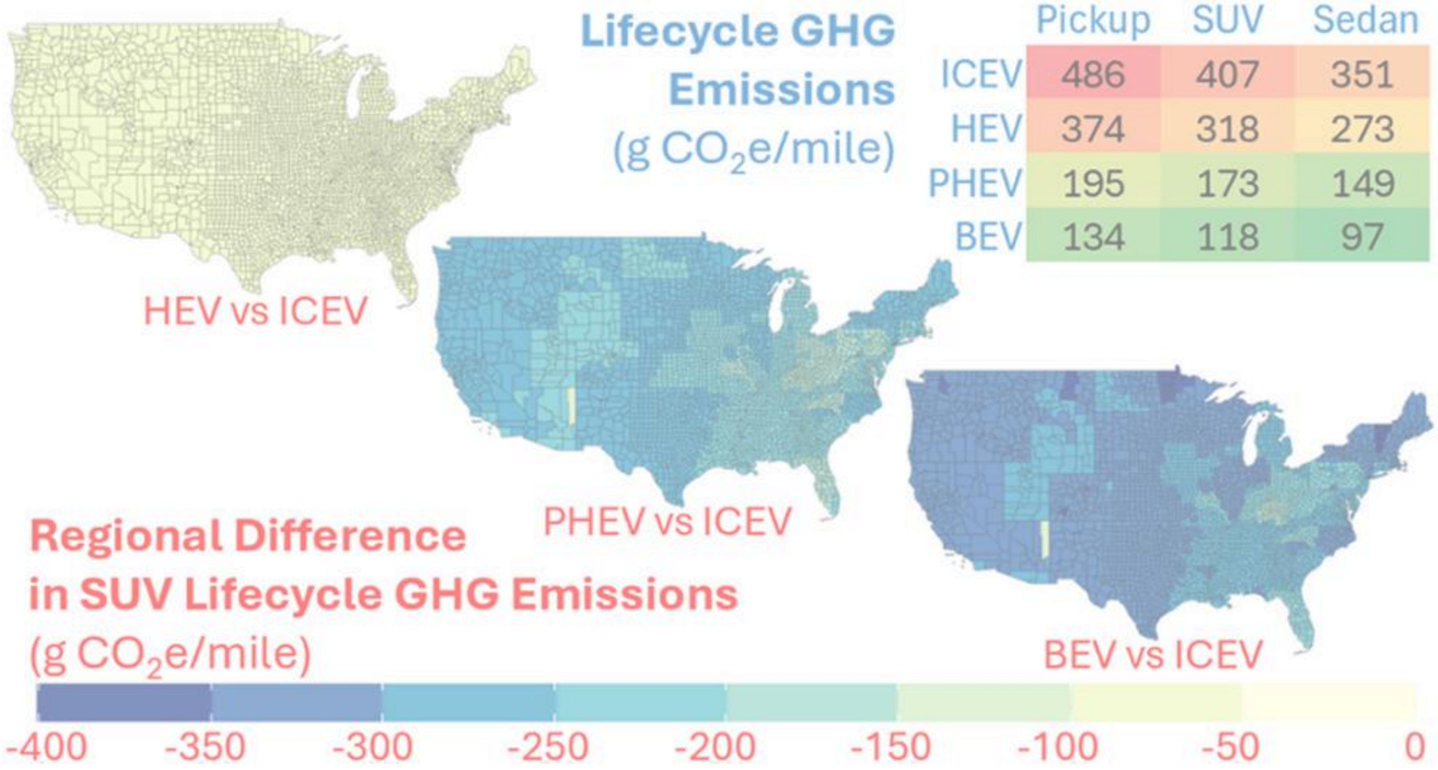
Recent LCA Studies: University of Michigan



Cradle to grave GHG emissions of BEVs (300 mile) have 30% lower emissions than PHEVs, 60% lower emissions than HEVs and 70% lower emissions than ICE across the US electricity system

Source: Smith et al., “Greenhouse Gas Reductions Driven by Vehicle Electrification across Powertrain, Classes, Locations and Use Patterns,” Science & Technology, August 2025.

Recent LCA Studies: University of Michigan



	Pickup	SUV	Sedan
ICEV	486	407	351
HEV	374	318	273
PHEV	195	173	149
BEV	134	118	97

"Unlike the carbon intensity of gasoline, which remains constant throughout the vehicle's lifetime, the grid emissions factor is updated throughout the vehicle lifetime."

