Transportation Electrification

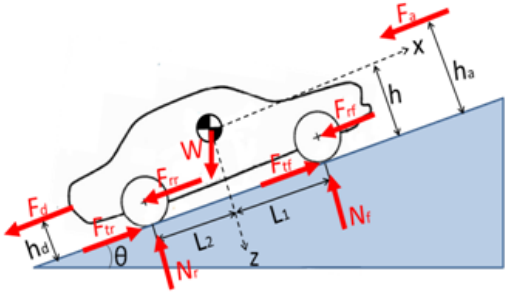
Motivation

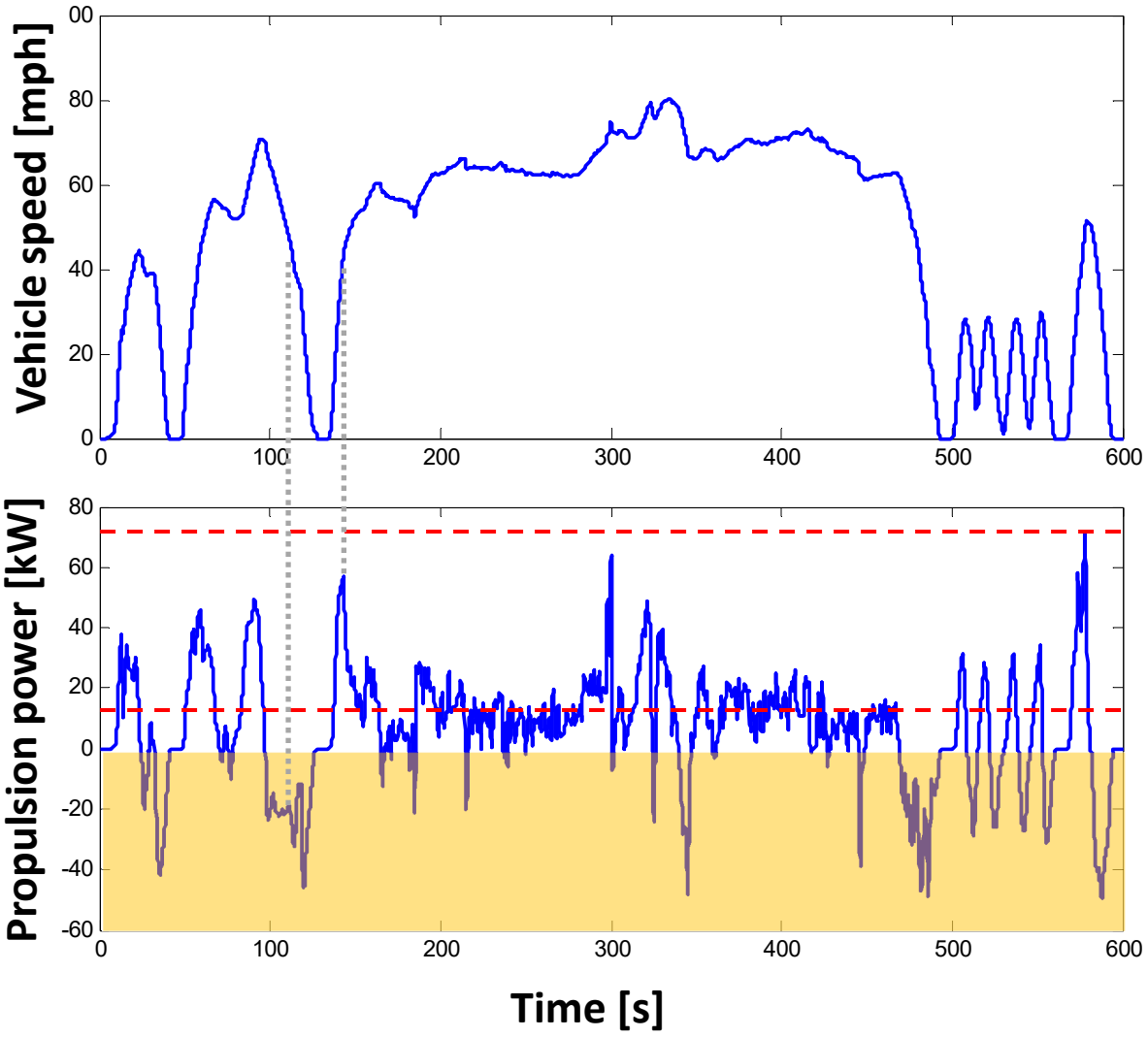
- Improve efficiency: reduce energy consumption
- Displace petroleum as primary energy source
- Reduce impact on environment
- Reduce cost

US Energy Information Administration:

- Transportation accounts for 28% of total U.S. energy use
- Transportation accounts for 33% of CO_2 emissions
- Petroleum comprises 90% of US transportation energy use

