

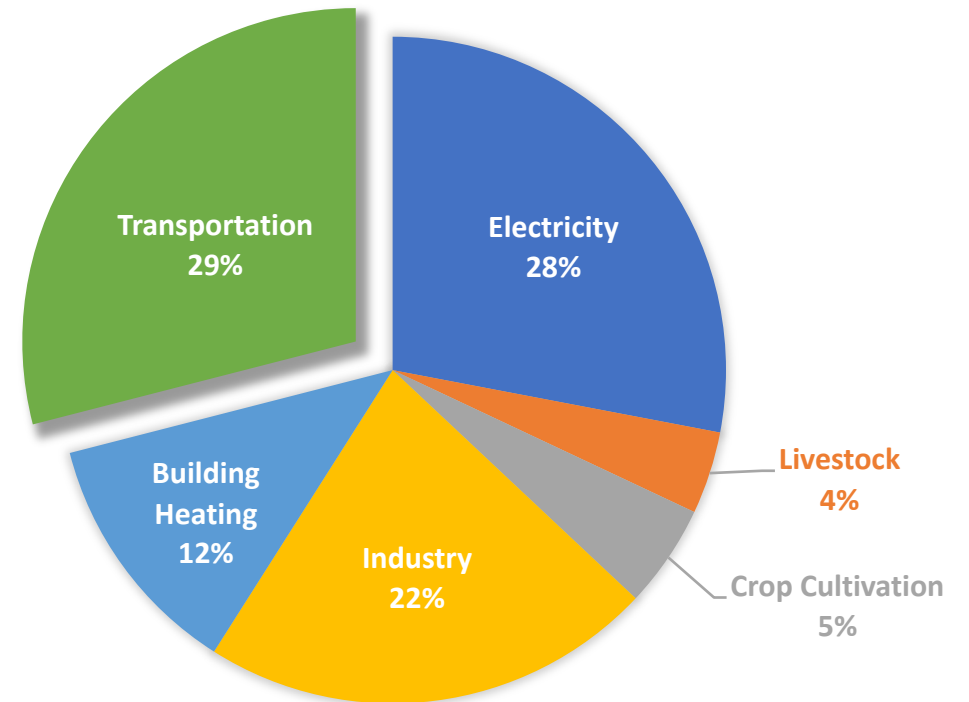


Understanding Electric Vehicles

Part of the Hydrogen Tech Brief Series

The Problem

- Halting global warming caused by CO₂ and other Green House Gases
 - All energy sectors must transition from fossil fuels to renewable energy
- The transportation sector needs a form of renewable energy that is
 - *Energy dense*
 - *Quickly transferred to vehicle*



US CO₂ Emissions by Sector - 2019

The Solution

- Two types of Electric Vehicles (EV's)
 - Battery EV's – Get their energy by charging
 - Fuel Cell EV's – Get their energy from hydrogen


	Batteries	Hydrogen	Impact
Energy Density	Low	High	Range & Travel Time
Speed of refueling	Slow	Fast	Travel Time

- In order to entice *all* drivers to switch to renewable energy
 - Vehicles need to offer the same *performance* and *convenience* as petroleum
 - Fuel Cell EV's provide the same user experience as gas & diesel:
 - ✓ 3-Minute Refueling
 - ✓ Range Undiminished by Cold Weather
 - ✓ Light, Compact, Abundant Energy for Trucks & RV's
 - ✓ Full Driving Range with Heavy Loads and Towing

The Customer's Perspective – Comparing Options

Characteristic	Battery EV	Petroleum Vehicles	Fuel Cell EV
Fuel cost per mile	3.5¢ (warm weather) 5.8¢ (cold weather)	11¢	11¢
Fueling Time Long Trips (450 mile example)	1 hour (2 stops, 30 minutes)	3 minutes	3 minutes
Refueling Temperature	Charge only when battery above 32° F	Any Temperature	Any Temperature
Range at Hot and Cold	Reduced 20% to 50%	Unaffected	Slight effect
Suitability for Large SUV Trucks and RV's	Battery weight, bulk & cost become limiting	Unlimited	Unlimited
Impact of Towing	Decreased Range	Decreased Mileage	Decreased Mileage
Fueling / Recharging	Charge at home or public chargers	Gas stations	Hydrogen Fuel Stations

