EV1 RETROSPECTIVE AND THE ELECTRIC VEHICLE REVOLUTION

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EV1 RETROSPECTIVE AND THE ELECTRIC VEHICLE REVOLUTION

Bio

- 32 years working for GM (including 5 for Hughes Aircraft Company)
- 27 years developing Power Electronics, Electric Motors, and complete Electric Traction Systems
- Gen I EV1 Power Electronics Mechanical Engineering Manager
- Gen II EV1 Power Electronics Program Manager
- Sr. Engineering Group Manager, Global Electric Motor Development
- VP Engineering – Flex Power Controls Inc.

EV1 RETROSPECTIVE AND THE ELECTRIC VEHICLE REVOLUTION

- EV1 Overview
- EV Landscape over the past 20 years
- EV Trends and industry direction
- OEM plans for EVs (The EV Explosion)

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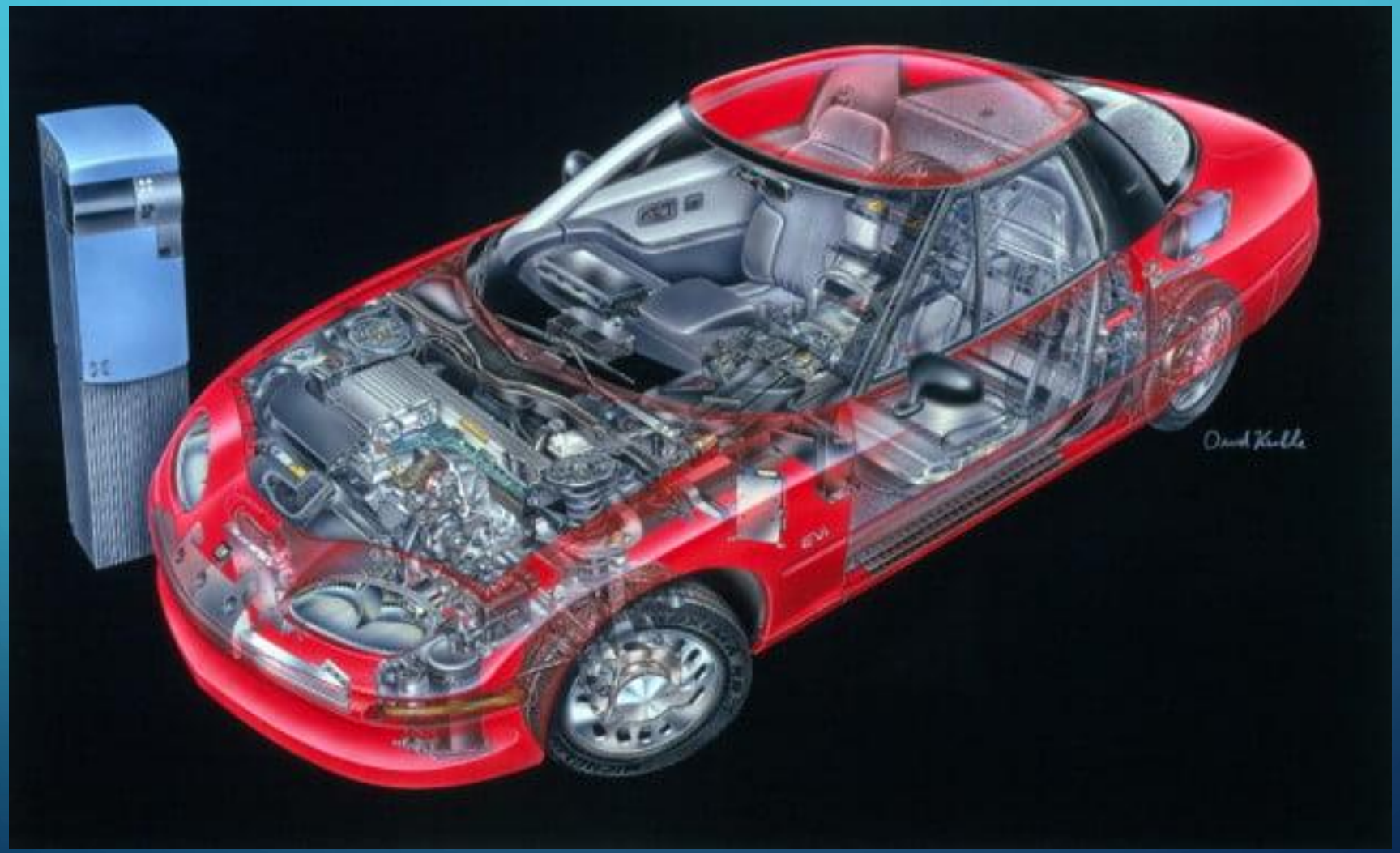

