2010 Advanced Energy Conference

Electrification Technology and the Future of the Automobile

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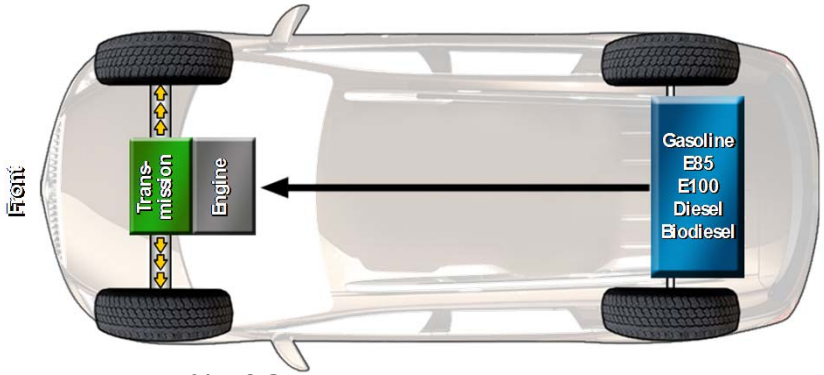
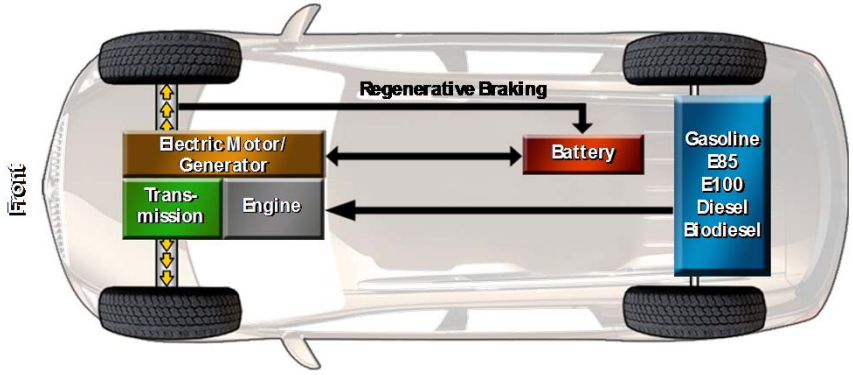
Transitioning From Mechanical to Electrical

Conventional Liquid-Fueled Vehicle



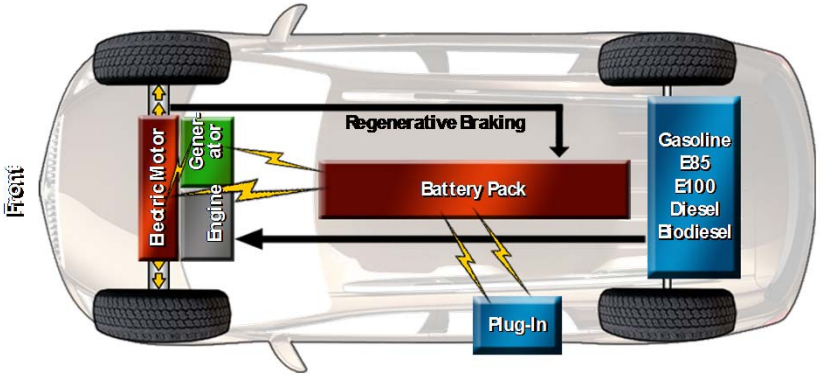
99% of Global Annual Vehicle Production

Hybrid Vehicle (HV)