Sweet Spot for
Battery EV's

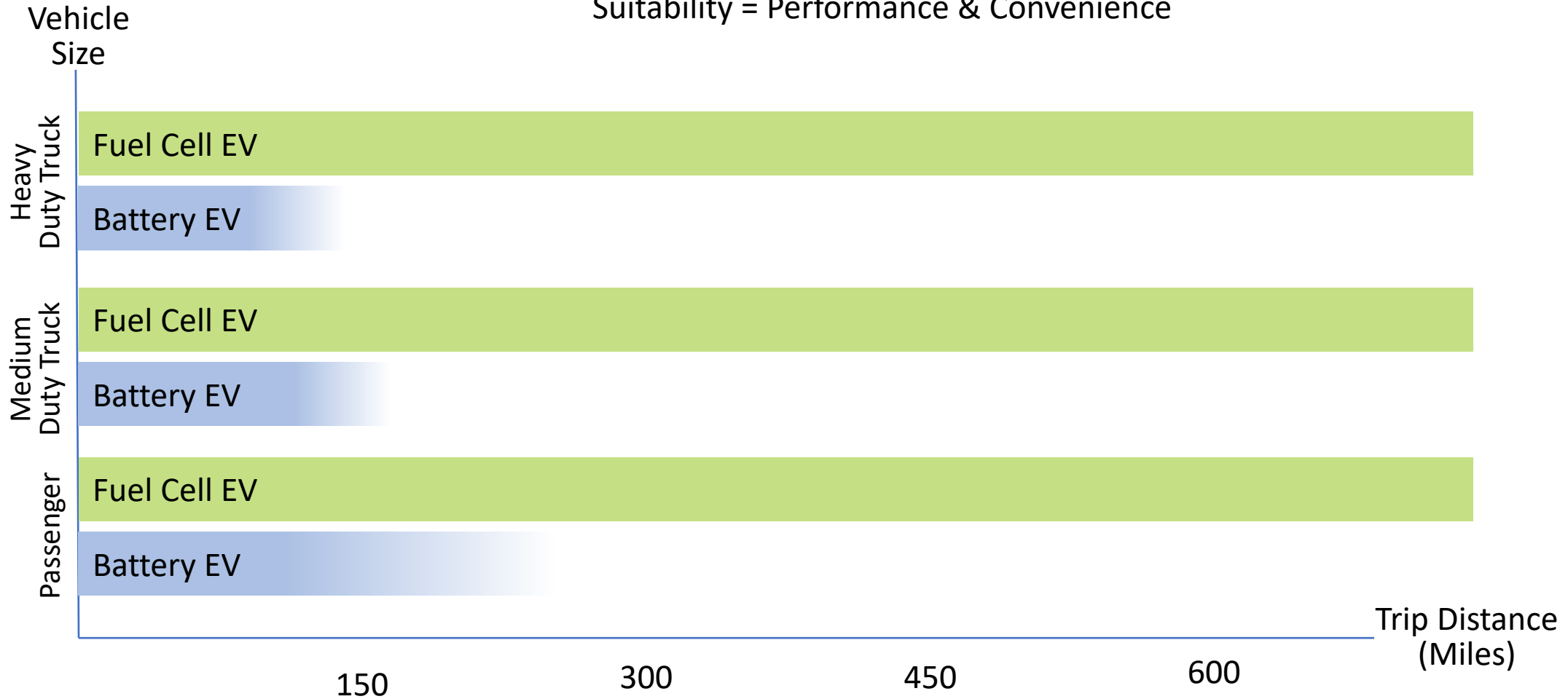


Sweet Spot for
Fuel Cell EV's



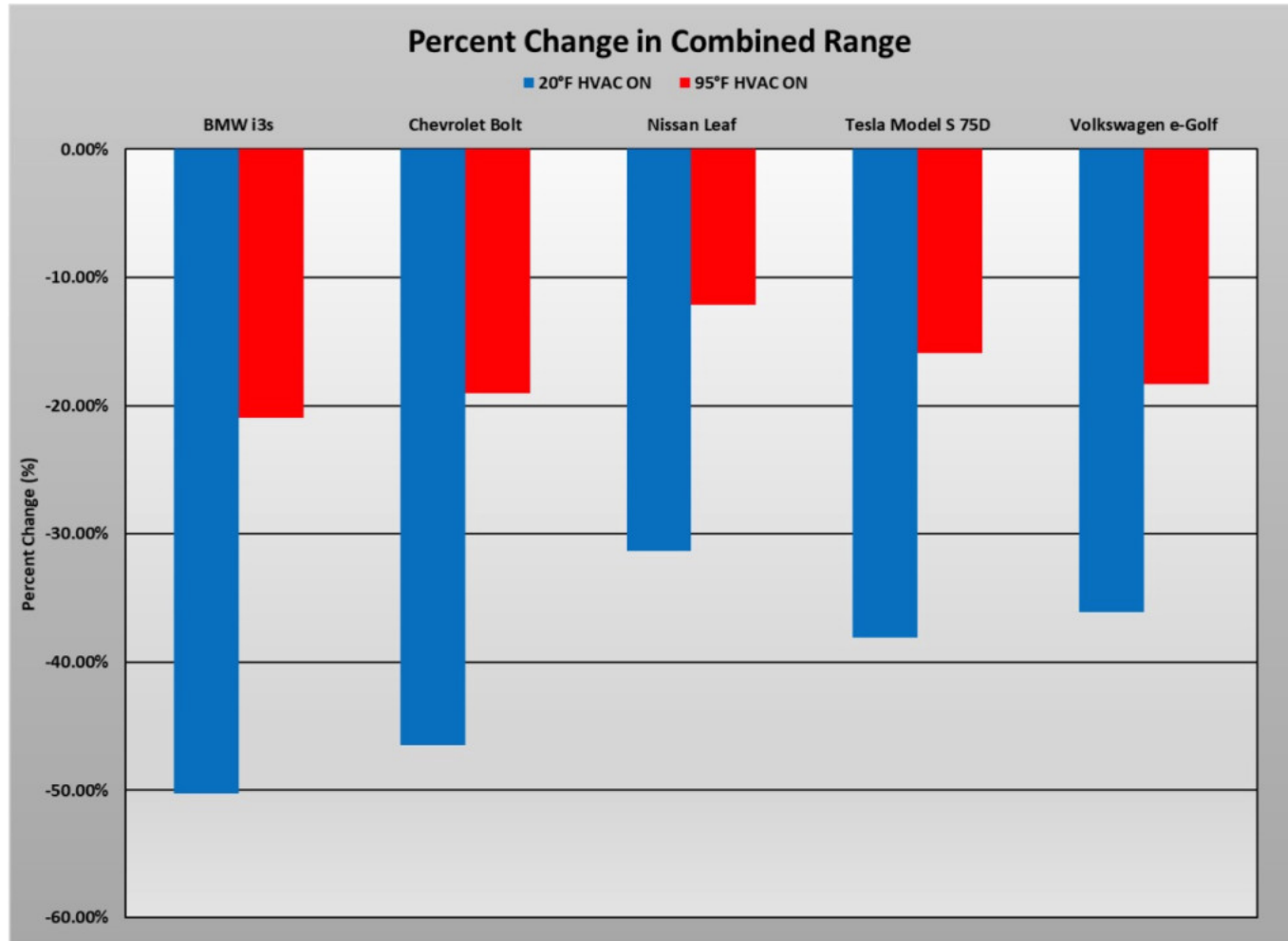
Suitability for EV Type by Range

Suitability = Performance & Convenience



Battery Temperature Performance

Change Relative to 75° F



Two Reasons

1. Battery output less at cold
2. Power-hungry Heater & A/C

Source: American Automobile Association <https://www.colorado.aaa.com/news/study-icy-temps-kill-electric-vehicle-range>

Refueling Comparison

	Charging	Hydrogen
Refuel Time	<ul style="list-style-type: none"> • 40 minutes per 300 miles • Frequent fast-charging harms the battery 	3 minutes per 400 miles
Availability	<ul style="list-style-type: none"> • Charge at home but . . . • Issues for apartments & low-income 	<ul style="list-style-type: none"> • Need build-out of stations but . . . • Stations can service hundreds of cars per day
Useable Life	<ul style="list-style-type: none"> • Battery lasts half the life of the vehicle • Replacement expensive 	Fuel Cell lasts the life of the vehicle
Zero Carbon?	Until grid is 100% renewable, not all vehicles will be charging with green power	H2 fuel stations can use 100% green power today via agreements with the utilities
In the Long Term	<ul style="list-style-type: none"> • Inability of the grid to supply wide-spread fast-charging • Problematic getting power for fast-charging to small towns and rural sites 	On-site electrolysis plus H2 delivery: <ul style="list-style-type: none"> • Delivery of hydrogen relieves the grid • Delivery suitable for small towns or rural stations

Take-Away

- To limit climate change,
we need to entice ALL users to switch to electric vehicles
 - Therefore we need vehicles that satisfy ALL use cases
 - Fuel Cell EV's for large vehicles, longer trips, cargo capacity, cold weather
 - Battery EV's for light vehicles and around-town trips
- Charge time for Battery EV's will never be as fast as fueling
 - Limited by the amount of power that can safely be applied to the vehicle