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EV1 Facts

- The IMPACT concept car was first exhibited at the LA Auto Show in 1990
- GM/Hughes Aircraft create small Power Electronics group in Southern California in 1990
- GM instituted a PrEView fleet of 50 IMPACT vehicles to be driven by the public in 1994
- GM made the decision to launch a production EV in response to the CARB ZEV mandate
- EV1 was introduced in December 1996 (Gen I)
- GM marketed and leased the GM EV1 through it's Saturn dealership network
- Cars were only available for lease in warm weather climates (CA, AZ, and limited availability in GA)
- Total sales of the vehicle were 1117: Gen I – 660, Gen II – 457
- The EV1 program was discontinued in 2002
- All EV1s were eventually repossessed and the vehicles were destroyed by GM
- An award winning documentary was made entitled "Who Killed the Electric Car" in 2006

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GEN I EV1 (1996-1997) - Traction System and Charging

- Power Electronics Bay (Power Inverter, Accessory Power Module, Power Steering Inverter)
  - Power Inverter
    - 110 kW IGBT based inverter (water cooled) including vehicle controller
  - Accessory Power Module (conduction cooled to inverter)
    - 12V DC-DC Converter for Accessory loads (1.2 kW)
    - 48V DC-DC Converter heated windshield or 48V PTC cabin heater (2 kW)
    - Compressor Motor controller (high voltage 5 kW inverter for HVAC)
  - High voltage 5 kW electric power steering inverter (conduction cooled to inverter)
- 102 kW/149 Nm 3 phase copper AC Induction motor (back iron cooled)
- Single speed reduction offset gearbox (oil lubricated)
- 16.5-18.7 kWh lead acid battery pack (air cooled) – later GEN I models received larger battery
- 6.6 kW Inductively Coupled Charger (Magne Charge)
- DC Charge Port (including electronics)
- Total range: 70 to 100 miles (estimated)