Example: US06 driving cycle

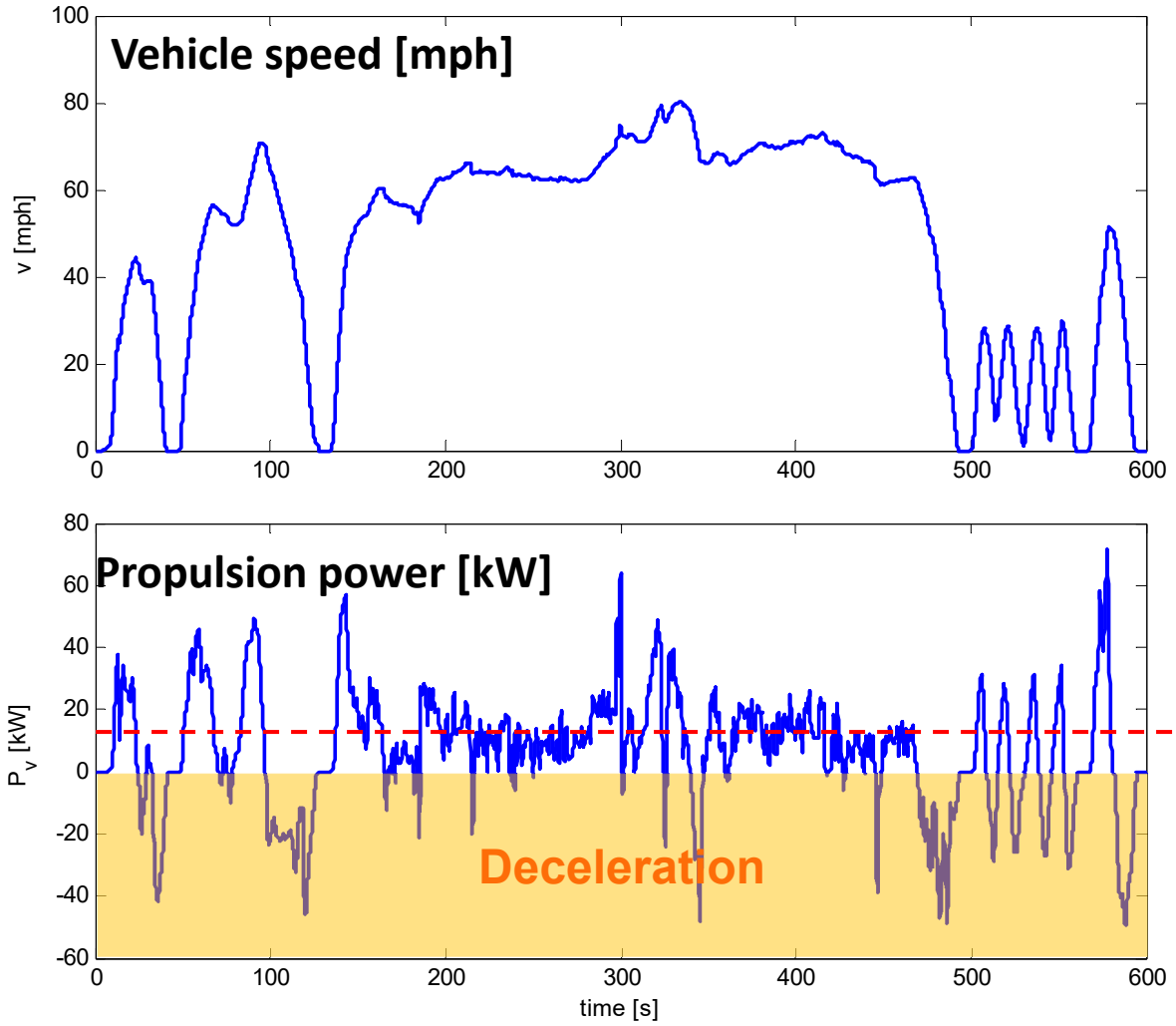




10-min
8 miles

Example:
Prius-sized
vehicle

Example: US06 driving cycle



10-min
8 miles

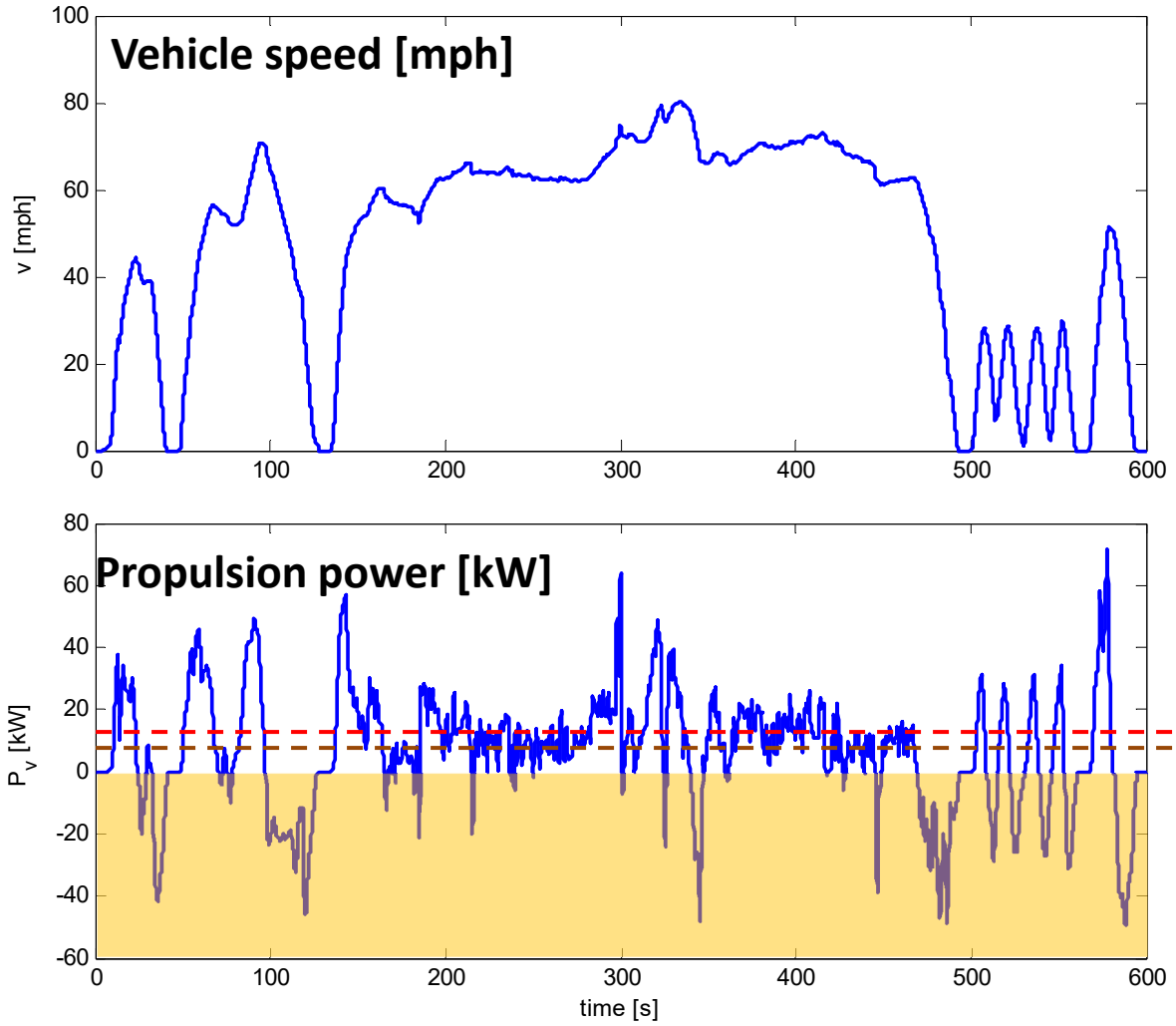
Prius-sized vehicle

Dissipative braking

P_{vavg} = 11.3 kW

235 Wh/mile

Average power and energy



Prius-sized vehicle

Dissipative braking

P_{vavg} = 11.3 kW

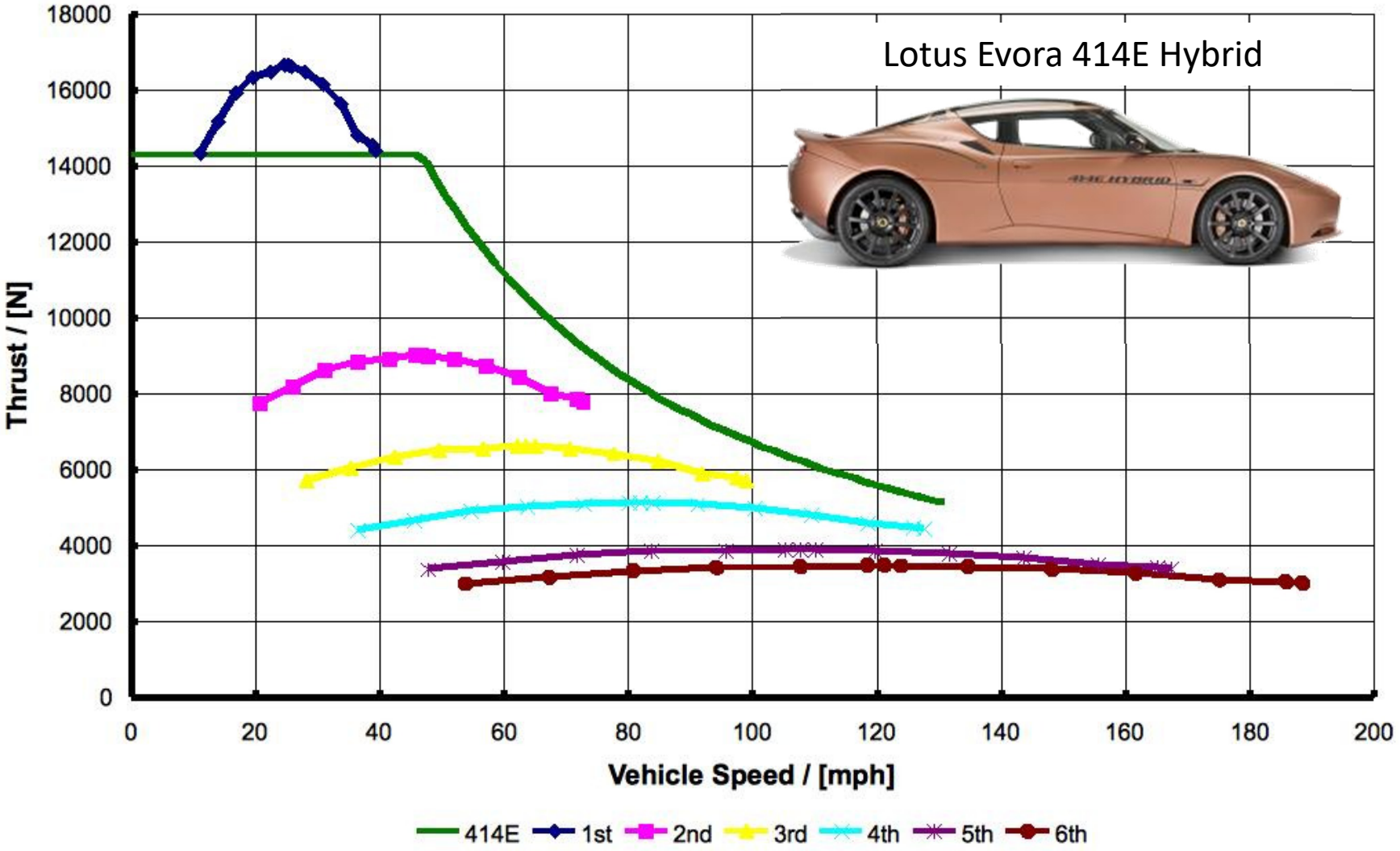
235 Wh/mile

Regenerative braking