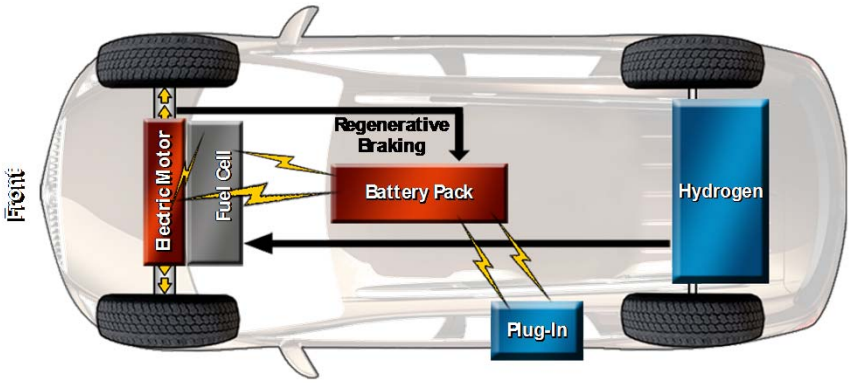
<1% of Global Annual Vehicle Production

Extended-Range Electric Vehicle (EREV)



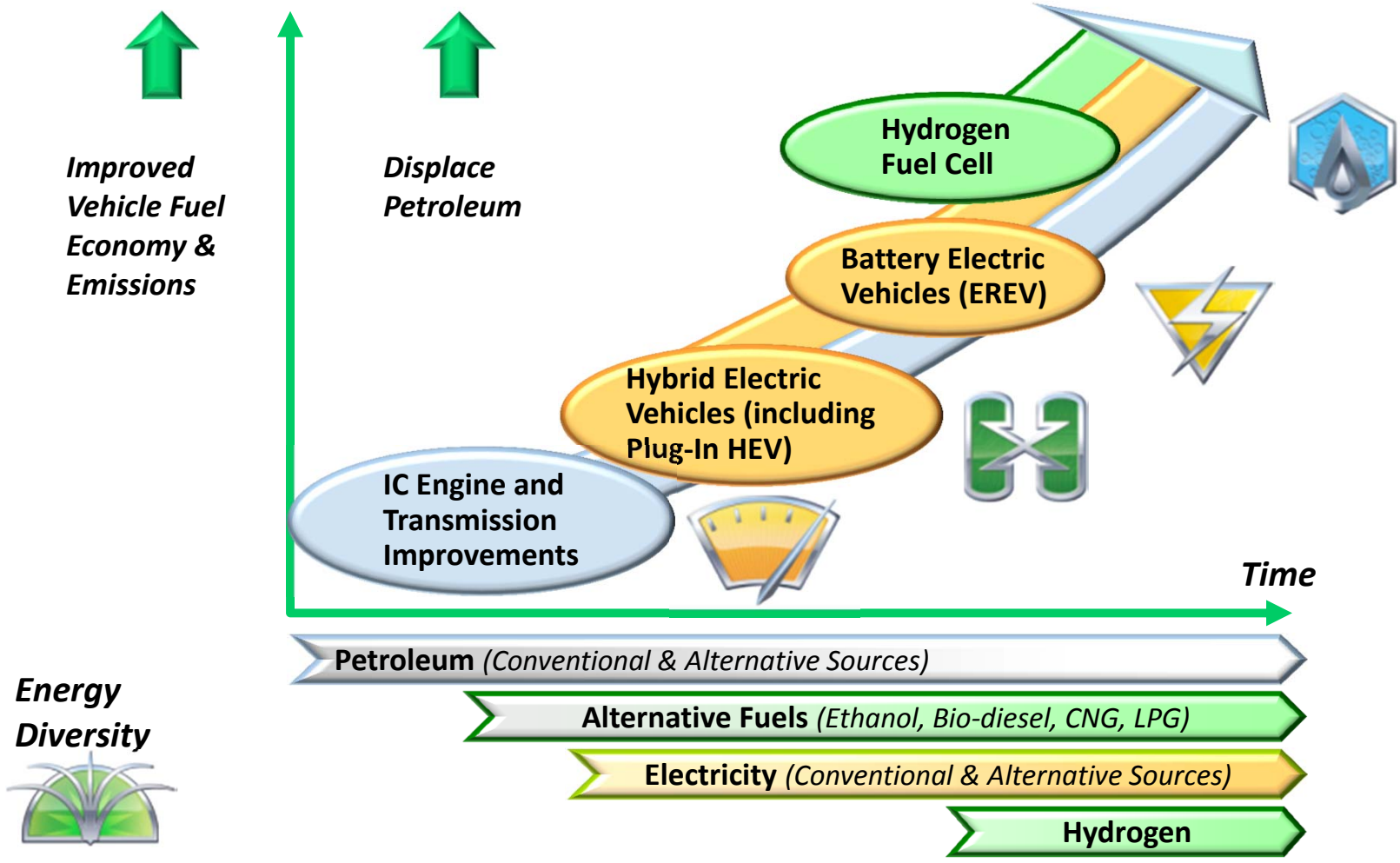
Battery Electric Vehicle (BEV) =
EREV – Engine – Generator – Fuel Tank