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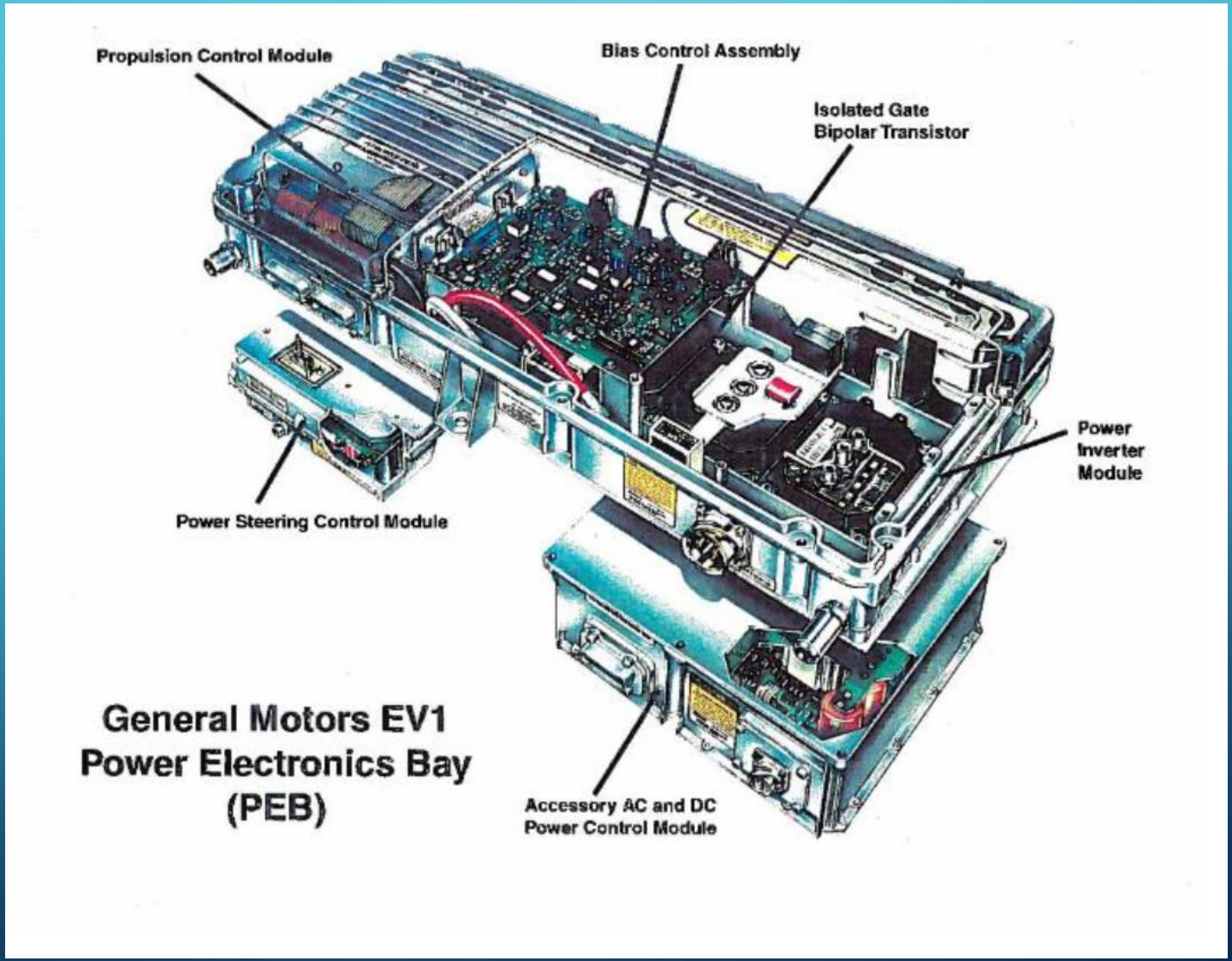

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GEN II EV1 (1999) – Traction System and Charging

- Power Electronics Bay Integrated into a single enclosure (48% volume reduction/40% cost reduction)
    - 110 kW IGBT based inverter (water cooled) including vehicle controller
    - 12V DC-DC Converter for Accessory loads (1.2 kW)
    - 48V DC-DC Converter heated windshield or 48V PTC cabin heater (2 kW)
    - Compressor Motor controller (high voltage 5 kW inverter for HVAC)
    - High voltage 5 kW electric power steering inverter (conduction cooled to inverter)
    - Charging components (rectifiers, 4th element film capacitor)
- 102 kW/149 Nm 3 phase aluminum AC Induction motor (back iron cooled)
- Single speed reduction offset gearbox (oil lubricated)
- 26.4 kWh NiMH battery pack
- Gen II 6.6 kW Inductively Coupled Charger (Magne Charge) – Lower Cost
- AC Charge Port (no power electronics)
- Total Range: 100 to 140 miles (estimated)