P_{vavg} = 7.0 kW

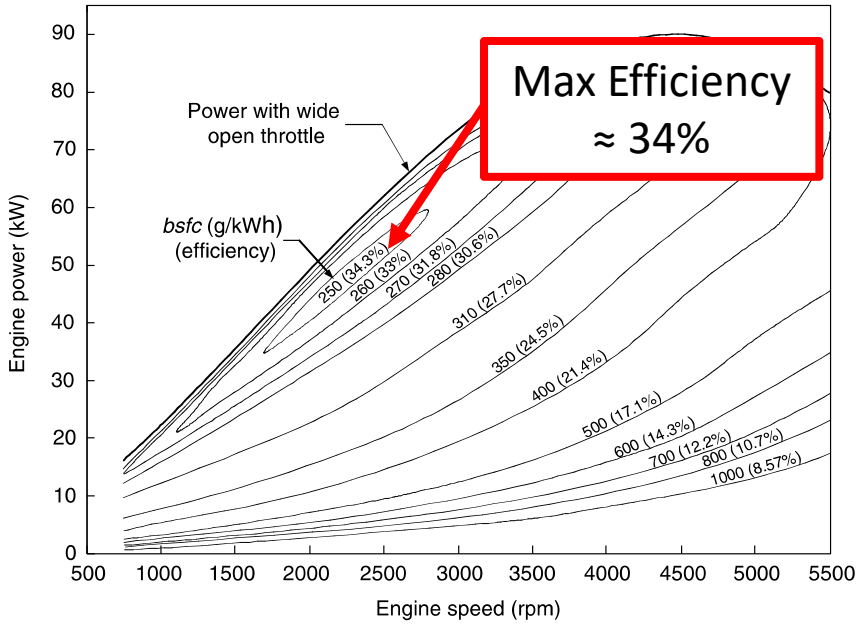
146 Wh/mile

ICE vs ED τ–ω

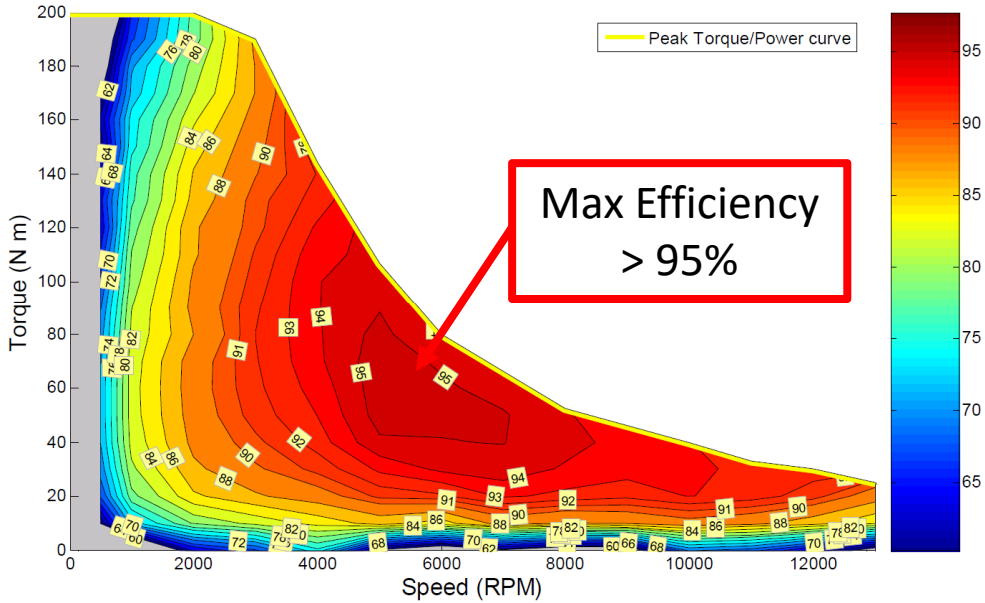


"Full Acceleration", proactive Magazine, Oct. 2012

ICE vs. ED η



Internal Combustion Engine (ICE)



Electric Drive (ED)

- $\eta_{ED,pk} \approx 95\%$; $\eta_{ICE,pk} \approx 35\%$
- ED offers full torque at zero speed
  - No need for multi-gear transmission

Conventional Vs. Electric Vehicle

(Commuter Sedan comparison)