Fuel Cell Electric Vehicle (FCEV)

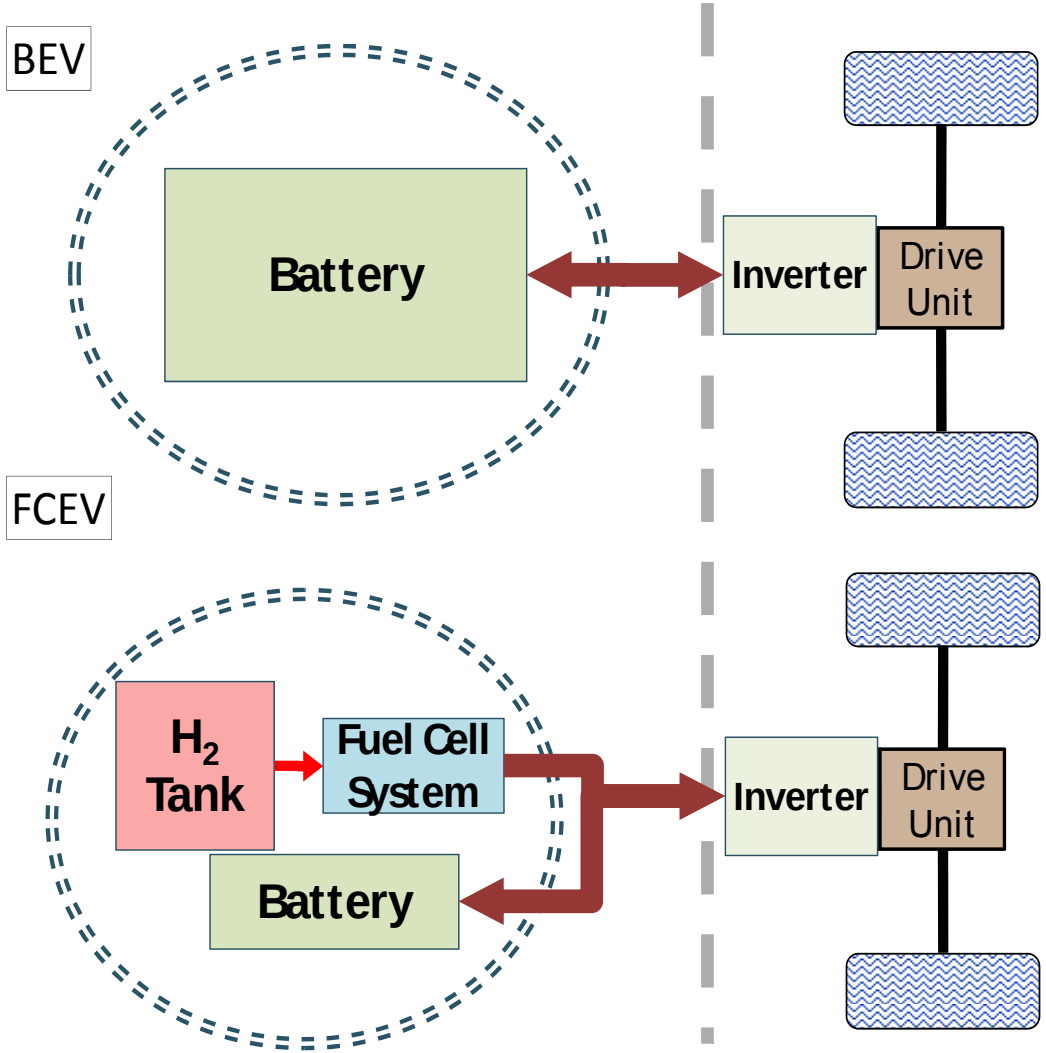


Three electric vehicle options: BEV, EREV, FCEV

Advanced Propulsion Technology Strategy
No single silver bullet exists



On-Board Electricity Generation
Battery vs. Fuel Cell



Source: F. T. Wagner, B. Lakshmanan, and M. F. Mathias, Electrochemistry and the Future of the Automobile, *The Journal of Physical Chemistry Letters*, 2010, 1, 2204-2219

Design of BEV and FCEV Energy Systems

Configuration	Main Electricity Generator	Energy Storage	Hybrid Battery