MECA Vehicle-Plus-Fuel LCA Scenarios

Vehicles	E10	E85	B20	Renew Diesel	Renew Gasoline	E-Gasoline	E-Diesel	RNG	CNG	H_2	Renew H_2	Low/Avg/ High Grid CO_2
City ICE Sedan	X	X			X	X						
City HEV Sedan	X				X	X						
City BEV Sedan												X
Family ICE SUV	X	X	X	X	X	X	X	X	X			
Family HEV SUV	X	X	X	X	X	X	X					
Family PHEV SUV	X	X	X	X	X	X	X	X	X			X
Family BEV SUV												X
Family FCEV SUV										X	X	
Pickup ICE	X	X	X	X	X	X	X	X	X			
Pickup HEV	X	X	X	X	X	X	X	X	X			
Pickup BEV												X
Pickup FCEV										X	X	

Assumptions for MECA's LCA Results in this Presentation

Lifecycle emissions modeled with vehicle and fuel pathways in GREET 2020

Year of analysis - 2030

Vehicle class: Family sport utility vehicle (SUV)

Vehicle miles traveled (VMT): Any combination with full useful life of 150,000 miles

BEV assumptions

- Original battery lasts life of vehicle
- Battery recycling not included
- Charging efficiency of 85%
- Battery range 300 miles

E-Fuel assumptions

- Renewable energy used for production, including H_2 gas generation via electrolysis at local plant (no transport) and no liquefaction of H_2
- E-gasoline "credit" equal to 75% of tank-to-wheels CO_2 (Based on Mobil methanol process efficiency)
- E-diesel "credit" equal to 90% of tank-to-wheels CO_2 (Based on Fischer-Tropsch process efficiency)

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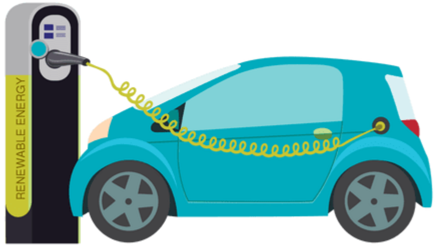
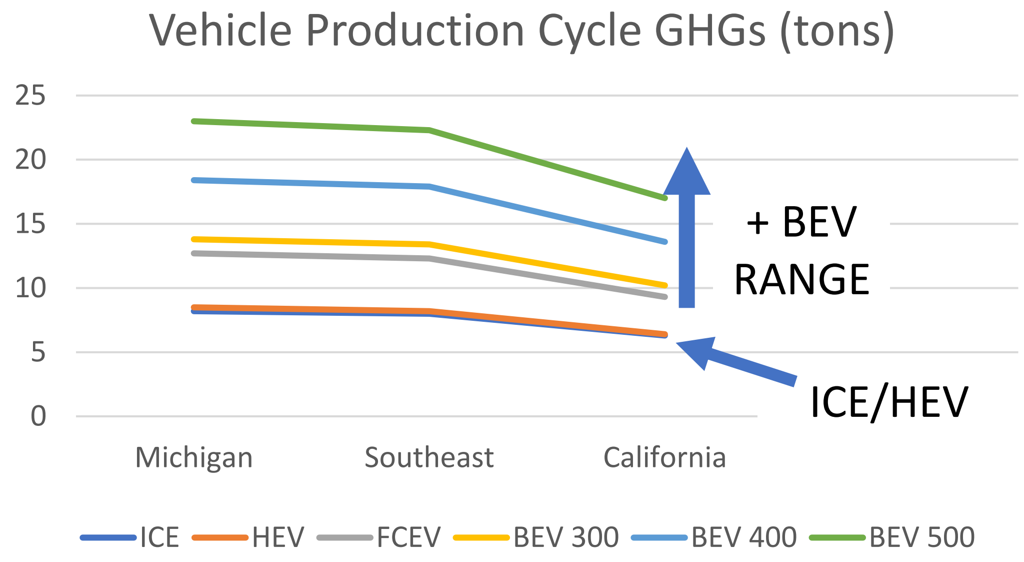
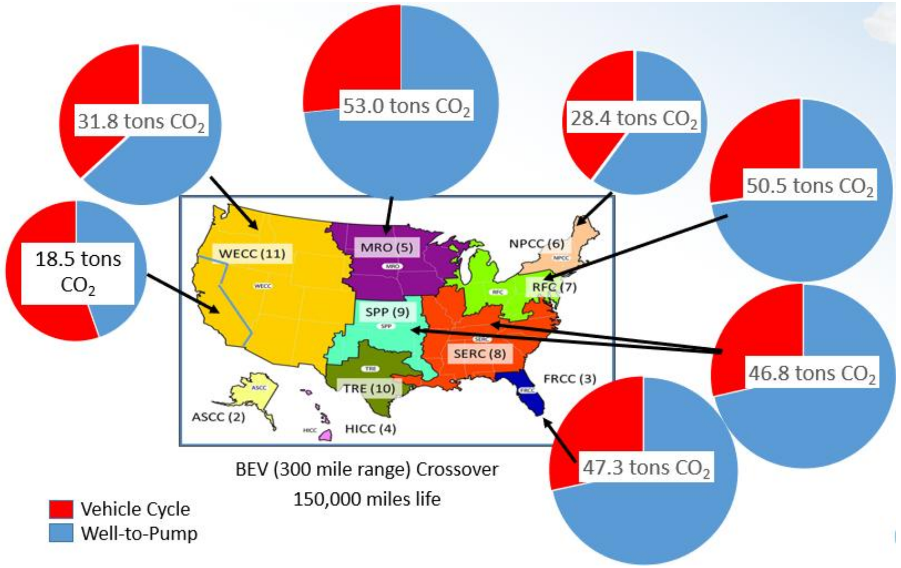
LCA Sensitivities: How the Assumptions Affect Results