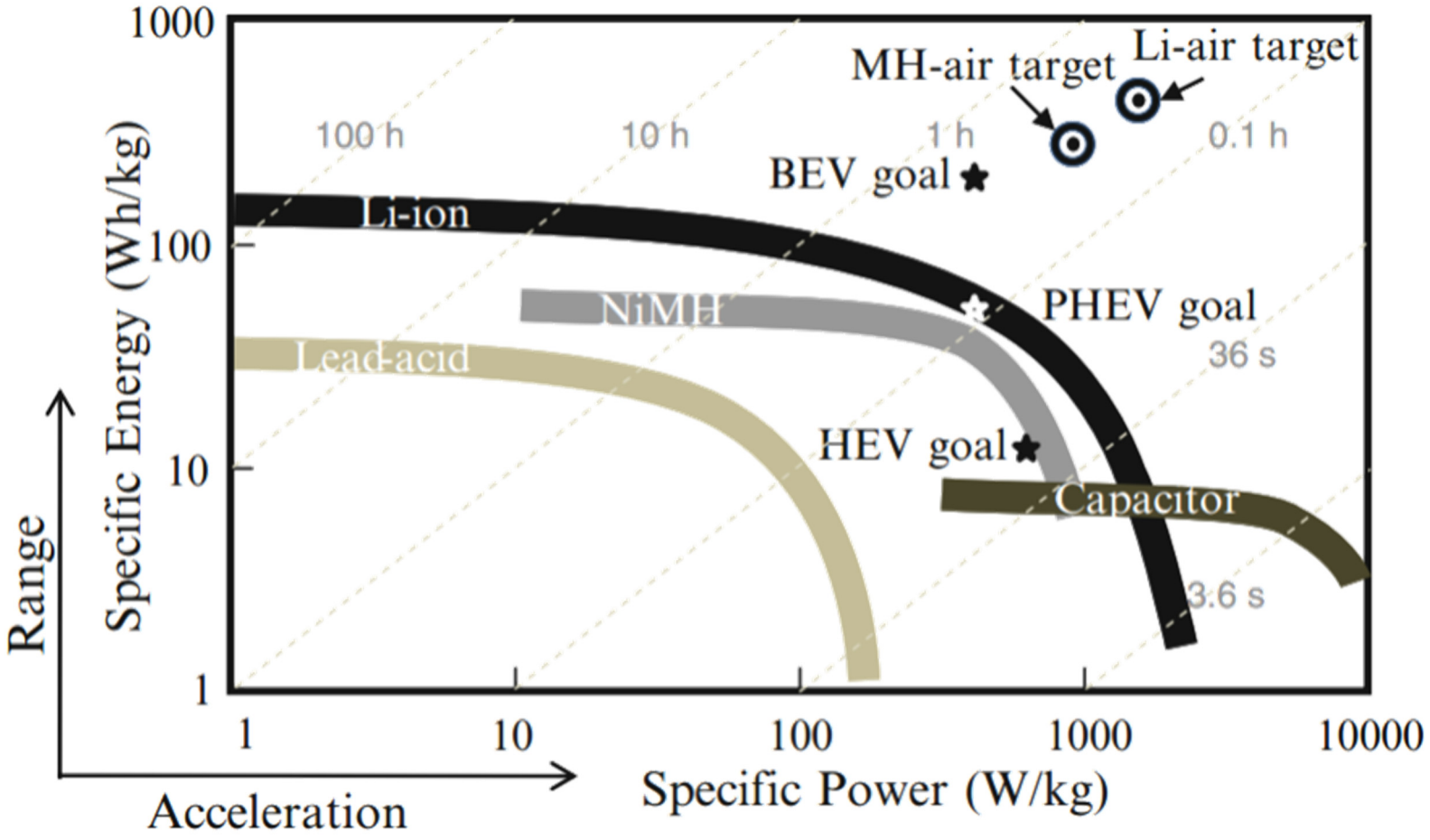
	Tank + Internal Combustion Engine	Electric Vehicle (EV) Battery + Inverter + AC machine
Regenerative braking	NO	YES
Tank-to-wheel efficiency	≈ 20% 1.2 kWh/mile, 28 mpg	≈ 85% 0.17 kWh/mile, 200 mpg equiv.
Cost	12 ¢/mile [$3.50/gallon]	2 ¢/mile [$0.12/kWh]
CO_2 emissions (tailpipe, total)	≈ (300, 350) g CO_2/mile	(0, ≈120) g CO_2/mile [current U.S. electricity mix]
Energy Costs (10-yr, 15k mi/yr)	$18,000	$3,000

