

Battery Electric Vehicles

Economic and Environmental Benefits And Enjoyment!

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ICEV = Internal Combustion Engine Vehicle (e.g., Honda Civic)

HEV = Hybrid Electric Vehicle (e.g., Toyota Prius)

PHEV = Plug-in Hybrid Electric Vehicle (e.g., Toyota Prius Prime)

BEV = Battery Electric Vehicle (e.g., Tesla Model 3)

EV = PHEV or BEV

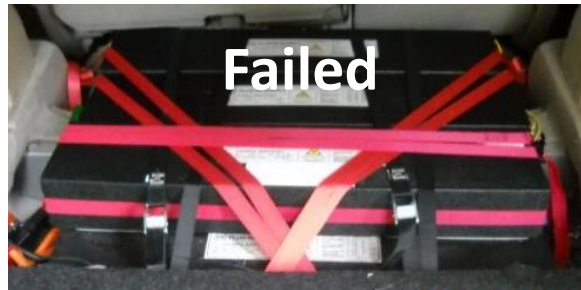
kWh = battery energy, kW = battery charging power

SOC = State Of Charge (0%-100%)

Burning 1-gallon gasoline = 33.7 kWh

tinyurl.com/BEVs2019

My Two PHEVs & Five BEVs



Failed to convert to Lilon.

2005 Prius converted to PHEV 2006 HiHy converted to PHEV 2007 Chinese Pickup lead-acid BEV



2012 Nissan LEAF 73 miles

2015 Nissan LEAF 84 miles



2017 Chevrolet Bolt EV 238 miles



Tesla Model 3 Long Range RWD 310-miles²



Roper garage
7.2-kW charging station

Tesla charging port



TM3LR windshield info

Talk Outline

- Environmental reasons to drive battery-electric vehicles (BEVs).
- Economic reasons to drive BEVs.
- Comparison to internal-combustion-engine vehicles (ICEVs).
- Details about BEVs.
- Enjoyment of driving BEVs.
- Renewable energy to charge BEVs.
- Current long-range BEVs (range > 200 miles).
- Medium-range BEVs for local driving (range < 200 miles) (Slide 69)
- BEV pickup trucks.
- Large BEV trucks and buses, including school buses.
- Charging BEVs. (Slide 77)
- Long trips in long-range BEVs.
- Plug-in hybrid vehicles (PHEVs).
- Future of cars.
- Appendix: Near-future long-range BEVs. (Slide 116)

Many graphs and pictures have
Internet links behind them.

Blue sections might be skipped.

El Niño increases global warming & La Niña decreases global warming.

NASA

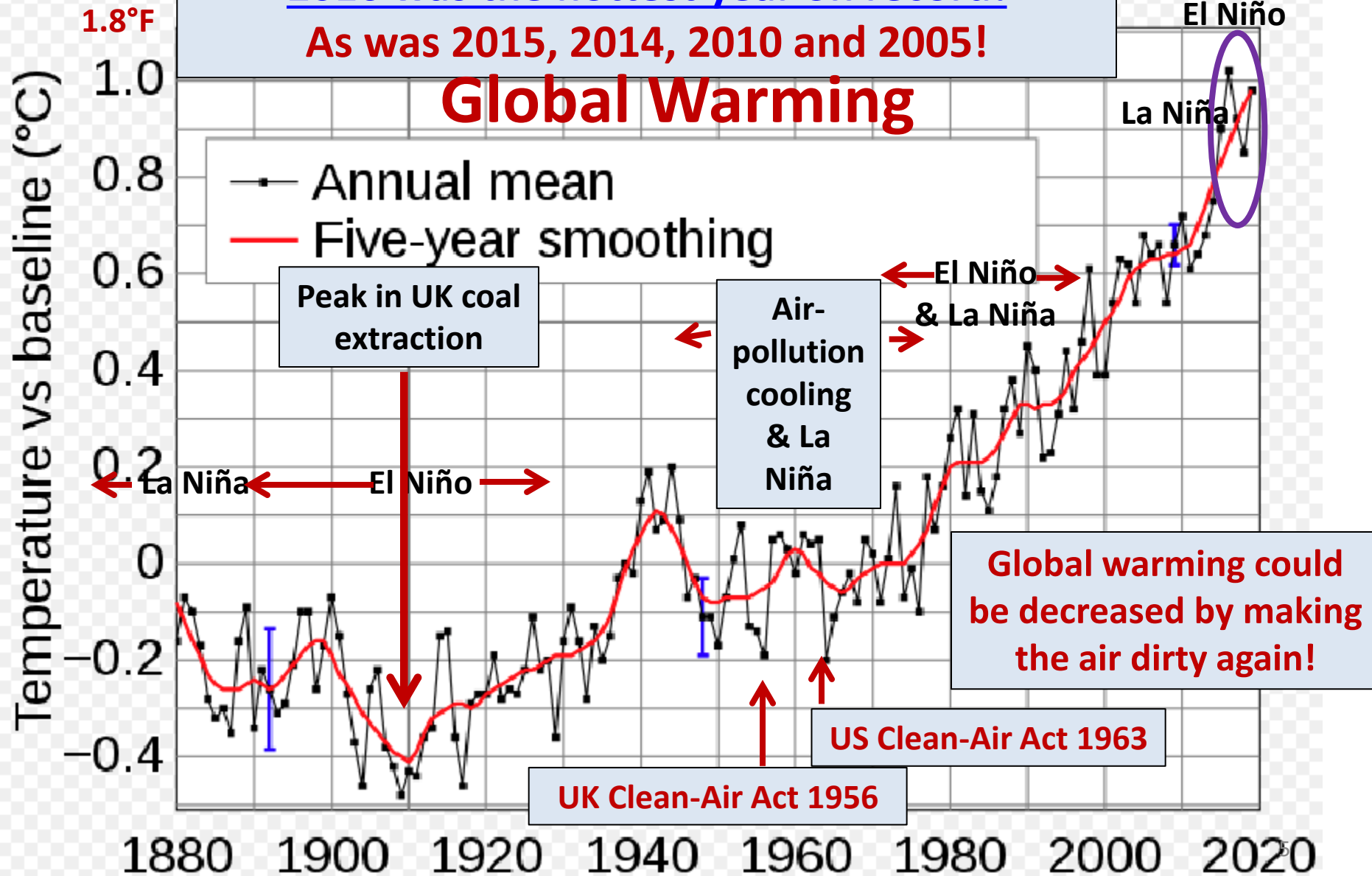
Tinyurl.com/GlobalWarmingRoper

1951-1980 base

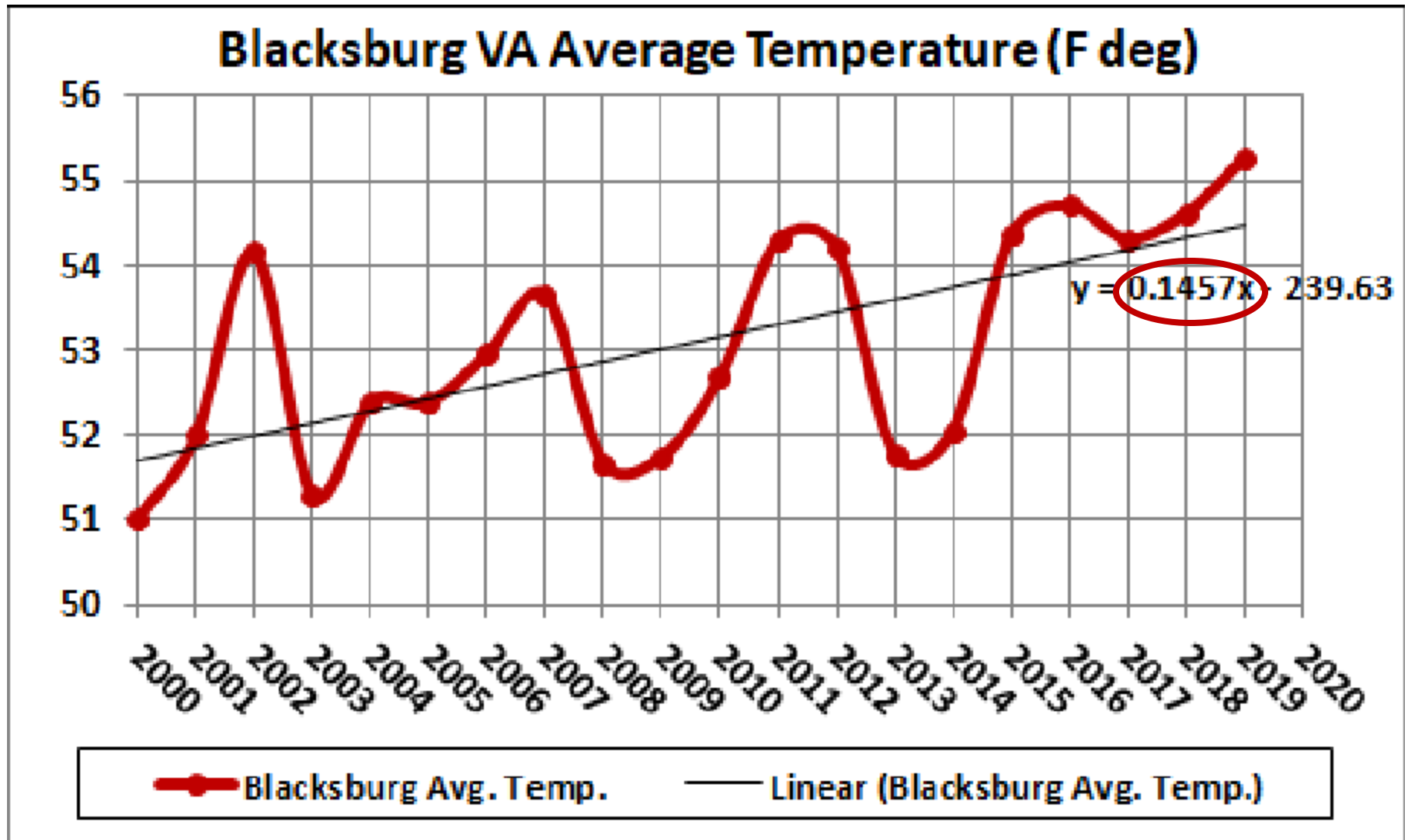
2016 was the hottest year on record!

As was 2015, 2014, 2010 and 2005!

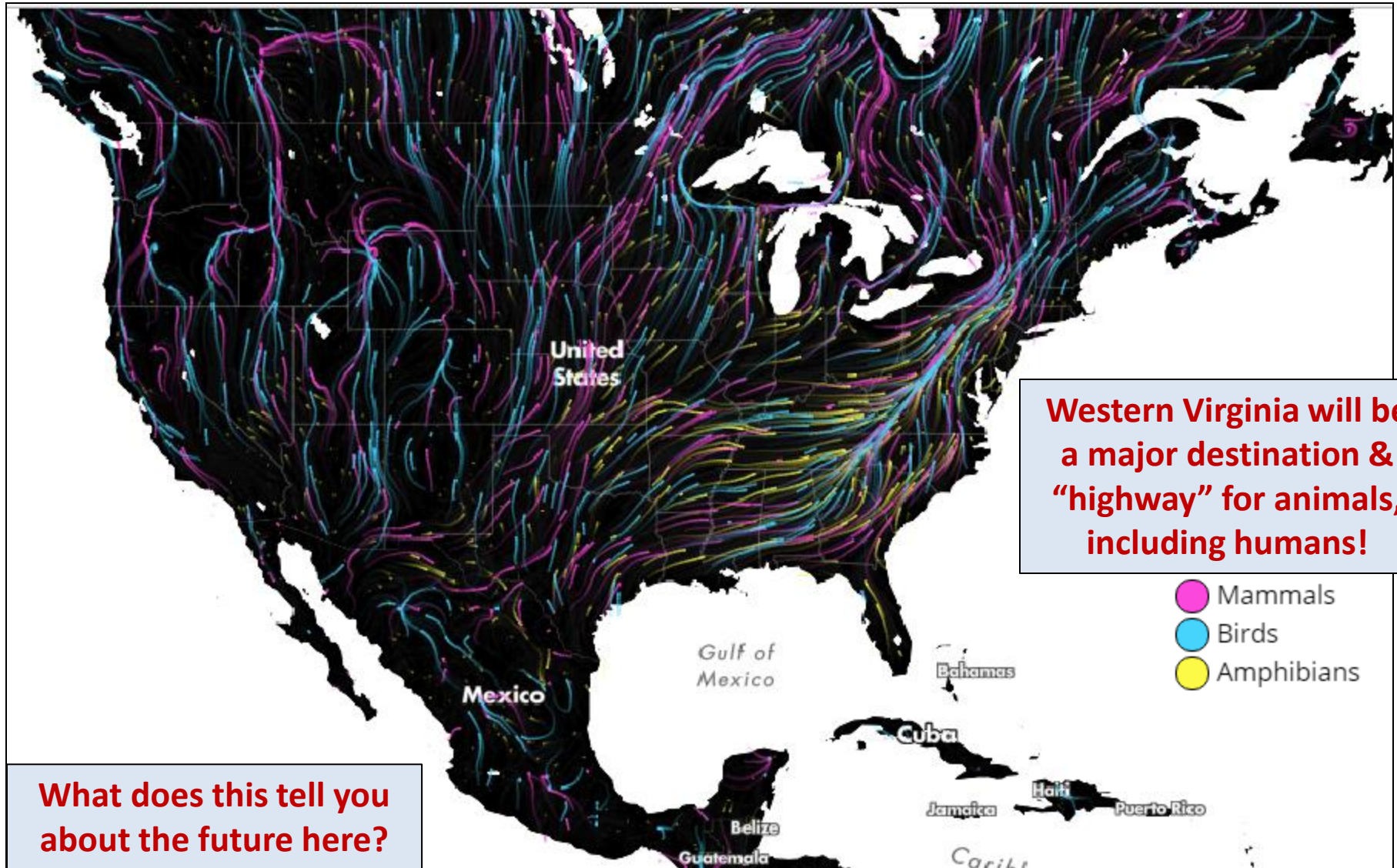
Global Warming



Local Global Warming



Where animals will move to new homes because of global warming:



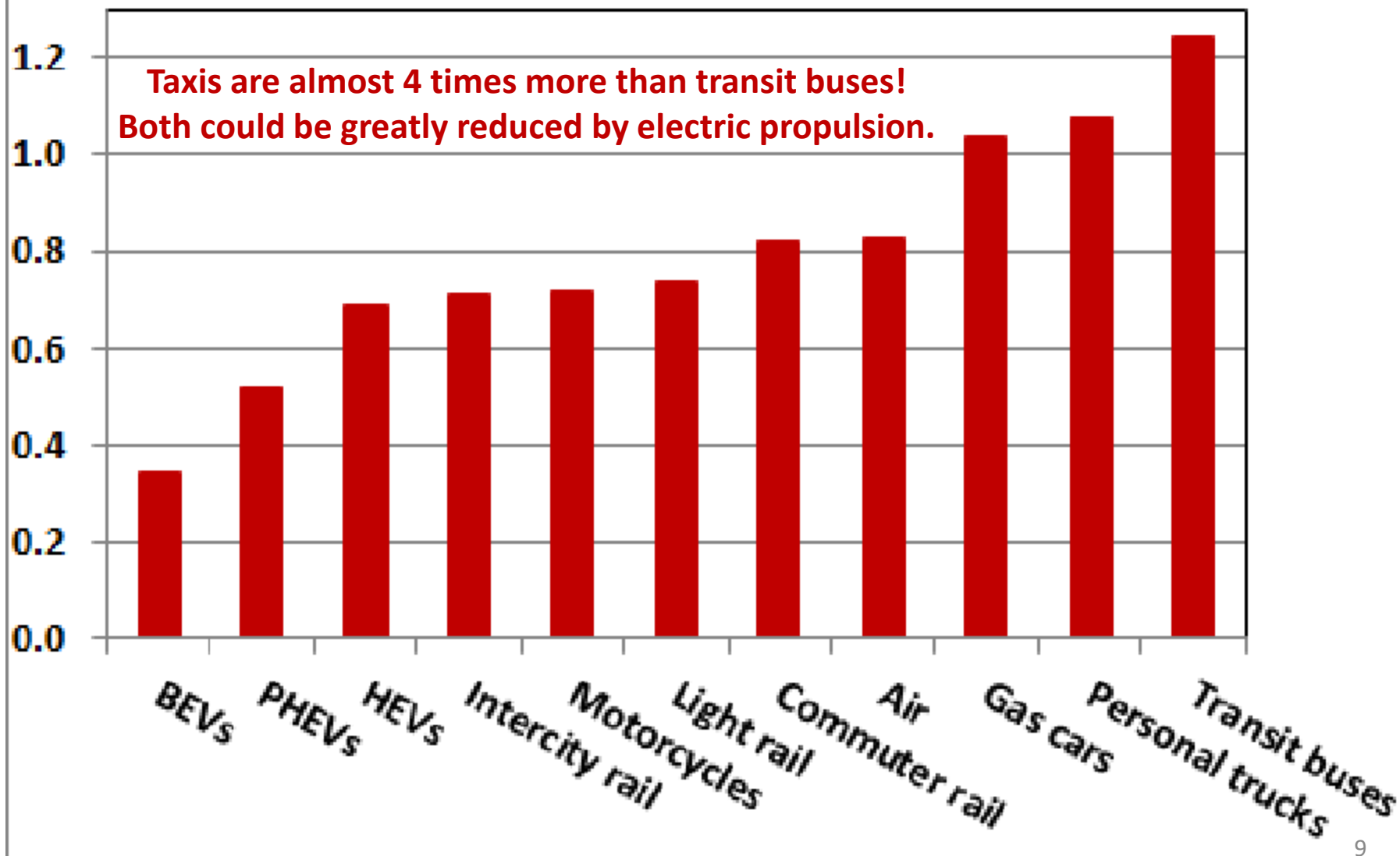
Environmental Aspect of BEVs

- Advantages
 - Reduction in carbon-dioxide emissions compared to ICEVs even with coal electricity.
 - Much lower operating and maintenance costs reduce environmental footprint compared to ICEVs.
 - Reduction in local pollutants.
 - Refuel (charge) at home, best using solar energy.
 - Low noise pollution.
- Disadvantages
 - Motors have some rare-earth and critical metals.
 - More carbon-dioxide emitted in manufacture than ICEVs.
 - Tires can wear out slightly quicker than for ICEVs because of high acceleration.

Energy-Usage Efficiency

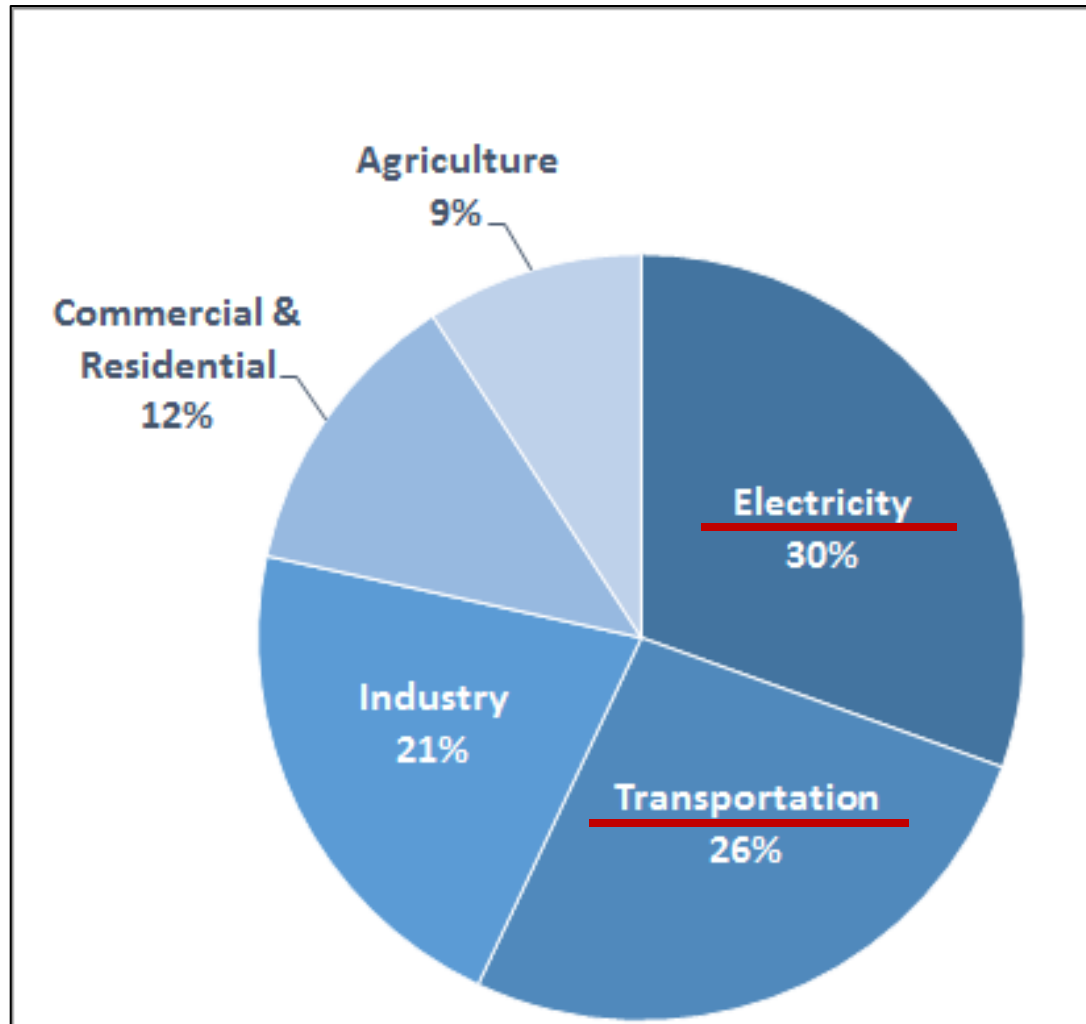
kWh/passenger/mile

Taxis are almost 4 times more than transit buses!
Both could be greatly reduced by electric propulsion.



Causes of Global Warming

Too many people is basic cause!



We need renewable electrical energy & electric cars!

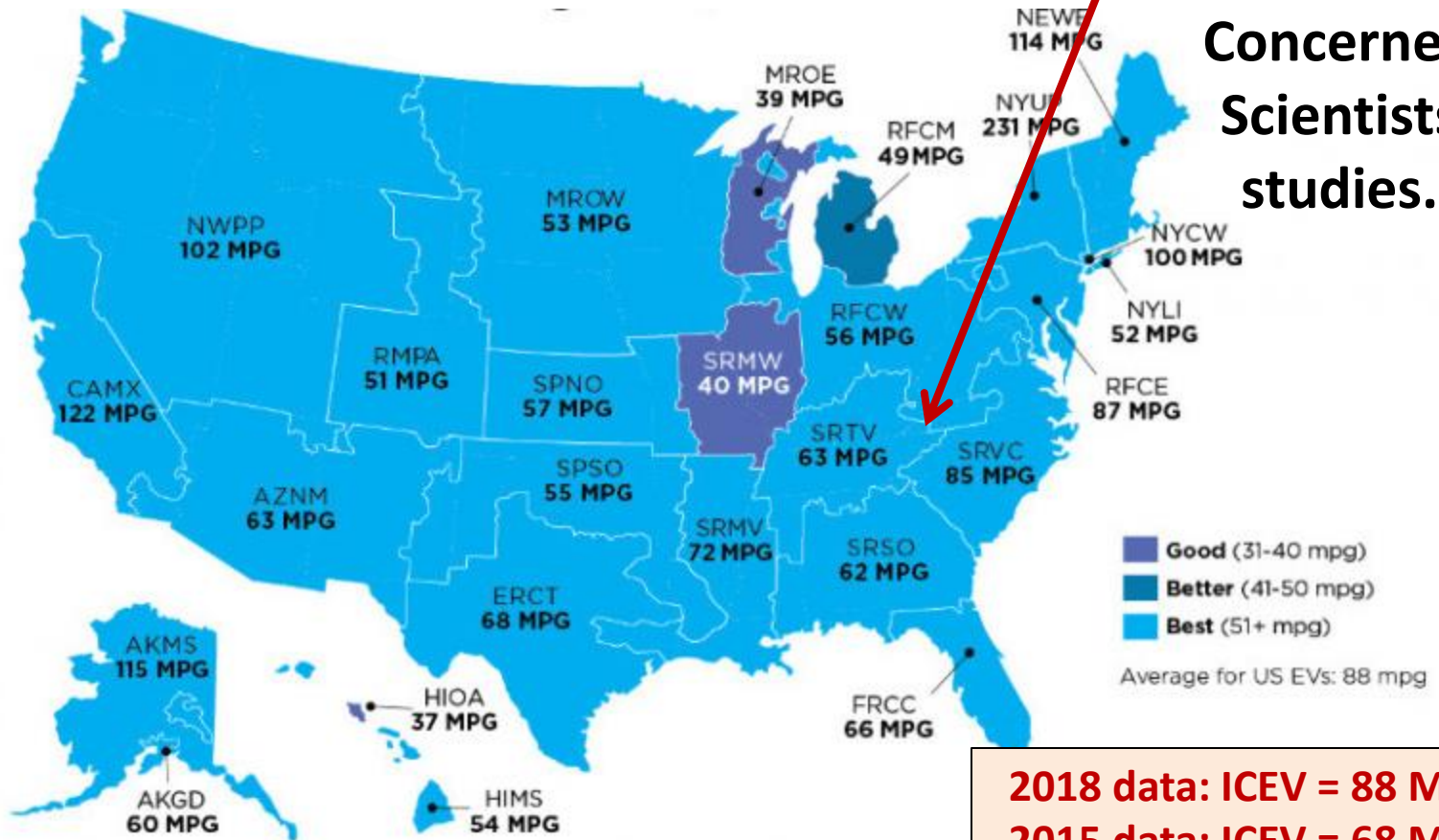
Electric Vehicles vs Gasoline Vehicles

GHG Emissions

65 mpg ICEV for Tesla Model 3.