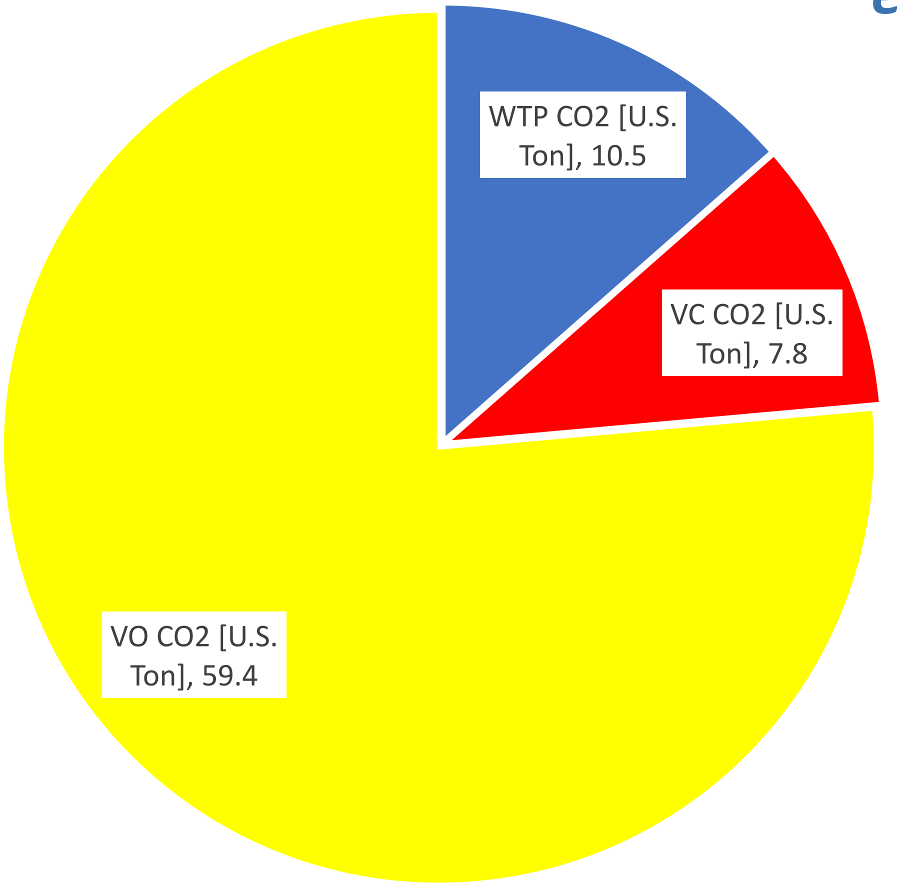




- Tailpipe GHGs scale with operation, so it is important to compare similar types of vehicles.
- Trends toward larger batteries result in higher production GHG emissions.
- Grid CO2 intensity has significant impact on upstream, and fuel carbon intensity significantly affects operation emissions

Vehicle-Fuel Combinations: Common LCA Comparison

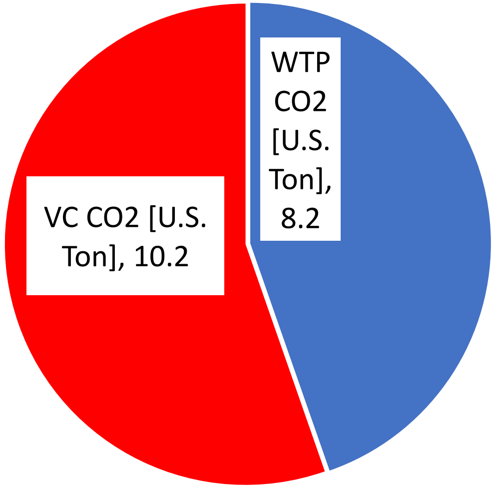
ICE SUV Running on E10
77.7 tons CO_2
470 g/mi



Battery Electric Vehicles, especially when charging from a renewable grid, are excellent technology choices for decarbonizing transportation.