Energy and Power Density of Storage

12000

2016 Camaro
6.2L V8

Mazda RX-8
1.3L Wankel



Conventional Vs. Electric Vehicle

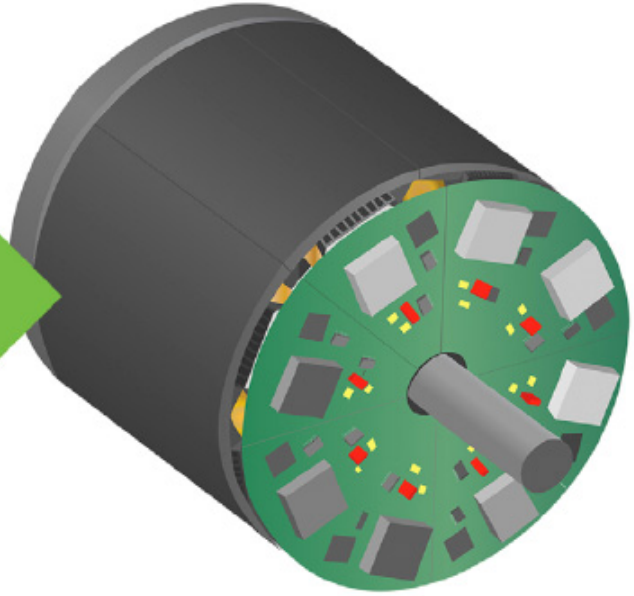
(Commuter Sedan comparison)

	Tank + Internal Combustion Engine (Ford Focus ST)	Electric Vehicle (EV) Battery + Inverter + AC machine (Ford Focus Electric)
Purchase Price	$24,495	$39,995
Significant Maintenance	$5,000 (Major Engine Repair)	$13,500 (Battery Pack Replacement)
Range	> 350 mi	< 100 mi
Curb Weight	3,000 lb	3,700 lb
Energy storage	Gasoline energy content **12.3 kWh/kg, 36.4 kWh/gallon**	$LiFePO_4$ battery 0.1 kWh/kg, 0.8 kWh/gallon
Refueling	5 gallons/minute **11 MW**, 140 miles/minute	Level I (120Vac): 1.5 kW, <8 miles/hour Level II (240Vac): 6 kW, <32 miles/hour Level III (DC): 100 kW, <9 miles/minute

EV Everywhere Grand Challenge

Advancements needed for an electric drive system to support meeting *EV Everywhere* targets