Battery (BEV)	80 kW, Li-ion battery[(a)], 95% efficient discharge	Li-ion battery, 80% of rated charge utilized	Not Needed
Fuel Cell (FCEV)	80 kW Fuel Cell System[(b)], 57% efficient	700 bar H_2 storage[(c)]	40 kW, 1.7 kWh, 30% of rated charge utilized[(d)]

(a) USABC Long-term goals for Advanced Batteries for EVs (300 Wh/l, **200 Wh/kg**)

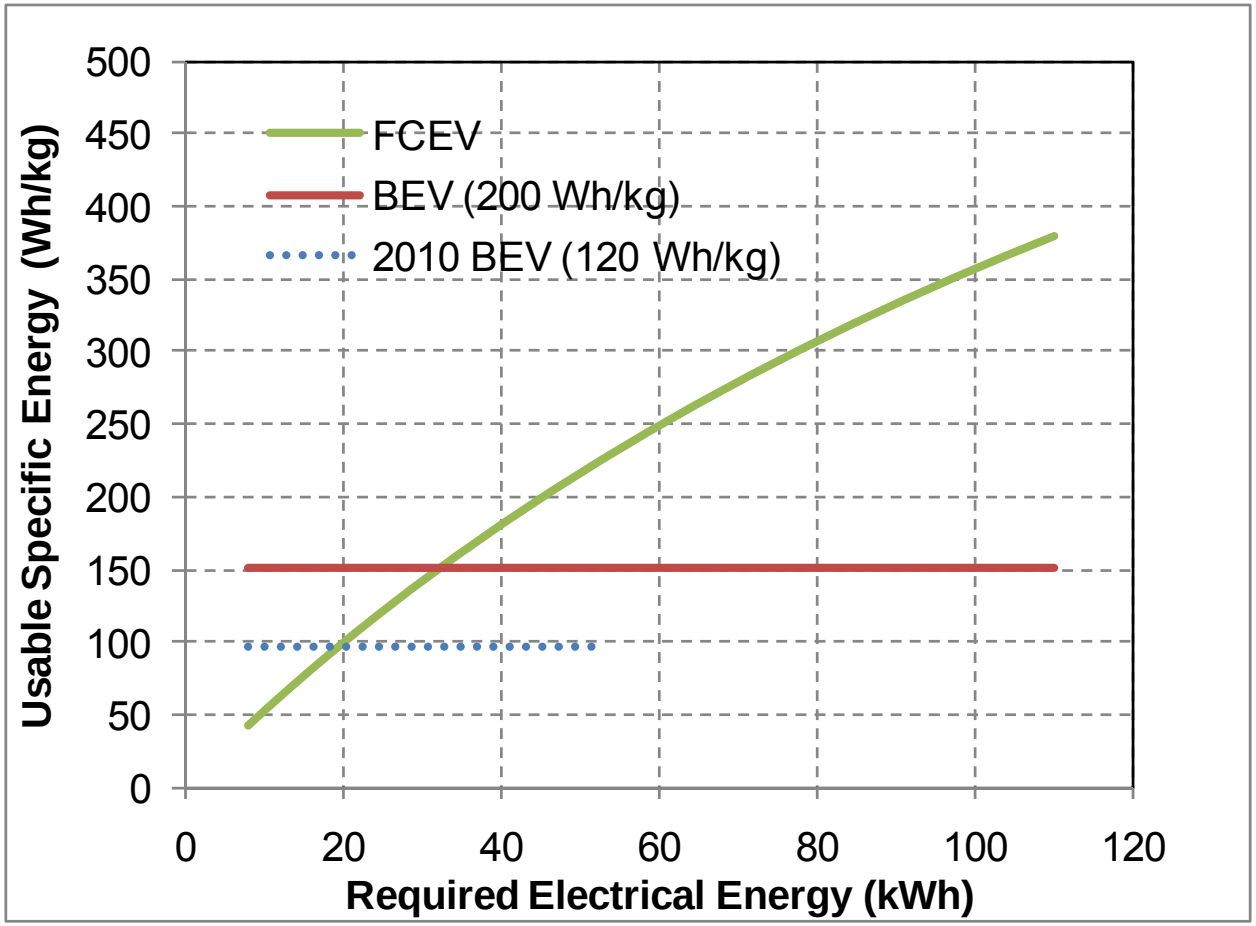
(b) DOE 2015 goals for Fuel Cell System (620 W/l, 650 W/kg → **123 kg** for 80 kW system)