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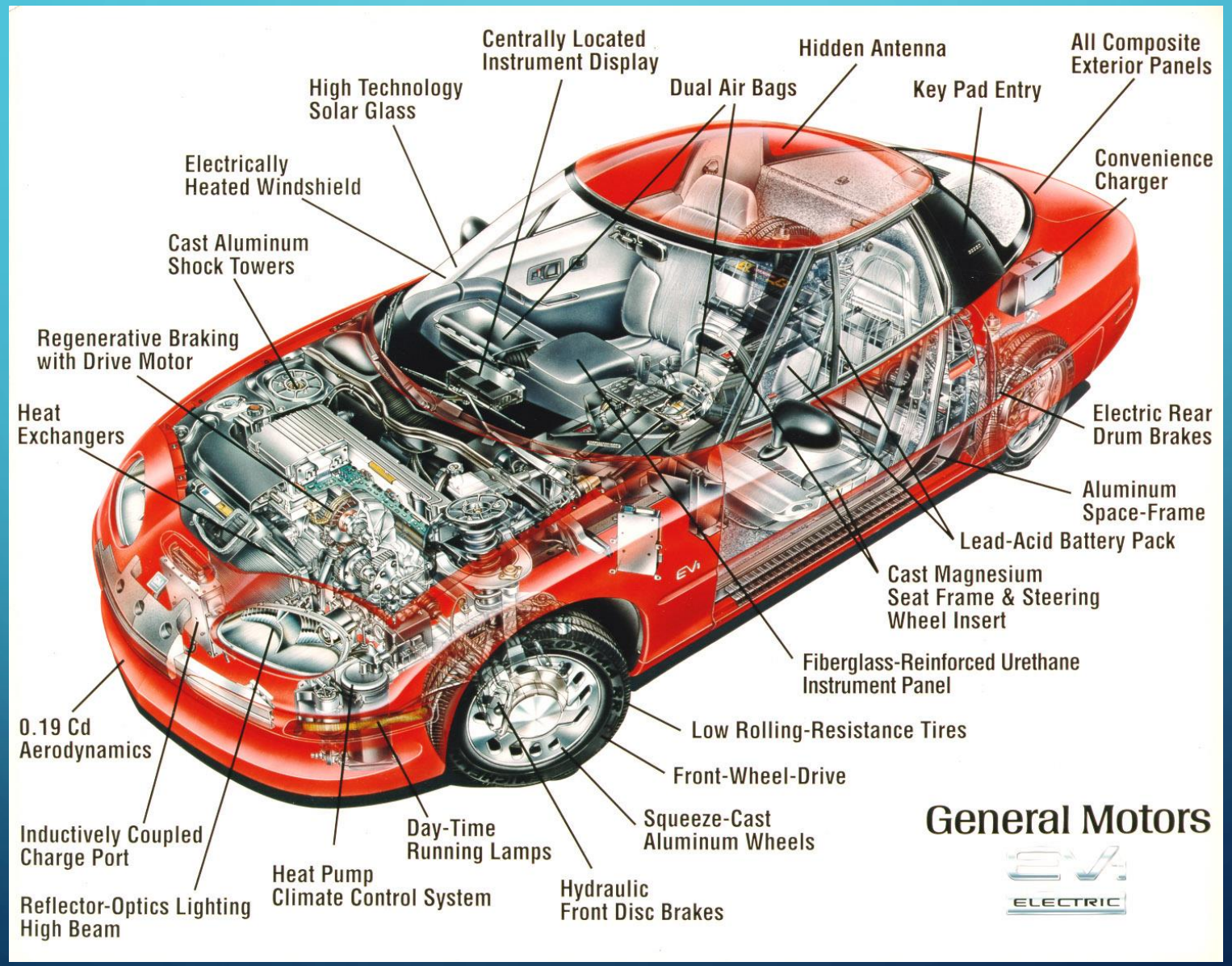

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EV1's Significant Innovations and Lasting Legacy

- First automotive high voltage IGBT based inverter (110 kW)
- First high voltage "Power Electronics Bay" for integrated PE, Cooling, and HV Safety
- Rapid Active discharge and HV disconnect safety circuitry
- Electric power steering (high voltage)
- Inductive charging (6.6 kW to 50 kW)
- Regenerative braking and brake blending
- Extensive light-weighting
  - Cast aluminum shock towers
  - Magnesium seat frames
  - Squeeze cast aluminum wheels
  - Cast aluminum cradle
  - Aluminum space frame
- Low rolling resistance tires
- Sealant tires with pressure check system
- Dual air bags
- Ultra low drag coefficient: $C_d = 0.19$

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1996 EV1

2017 Chevy Bolt

Car Type	2 door electric coupe	5 door electric hatchback
Length	169.7	164
Width	69.5	69.5
Height	50.5	62.8
Mass (lbs)	3086 (Lead Acid)/2908 NiMH	3563
Battery Capacity	16.6-18.7 kWh (Lead Acid)/26.4 kWh (NiMH)	60 kWh (Li-ion)
Power	102 kW/137 bhp	150 kW/200 bhp
Torque	149 Nm/110 lb-ft	360 Nm/266 lb-ft
Range (Miles)	70-100 (Lead Acid)/100-140 (NiMH)	238 (EPA)

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Major OEM BEV Introductions since the EV1