4X Cost Reduction
35% Size Reduction
40% Weight Reduction
40% Loss Reduction

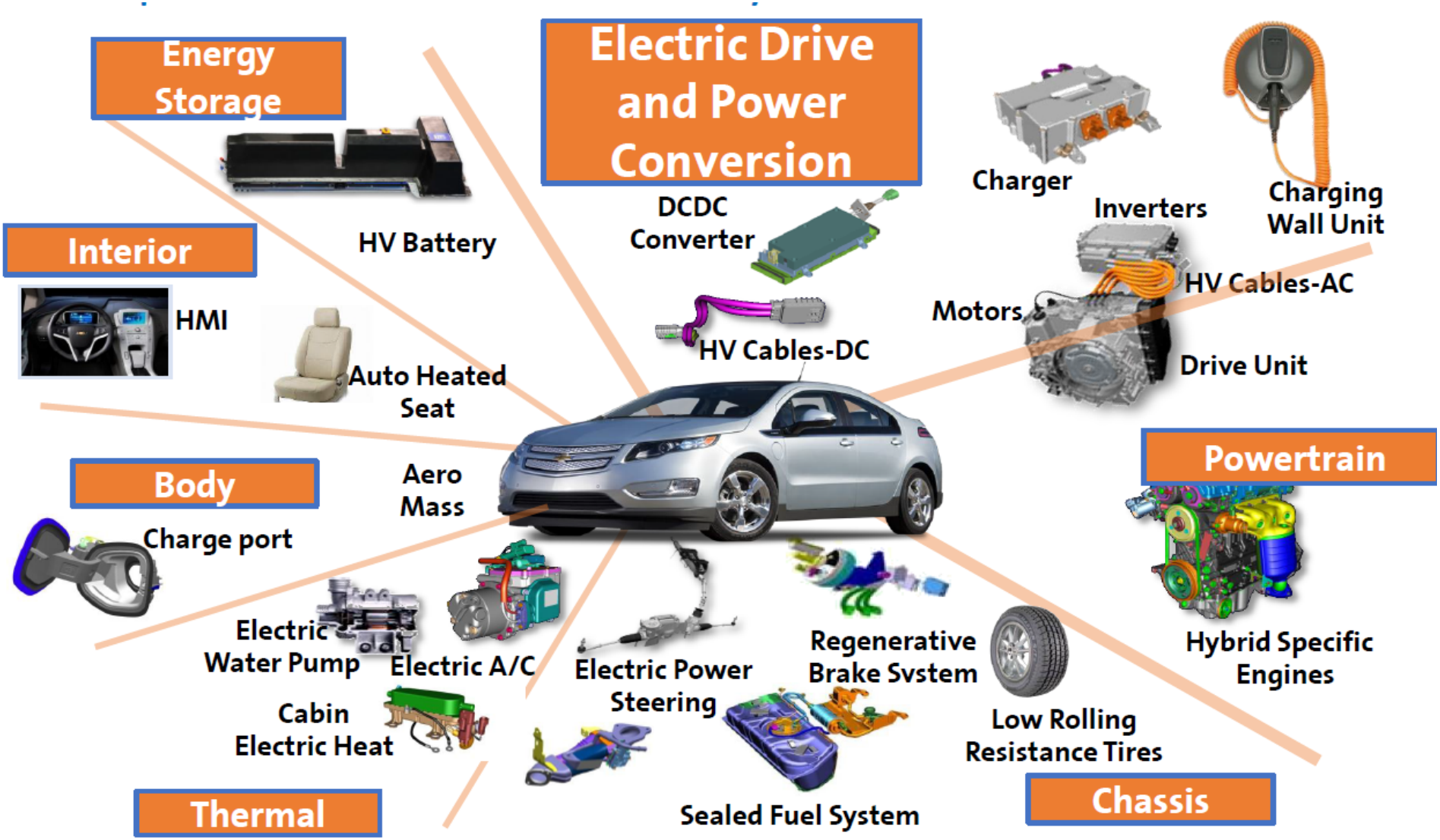


2012 Electric Drive System
$30/kW, 1.1 kW/kg, 2.6 kW/L
90% system efficiency

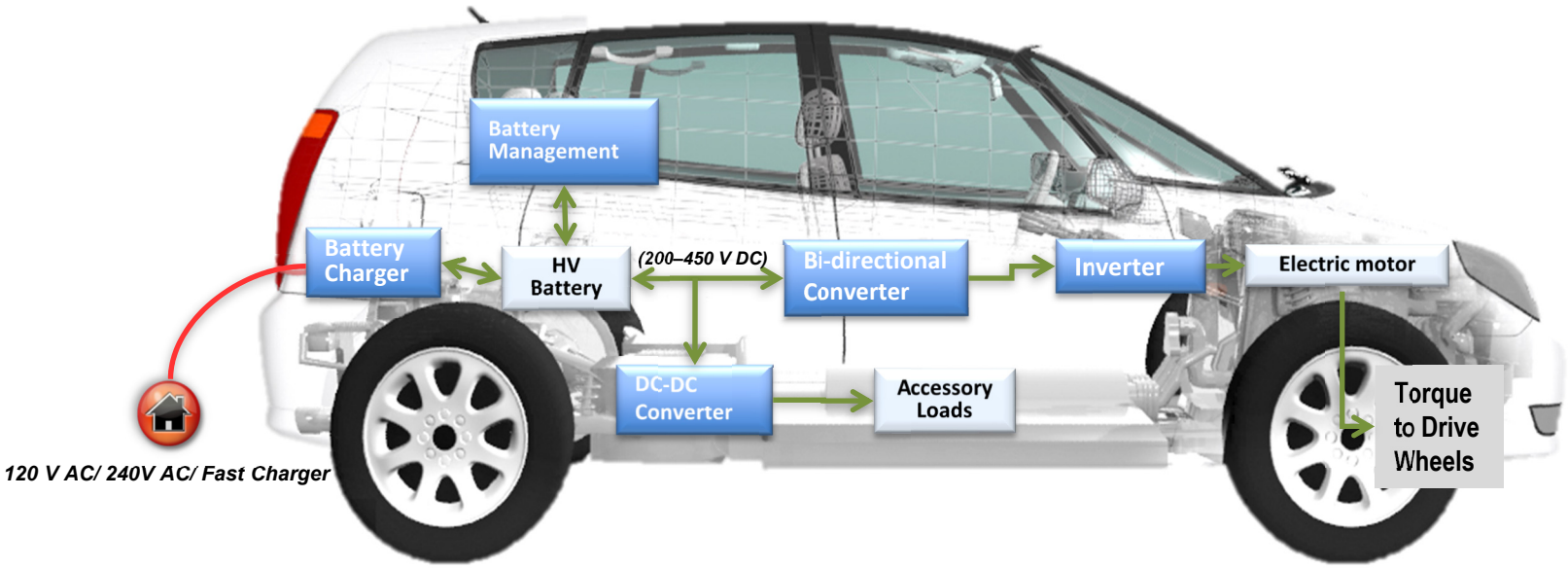
Today
$12/kW
1.2 kW/kg
3.5 kW/l
>93% efficiency