(b) DOE 2015 H_2 Storage System goals of 1500 Wh/l and **1800 Wh/kg** based on lower heating value of hydrogen 33.3 kWh/kg translating to 4.5% hydrogen stored on a mass basis.

(d) USABC 2015 goals for Maximum Power-Assist Battery (45 l, **60 kg**)

Source: F. T. Wagner, B. Lakshmanan, and M. F. Mathias, Electrochemistry and the Future of the Automobile, *The Journal of Physical Chemistry Letters*, 2010, 1, 2204-2219

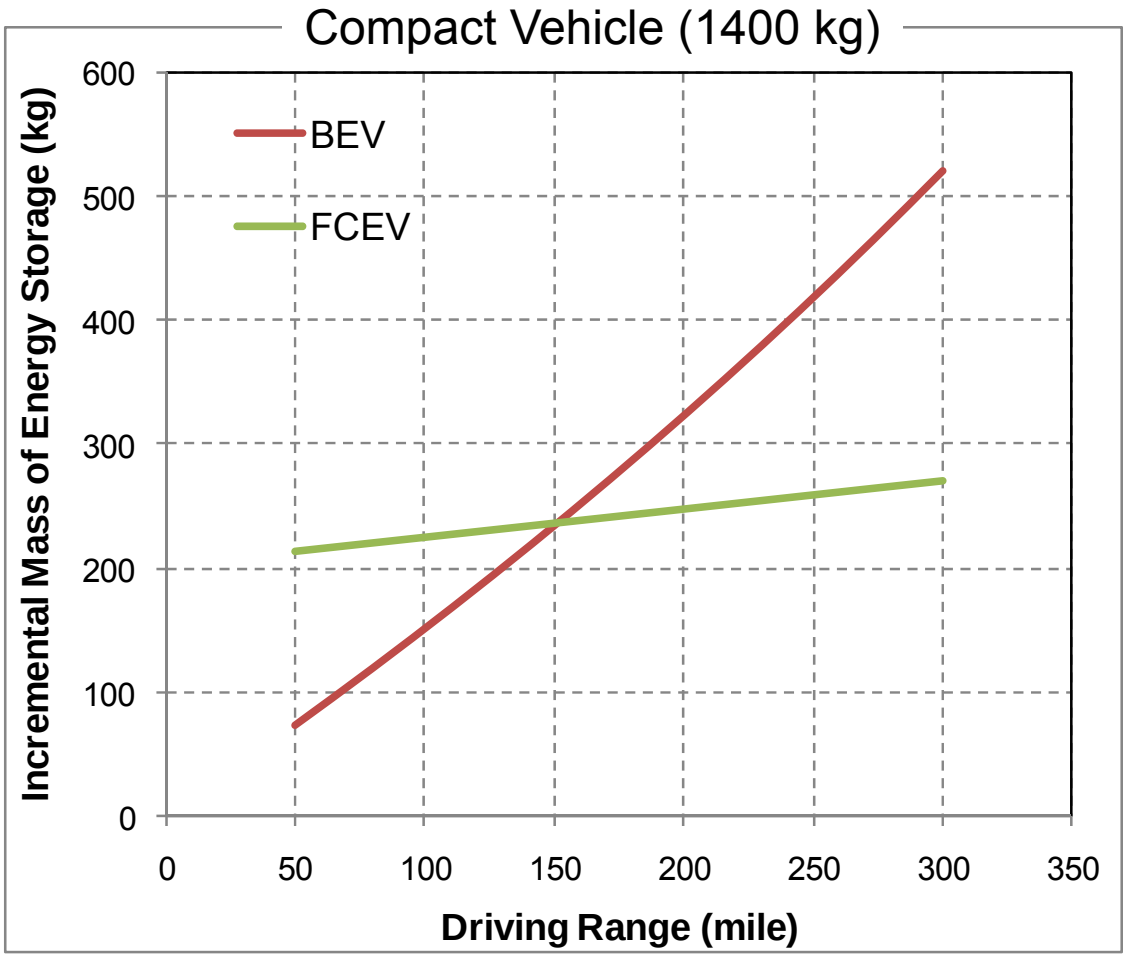
Specific Energy vs. Energy Required



It is the fundamental dependence of the specific energy on the amount of electricity required which determines the applicability of these systems in vehicles of various size and range.

Source: F. T. Wagner, B. Lakshmanan, and M. F. Mathias, Electrochemistry and the Future of the Automobile, *The Journal of Physical Chemistry Letters*, 2010, 1, 2204-2219