GM: EV1 (1996), Spark EV (2011), Volt EREV (2013) Volt GEN II EREV (2016), Bolt EV (2017)
Toyota: RAV4 Gen 1 (1997), Gen II (2012)
Nissan: Leaf Gen 1 (2011), Gen II (2017)
VW: eGolf (2015)
Honda: Fit EV (2012), Clarity (2018)
Tesla: Roadster (2008), Model S (2012), Model X (2015), Model 3 (2017)
Ford: Focus EV (2012)
Chrysler: Fiat 500e (2013)
Hyundai/Kia: IoniQ (2016) and Soul (2015)
BMW: I3 (2014)
Mercedes: B Class Electric Drive (2015)

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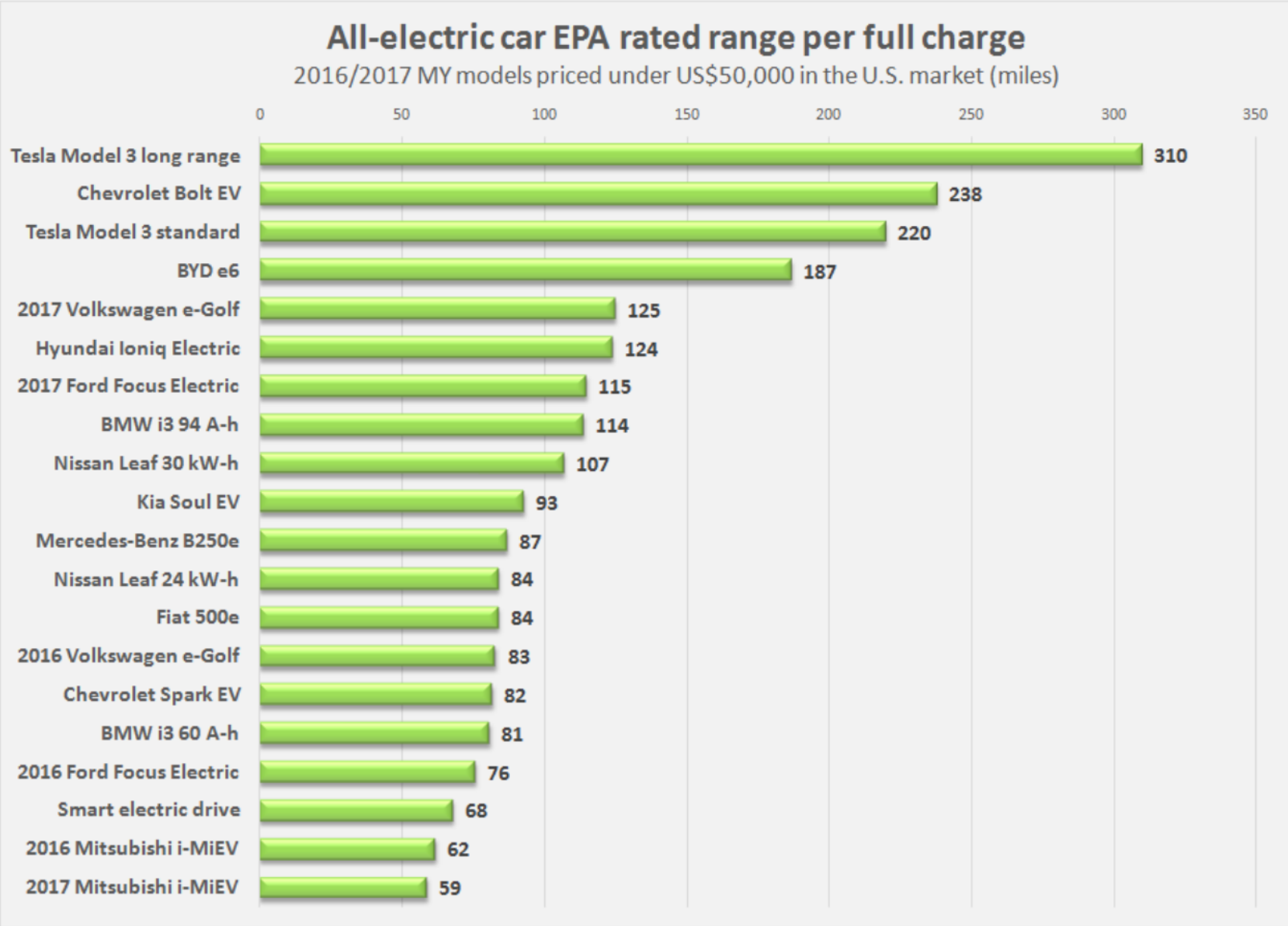