Minimum MPG for ICEV to match BEV GHG emissions.

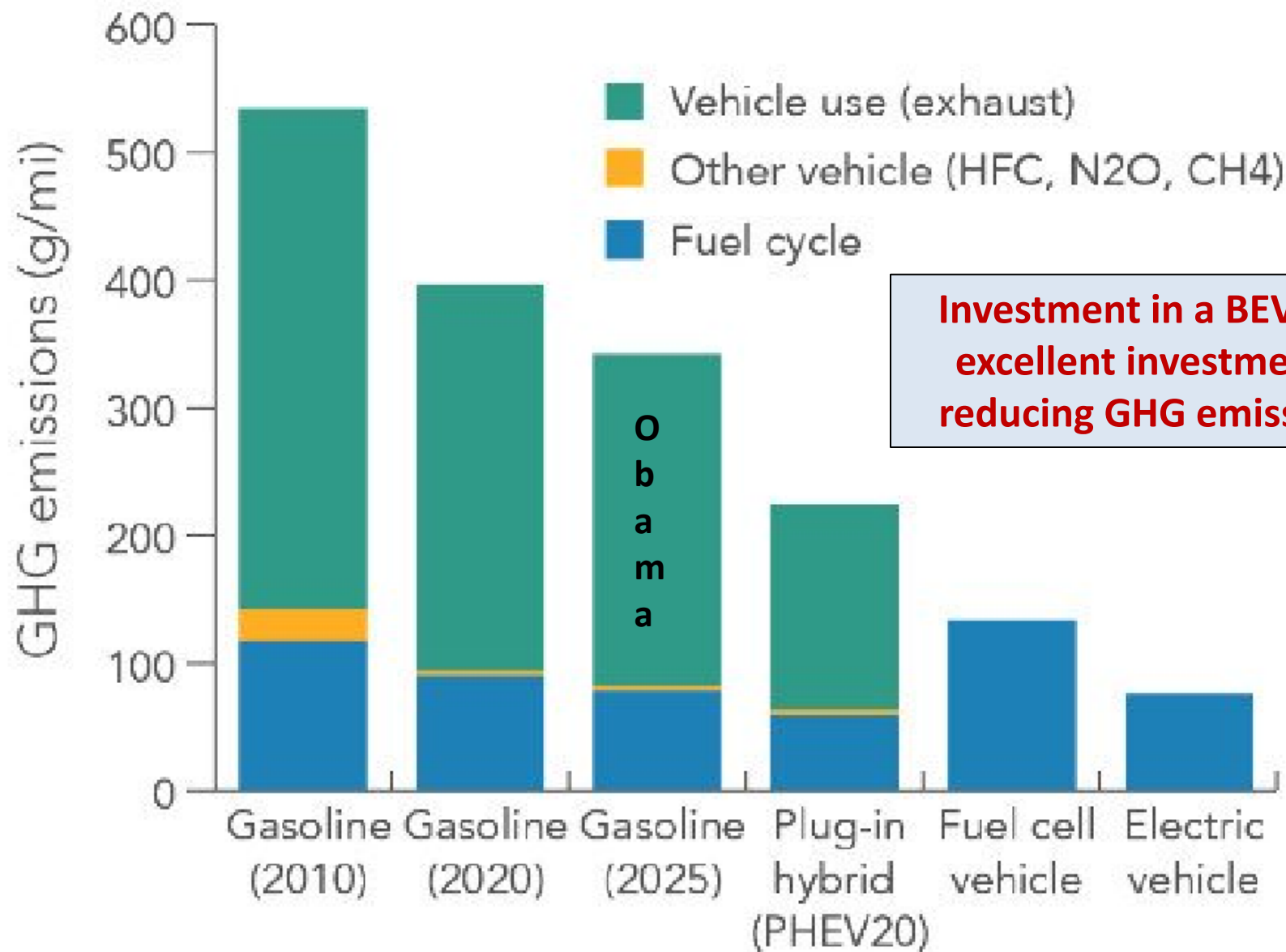
Union of
Concerned
Scientists
studies.



2018 data: ICEV = 88 MPG
2015 data: ICEV = 68 MPG

2018 US ICEV average = 22 MPG
Toyota Prius Eco = 56 MPG

Well to Wheel Greenhouse Gas Emissions Comparison

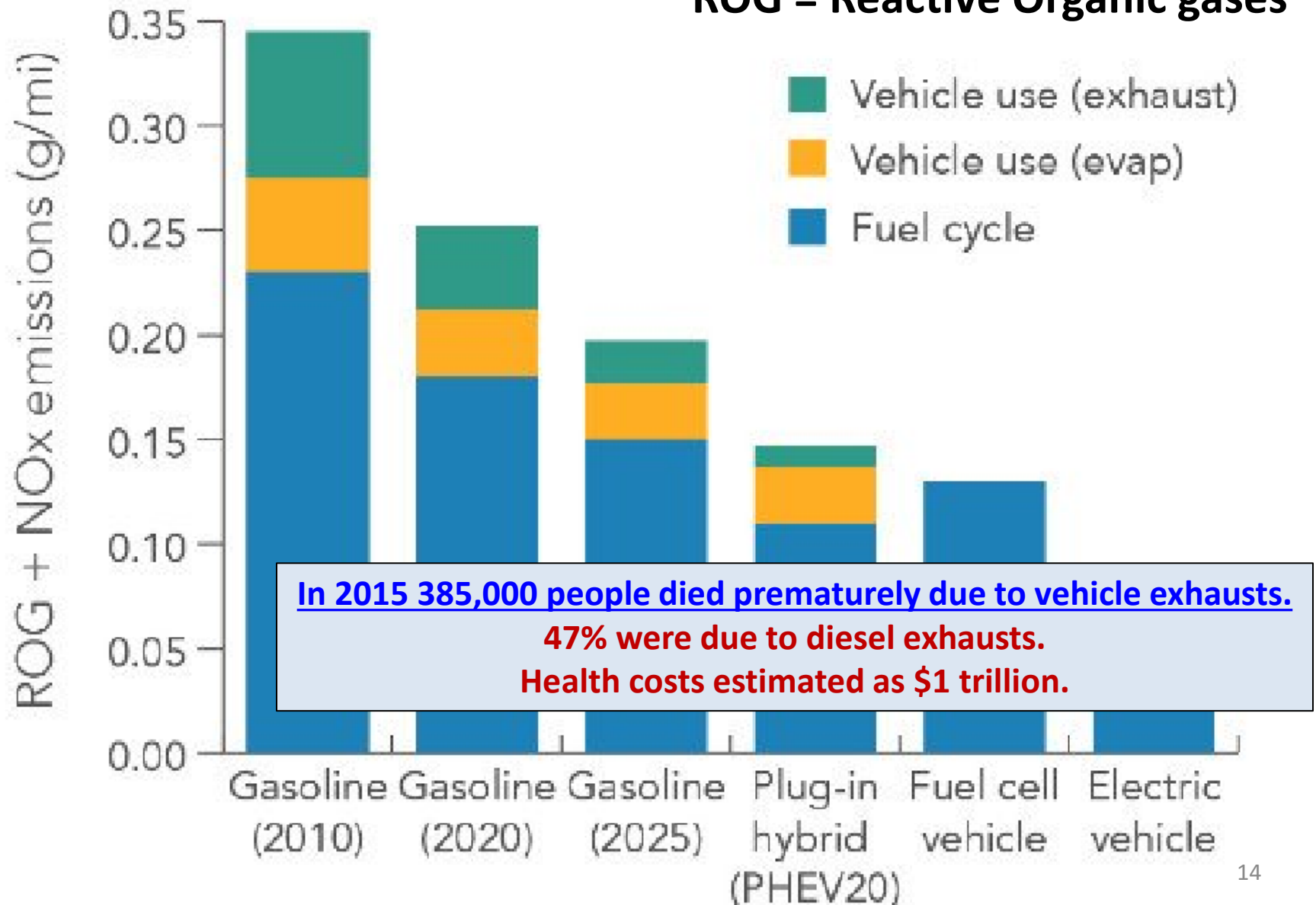


Car Carbon Dioxide Emissions

- Burning **1 gallon gasoline** (6.3 lbs) creates **20 lbs CO₂**.
- The average gasoline car emits about **6 tons of CO₂ per year**.
- Per year U.S. gasoline cars spew about **1,600,000,000 tons of CO₂** into the atmosphere.
- Tesla BEVs have saved about 3,600,000 tons of CO₂ spewed into the atmosphere.

Well to Wheel Smog-Forming Pollution Emissions Comparison [NO_x + ROG]

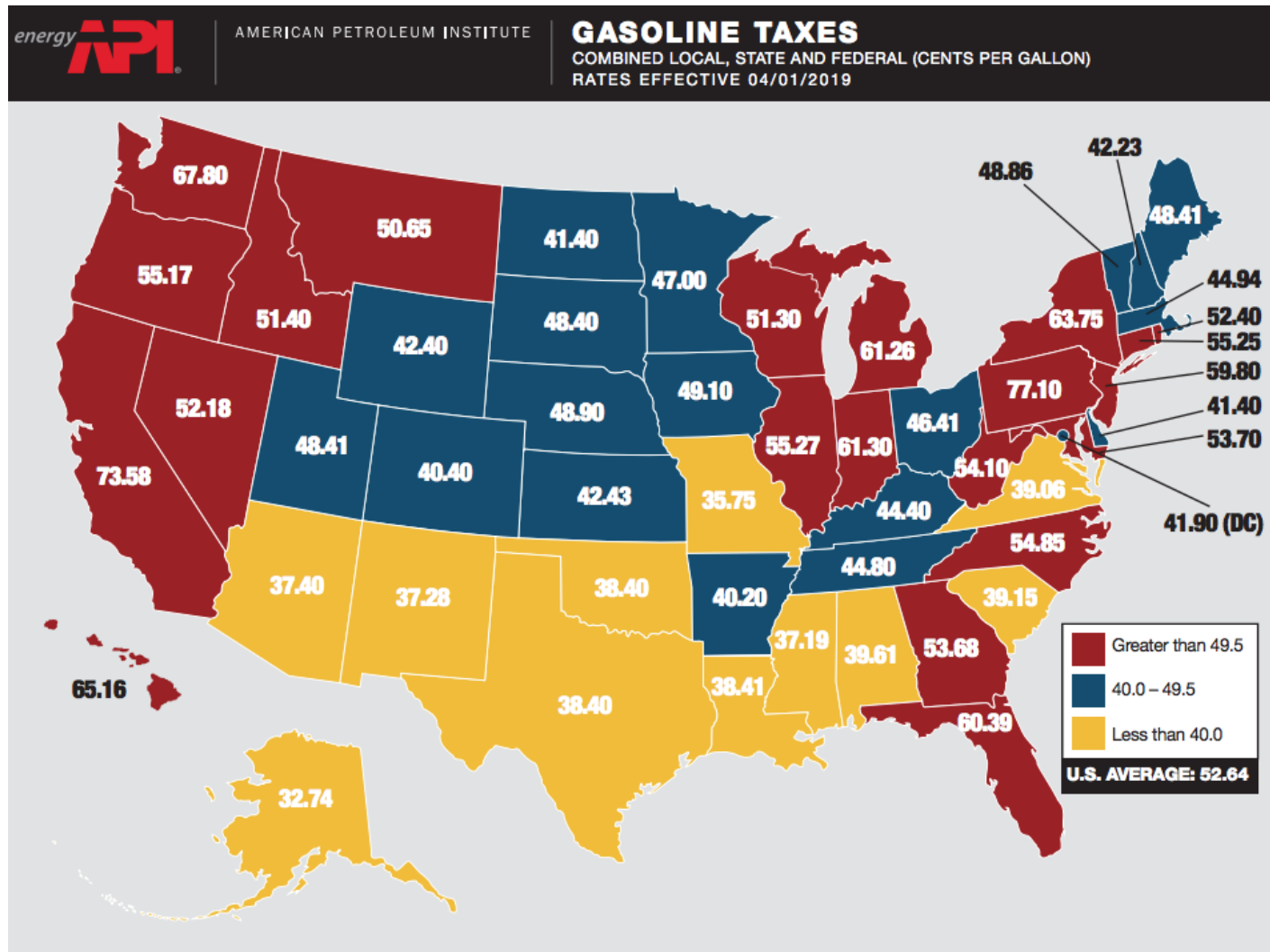
ROG = Reactive Organic gases



Government ICEV Restrictions

- Countries will ban sales or registrations of ICEVs
 - 2025: Norway
 - 2030: Denmark, Iceland, Israel, Netherlands, Slovenia, Sweden
 - 2035: United Kingdom
 - 2040: France, Sri Lanka
- 23 cities/states will ban driving ICEVs
 - 2025: Mexico City, Paris, Madrid, Rome, Athens
 - 2030: Los Angeles, Seattle, Vancouver Canada, London
 - 2030: British Columbia Canada
 - 2050: CA, CT, MD, MA, NY, OR, RI, VT & Quebec
- FCA (Fiat-Chrysler) will pay Tesla ~\$3.2-billion for European low-carbon-emissions credits. (Will pay for new Tesla German Factory!)

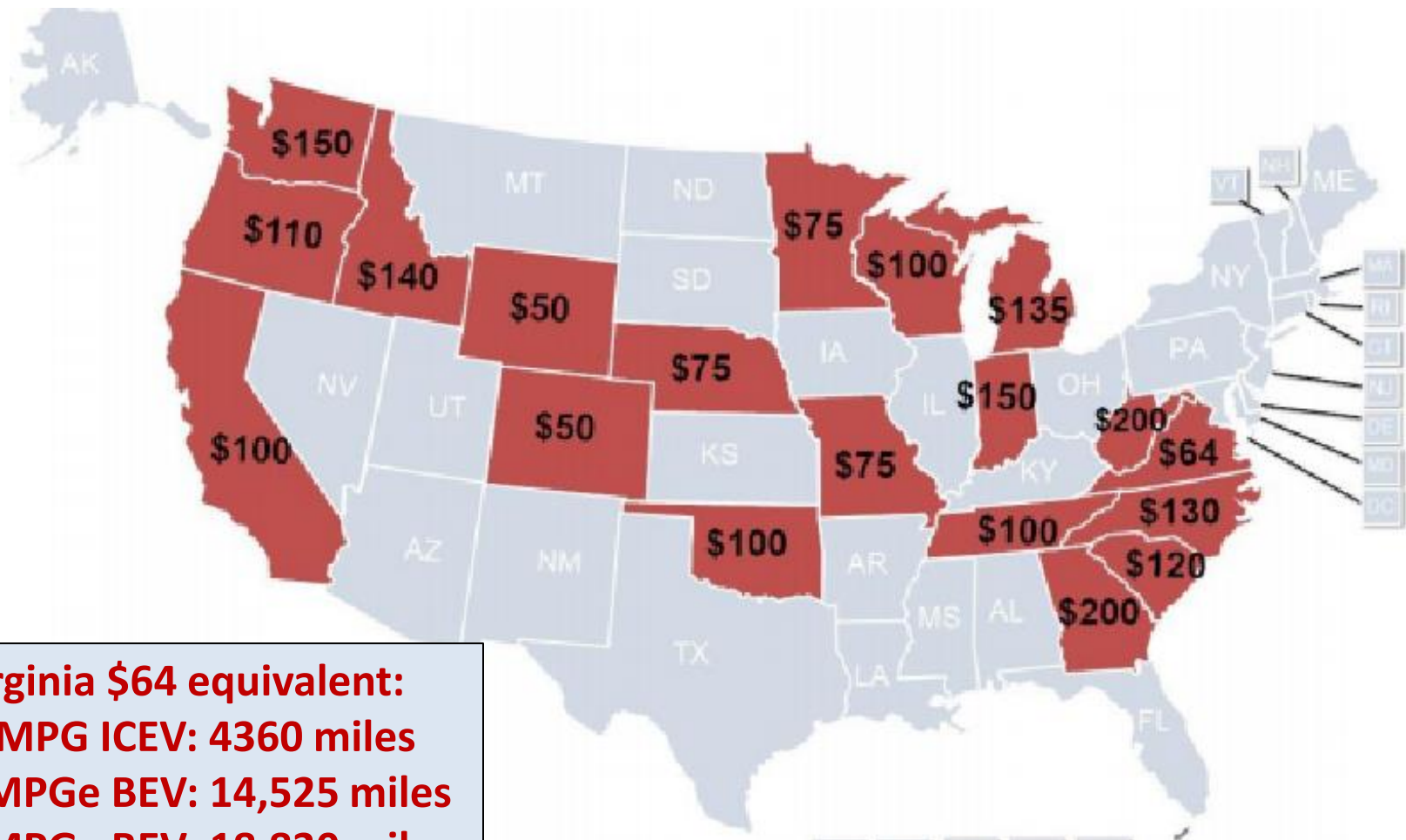
U.S. Gasoline Taxes



Combined 2019 local, state and federal rates (cents/gallon)

Virginia: Up 5 cents in 2020 & 2021, 2.1% more in I-81 corridor.

Extra Registration Fees on HEVs & EVs



Virginia \$64 equivalent:
30 MPG ICEV: 4360 miles
100 MPGe BEV: 14,525 miles
130 MPGe BEV: 18,830 miles

Extra fees to account for low or no fuel tax.

Better to have a fee for all vehicles according to the miles traveled.

Average BEV vs Average ICEV Fuel Cost

1 gallon releases 33.7 kWh energy when burned.

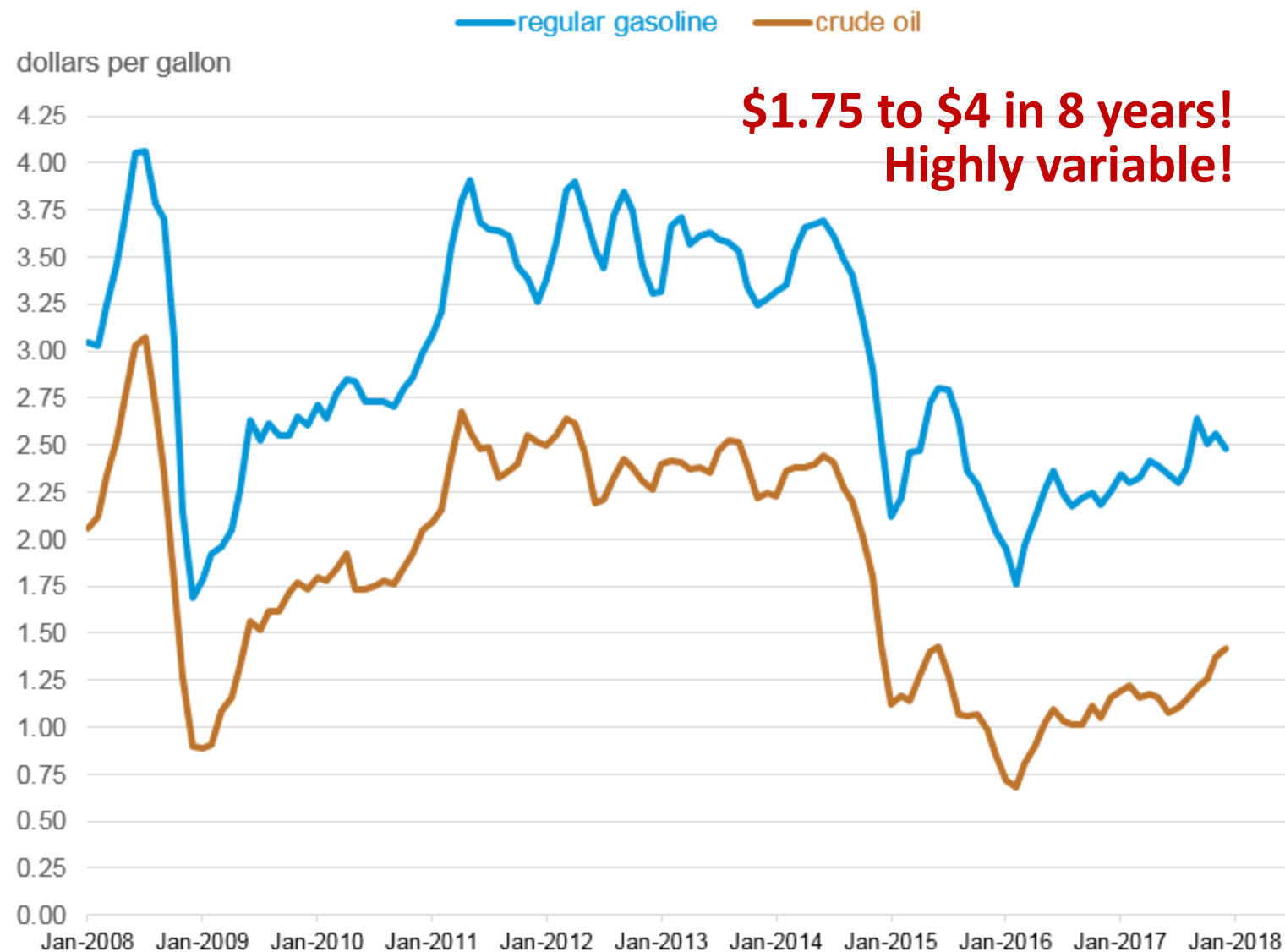
- 2018 US average ICEV MPG = 22 = 0.653 miles/kWh
- 2018 average BEV MPGe = 102 = 3.03 miles/kWh
 - **Tesla Model 3 SR+ = 141 MPGe = 4.18 miles/kWh**
- 2019 US average \$/gallon = \$2.49
- 2018 US average \$/kWh = \$0.125
- ICEV \$/mile = $\$2.49/22 = \mathbf{\$0.113/mile}$
- BEV \$/mile = $\$0.125/3.03 = \mathbf{\$0.0413/mile}$
 - TM3SR+ \$/mile = $\$0.125/4.18 = \mathbf{\$0.0299/mile}$
- **ICEV/BEV Cost = 2.74, ICEV/TM3-SR+ Cost = 3.77**
- **Electricity price is more stable than gasoline price.**