Transportation Transition

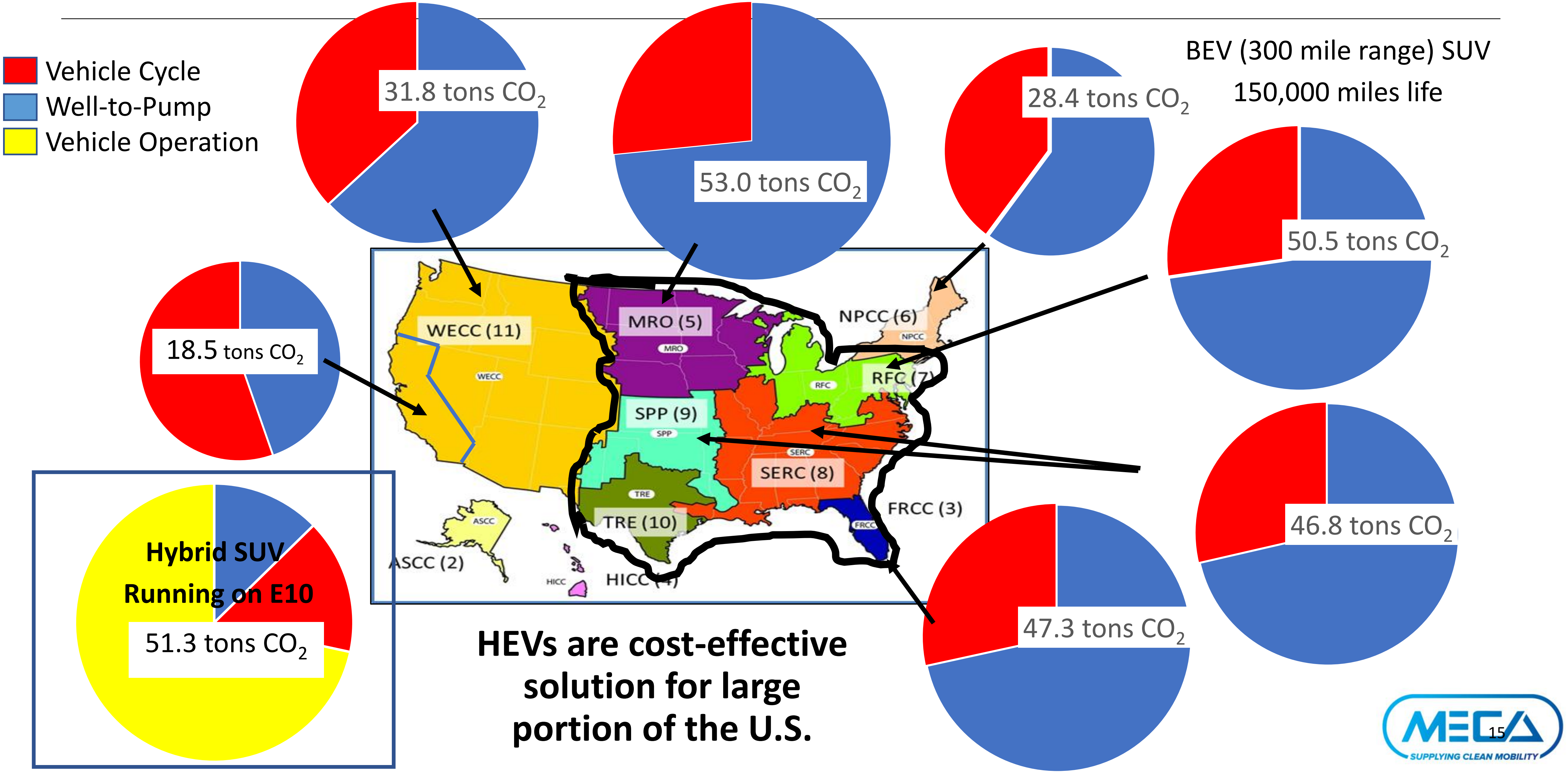
BEV (300 mile range) SUV
Running on California Grid
18.5 tons CO_2
112 g/mi



VO: Vehicle Operation
VC: Vehicle Cycle (manufacturing)
WTP: Well to Pump (fuel cycle)