Electric Power System Mass vs. Vehicle Range



Fuel cells are preferred electrification approach for long-range driving

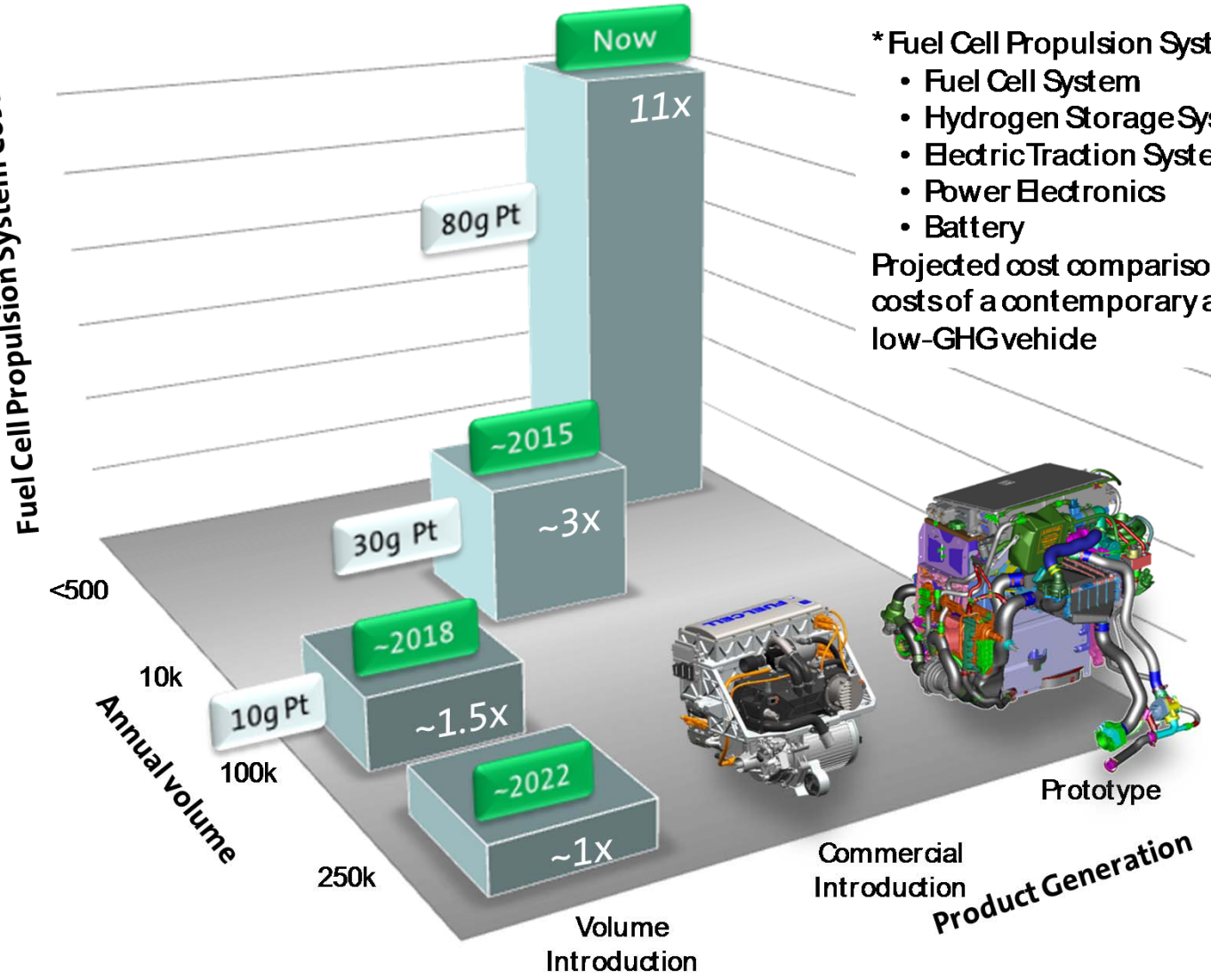
Source: F. T. Wagner, B. Lakshmanan, and M. F. Mathias, Electrochemistry and the Future of the Automobile, *The Journal of Physical Chemistry Letters*, 2010, 1, 2204-2219

Comparison of Electric Vehicles

	Battery-Electric Vehicle (BEV)	Fuel Cell-Electric Vehicle (FCEV)
Vehicle Size	≤ Small	≤ Family
Refueling Time	Hours	Minutes
Range (Miles)	100+	300-400
Performance	Excellent	Excellent
Vehicle Emissions	Zero	Zero
Energy Source	Diverse/petroleum free	Diverse/petroleum free
Refueling Infrastructure	Available at home with cost	Must be deployed
Fuel Cost	3¢/mile (3 mile/kWh, 10¢/kWh)	4¢-8¢/mile (70 mile/kg, $3-6/kg)