Most Efficient BEV vs Most Efficient HEV

Tesla Standard Range+ vs Prius Eco Fuel Cost

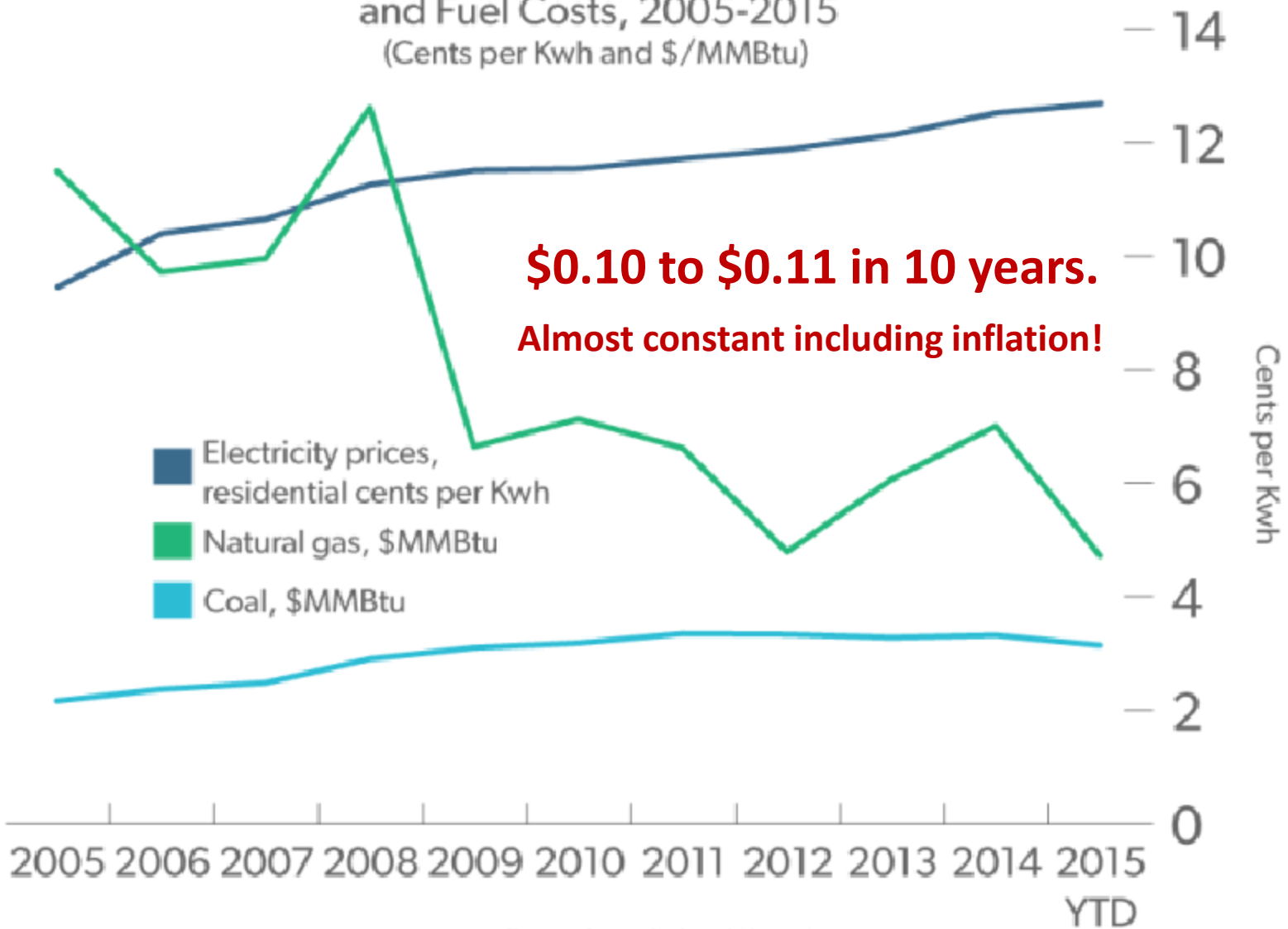
- Toyota Prius Eco (HEV) MPG = **56** = 1.66 mi/kWh
- Tesla SR+ (BEV) MPGe = **141** = 4.18 miles/kWh
- **Efficiency Ratio = 2.51**
- 2019 US average \$/gallon = \$2.49 (= \$0.0739/kWh)
- 2018 US average \$/kWh = \$0.125 (= \$4.21/gallon)
- HEV \$/mile = $\$2.49/56 = \mathbf{\$0.0445}$ per mile
- BEV \$/mile = $\$0.125/4.18 = \mathbf{\$0.0299}$ per mile
- **Cost Ratio = 1.49**
- **Electricity price is more stable than gasoline price.**

U.S average monthly gasoline and crude oil prices, 2008–2018



Note: Regular gasoline price is the retail price including taxes for all formulations of regular grade gasoline. Crude oil price is composite refiner acquisition cost of crude oil.
Source: U.S. Energy Information Administration, *Petroleum Marketing Monthly*, May 2019

Comparison of Residential Electricity Prices and Fuel Costs, 2005-2015 (Cents per Kwh and \$/MMBtu)



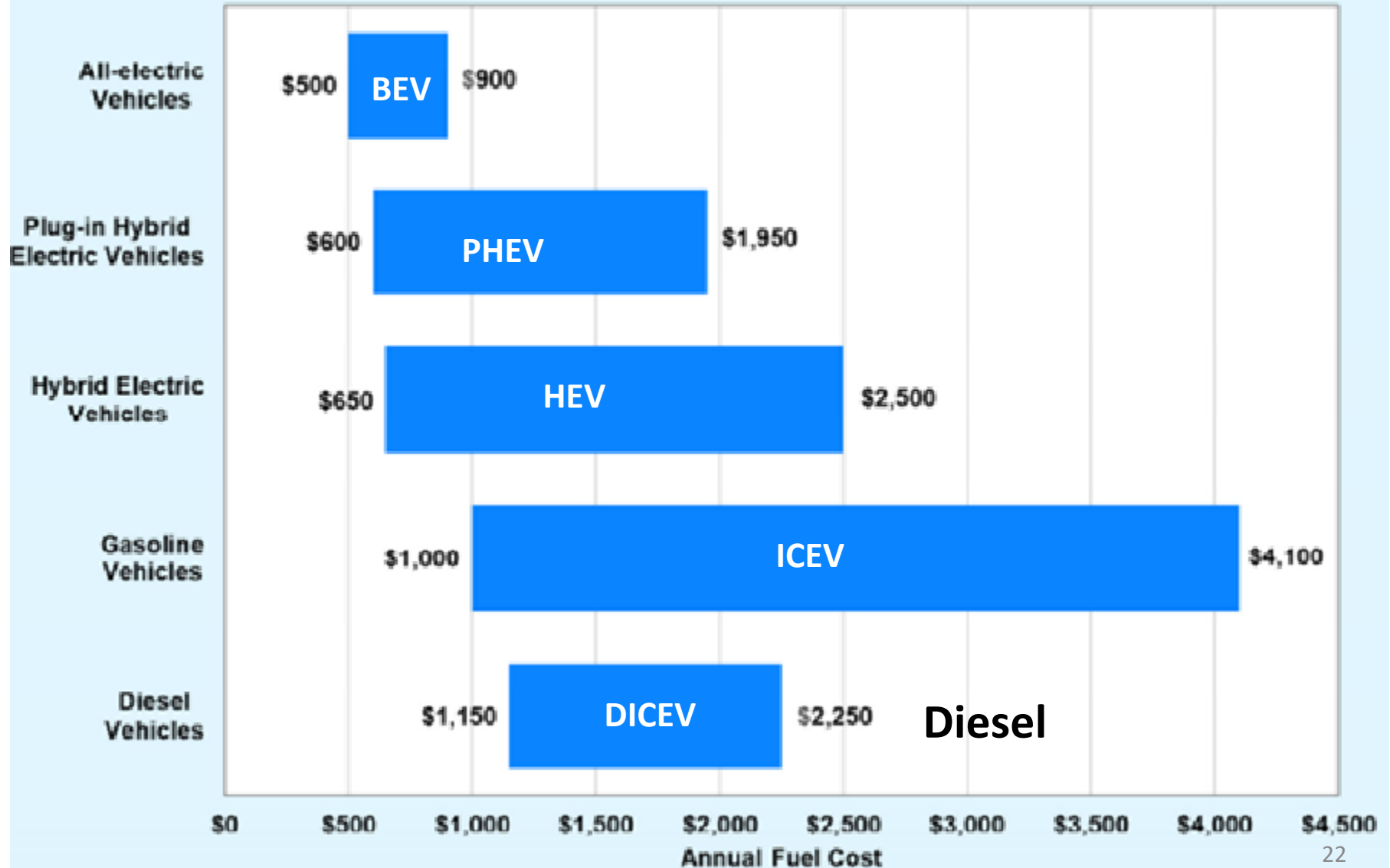
Source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec9_11.pdf,
http://www.eia.gov/totalenergy/data/monthly/pdf/sec9_13.pdf

IER INSTITUTE FOR ENERGY RESEARCH

Considering inflation \$0.13/kWh in 2015 is equivalent to \$0.106/kWh in 2005.

BEV vs ICEV Fuel Cost Range

Annual Fuel Cost Ranges by Technology Type, MY 2019



ICEV vs BEV Needed Maintenance

ICEV maintenance NOT needed for a BEV

- Mechanical brakes (used constantly)
- Oil and oil-filter regular changes
- Transmission fluid changes
- Mufflers and tail pipes
- Catalytic converters
- Belts
- Spark plugs
- Many engine moving parts to wear out

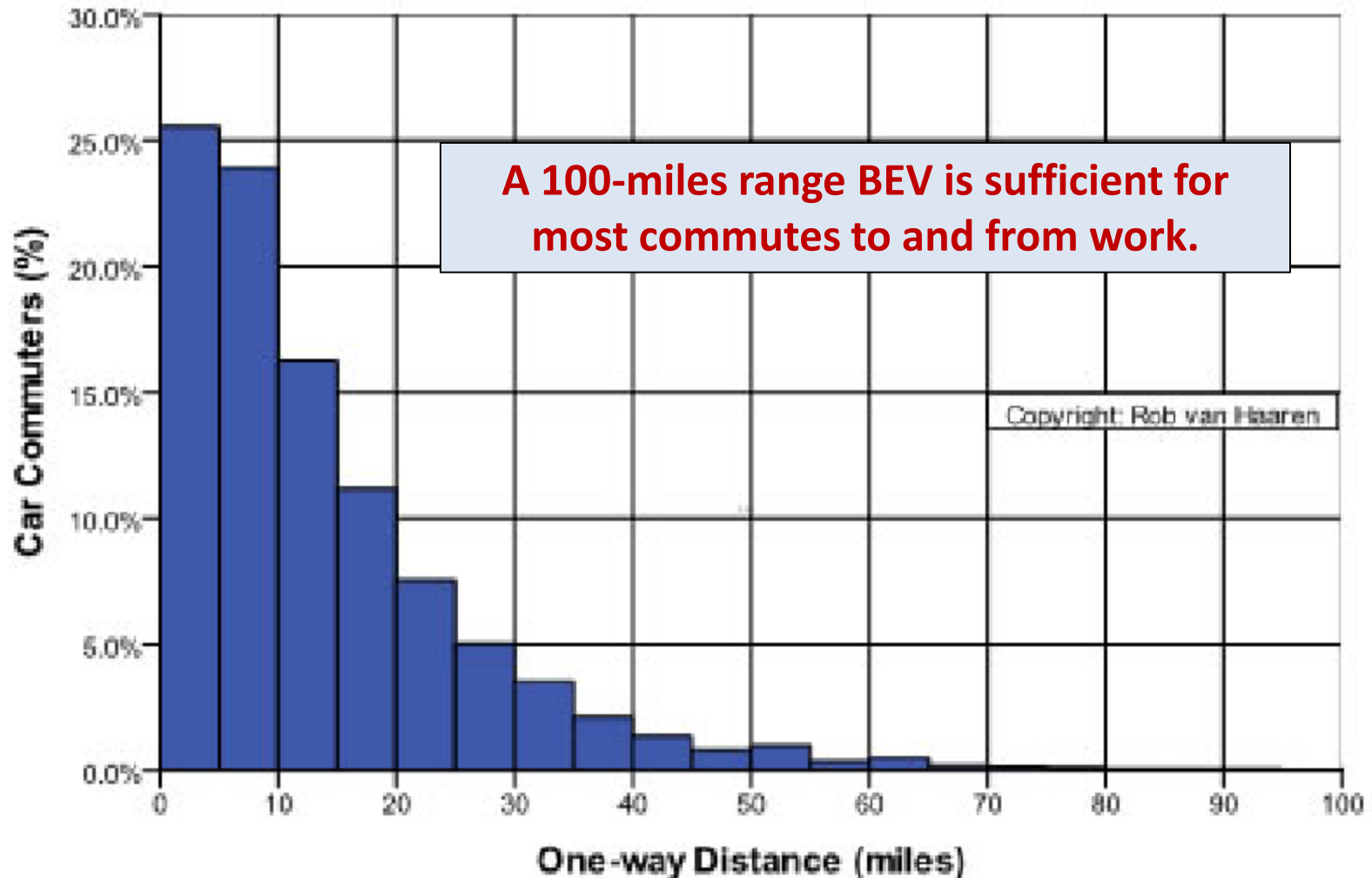
• BEV maintenance

- Mechanical brakes are **used only in emergencies and at low speed**. Otherwise **electricity regeneration** slows or stops a BEV.
- Electric motors usually run 24/7 for many years without maintenance or repairs.
- Rotate tires at about 10,000-miles intervals.
- Battery/electronics coolant change at 50,000 miles.
- Solid-state electronics are very reliable.

Questions about BEVs

- Q: What do you do when you run out of electricity?
- **A: What do you do when you run out of gasoline? You don't, because you watch the fuel gauge. You fill it up when needed.**
- Q: Do you have “range anxiety” when you drive?
- **A: No, because I plan my trips.**
- Q: What do you do when you go up a steep hill?
- **A: You step on the accelerator and pass the gasoline cars.**
- Q: Is a charged battery dangerous?
- **A: Not nearly as dangerous as a tank of gasoline!**

U.S. Car Commute Distance Distribution (n = 106,681)



“Driving an Escalade to buy groceries is like hanging a picture with a sledge hammer!”

EV Buying Experience

- Sales persons are often poorly informed about features and technology of EVs.
- Sales persons are often poorly informed about different available charging possibilities.
- Customers are often poorly informed about features, technology and charging for Evs.
- Dealers do not like the fact that it takes longer to inform customers about EVs than ICEVs.
- Dealers do not like low maintenance costs for BEVs.
- **For the above reasons Tesla decided to not sell their BEVs through dealers.**

State Laws about Buying Teslas

- 16 states that forbid sales of Tesla BEVs: **AL, AR, CT, IA, KS, KY, LA, MI, MT, NE, ND, OK, SC, SD & TX**
- 9 states that limit the number of Tesla stores: **CO(1), NC(1), VA(2), GA(5), MD(4), NJ(4), NY(5), OH(3) & PA(5)**
- **Michigan law:** “A manufacturer shall not...sell any new motor vehicle directly to a retail customer other than through franchised dealers.”
 - **A Michigan legislator:** “The Michigan dealers do not want you here. The local manufacturers do not want you here. So you’re not going to be here.”

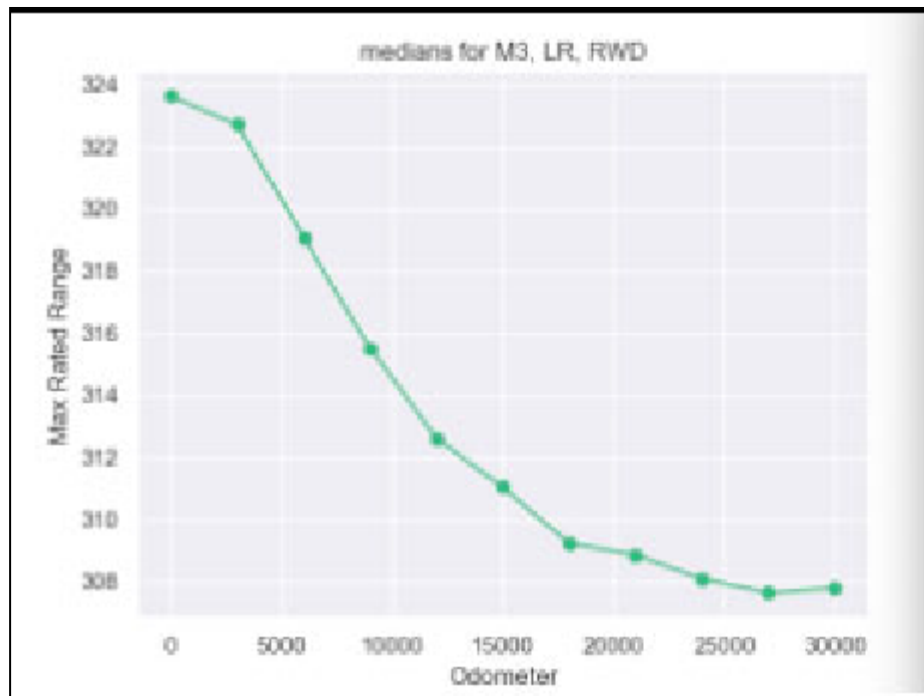
What about BEV Batteries?

- BEV batteries are guaranteed for defects for 8 years and 100,000 miles. (**Tesla Model 3 Long Range for 120,000 miles**)
- Lithium-ion batteries lose capacity with time, usually quicker at first and slower later=.
- [Tesla Model 3](#) has a 70% degradation warranty within 8 years. Most will degrade much less than that depending on how they are driven and charged. **Projected lifetime (70% capacity) = 300,000-400,000 miles.**
- New batteries that will last longer and cost less are being developed. **Tesla states next battery will last 1-million miles and will be available soon!**

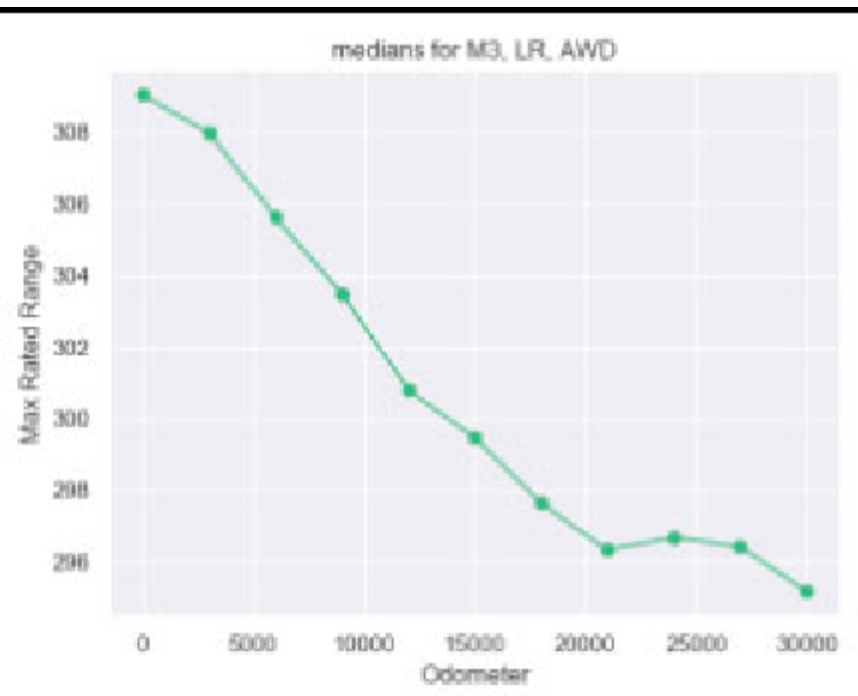
Battery Reuse and Recycling

- When capacity down to about 70% BEV batteries can be used to store solar and wind energy and to store energy during time-of-day (TOD) low rates to be used during TOD high rates.
- When reused BEV batteries are down to about 20% they can be recycled.
- Toxco Inc. awarded \$9.5-million DOE grant to recycle lithium batteries.

Tesla Model 3 Battery Capacity Loss



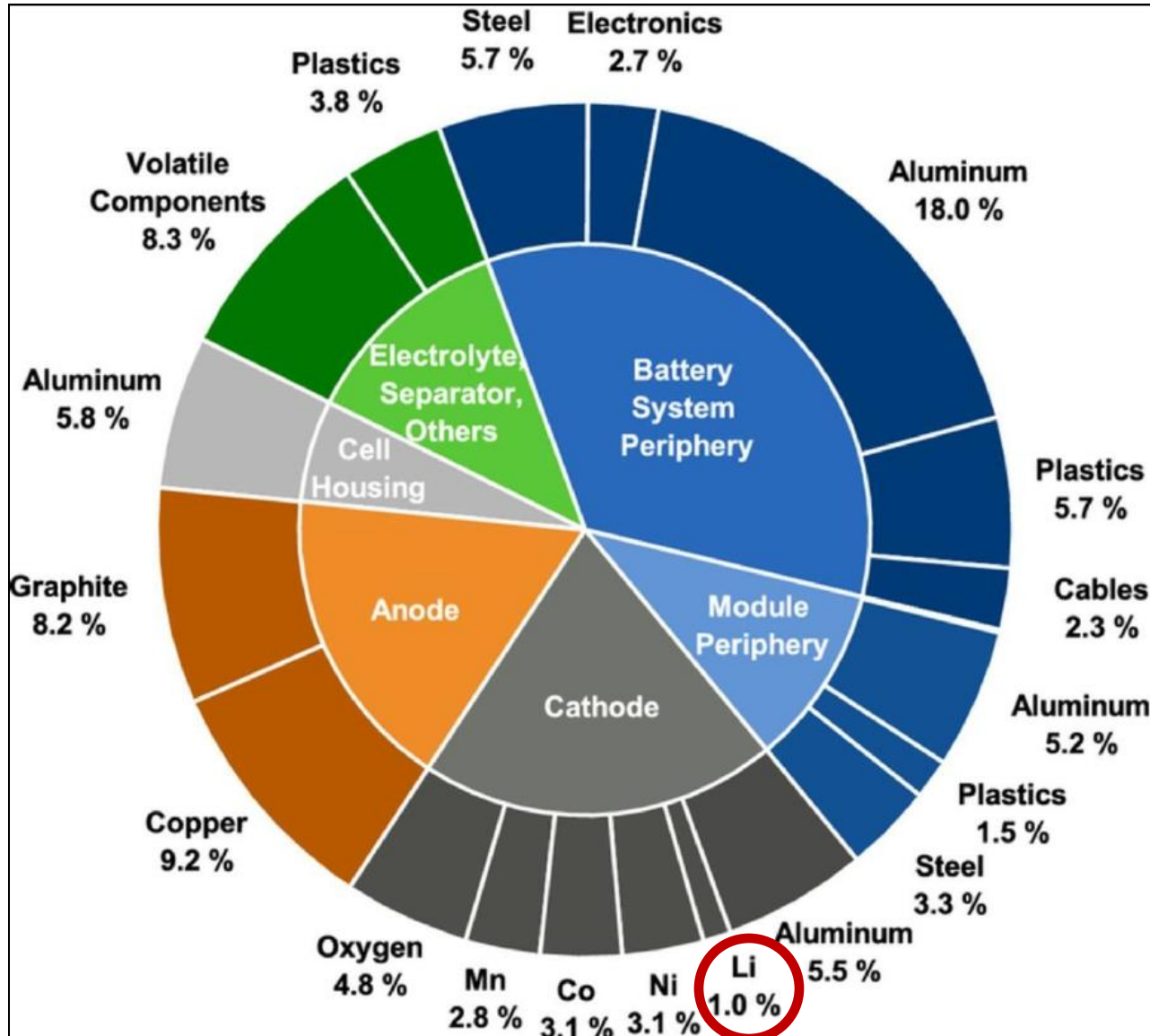
Medians for TM3LR RWD vs miles



Medians for TM3LR AWD vs miles

Lithium-ion capacity loss occurs faster initially, then approaches an asymptote.