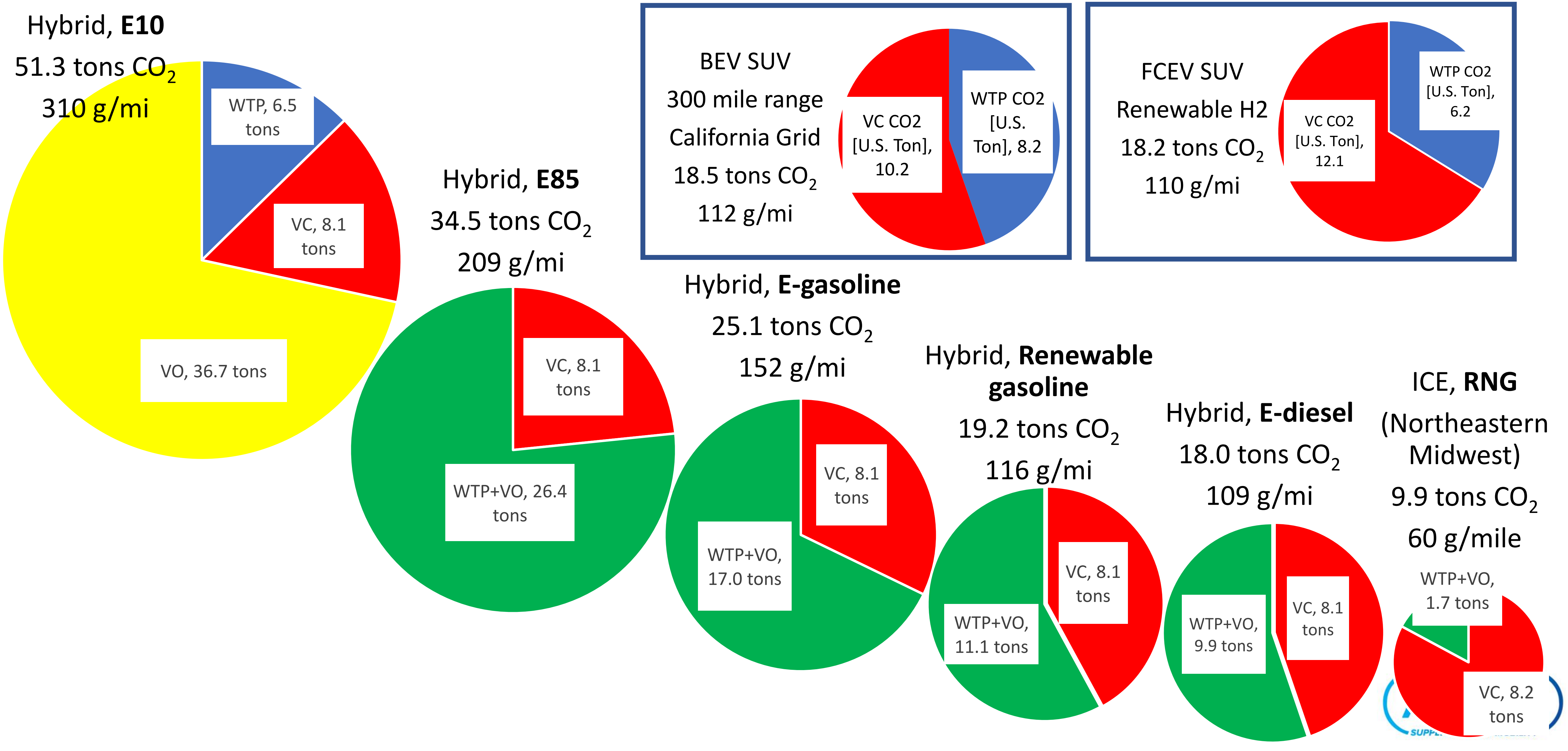
MEGA SUPPLYING CLEAN MOBILITY

Hybrids and BEVs Provide Similar GHG Benefits in 2030 in a Large Part of the U.S.



HEVs are cost-effective solution for large portion of the U.S.