Fuel Cell Propulsion System Commercialization

Automotive Competitive Cost Glide Path – Compact Sedan



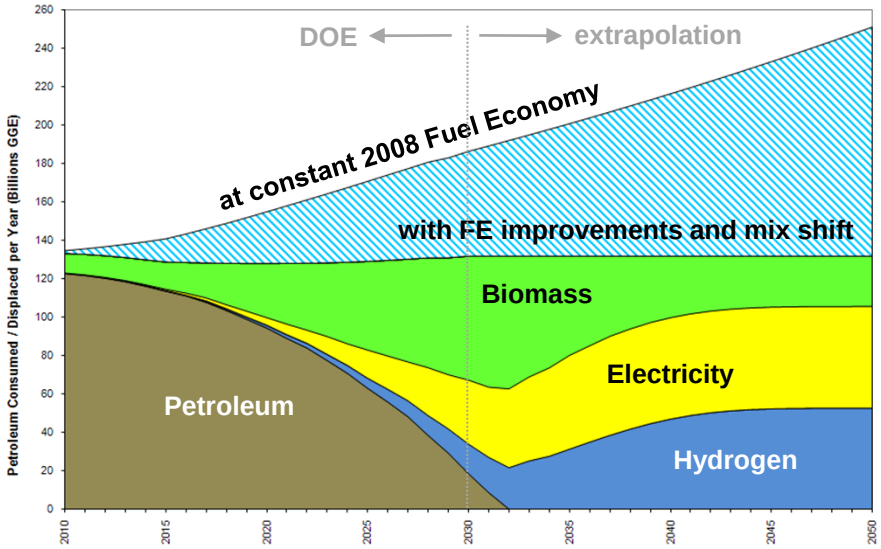
*Fuel Cell Propulsion System:

- Fuel Cell System
- Hydrogen Storage System
- Electric Traction System
- Power Electronics
- Battery

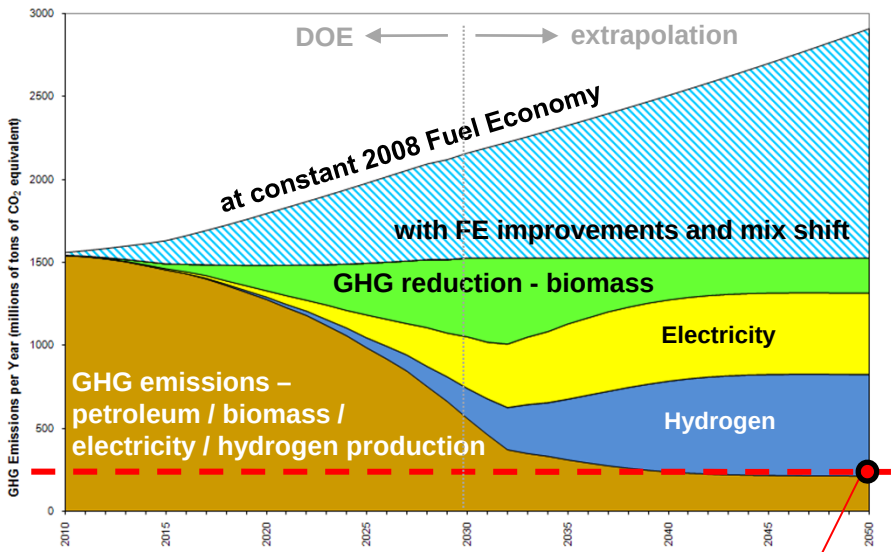
Projected cost comparison to costs of a contemporary adv tech low-GHG vehicle

Aggressive approach with portfolio of technologies

Petroleum Consumption



Greenhouse Gas Emissions



Goal – 80% reduction from 1990 level by 2050

- Cellulosic biomass ramps to high volume; Electric and plug-in vehicles make 40% of miles traveled electric; Fuel cell vehicles penetrate to 40% of on-road fleet by 2050
- Light duty vehicle fleet mostly transitioned to electric drive and zero-emission vehicle solutions
- U.S. electric grid greenhouse gas emissions modeled at 80% lower than 2008 levels
- Hydrogen from cellulosic biomass or clean electricity

Start soon with early options; finish with strongest long-term portfolio

Summary

- Whereas several interesting options for vehicle electrification exist, there is still large uncertainty on business case scenarios
- Emerging battery technology (Li-ion) is heavy relative to the fuel cell option, resulting in preferred use in small, short-range applications
- Must continue aggressive work on Battery and Fuel Cell vehicles, and supporting infrastructure development