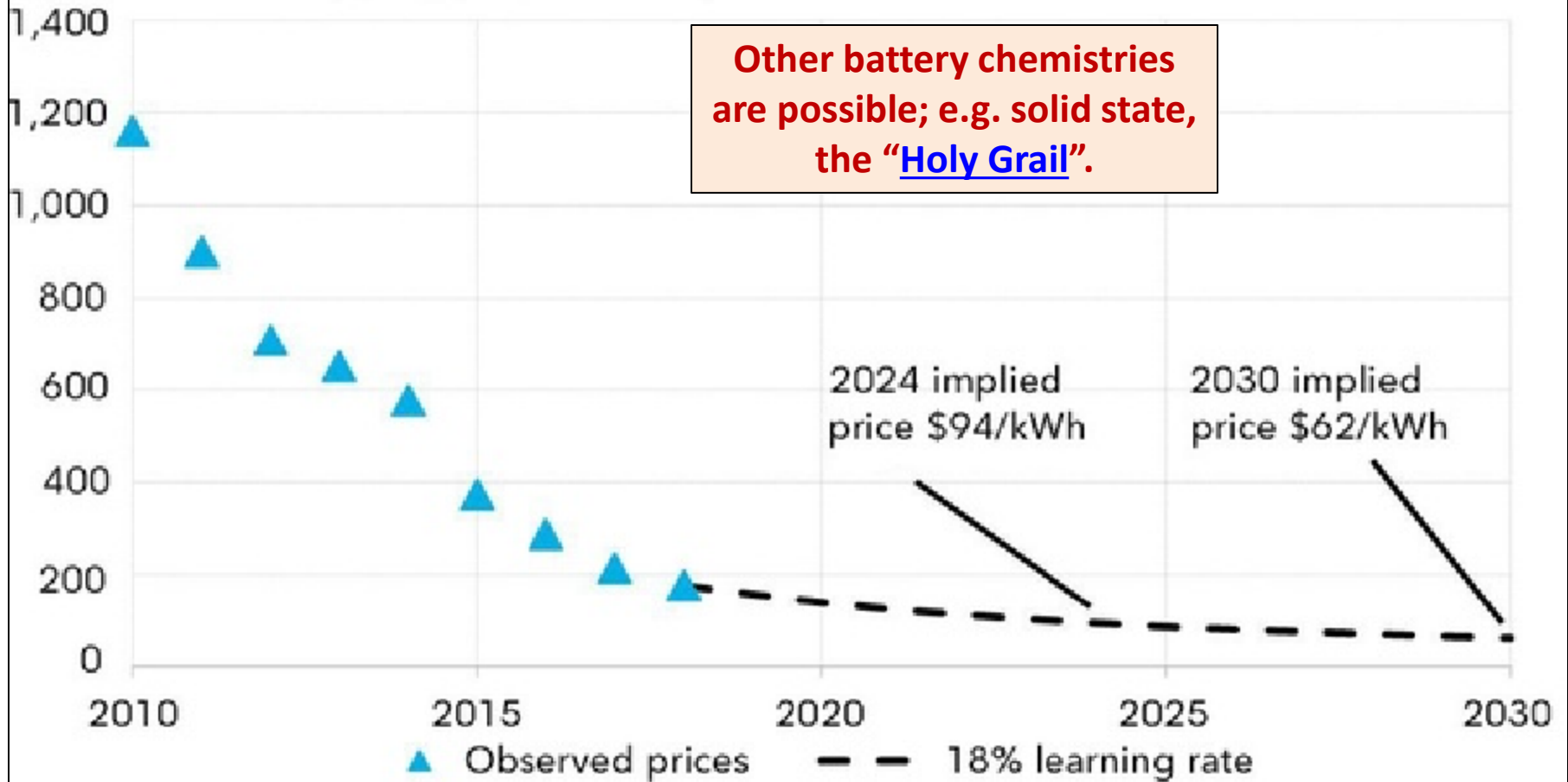
Lithium-Ion Battery Components



Note that Lithium (Li) is a small fraction. The main abundance problems are for Cobalt (Co) and Nickel (Ni). Tesla plans to eliminate Cobalt in Lithium-Ion batteries.

Lithium-ion battery price outlook

Lithium-ion battery pack price (real 2018 \$/kWh)



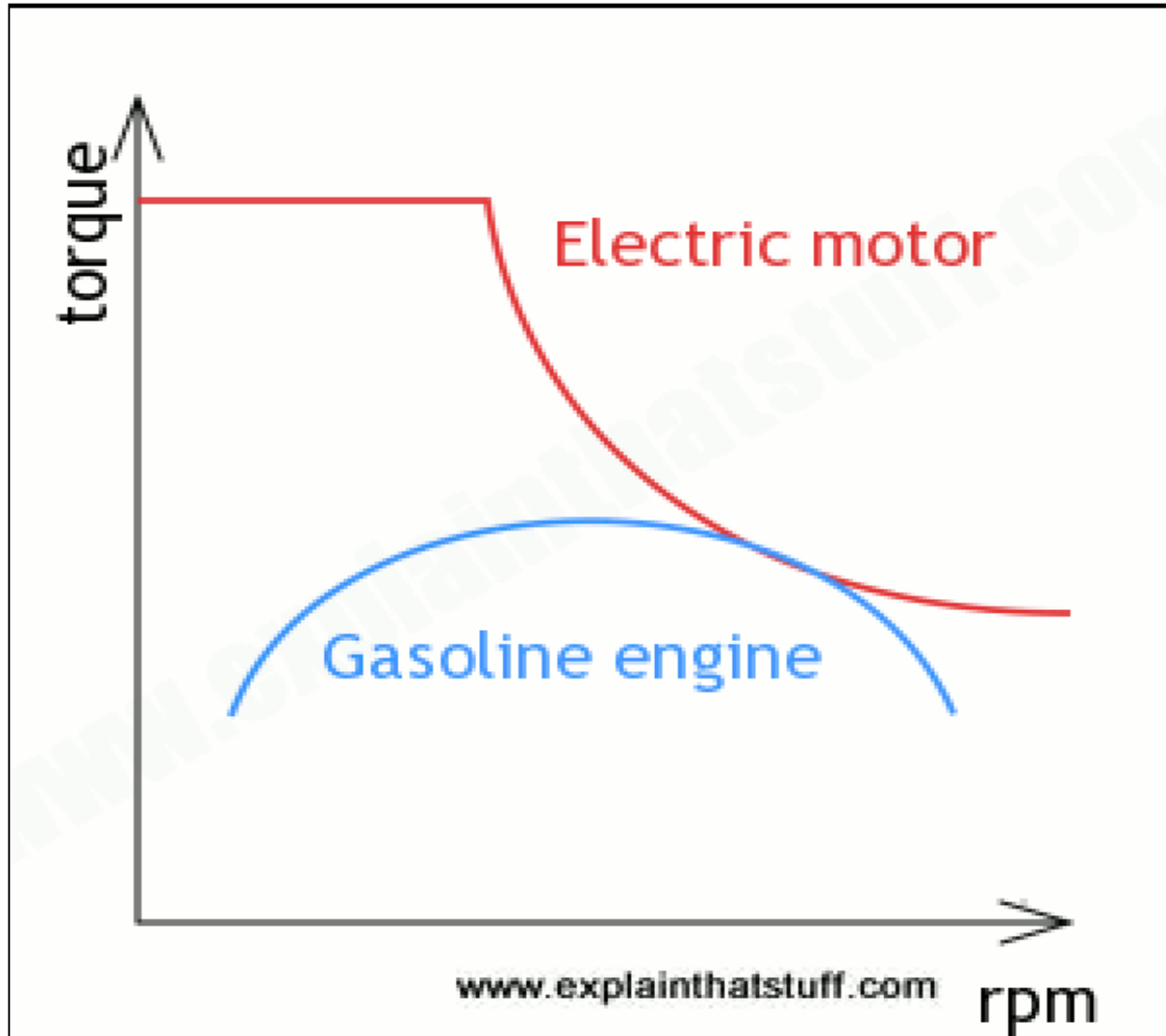
Source: BloombergNEF

Enjoyment!

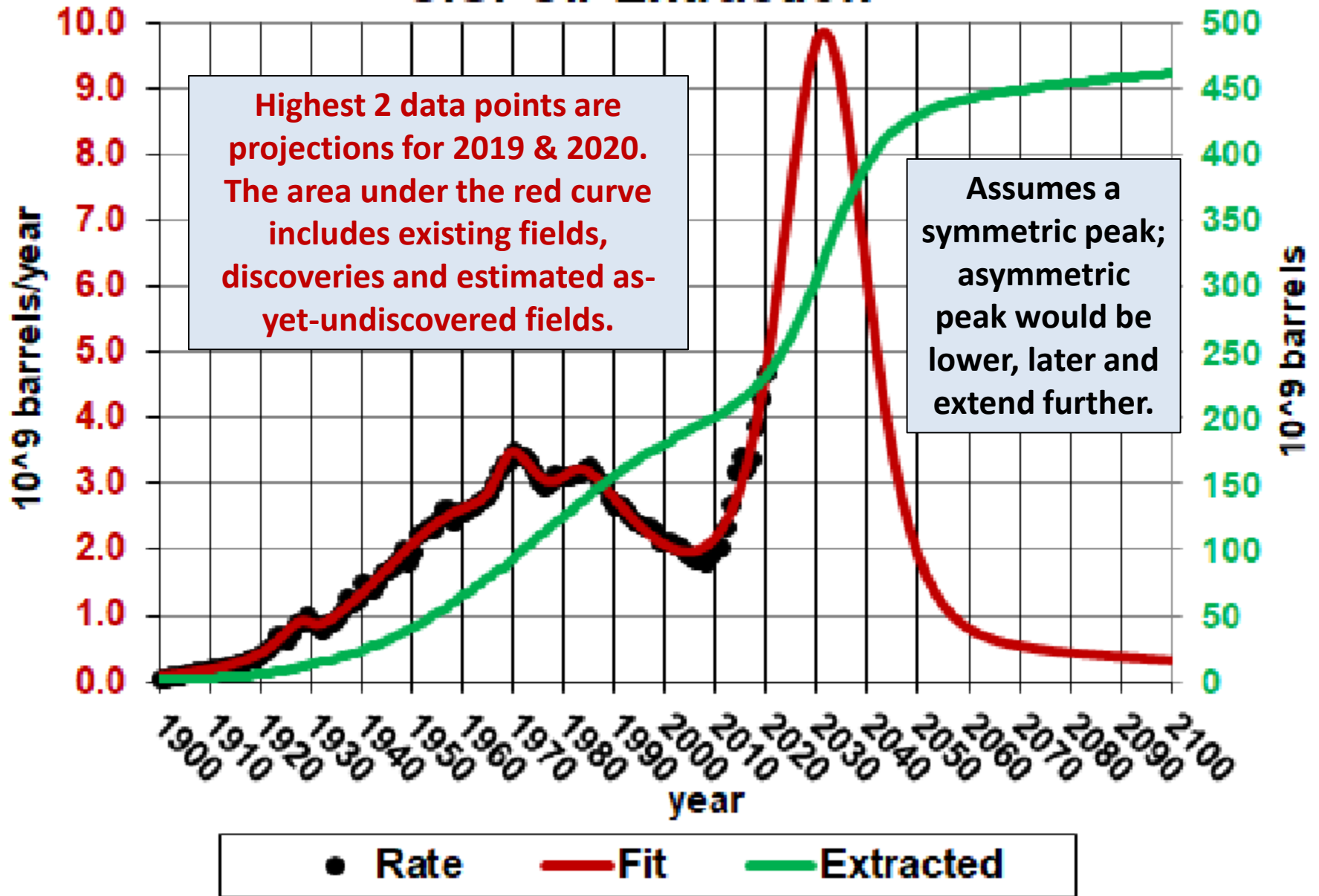
- Very quiet. ([New regulations](#) require sound below 19 mph.)
- High acceleration! (See next slide.)
- Most battery charging overnight at home.
 - No fumes or bad weather when charging.
- Much free < 10-kW public charging.
- Low center of gravity enhances safety and performance (heavy battery underneath).
- One-pedal driving = foot off pedal stops BEV.

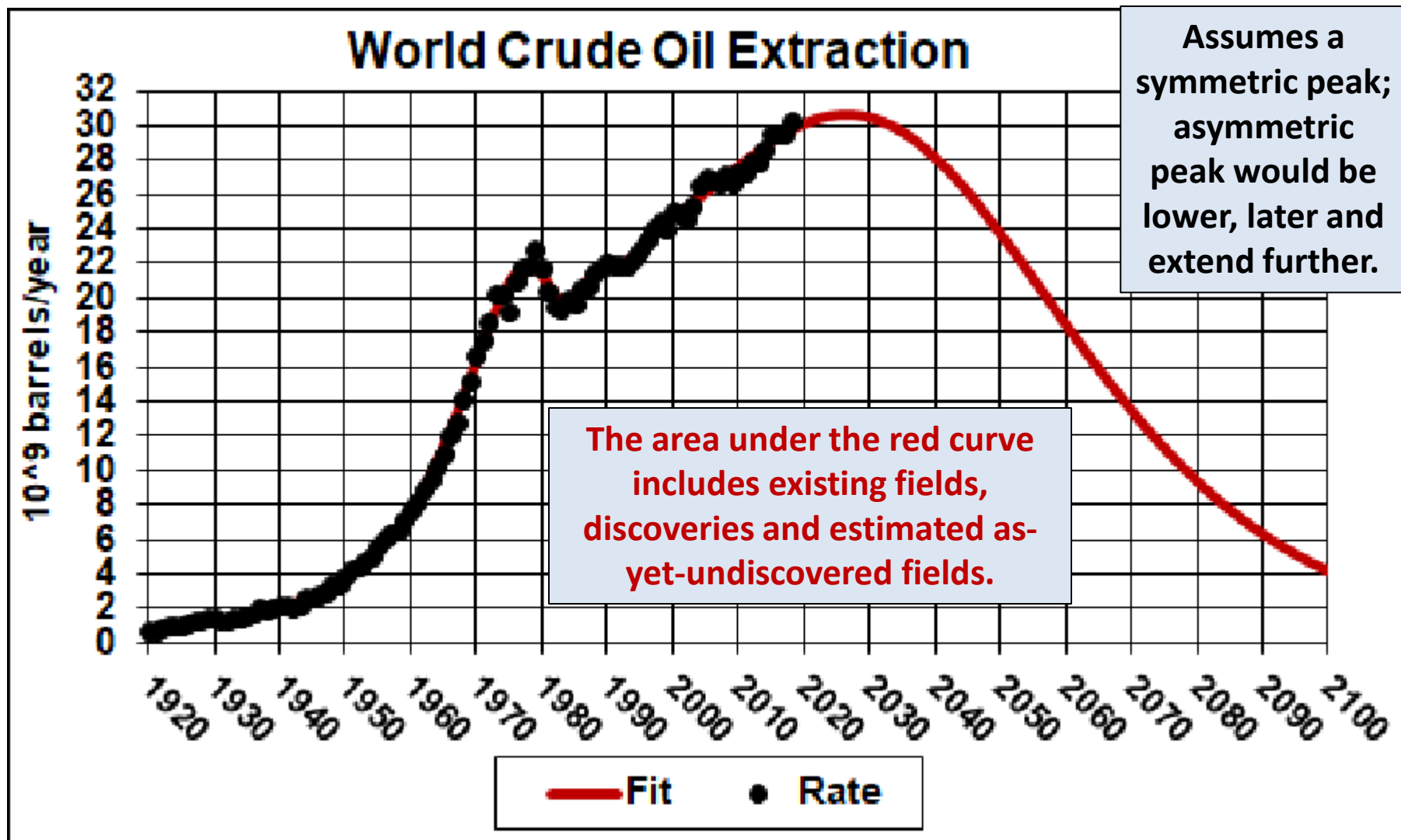
0-30 mph Acceleration is a **BIG DEAL!**

- **High torque at low speed! Triple acceleration same efficiency as for ICEV.**
- Can get to the next traffic light far ahead of ICEV cars with no roar.
- Can maneuver much better in tight traffic.



U.S. Oil Extraction

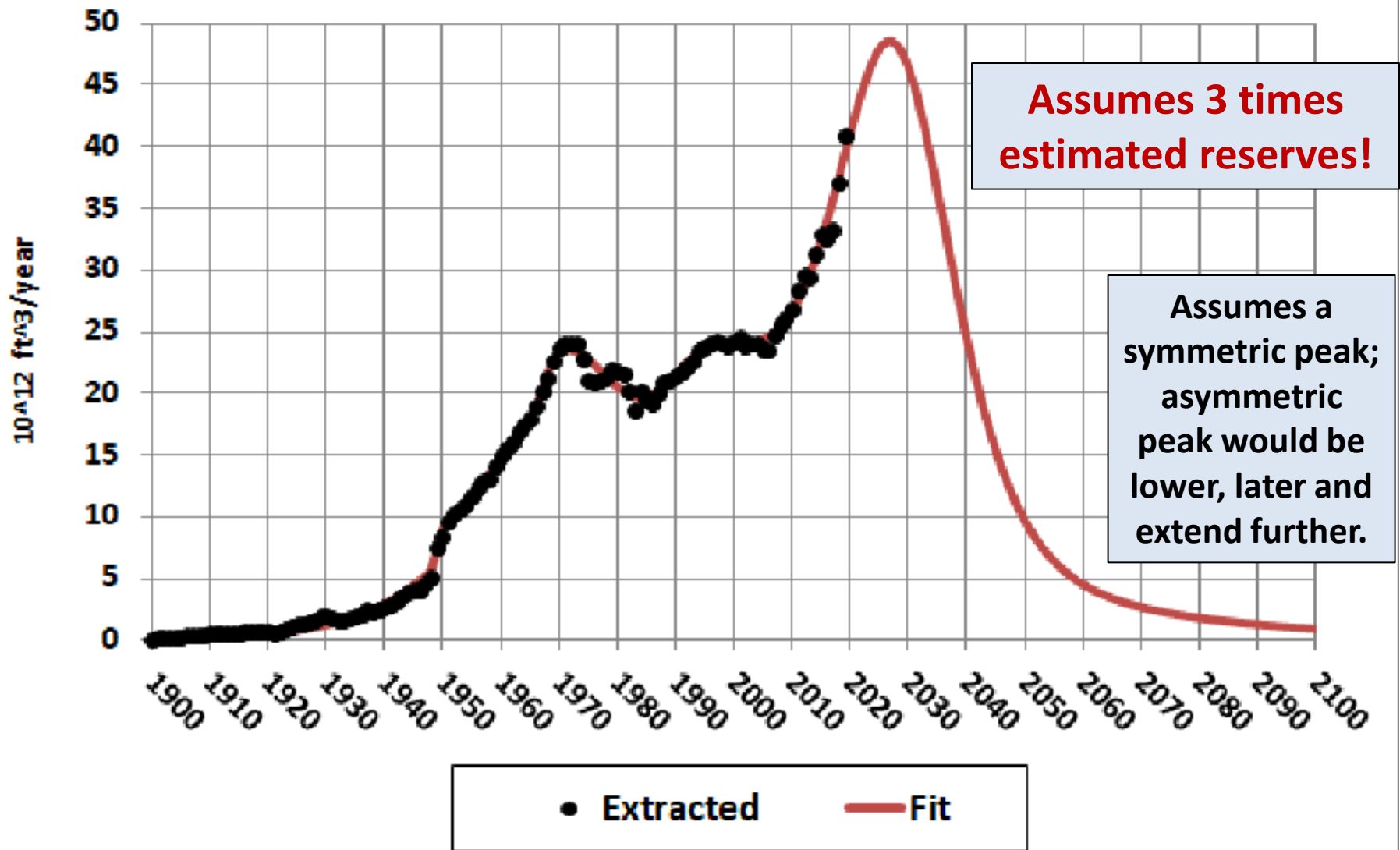




Current crude-oil price = **\$55-\$60/barrel**.

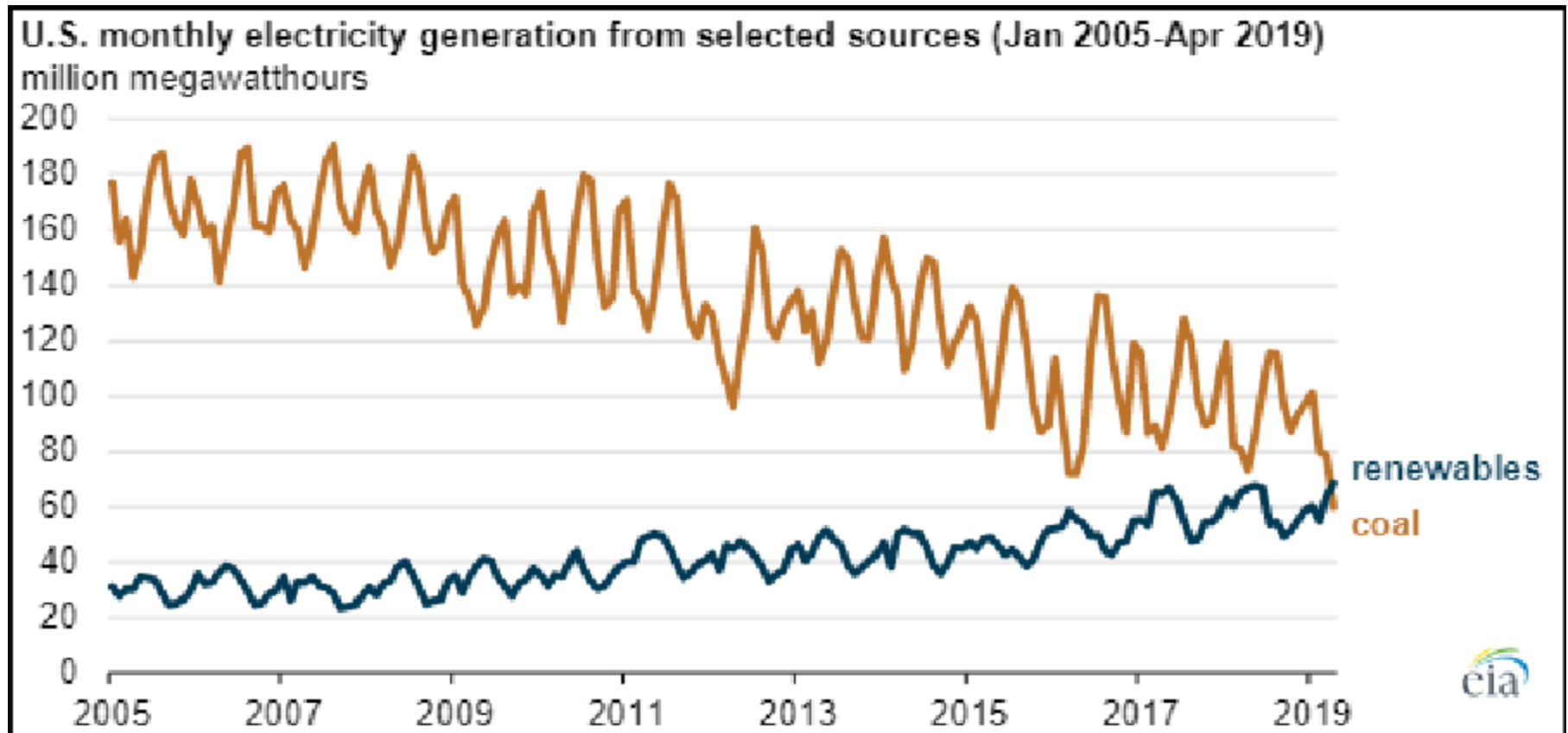
[A recent study](#) shows that crude-oil price **must be no higher than \$10/barrel** for ICEVs to match the operating cost of BEVs fueled by solar and wind energy!

United States Natural-Gas Extraction



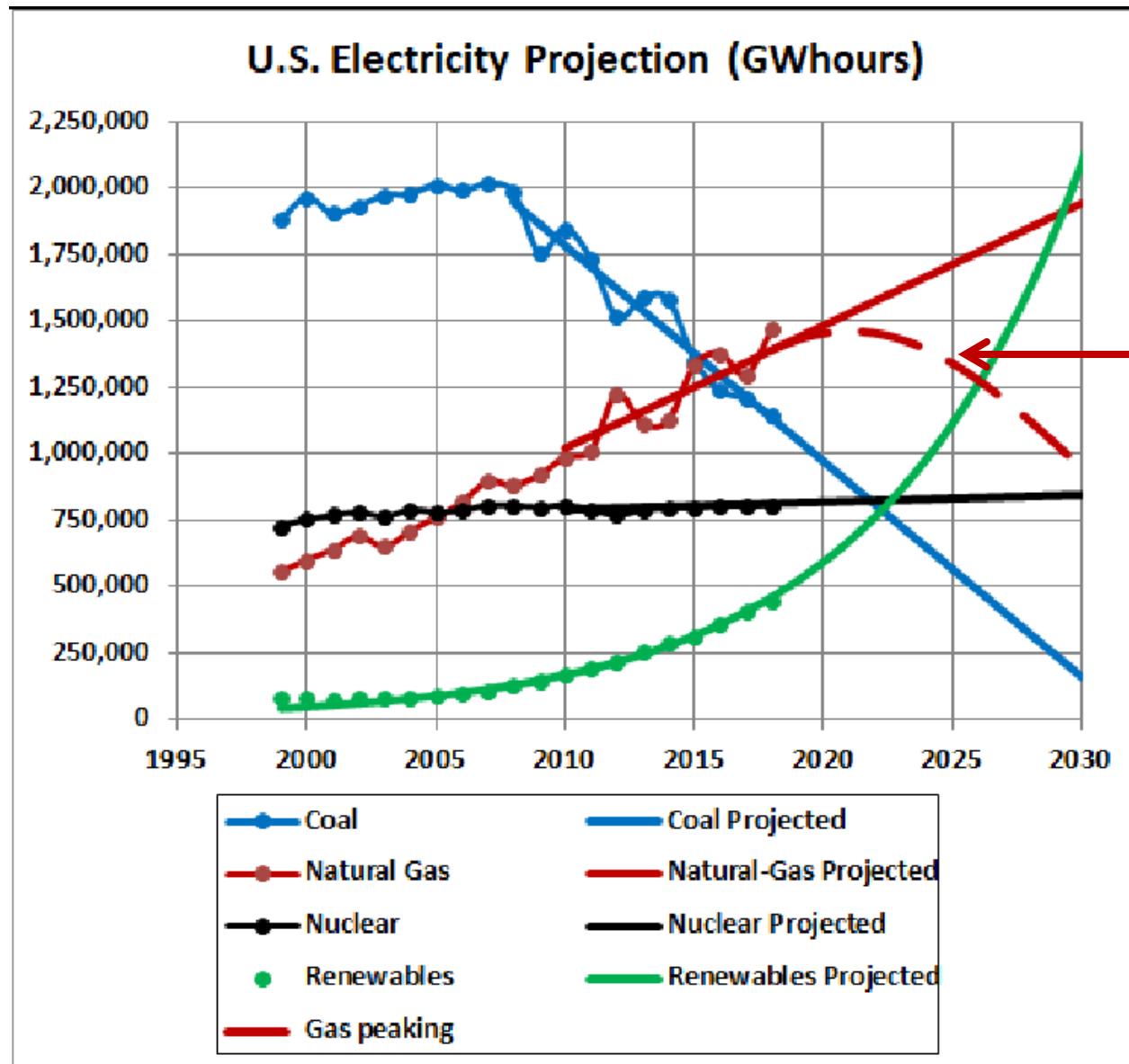
Do not plan to power future vehicles with natural gas!