2022 Electric Drive System
$8/kW, 1.4 kW/kg, 4.0 kW/L
94% system efficiency

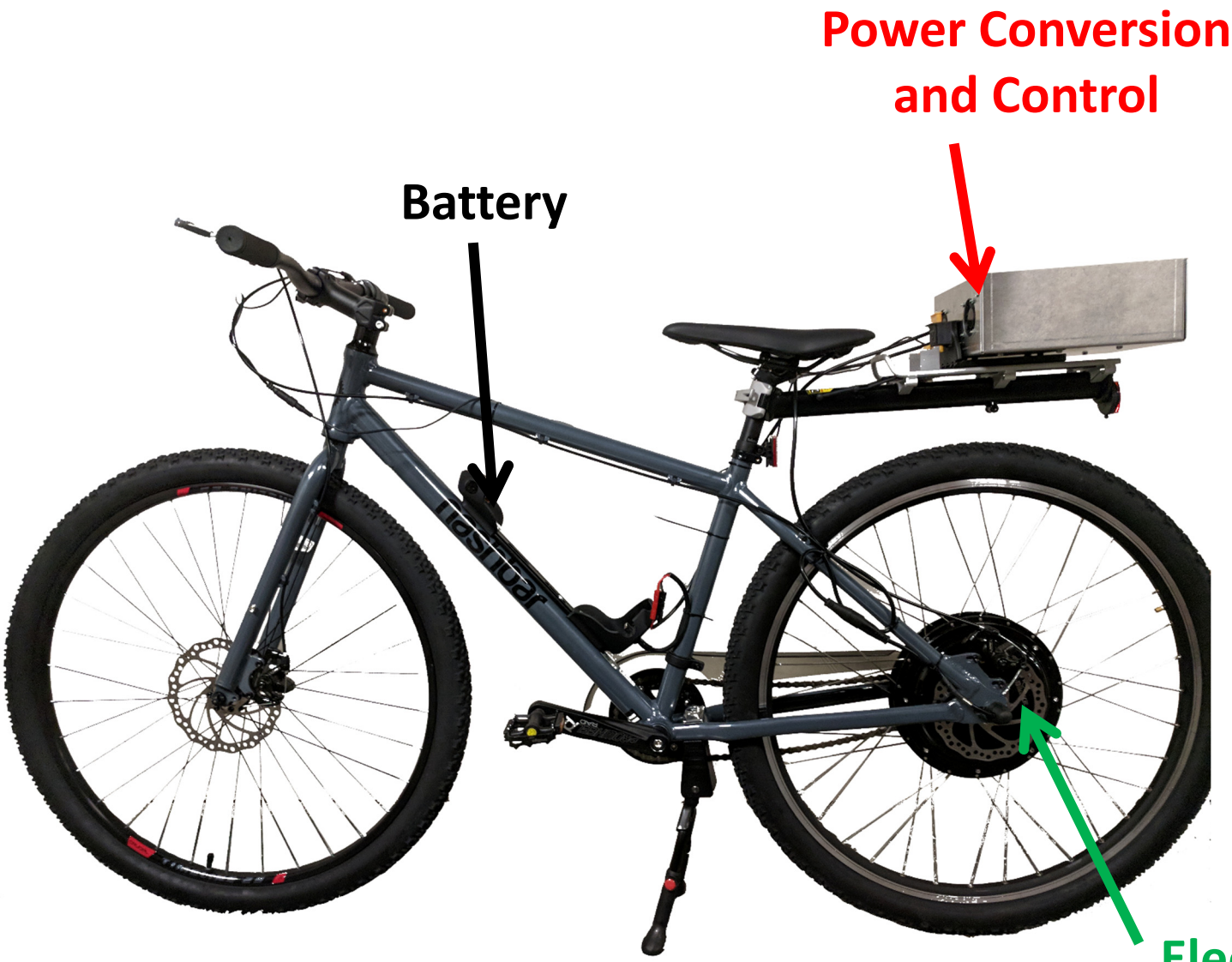
Power Electronics in Electric Vehicles



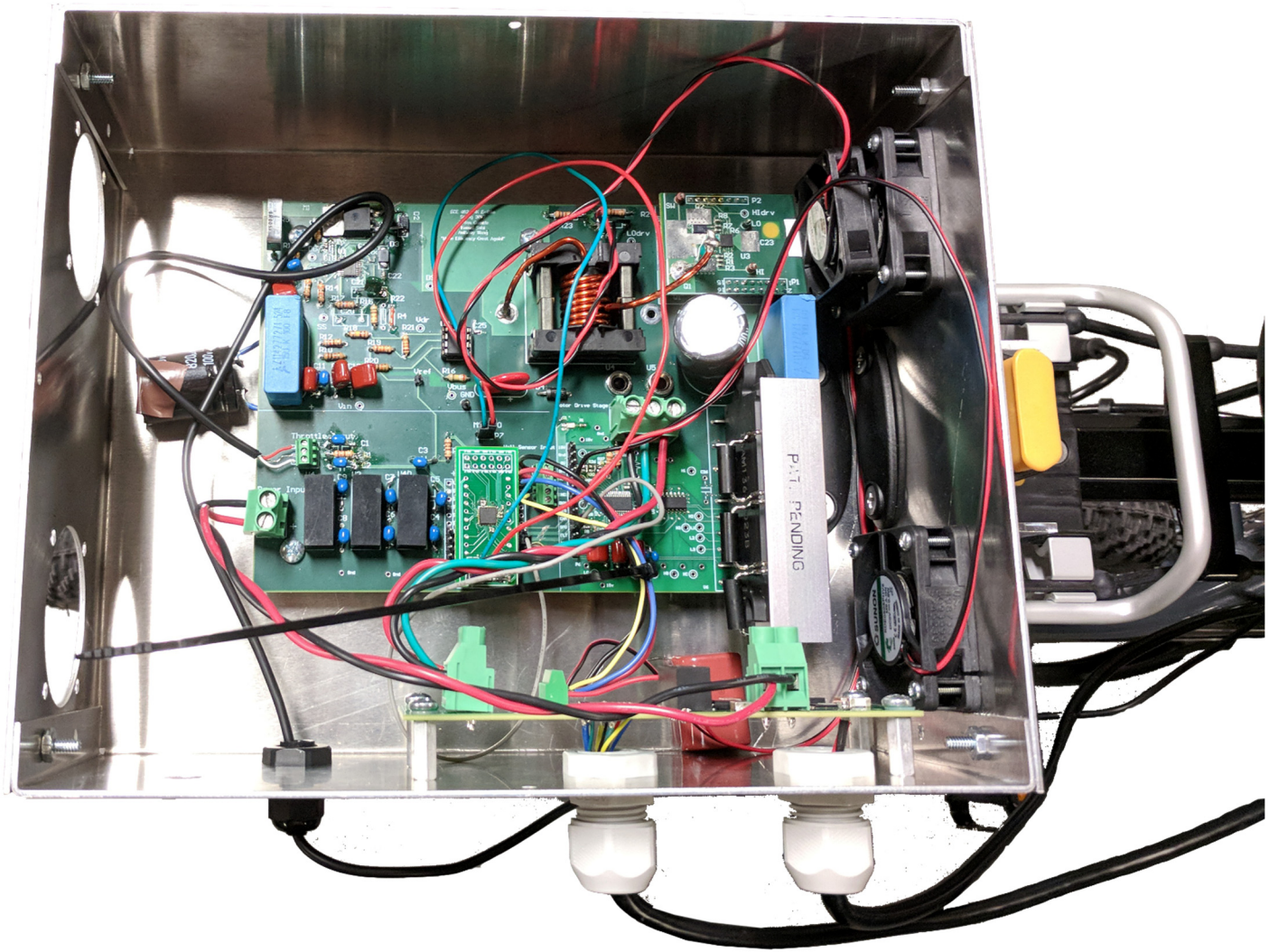
Electric Vehicle Components



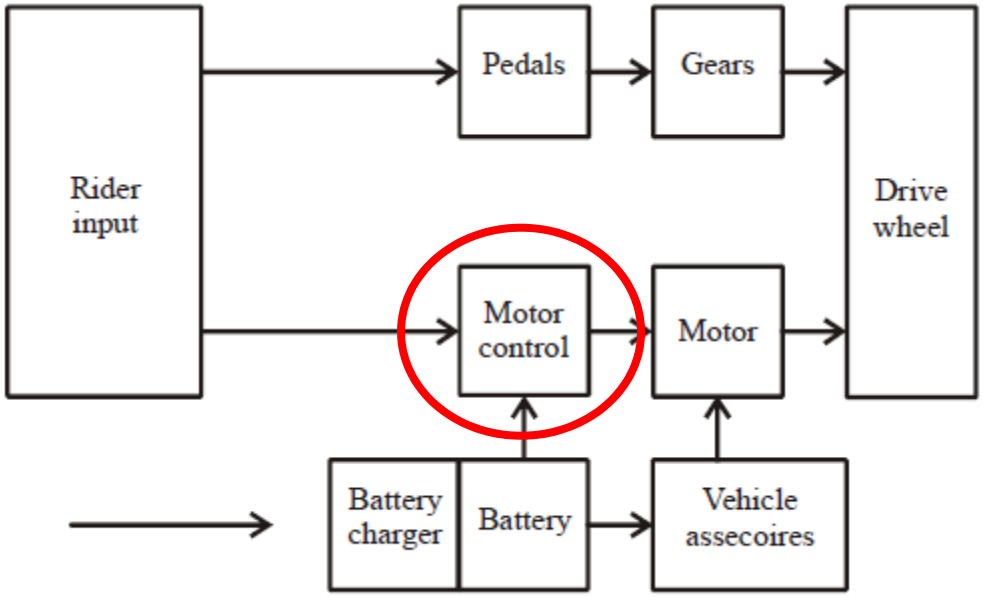
Electric Bicycle Platform



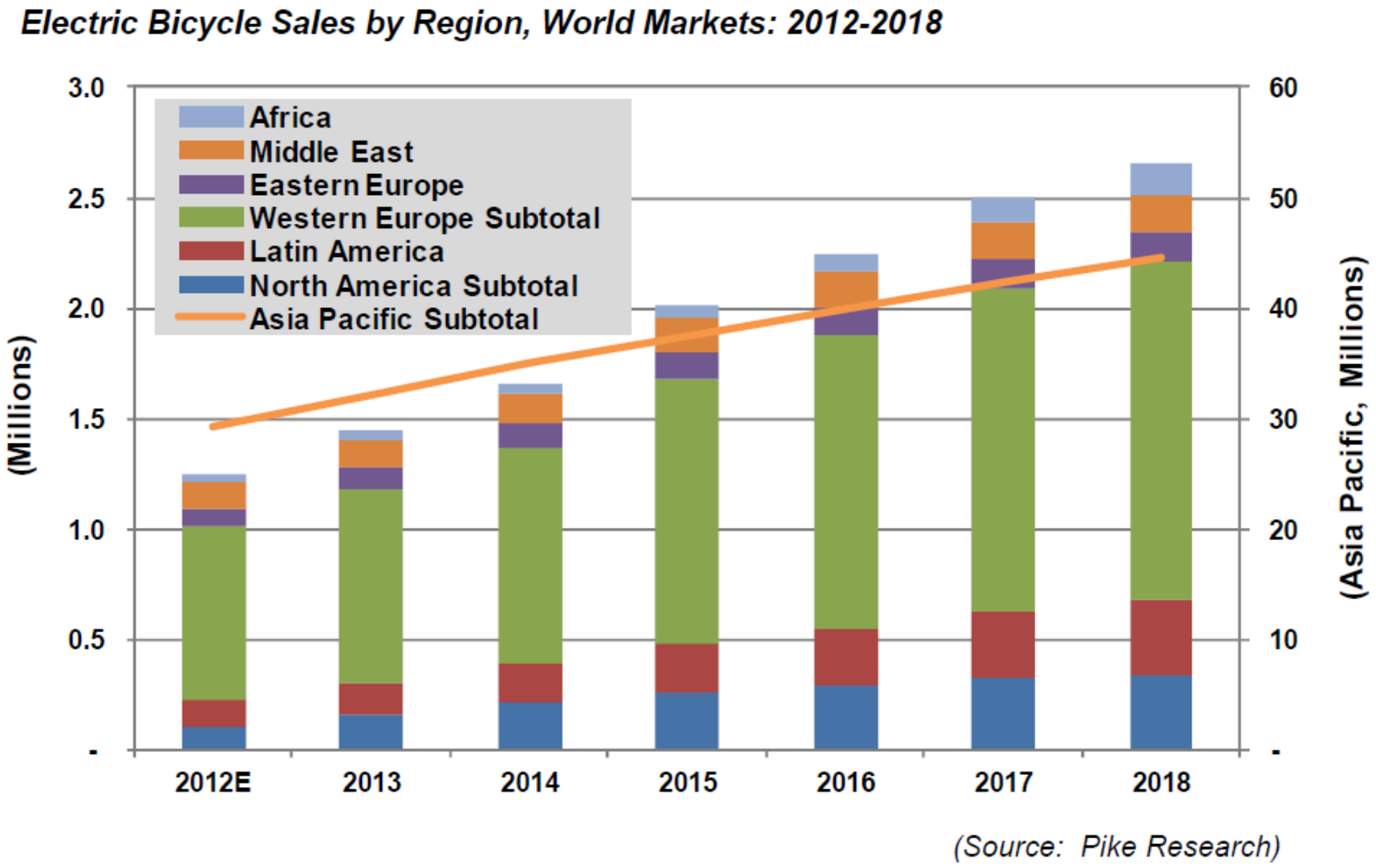
Electrical Build Space



Electric Bicycle System



Growing Popularity of E-bikes



Electric Bicycles Worldwide

- E-bikes accounted for $6.9 billion in revenue in 2012
- By utilizing sealed lead-acid (SLA) batteries, the cost of e-bicycles in China averages about $167 (compared to $815 in North America and $1,546 in Western Europe)
- China accounts for 90% of world market
- Western Europe accounts for majority of remaining 10% despite $1,546 average cost
- North America: 89,000 bicycles sold in 2012