Alternative Fuels Offer ICE Pathway to Reduce GHGs

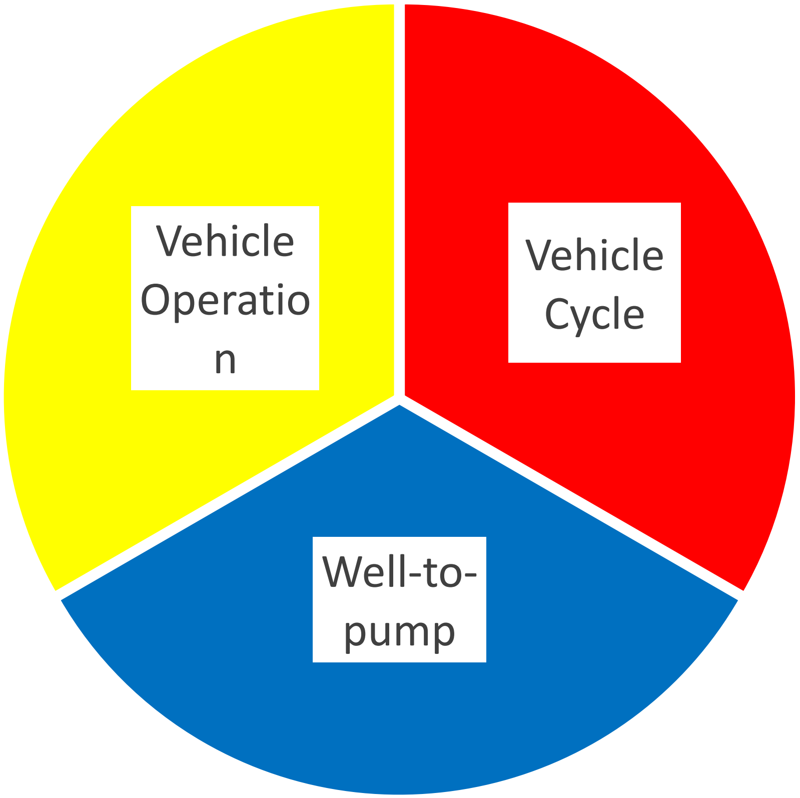


LCA Offers Balanced Approach to Reducing Transportation GHGs

ICEs: Downsized turbocharged engines, EGR, advanced fuel systems, variable valve actuation, advanced transmissions, hybridization

BEVs: High efficiency motors, thermal management

Fuels*: Low carbon fuels (bio, renewable, electro)

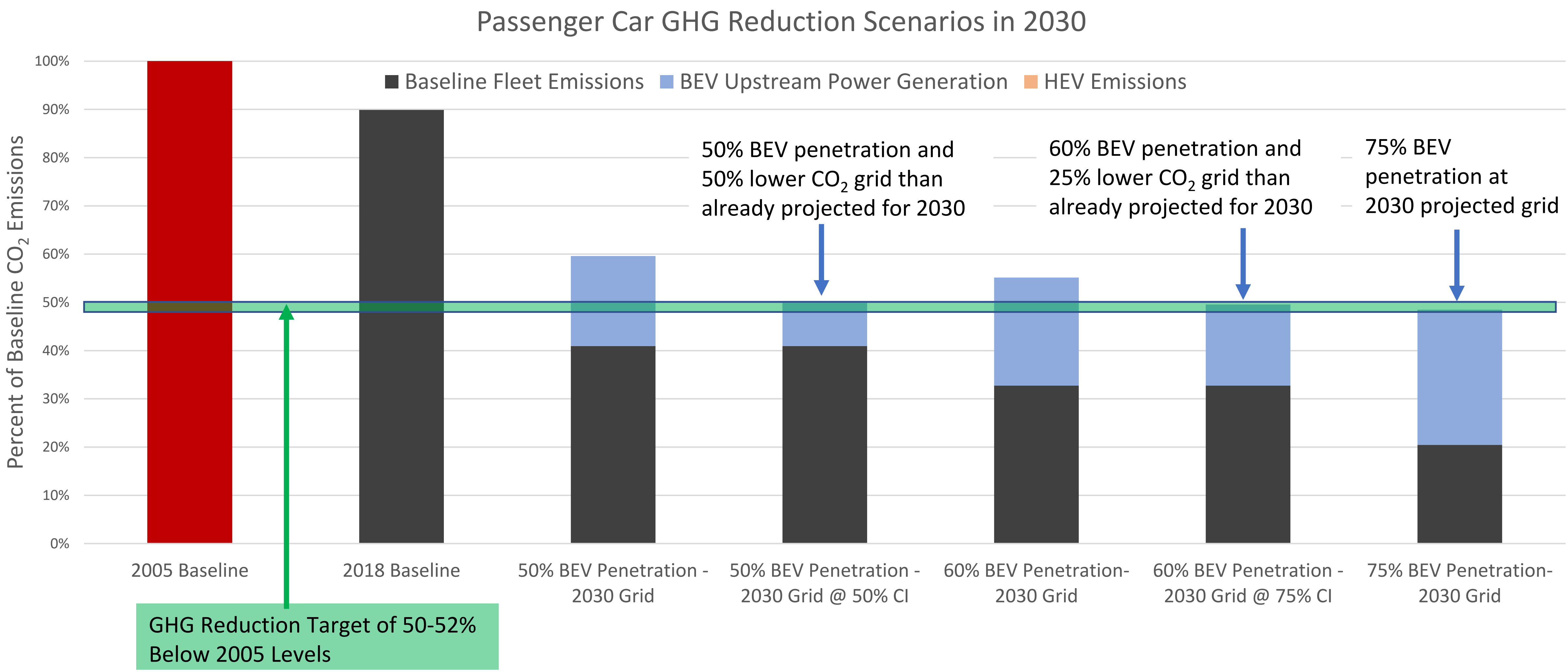


Sustainable manufacturing, recycled materials, battery chemistry, battery durability