“Renewables” are Passing Coal for U.S. Electricity Generation



Renewables = hydropower, wind, solar, geothermal and biomass.
(Note it **includes hydropower**, which is **arguably not renewable**.)

Solar/Wind/Biomass are Passing Coal for U.S. Electricity Generation



Natural-gas curve will bend downward because U.S. extraction will peak soon.

Renewables dominate by 2030!

Renewables = wind, solar, and biomass, **not including hydropower**.

Are You Convinced of the Necessity and Desirability to **Drive BEVs**?

- What BEVs are available or will be available soon?
- How do they compare?
- Buying price minus tax credits?
- Range (miles/full-charge)?
- Operating price (efficiency: MPGe)?
- Safety?
- Reliability?
- Attractive design?
- Performance (0-60 mph seconds)?

Tesla Model 3

Consumer Reports:
Tesla Model 3 is “most satisfying” car, more than Porsche or Corvette.



TM3 is managed by smartphone or RFID card or fob. Auto open and close with smartphone.

Average gasoline car in 2018: 25 MPG

TM3 had 8 Car-of-the-Year awards in 2018-20.

Model	EPA Range	MPGe	Price
Standard Range *	220	131	\$35,900
Standard Range Plus	250	141	\$39,990
Long Range *	330	130	\$45,900
AWD	322	121	\$48,490
Performance (AWD)	322	121	\$56,990

Autopilot software is included in all 5 versions. Order online. * = phone order. If leased, returned to Tesla.

US 2018 average price of a light vehicle was \$37,577.

Tesla Model 3 Dashboard

A photograph of the interior of a Tesla Model 3, showing the dashboard and steering wheel. The dashboard is a large, horizontal screen displaying a map and navigation information. The steering wheel is black with the Tesla logo in the center. The interior features a combination of black and light-colored wood trim.

Tesla BEVs have regular software updates, about one per month, to add new features and fix problems. My TM3LR-RWD had 24 updates in first 20 months. It now has many features it did not have originally.

**All car controls are on the 15" screen or on the steering wheel and steering column.
Adaptive cruise control is simplest.
Cabin air flow is across entire dashboard.
Excellent navigation including Superchargers and Destination Chargers.**

Tesla Model 3 Updates Since May 2018

- Range, power, efficiency & regeneration increased
- Many improvements to Autopilot and Full Self Driving
- Summon and Smart Summon in parking lots
- DashCam & location-based Sentry Mode with 4 cameras
- Supercharging improvements; e.g. pre-conditioning & V3
- CHAdeMO fast-charging support
- Connection to home WiFi
- Feature improvements, e.g. auto wipers & air venting
- More options for driving modes; e.g. [1-pedal driving](#)
- Air conditioning modes: Parking, [Dog](#) & Camp Modes
- Key fob support; GPS side-mirrors auto folding
- Spotify, Hulu, YouTube, Netflix, Romance Mode, etc.
- Text messages receive and answer
- Many games, Chrome browser, Caraoke & Chess
- More car functions in Tesla app, e.g. close or vent windows

Tesla Dog Mode



What is Tesla Autopilot?

- **Requires slight torque on steering wheel.**
- 8 cameras, 12 ultrasound sensors & forward radar
- Automatically brakes as leading car slows.
 - Also, occurs with adaptive cruise control (TAAC).
- Stays between lane lines; changes lanes after turn-signal activation.
- **Makes driving on long trips less tiring since attention can be concentrated on nearby traffic instead of lanes, acceleration and braking.**
- **Full Self Driving (FSD, extra cost)(in development)**
 - Auto Lane Change, Autopark, Summon, Smart Summon
 - Automatically turns onto ramps when navigating trips.
 - **Future:** respond to stop lights/signs, auto city driving.

Tesla Model Y SUV



Built on Model 3 skateboard.

Model	Range (mi)	MPGe	Price
LR RWD	300	137	\$48,000
LR AWD	316	121	\$52,990
Performance	315	121	\$60,990

Chevrolet Bolt EV



**Federal
tax credit
= \$1875
until 31
Mar 2020.**

Range: 259 miles MPGe: 119 Price: \$36,620

US 2018 average price of a light vehicle was \$37,577.

There are
two trims
in order of
increasing
cost: LT &
Premium.
⁴⁷

Chevrolet Bolt EV Dashboard



**GM OnStar,
Apple CarPlay or
Android Auto for
Navigation**

Nissan LEAF II e-Plus



Model	EPA Range	MPGe	Price
LEAF	150	112	\$31,600
LEAF ePlus	226	108	\$38,200

**Federal
tax credit
= \$7500.**

US 2018 average price of a light vehicle was \$37,577.

**These two
models have
3 variants in
order of
increasing
cost:
S, SV, & SL.**

Hyundai Kona Electric



Range: 258 miles

MPGe: 120

Price: \$36,450

US 2018 average price of a light vehicle was \$37,577.

Hyundai Ioniq Electric



Range: 170 miles

MPGe: 133

Price: \$30,315

US 2018 average price of a light vehicle was \$37,577.

Kia Niro Electric



Range: 239 miles MPGe: 112 Price: \$39,495

US 2018 average price of a light vehicle was \$37,577.

Kia Soul Electric



Range: 243 miles

MPGe: 114

Price: \$33,950

Tesla Model S AWD



Model	EPA Range	MPGe	Price
Long Range (AWD)	390	111	\$79,990
Performance (AWD)	348	104	\$99,990

**Autopilot
software
included in both
versions.
Order online.
**Free
Supercharging!****

Tesla Model X AWD SUV



Model	EPA Range	MPGe	Price
Long Range (AWD)	351	96	\$84,990
Performance (AWD)	305	90	\$104,990

**Autopilot
software
included in both
versions.
Order online.
**Free
Supercharging!****

Jaguar i-Pace AWD



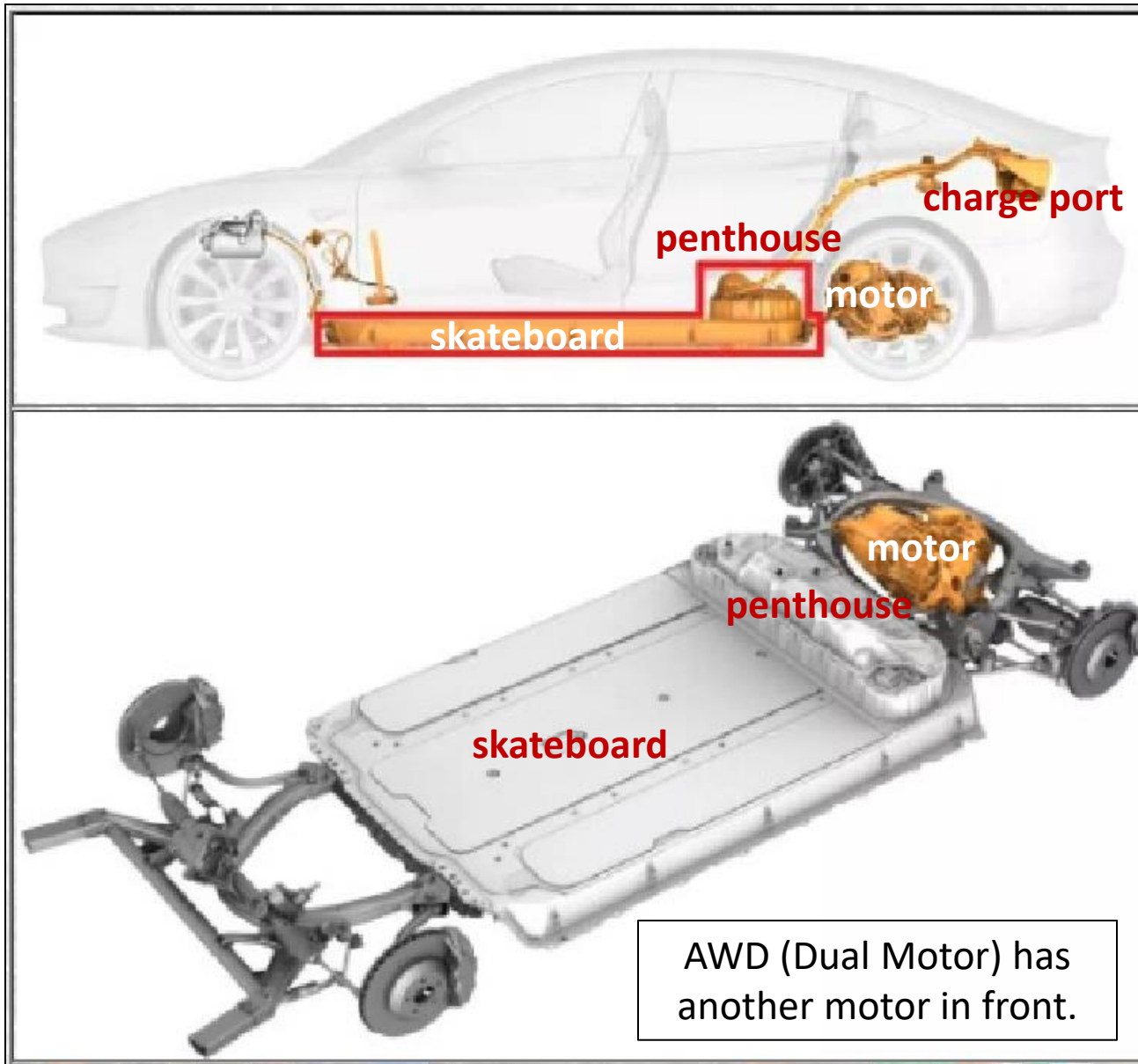
Price	Range	MPGe	0-60
\$69.500	253	76	4.5

Audi e-Tron AWD

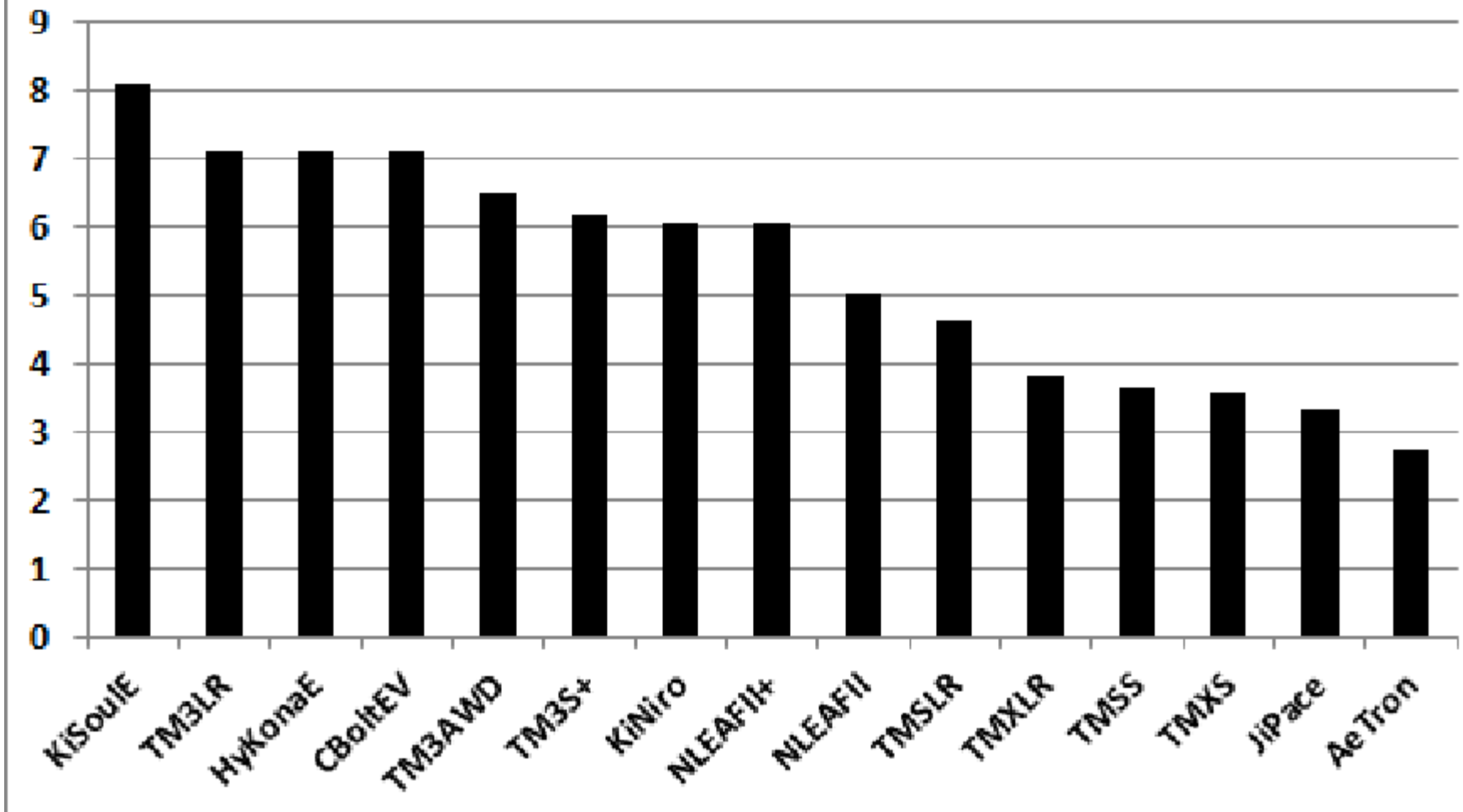


Model	Price	Range	MPGe	0-60
50	\$56,100	186	97	6.8
55	\$74,800	242	94	5.5

Tesla Model 3 Drive Train



Range (miles)/Price(\$1000)



KiSouIE=Kia Soul Electric, **TM3LR**=Tesla Model 3 Long Range, **HyKonaE**=Hyundai Kona Electric
CBoltEV=Chevy Bolt EV, **TM3AWD**=Tesla Model 3 AWD, **TM3S+**=Tesla Model 3 Standard Plus
KiNiro=Kia Niro, **NLEAFII+**=Nissan LEAF II Plus, **NLEAFII**=Nissan LEAF II, **AeTron**=Audi eTron
TMSLR=Tesla Model S Long Range, **TMXLR**=Tesla Model X Long Range, **JiPace**=Jaguar iPace

What About Depreciation?

- Almost all BEVs besides Tesla's have about twice the annual depreciation as similar ICEVs.
- Great opportunity to buy used BEVs!

Annual U.S. comparison of (Chevy Bolt EV, Hyundai Ionic EV, Kia Soul EV, Nissan LEAF, VW e-Golf) versus (Chevy Cruze, Honda Civic, Hyundai Elantra, Nissan Sentra, Toyota Corolla).



	EV	ICE	Difference
Fuel:	546	1,255	709
Maintenance/repair/tires:	949	1,279	330
Insurance:	1,214	1,328	114
License/registration/taxes:	-579	466	1,045
Depreciation:	4,806	2,240	-2,566
Finance:	768	546	-222
Total per year	7,704	7,114	-590

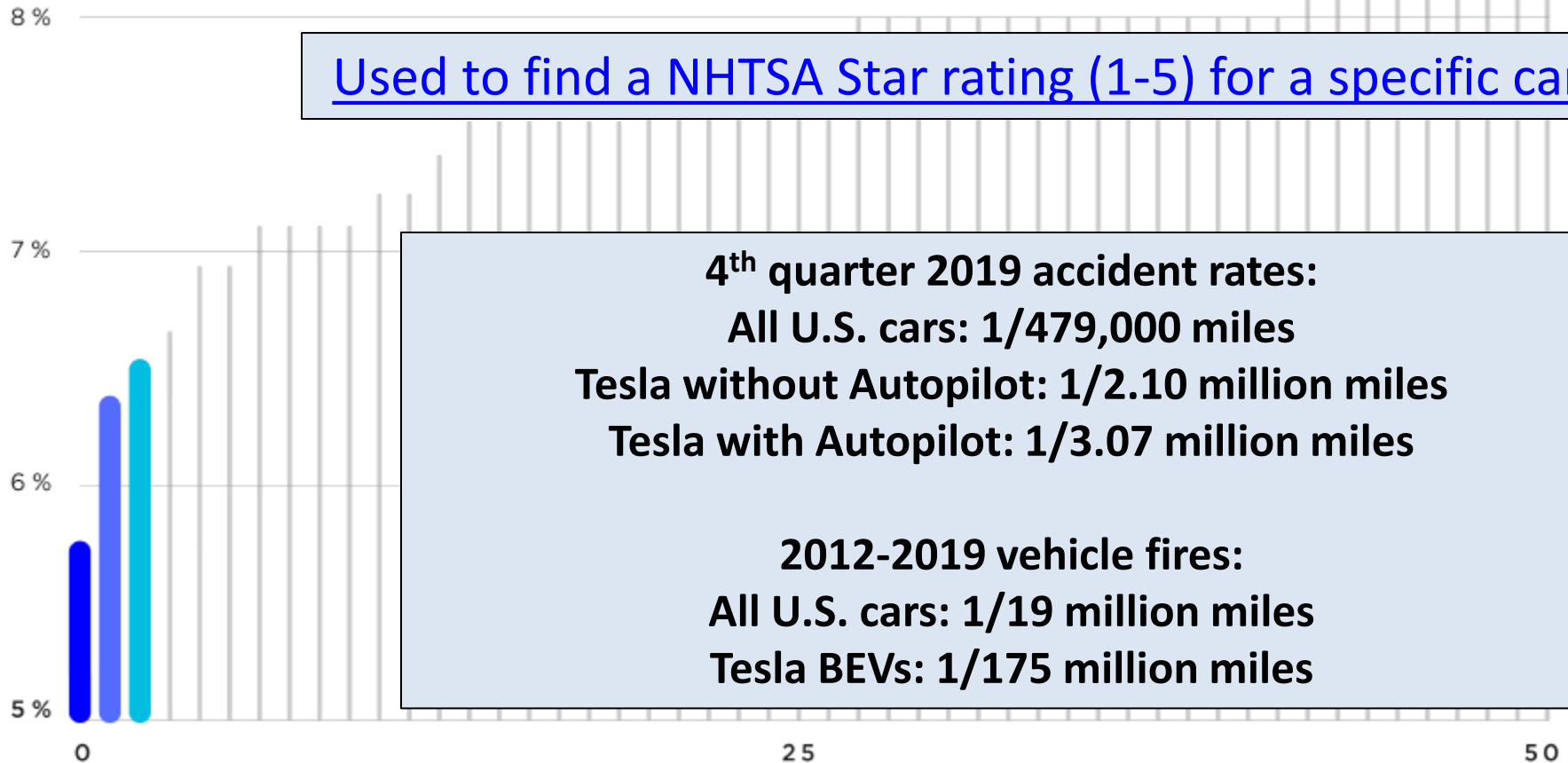
Kelly Blue Book: **TM3 estimated value = 69% @3 years & 49% @ 5 years**
Tesla Model 3 has caused the ICEV premium sedans to depreciate more than before.

LOWEST PROBABILITY OF INJURY

TESTED BY NHTSA

NHTSA = National Highway Traffic Safety Administration

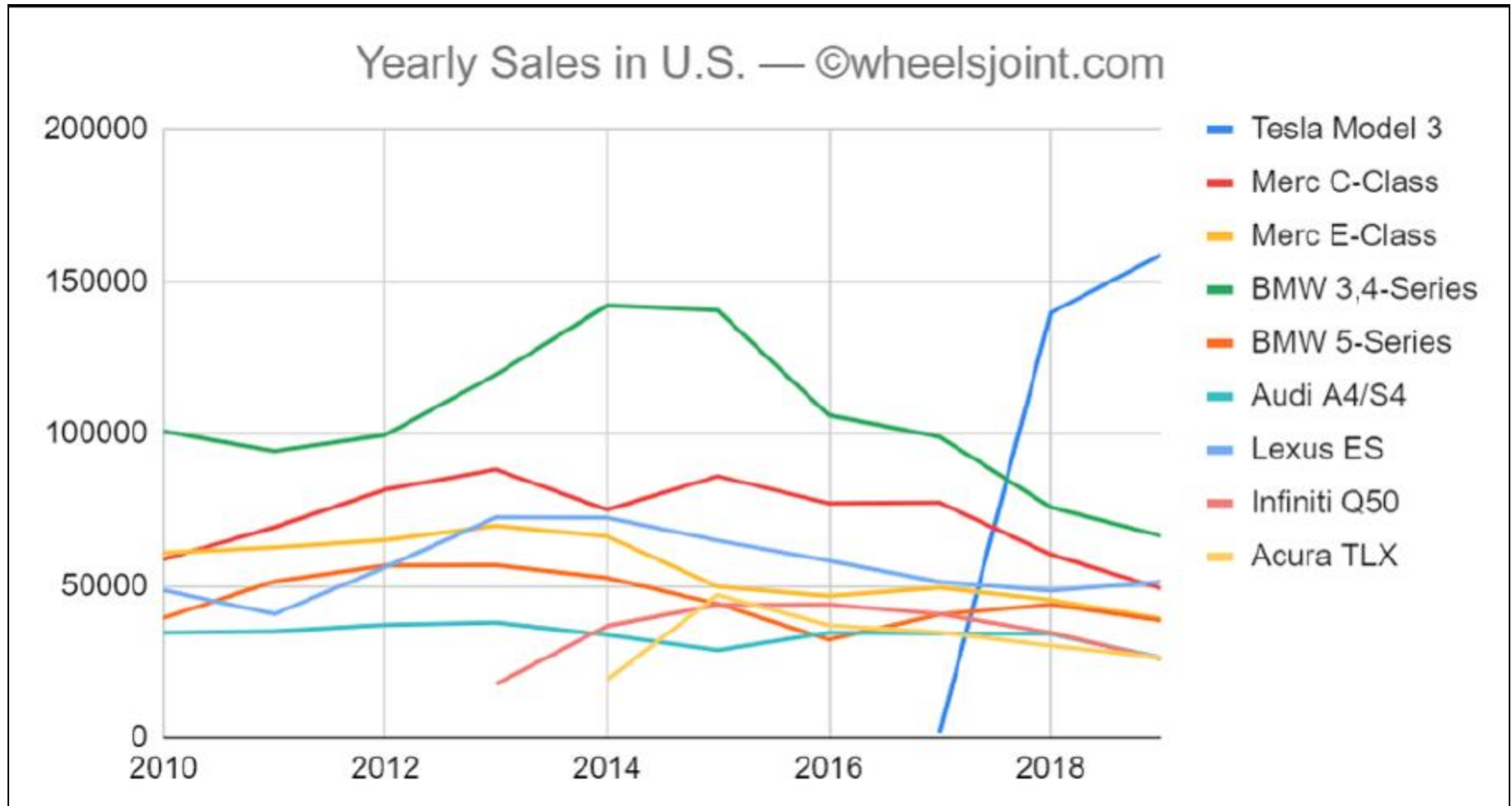
[Used to find a NHTSA Star rating \(1-5\) for a specific car.](#)



MODEL 3 MODEL S MODEL X

TOP 50 VEHICLES TESTED
BY NHTSA (SINCE 2011)