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Vehicle Sales Worldwide and US

- Estimated Sales of 90 Million Vehicles worldwide in 2017
  - Record sales volume
- Total Electric Vehicle (PEV) Sales – approx. 1 million
  - Roughly 1% total vehicle sales

- Estimated Sales of 17 Million Vehicles in the US in 2017
  - Down for the first time since 2009
- Total Electric Vehicle Sales 199.8K
  - Up 25% over
  - Subsidies and tax breaks nearing the end

- Estimated Sales of 29 Million Vehicles (estimated) in China
  - Total Electric Vehicle Sales 500K in 2016
  - Estimated to drop in 2017 due to reduction in subsidies

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Why is the EV Revolution Happening Now?

- China
- China
- China
- "Dieselgate"
- Tesla
  - Major Luxury OEMs are tired of losing sales to Tesla
  - Model 3
- General Motors
  - **Bolt was a game changer (238 miles range)**

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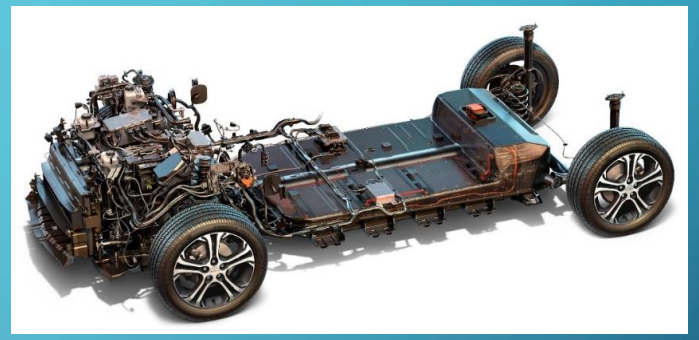
Trends Looking Forward



- Move towards pure Electric and away from Hybrid (HEV)
  - 200 plus mile range (except city cars)
  - ≥ 60 kWh energy storage
  - Mass of vehicles > 3,500 lbs.
    - Larger vehicles (increased utility)
    - Vehicle structures mass being reduced, but greater energy storage being required
    - Efficient Fundamentals
  - Propulsion power ≥ 150 kW
    - Meet reasonable acceleration
    - Must be "fun to drive"
- Packaging
  - "Skateboard" chassis allows for production reuse and multiple vehicle types
  - Integration into flat package

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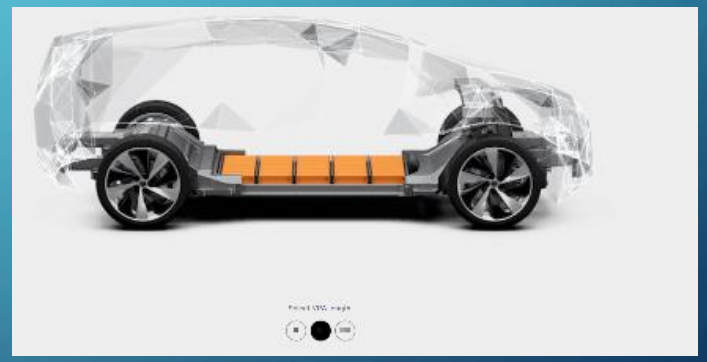
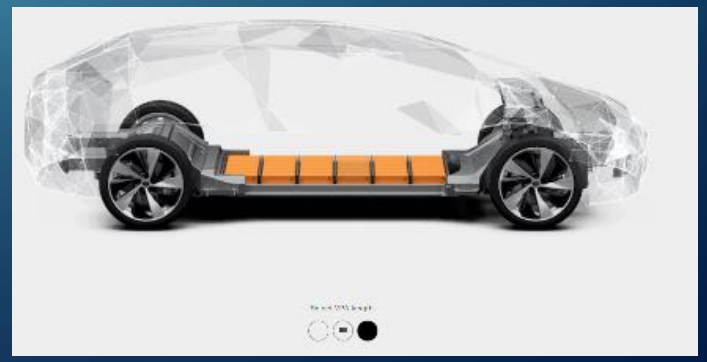
Faraday Future VPA