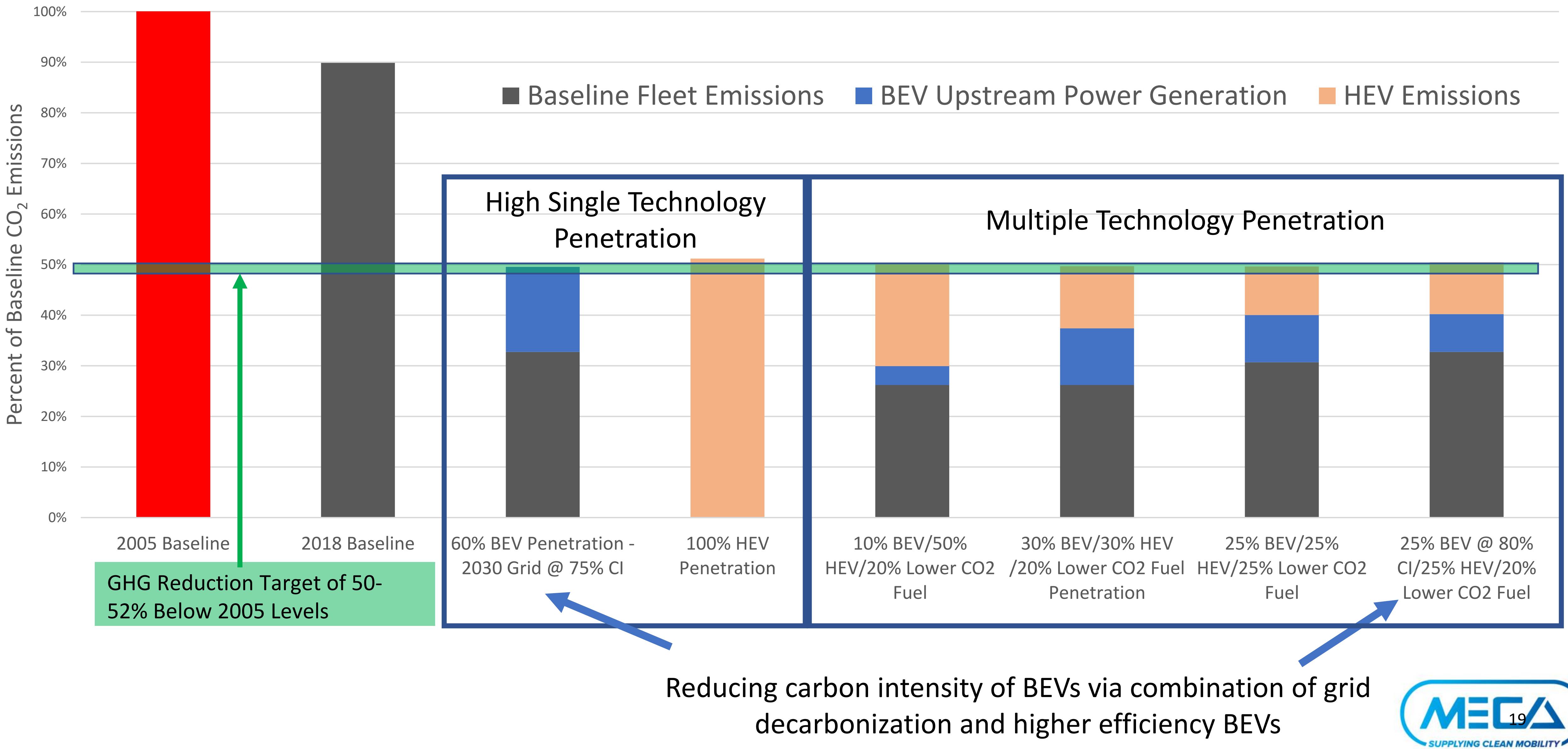
Increased renewable electricity for both vehicle charging and for fuel production and refining

**Fuel carbon may be discounted upstream (in well-to-pump) rather than during vehicle operation*

Meeting Climate Targets with only BEVs



Meeting Climate Targets with Multiple Solutions in 2030



Summary and Conclusions

- LCA is a tool to help technology suppliers understand future powertrain markets and inform regulators when developing GHG reduction strategies
- LCA outputs are sensitive to the baseline assumptions and future projections
- Policies that incentivize the efficiency of all powertrains, ICE and electric, will lead to maximum GHG benefits.
- Policies that decarbonize the grid and incentivize alternate fuel for in-use and new ICE vehicles will yield the greatest and fastest GHG benefits.