U.S. Premium-Sedans' Sales



**Tesla Model 3 has taken over the premium-sedans market in the U.S.
and is beginning to do so in Europe.**

BEV Supercar: Porsche Taycan



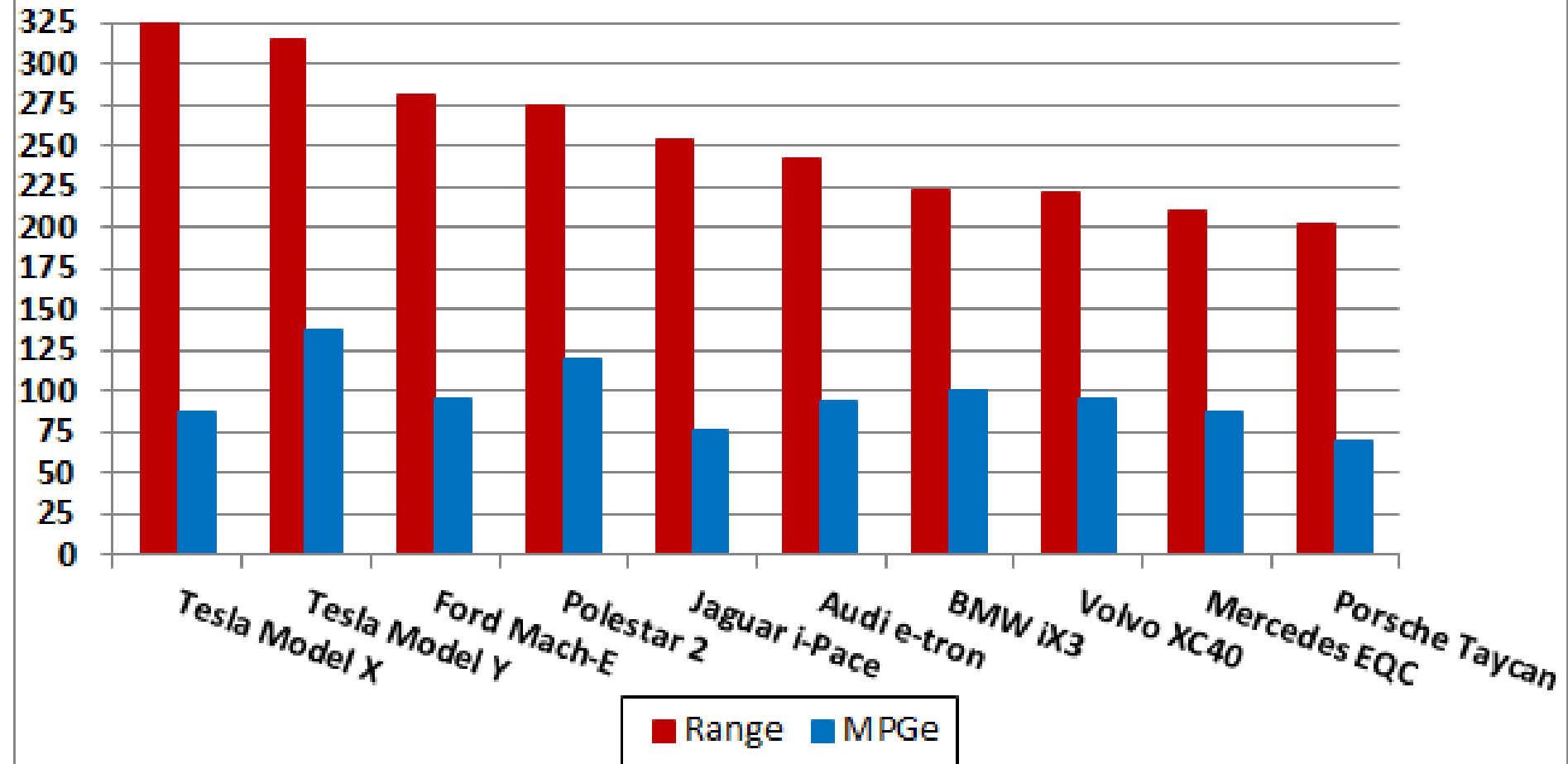
Model	Range (mi)	MPGe	Price
<u>4S</u>	226-257	96-92	\$103,800
<u>Turbo</u>	201	69	\$150,900
Turbo S	192	68	\$185,000

Available now

<https://electrek.co/2019/12/11/porsche-taycan-turbo-201-mile-epa-range/>

BEV-SUVs Range & MPGe Comparison

BEV SUVs



Probably range is more important than efficiency.

Volkswagen BEV Plans



ID.3

ID. Buzz

ID. Crozz



ID. Vizzion



ID. Beach Buggy

Volkswagen ID.Crozz (ID.4)



Model	Range (mi)	MPGe	Price
ID.Crozz	310	?	\$?

Available 2021

Ford Mustang Mach-E



**Federal
tax credit
= \$7500**

Model	EPA Range (miles)	Efficiency (MPGe)	Price
Standard Range RWD	230	<u>102</u>	\$39,000
Long Range RWD	300	102	\$48,000
Long Range AWD	280	96	\$52,000
Performance (AWD)	280	96	\$61,000

**Available in
early 2021.**

Average gasoline car in 2018: 25 MPG

US 2018 average price of a light vehicle was \$37,577.

Ford Mustang Mach-E Dash



**Federal
tax credit
= \$7500.**

Model	EPA Range (miles)	Efficiency (MPGe)	Price
Standard Range RWD	230	102	\$39,000
Long Range RWD	300	102	\$48,000
Long Range AWD	280	96	\$52,000
Performance (AWD)	280	96	\$61,000

Average gasoline car in 2018: 25 MPG

US 2018 average price of a light vehicle was \$37,577.

BEV Mini-Compacts



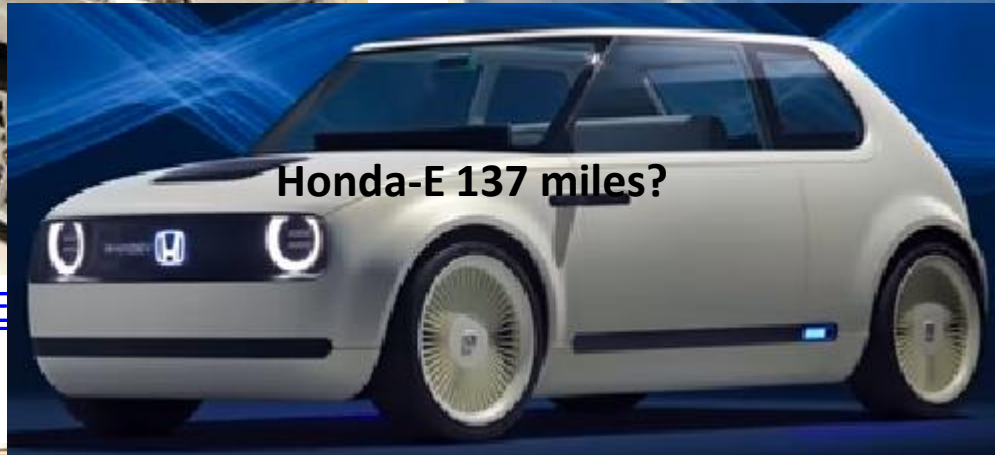
Smart ForTwo EV

68 miles 75 mph



EV

\$13,095



Mini Cooper SE Electric

110 miles \$29,900



Fiat 500e ~125 miles \$?

Electric Pickup Trucks



- [Rivian](https://www.rivian.com) electric pickup and SUV (rivian.com).
- [Tesla Cybertruck](#)
- [Ford F150 electric promised.](#)
- [Many Electric trucks promised](#)
- [Top 10 future electric pickup trucks](#)

Tesla Cybertruck



Type	Range (Miles)	0-60 mph	Storage (ft^3)	Towing (lbs)	Clearance (in)	Price (\$)
SM RWD	250	6.5	100	7,500	16	\$39,900
DM AWD	300	4.5	100	10,000	16	\$49,900
TM AWD	500	2.9	100	14,000	16	\$69,900

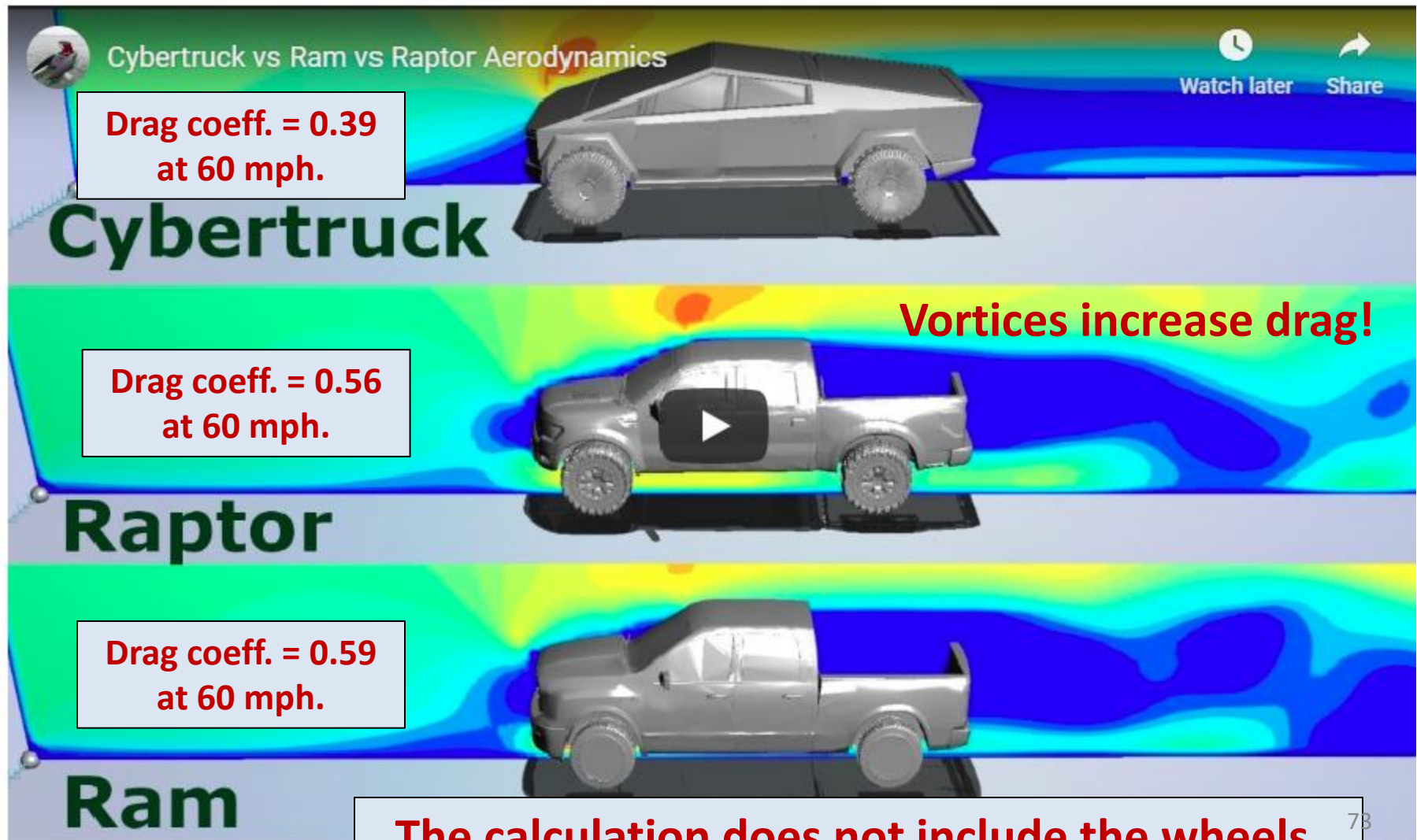


Tesla Cybertruck

Cybertruck tooling cost

Aerodynamics of Pickup Trucks

Tesla Cybertruck Tops Ram 1500, Ford F-150 Raptor In Aerodynamics



Large Electric Trucks

- [Tesla Semi](#)  300-500 mi, \$150k-180k
 - 67 MPGe vs 6.5 MPG for an average diesel semi truck.
- [Nikoli Semi](#)  500-750 mi, fuel cell
- [Volvo Semi](#) 
- [Daimler Semi](#) 
- [e-Garbage trucks](#) 
- [Autonomous Trucks](#)
 - [Volvo Vera](#) 

Electric Buses

- About 650 e-buses on US roads at end of 2019, more than double 2018.
- Hundreds of thousands of e-buses in China.
- California replacing 200 polluting diesel school buses by e-buses.
- 50 e-school-buses in Virginia by end of 2020.
- <http://www.roperId.com/science/ElectricSchoolBuses.pdf>



e-Vans



ZEV States in U.S.

- 2013: [Multi-state ZEV Task Force](#) formed: California, Connecticut, Maryland, New York, Oregon, Rhode Island & Vermont.
- 2018: Maine, Massachusetts & New Jersey joined the ZEV Task Force.
- 2019: Colorado joined the ZEV Task Force
- Delaware, District of Columbia, Pennsylvania & Washington follow the [California LEV standards](#).

BEV Charging Terms

- Battery energy is in **kilowatt-hours (kWh)**
 - Burning 1 gallon of gasoline = 33.7 kWh
 - E.g., Tesla Model 3 LR (TM3LR) has a 78-kWh battery
- Charging power is in **kilowatts (kW)**
 - Chargers start at peak power, then decrease power.
 - Typical garage charger provides **7.2 kW peak power**.
 - E.g., charging TM3LR: $(75\text{-kWh}/7.2\text{-kW})/85\% = 12$ hours
 - Tesla V2 Supercharger (150 kW) charges TM3LR = 35 min
 - Tesla V3 Supercharger (250 kW) charges TM3LR = 21 min

Charging BEVs

- **Level-1: 120-volts AC, 1.12-kW**, for all EVs
(Everywhere!) (**SAE-J1772 portable charging station that comes with an EV**)
- **Level-2: 240-volts AC, 3.3-kW to 19-kW charging station** with SAE-J1772 plug, for all BEVs & PHEVs
(Your parking space, Kroger, InnVT, Campus Automotive)
- **Level-3: 480-volts DC, 35-kW - 350-kW**, only for BEVs (Blacksburg Town Hall 40-kW)
 - CHAdeMO standard (**Asian**) (maximum 150-kW in 2017)
 - SAE CCS standard (**USA & Europe**) (Level-2/3 one plug)

Charging BEVs

- **SAE-J1772 cord that comes with an EV** can have a [pigtail that allows level-2 charging](#) with a standard 240-volts outlet or 120-volts outlet.
- An [adaptor is available](#) to allow Teslas to charge at level-2 SAE-J1772 charging stations.
- 250-350 kW charging stations are being installed.
- [Tesla Wall Connector](#): **240-volts AC, 11.5-kW** for Tesla BEVs.
- [Tesla Superchargers](#): **480-volts DC, 125-150-kW** only for Tesla BEVs
([Version 3](#) now being installed for **250-kW**
77 installed or under construction)

Charging

- Most charging takes place overnight at home.
- Tesla has by far the most fast ([Superchargers](#)) and [overnight](#) charging stations at hotels for long trips.
- [Electrify America](#) is quickly building fast charging stations for all BEVs. (I-81 Exit 155 and Wytheville)
- [Plugshare.com](#) is the best web page for finding charging stations.
- [ABetterRoutePlanner.com](#) is an excellent program for planning BEV trips.
- Tesla has excellent navigation showing where [Superchargers](#) are and how long to charge there.
 - Shows number of charging stalls available at next SC.

Charging BEVs

- **Most charging occurs at home in a garage, driveway or parking space. For me ~95% of time.**
- Charging at work doubles the range.
- I charge my Tesla Model 3LR when it gets below 30% up to about 75% (about once a week), unless there will be a long trip the next day.
- **Never fully charge** at intermediate charging stops.
- I like to have **~20% SOC left** when I get to a destination to allow for delays due to wrecks and detours.
- **ICE'd!** Leave firm polite note on windshield of ICEV.
- Road-charging etiquette
 - Charge only when necessary.
 - Charge up and move on.
 - Don't unplug a charging car.
 - Leave note asking charging car to plug yours in.
 - Neatly wind the cable on its holder after charging.

How Fast Do BEVs Charge

- Terms: **kWh** = battery energy, **kW** = energy/hour

- Tesla BEVs:

- Model 3 SR+: 250 miles, 54 kWh, 170 kW
- Model 3 LR: 322 miles, 75 kWh, 250 kW
- Model S: 390 miles, 100 kWh, 200 kW
- Model X: 351 miles, 100 kWh, 200 kW

**Average power
= 85% of
maximum
power for
battery fillup.**

- Chevrolet Bolt EV: 259 miles, 66 kWh, 50 kW
- Nissan LEAF II: 226 miles, 62 kWh, 44 kW
- Jaguar i-Pace: 234 miles, 90 kWh, 100 kW
- Audi e-tron: 242 miles, 95 kWh, 150 kW
- Porsche Taycan: 257 miles, 93 kWh, 270 kW
- Ford Mach-E: ~300 miles, 99 kWh, 150 kW

Tesla Supercharger in Carlisle PA



Tesla Supercharger in Future

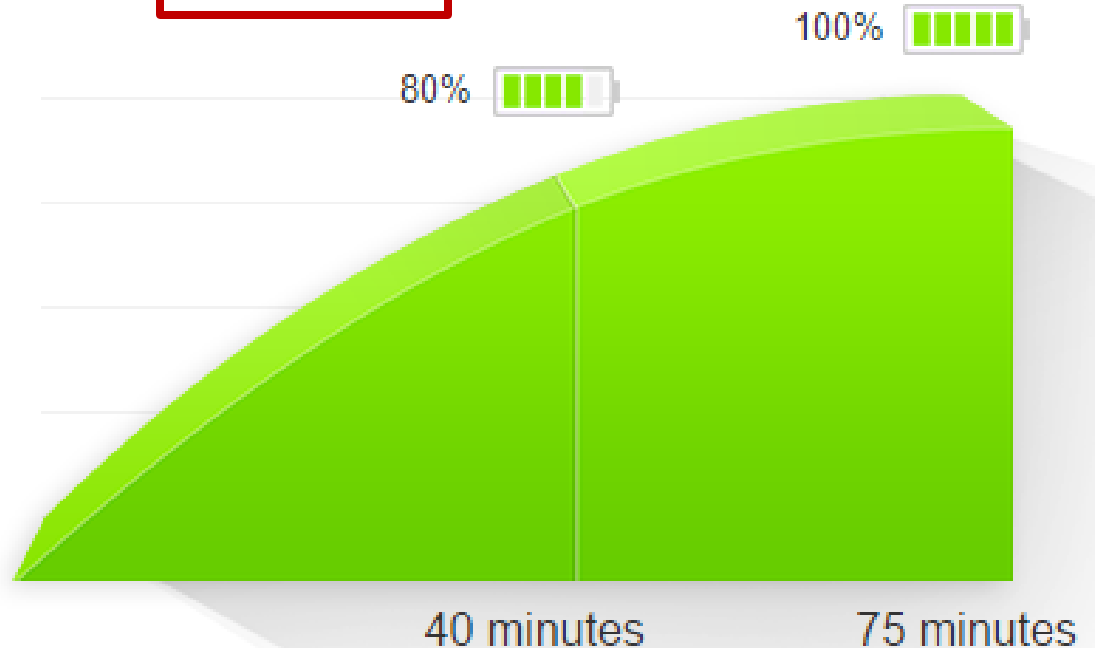


Charging Times for Fast Chargers

Charging starts off fast and decreases slowly at first and then decreases faster toward the end.

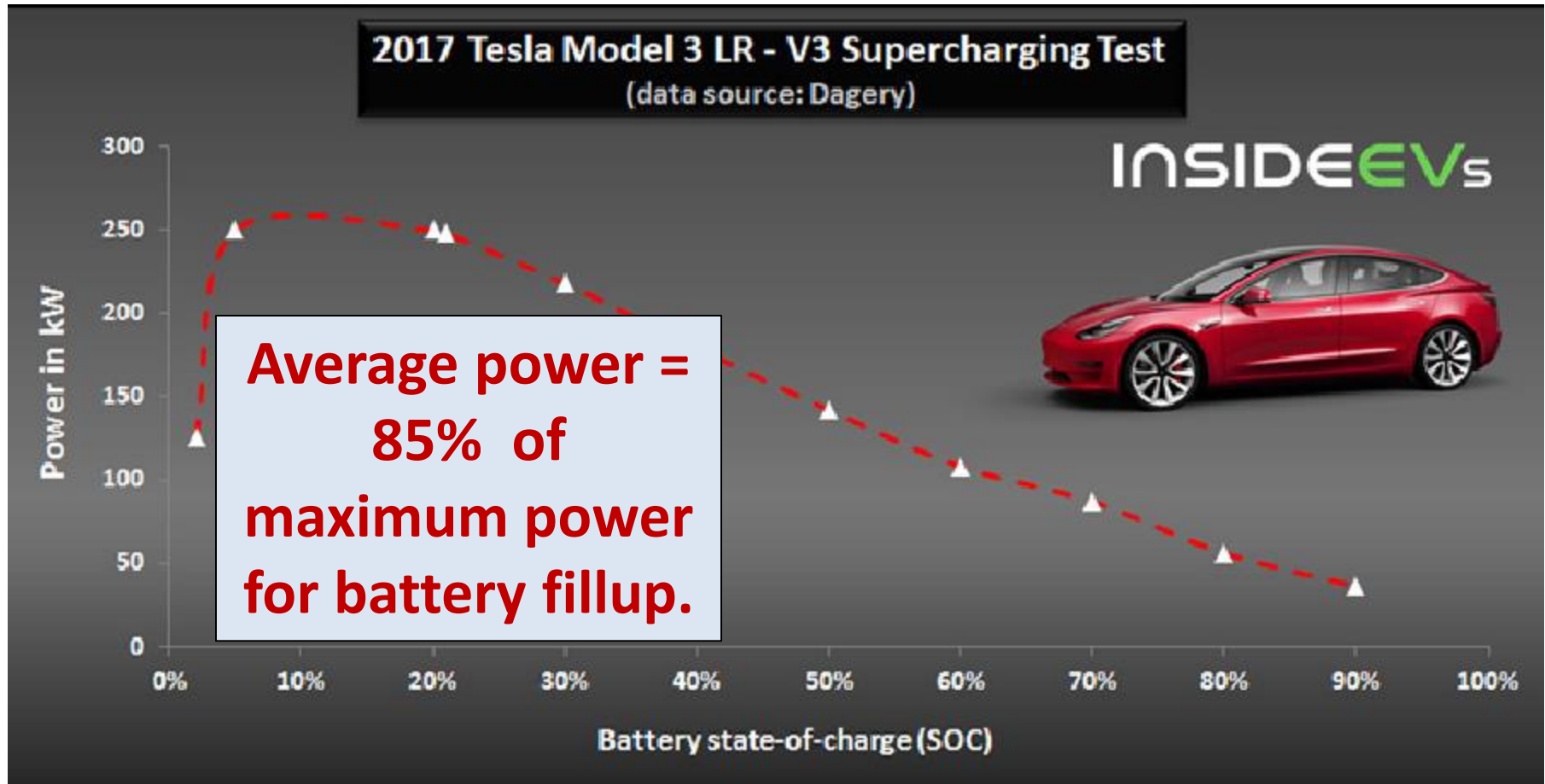
Supercharger Charging Profile

Based on 90 kWh Model S



Charging from 10% to 80% is quick and typically provides ample range to travel between most Superchargers. Charging from 80% to 100% doubles the charge time because the car must reduce current to top off cells. Actual charge times may vary.

Charging Times for Fast Chargers



Charging starts off fast and decreases slowly at first and then decreases faster toward the end.

Tesla Superchargers Upgrades

AVERAGE TIME SPENT CHARGING

120-kW V2s are being upgraded to 150-kW, so first two bars will be decreased by 1/4th.

TIME
SPENT

V2 Superchargers

25% DECREASE

V3 Superchargers

50% DECREASE

120 KW

120 KW

WITH ON-ROUTE
BATTERY WARMUP

250 KW

WITH ON-ROUTE
BATTERY WARMUP

A map of West Virginia and surrounding areas in the United States. The map shows major cities like Charleston, Parkersburg, Athens, and Roanoke. It also highlights national forests: Monongahela National Forest and George Washington and Jefferson National Forest. Several red location pins are placed across the state, indicating charging stations. A text box with a red border and white background contains the text "I have used several of them." Interstate highways are marked with their respective shields (68, 66, 81, 64).