- All electric
- Front and Rear electric motors
- Battery flat pack
- One platform that scales
  - Passenger and SUV
- Expandable platform
  - Increase energy storage for larger vehicles
  - Increase voltage (possibly max of 650 to 700V)





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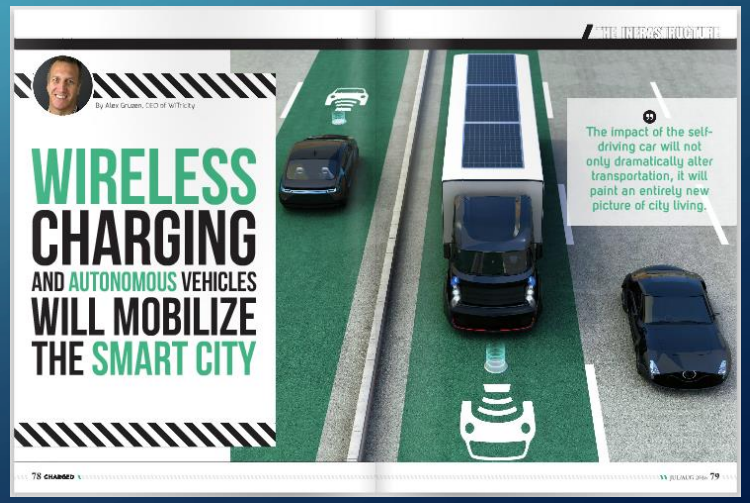
Trends Looking Forward

- Transformation of Transportation "Mobility as a Service"
  - Autonomous EVs
  - 15 year/300K miles
  - Charging
    - Extreme Fast Charging
    - Wireless dynamic charging
    - Autonomous charge (wireless with auto docking)
  - Secondary impacts
    - Electric Grid infrastructure improvements



By Alex Gruzen, CEO of WiTricity

WIRELESS CHARGING AND AUTONOMOUS VEHICLES WILL MOBILIZE THE SMART CITY

The impact of the self-driving car will not only dramatically alter transportation, it will paint an entirely new picture of city living.

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Enablers for Future EVs

- WBG Devices (SiC and GaN)
  - Higher Switching Frequencies
  - Lower power dissipation
  - Higher operating voltages
  - Higher power density
- Higher voltage battery packs
  - Lower motor phase currents
  - Lower charging currents for DC Fast Charge
- Lower battery costs with increased scale, improved chemistry, manufacturing capability, and new suppliers

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Announced Plans – "The EV Explosion"

GM: 3 new models in 18 months, 20 new models by 2023
Toyota: 10 new models by early 2020s
Nissan/Renault/Mitsubishi: 12 new models by 2022
VW Group: 300 models will have electric variant by 2030 ($84B investment in Electric Vehicles)
Honda: 2 new EVs in 2018, 2/3 of all vehicles will be "electrified" by 2030
Tesla: New Roadster, Semi-Truck
Ford: Electric SUV in 2019, 15 new models for China by 2025
FCA: 2 electric Maseratis by 2020
Hyundai/Kia: 14 new EV models by 2025
BMW: 12 EVs by 2025
Mercedes: Electric versions of every vehicle by 2022 (EQ brand)

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What Has to Happen to Insure Mass Market Adoption

- Legislation (already occurring in China and Europe)
  - China is driving the EV market and vehicle development
- Tax Credits continue in the short term (U.S.)
- Higher Gas Prices in the U.S. (We love our SUVs and Full Size Trucks)
- Significant Infrastructure Changes to the Electric Grid
- Real Commitment from the Automotive OEMs
  - Competitive vehicles with adequate range and utility
  - Competitively priced options vs. conventional powertrains
  - Styling and performance equivalent to IC engine variants
- EV components continue to come down the cost curve (PE, Batteries, Motors)
- New Urban Mobility models emerge in large cities
  - Allows for higher sales of EVs
  - Car sharing services utilizing EVs (Lyft, Uber, Maven, Zip Car)
  - Autonomous EVs (allows for lower operating costs)