Thank You!

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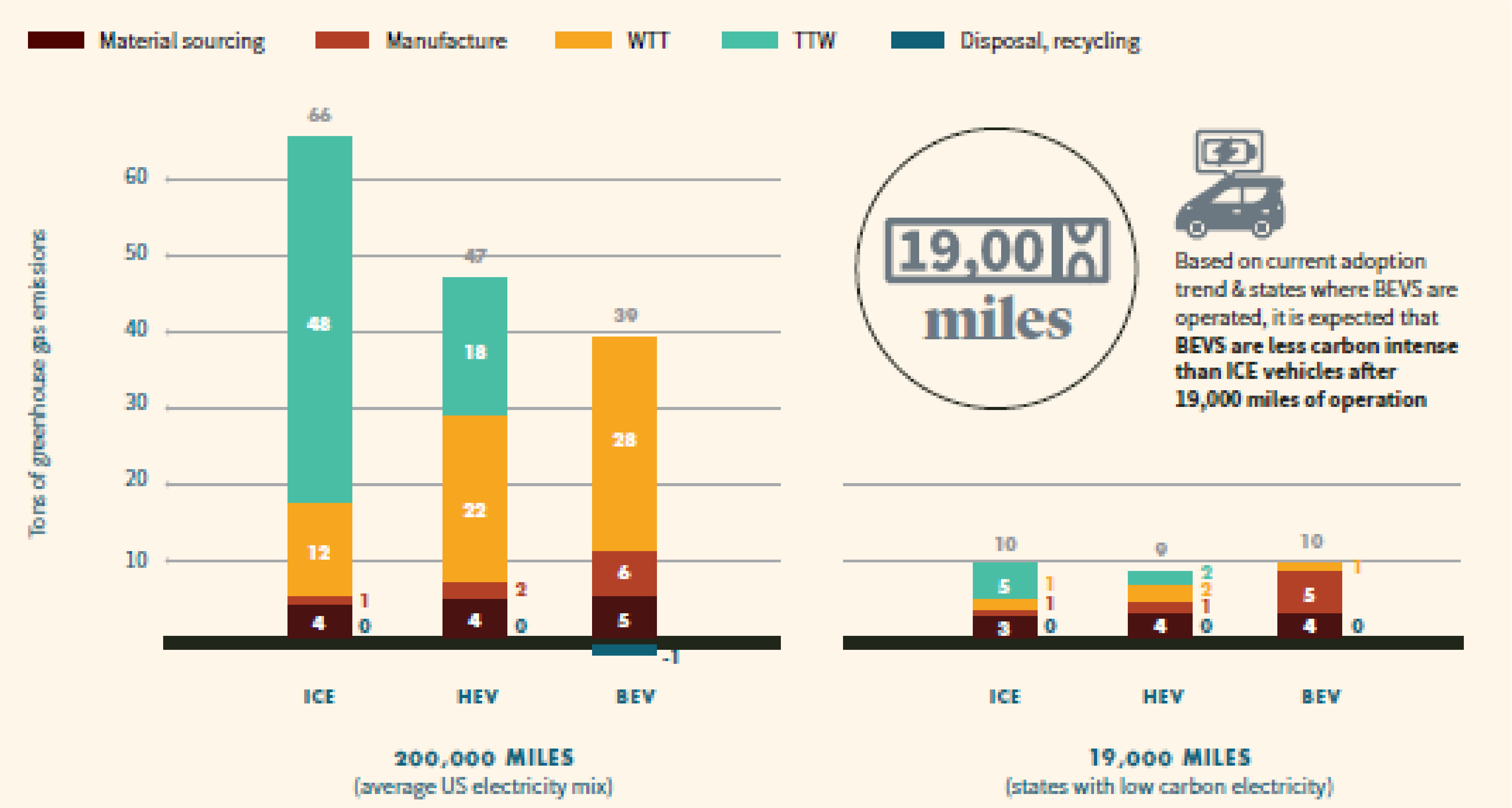
LCA Studies: Fuels Institute



Source: “Life Cycle Analysis Comparison,” Fuels Institute, January 2022.