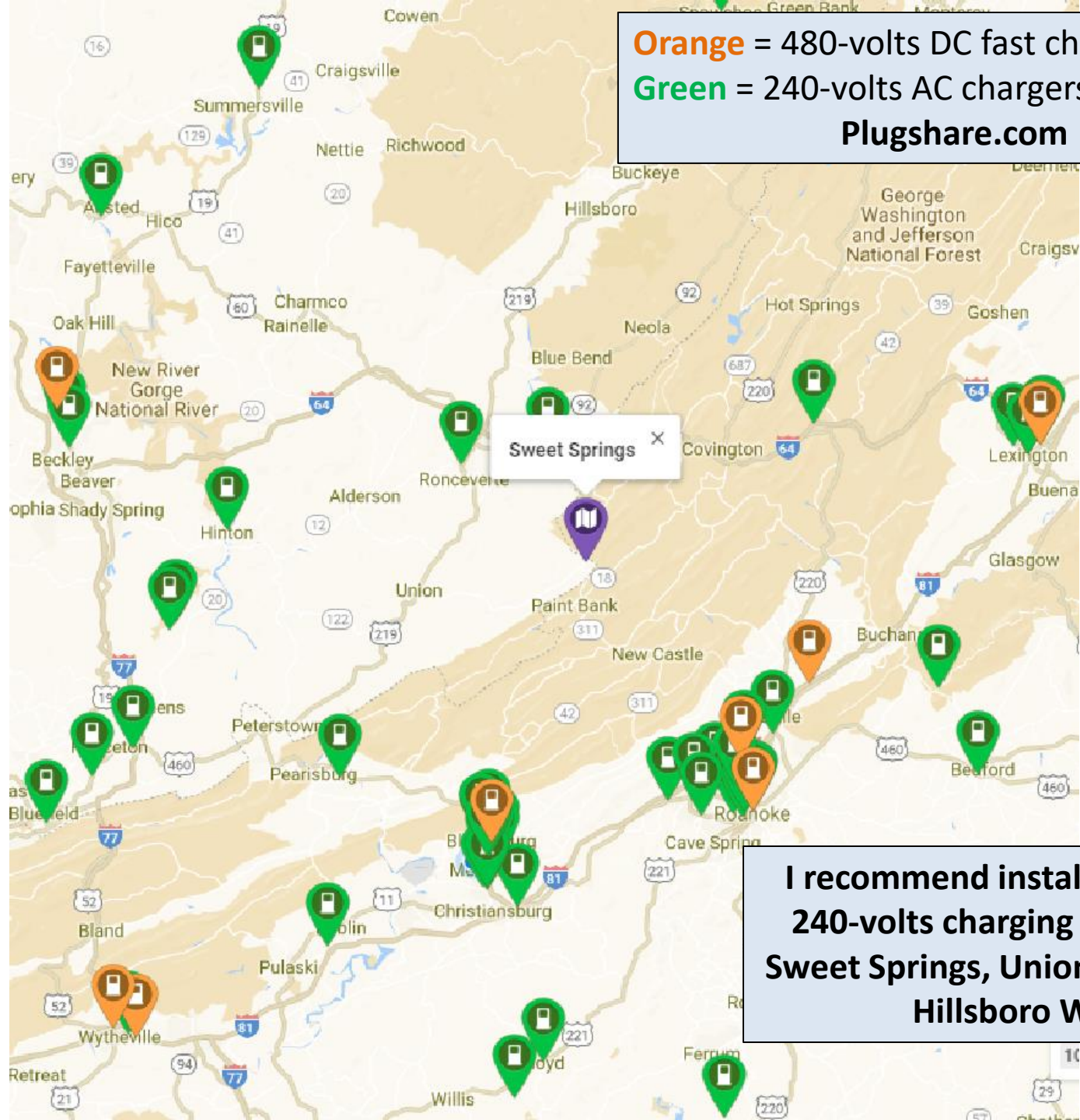
I have used several of them.

West Virginia State Parks' Charging Stations

Orange = 480-volts DC fast chargers

Green = 240-volts AC chargers

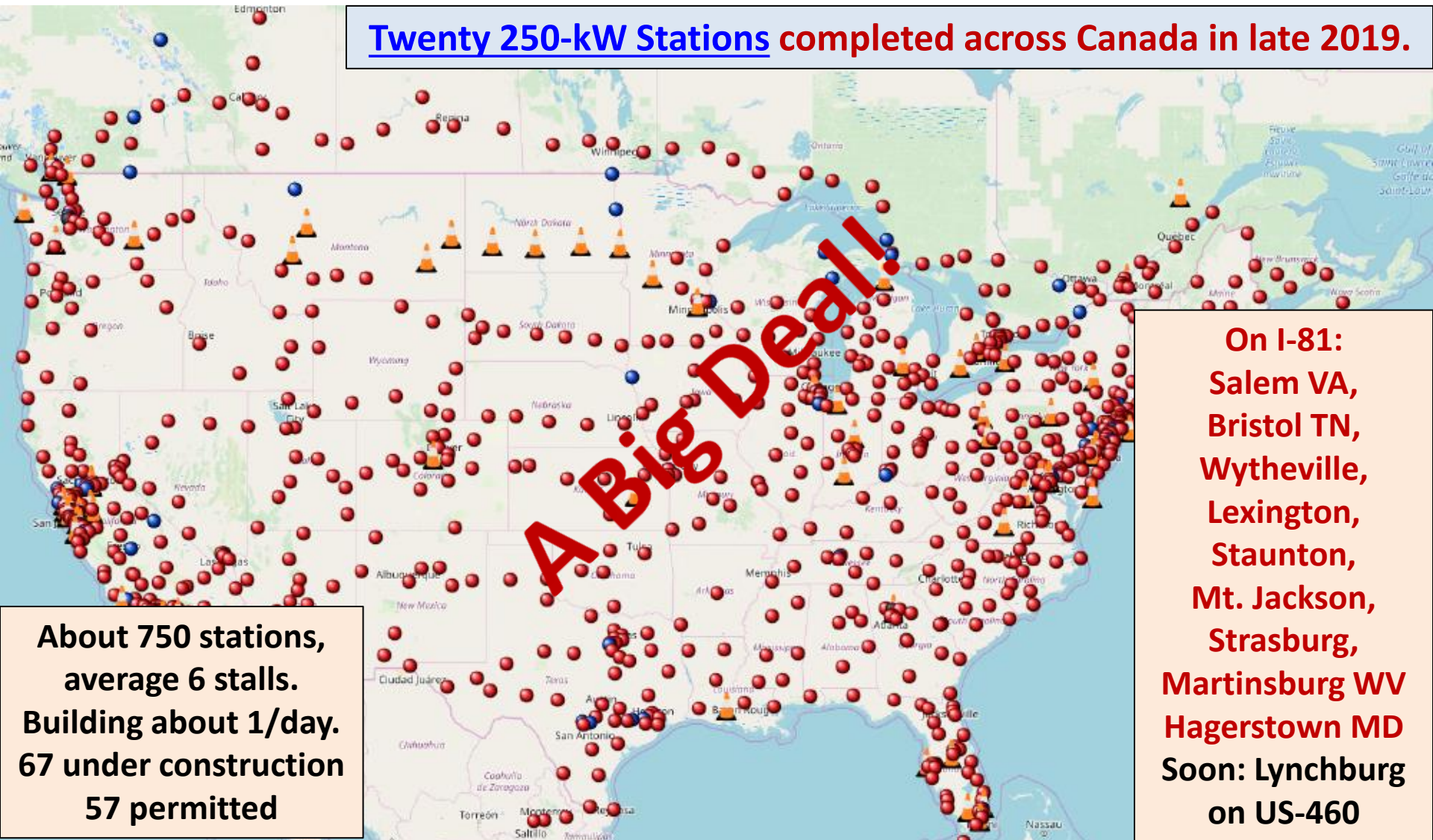
Plugshare.com



**I recommend installing level-2
240-volts charging stations at
Sweet Springs, Union, Rainelle &
Hillsboro WV.**

Tesla Superchargers

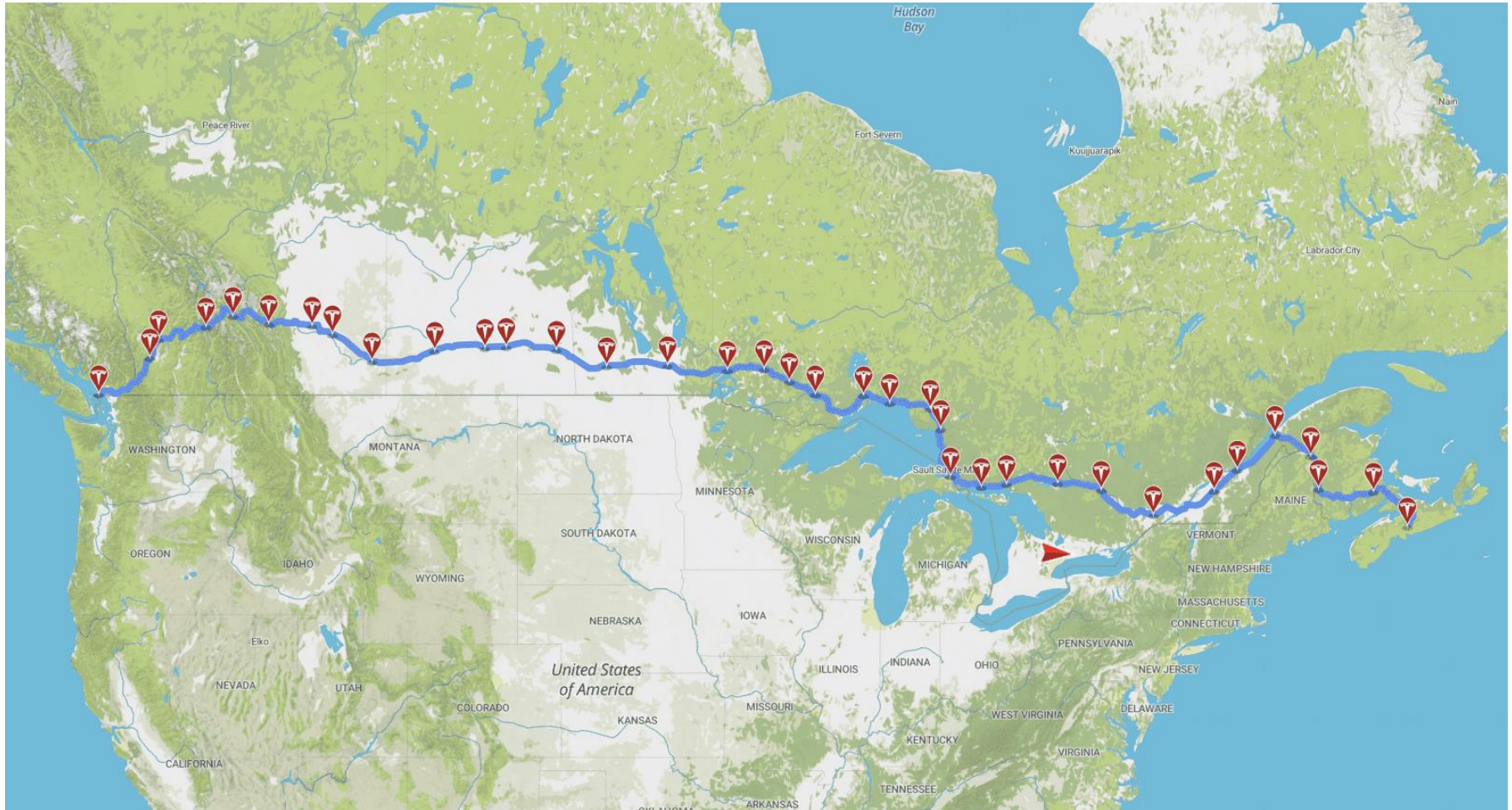
Twenty 250-kW Stations completed across Canada in late 2019.



Roper home charger: 9.6 –kW; **Tesla Superchargers: 150-kW** being updated to **250-kW**.

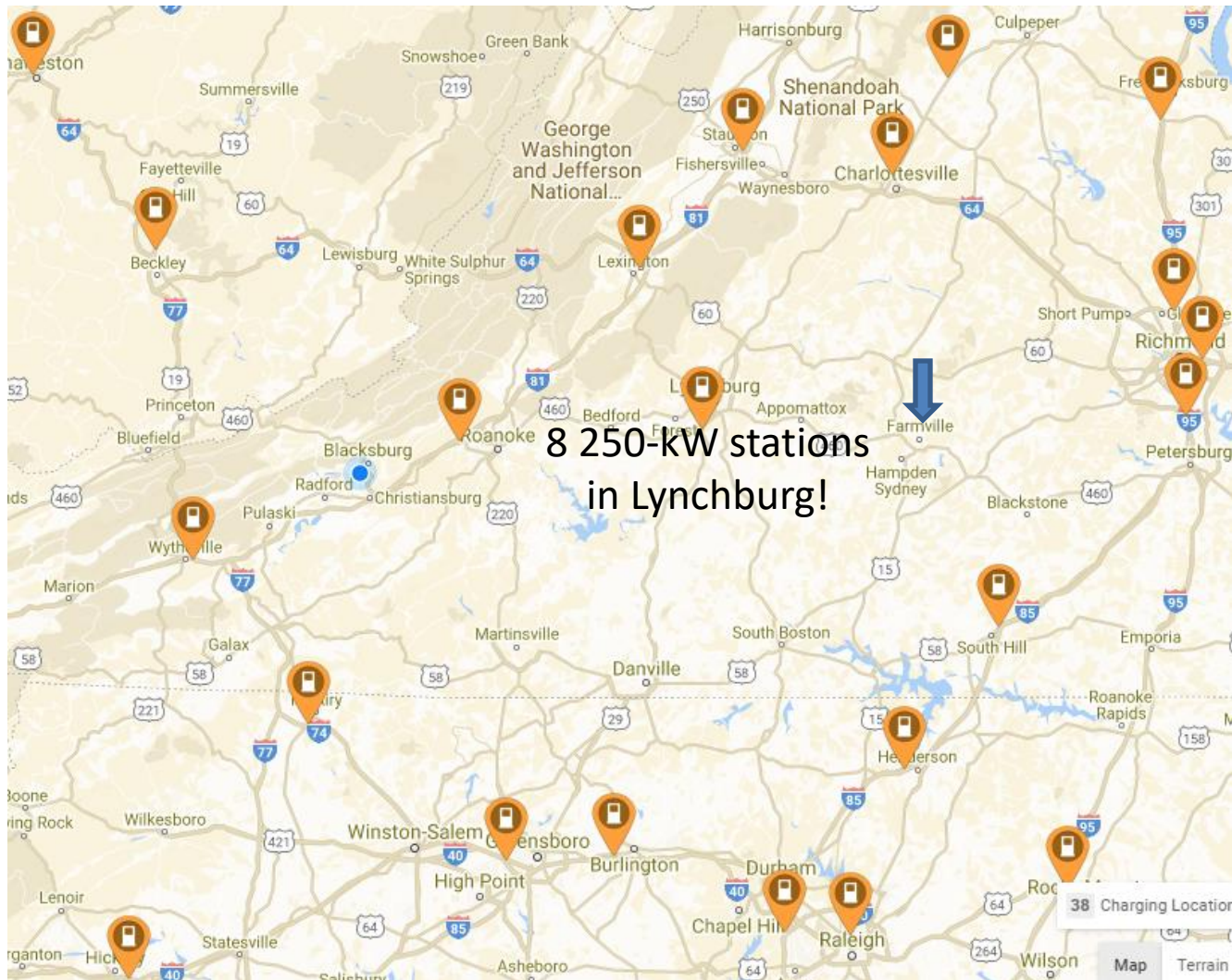
The Lynchburg Supercharger will have 250-kW capability!

Tesla Superchargers Across Canada



36 superchargers, most of which are 250-kW Version 3!

Tesla Superchargers in Southern Virginia



**2 SCs in
Richmond
with 20
stations
each!**

A Tesla Supercharger is being built in Farmville VA that will allow direct Tesla travel between Blacksburg/Roanoke and Richmond on US-460 and direct travel between Charlottesville and Tricities North Carolina on US-15.

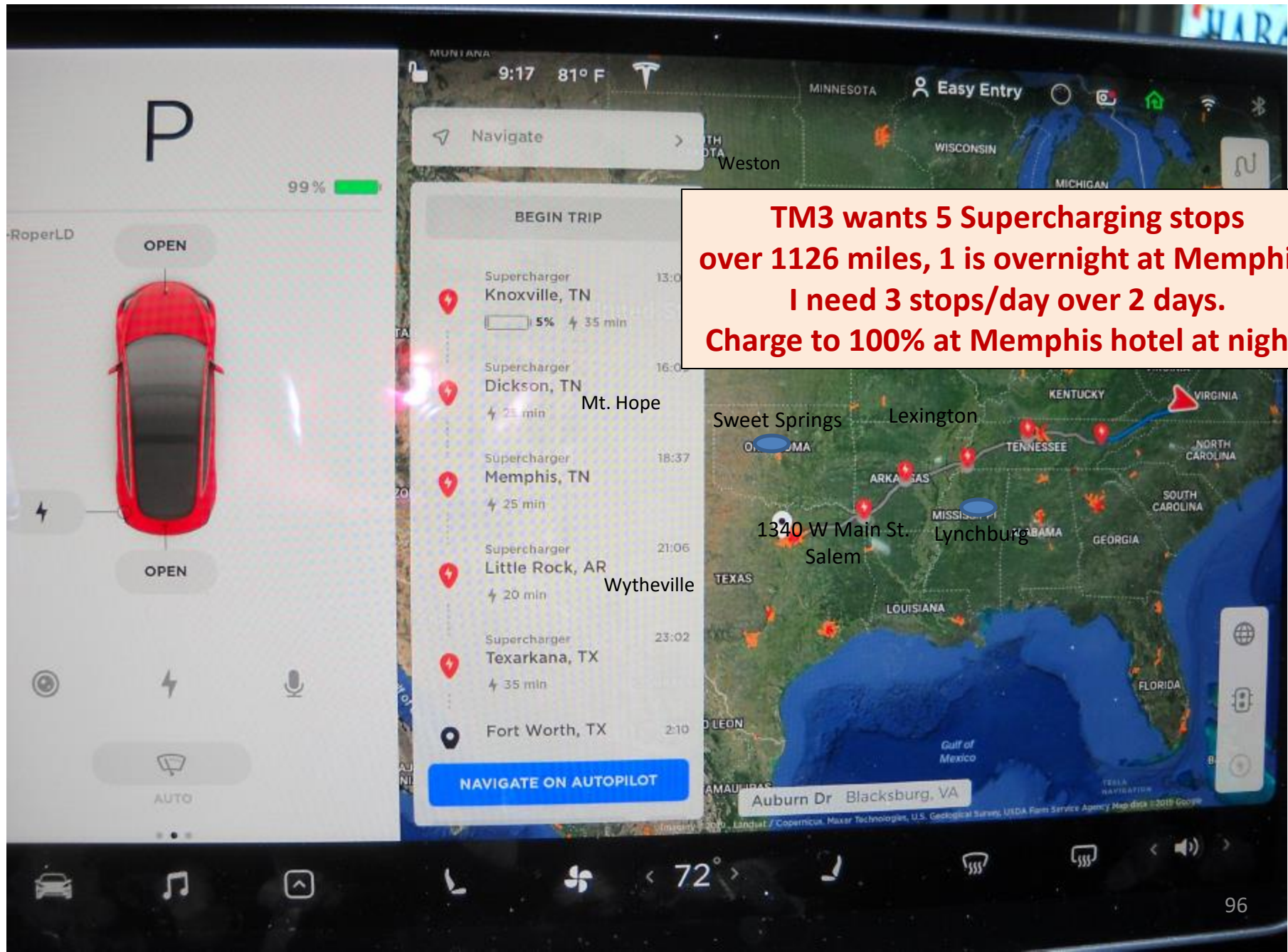
What It's Like to Use Superchargers

- You can see a list of nearby Superchargers (SCs) on the Tesla large fast screen.
- SCs are at shopping centers, hotels, recr and gasoline stations, such as Sheetz.
- Simply plug Tesla in and go do what you need or want to do; payment is automatic to credit card.
- Can [use Tesla screen](#) while charging to play many games, listen to music, play chess, watch TV shows or movies using Netflix, YouTube or Hulu and sing along with Caraoke.
- You can see charging status on your smartphone.

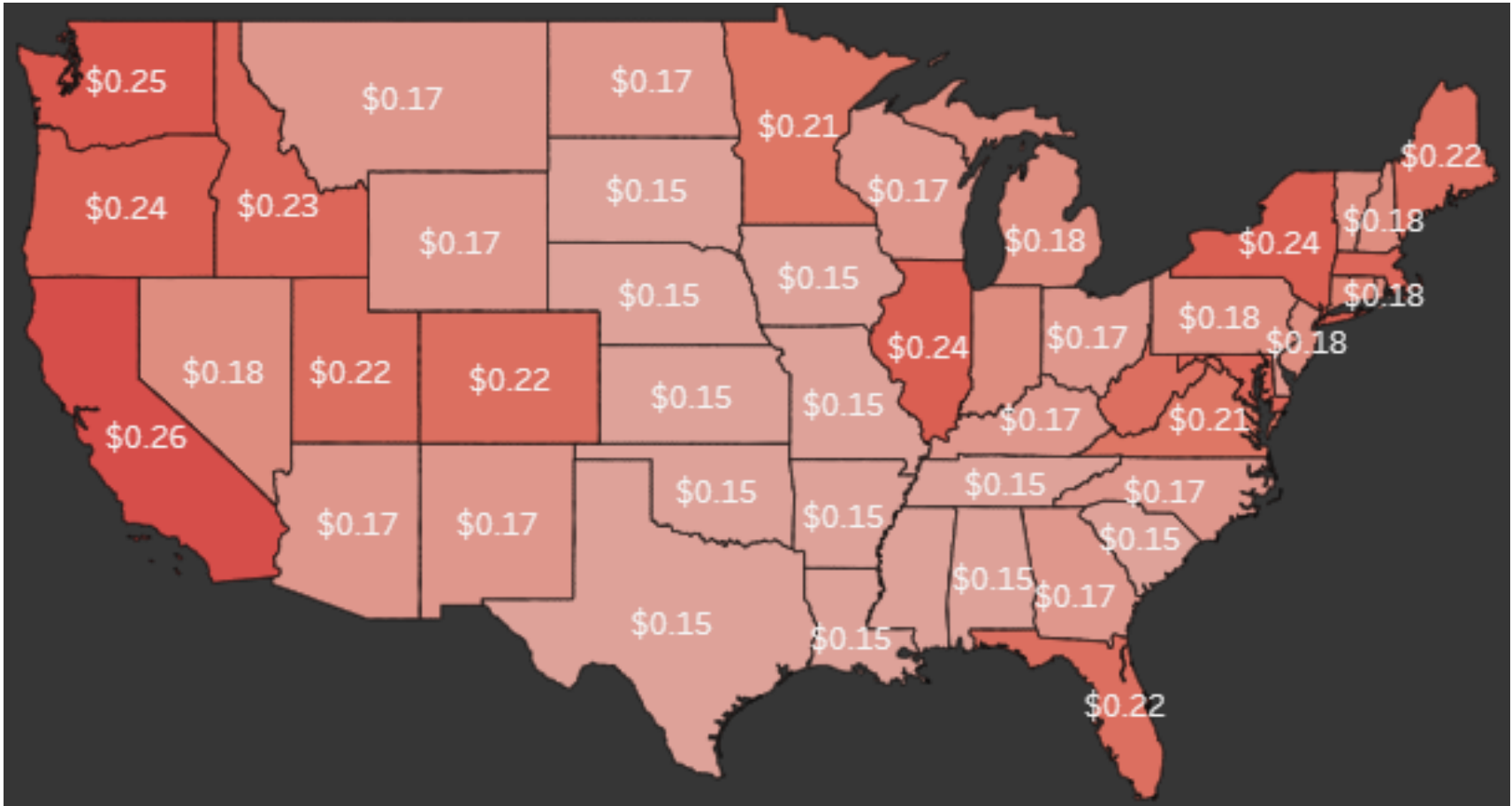
How to Drive a Tesla Long Distance

- Charge to near 100% at home.
- Use Tesla Navigation on the car screen.
- Charge at screen-indicated Superchargers or more often to the amount desired to get to the next Supercharger on the route.
- Choose a hotel with a charging station for overnight sleep to charge near 100% for the next day. (Most good hotels have charging stations, usually provided by Tesla. Use plugshare.com to find them.
- With charging stations provided by Electrify America, EVGO and other companies, similar long trips may be possible for other long-range BEVs in a few years.

Tesla Model 3 trip from Blacksburg VA to Fort Worth TX

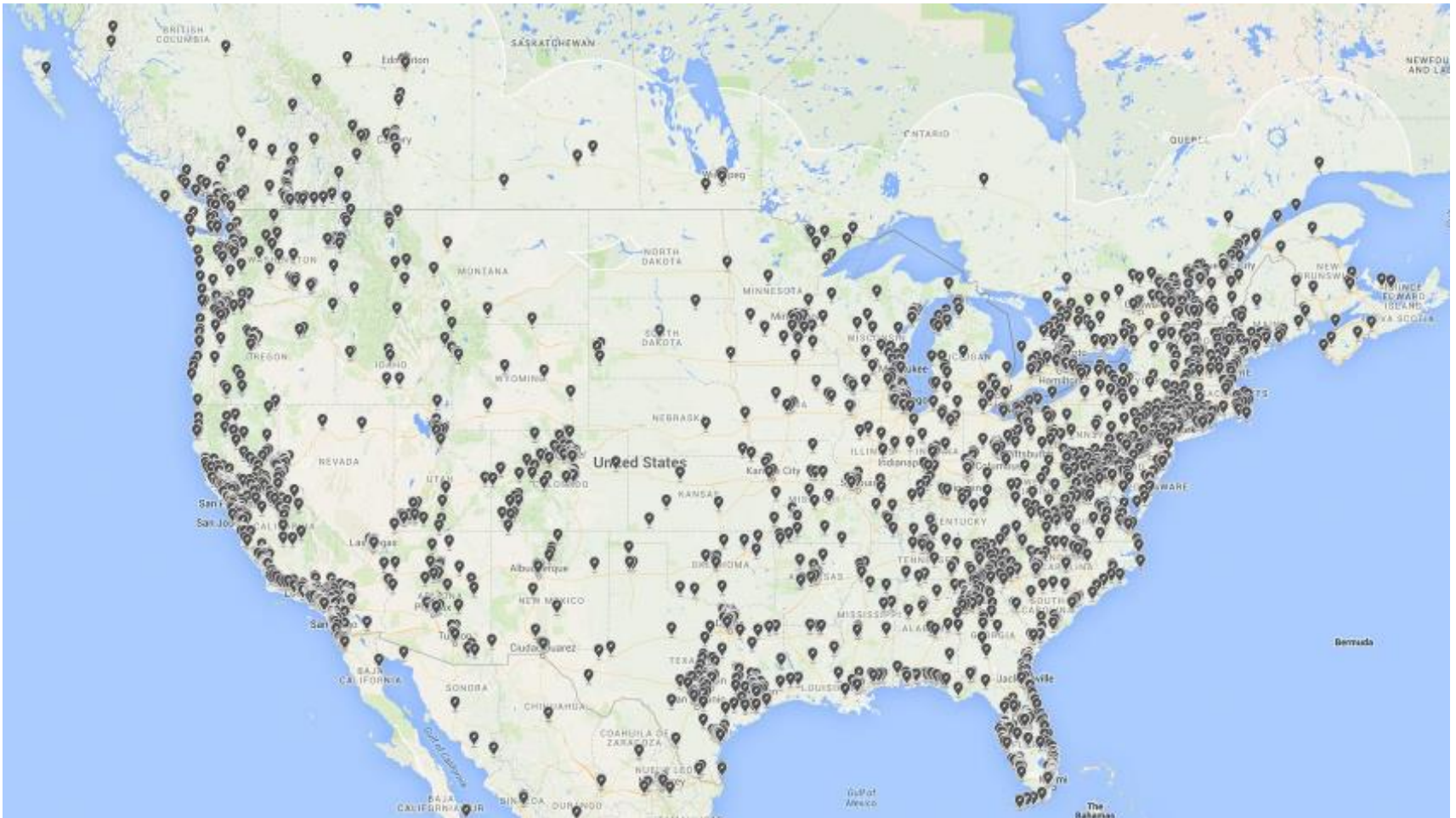


Tesla Supercharger Rates (\$/kWh)



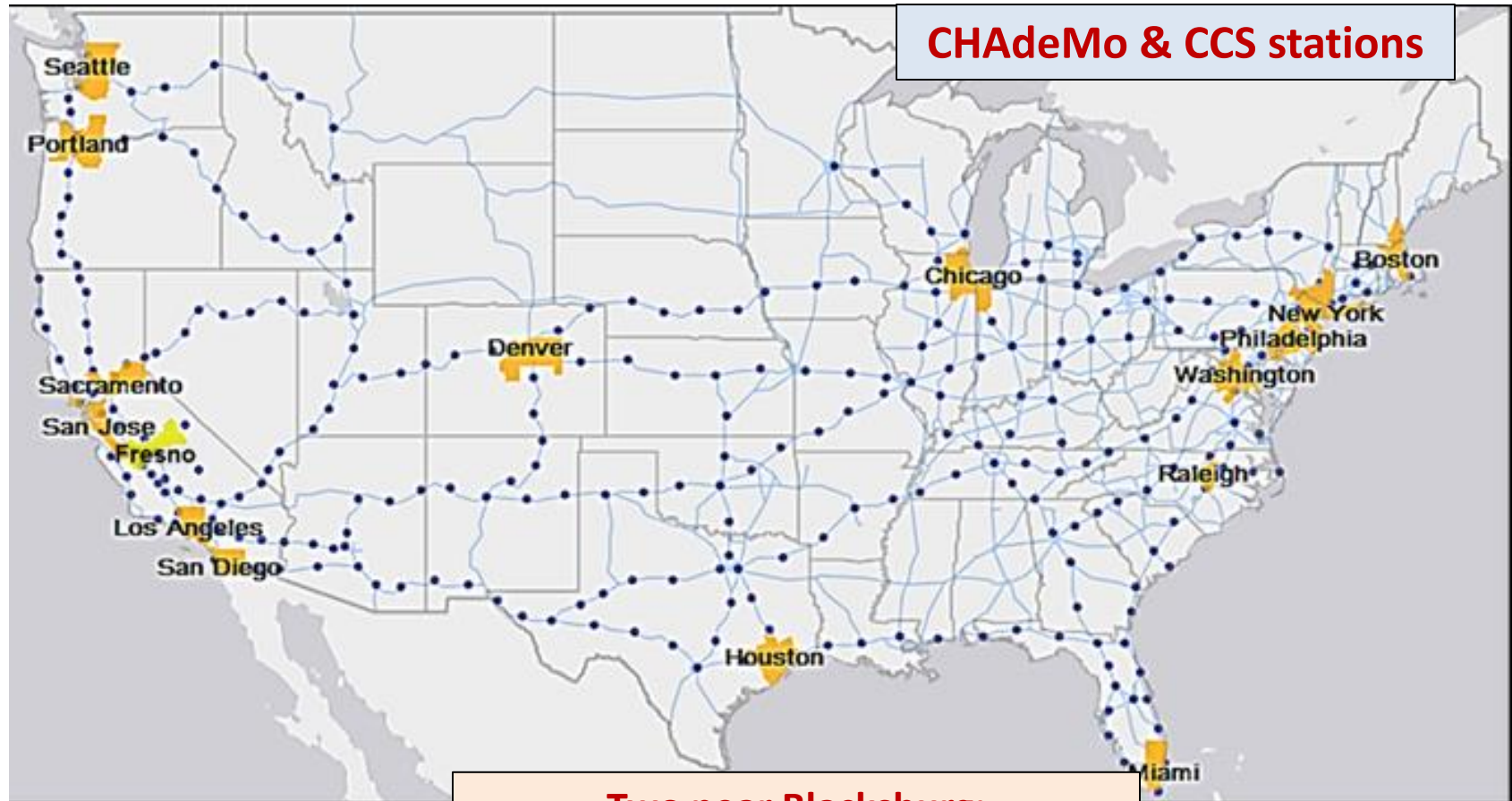
I pay APCO about \$0.11/kWh in our garage.

Tesla Destination Chargers



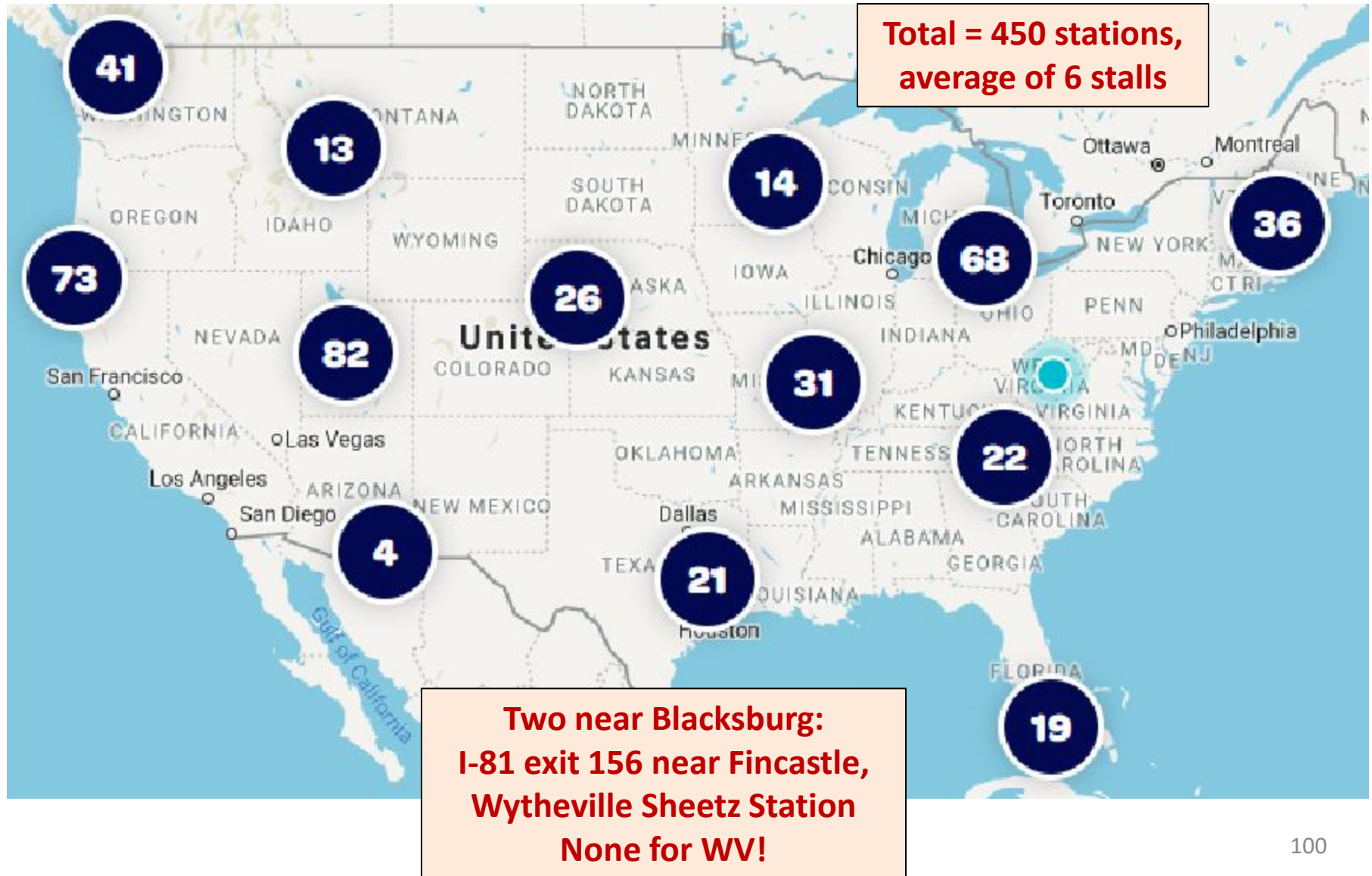
**At hotels, parks, businesses, multi-family complexes and workplaces.
Usually there is no fee to use Destination Chargers.**

Electrify America Fast-Chargers Plan



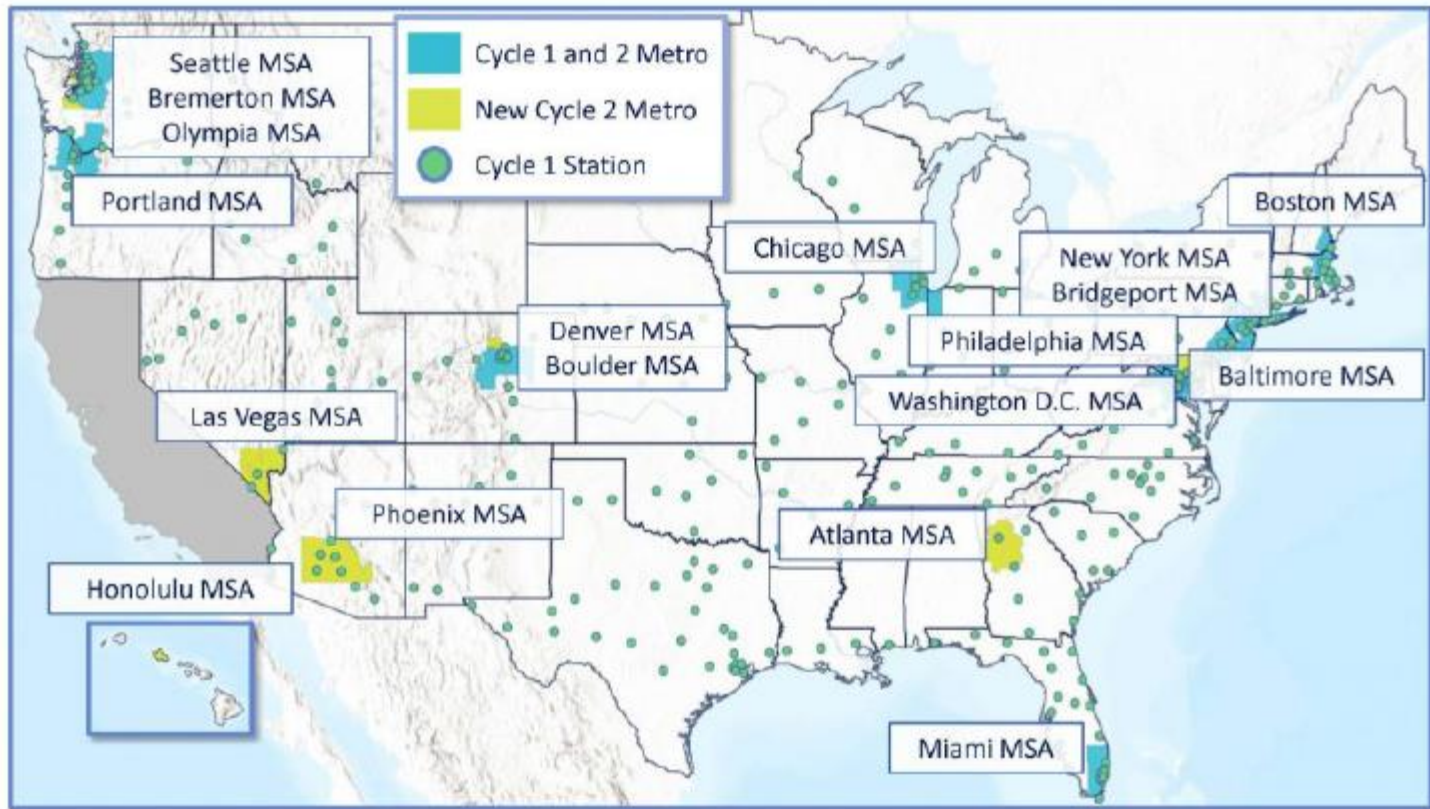
**Two near Blacksburg:
I-81 exit 156 near Fincastle and
Wytheville at a Sheetz Station.
One is under construction at a
Sheetz station on Peters Creek Road.**

Electrify America Chargers



Electrify America Chargers Plans

Cycle 2 investments will be made in 18 metropolitan areas across the country



Petro-Canada Fast Charging Net



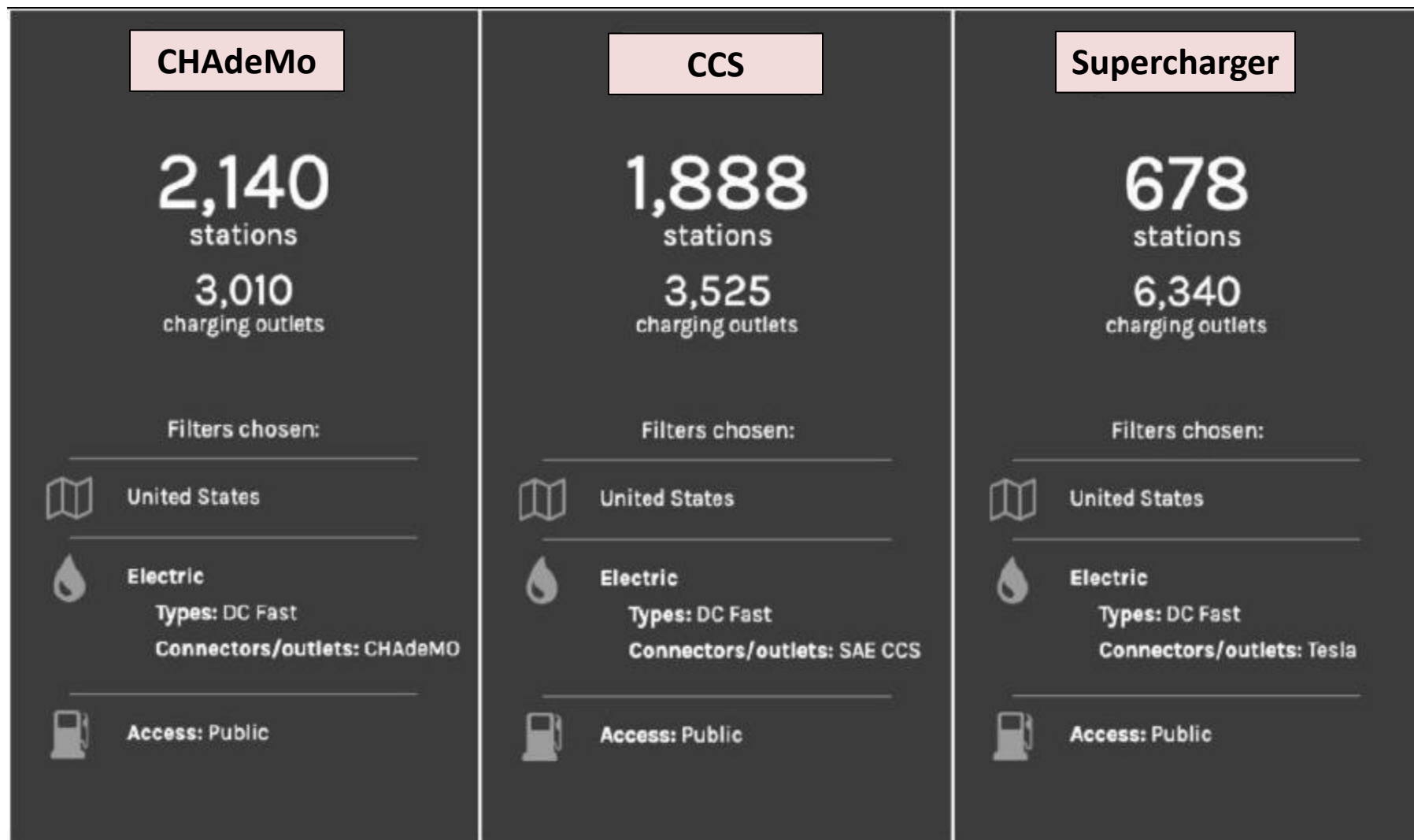
Fifty sites with CHAdeMO and CCS rated up to 200-kW.

Other U.S. Charging Networks

- [Blink](#) ~1680 sites
- [Chargepoint](#) ~6083 sites
- [EVgo](#) ~774 sites
 - Evgo is starting to [add a 50-kW Tesla connector at its sites.](#)
- [Greenlots](#) ~392 sites (subsidiary of Shell)
- [Semaconnect](#) ~1166 sites
- [Webasto](#) ~164 sites

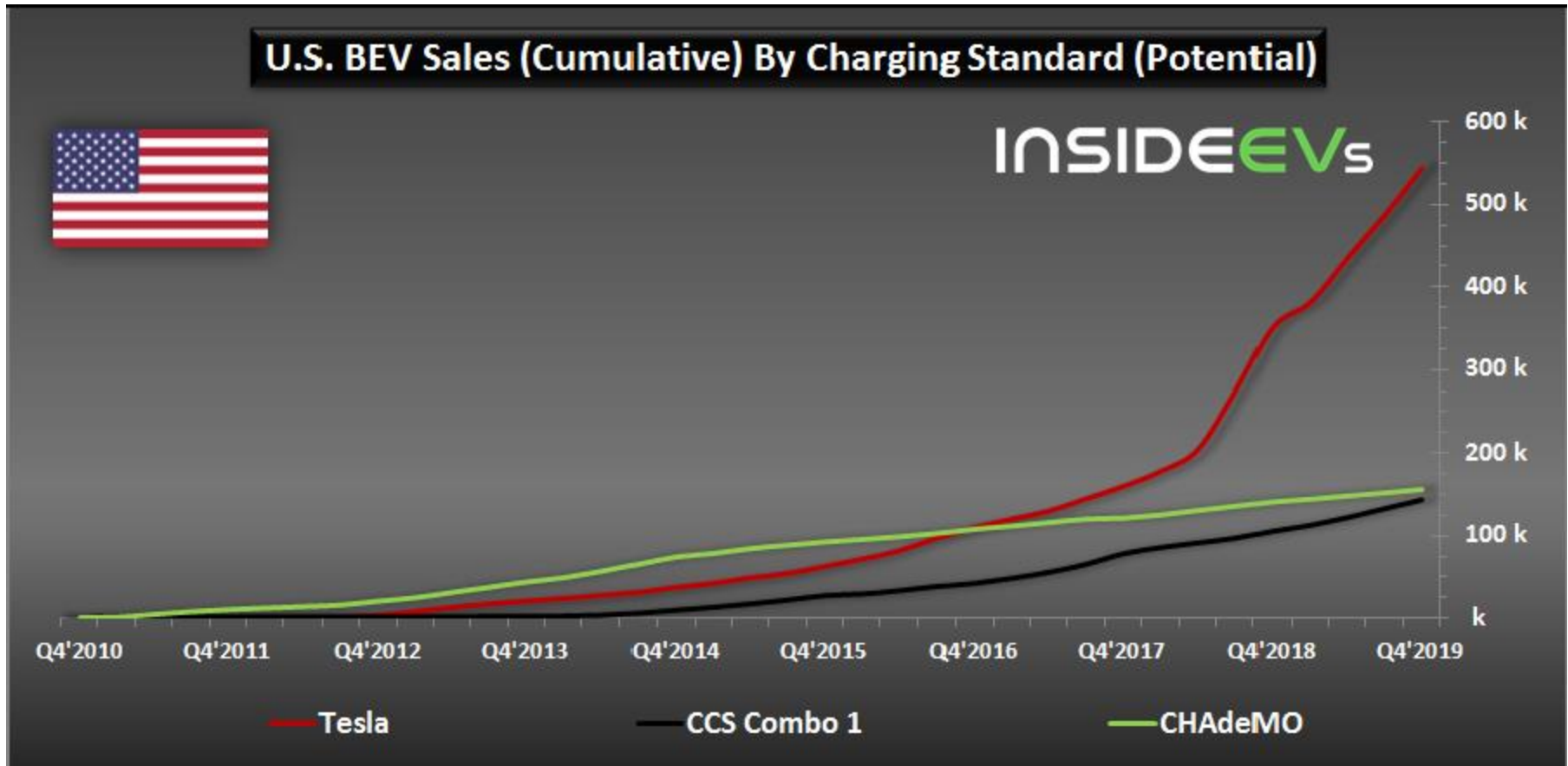
Many < 10-kW chargers have no fee to use.

Fast Chargers in the U.S.



CHAdeMO, CCS, and Supercharger - Alternative Fuels Data Center, Aug. 20, 2019
With a \$450 adapter Teslas can use CHAdeMO stations as well as Superchargers,
for a **total of 2,818 locations and 10,124 charging stations!**

U.S. BEV Sales by Charging Standard



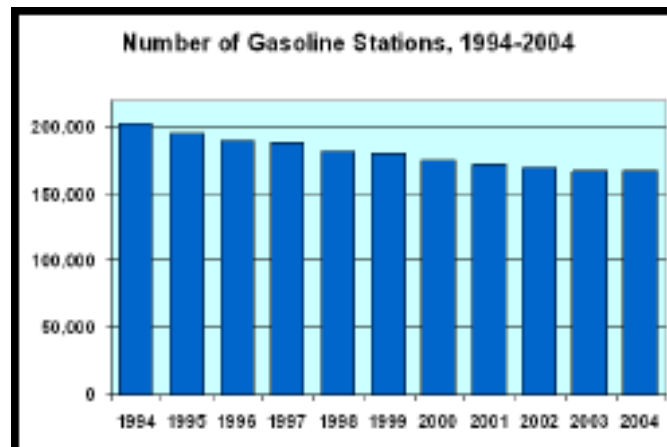
Very soon CCS standard will quickly grow more than the CHAdeMO standard.

APCO TOD Rate for EV Charging

- Night-time lower rates for EV charging will save \$0.032/kWh.
- Extra meter required for EV charging.
- One bill will combine residential and car charging.

Fuel in the Middle of “Nowhere”?

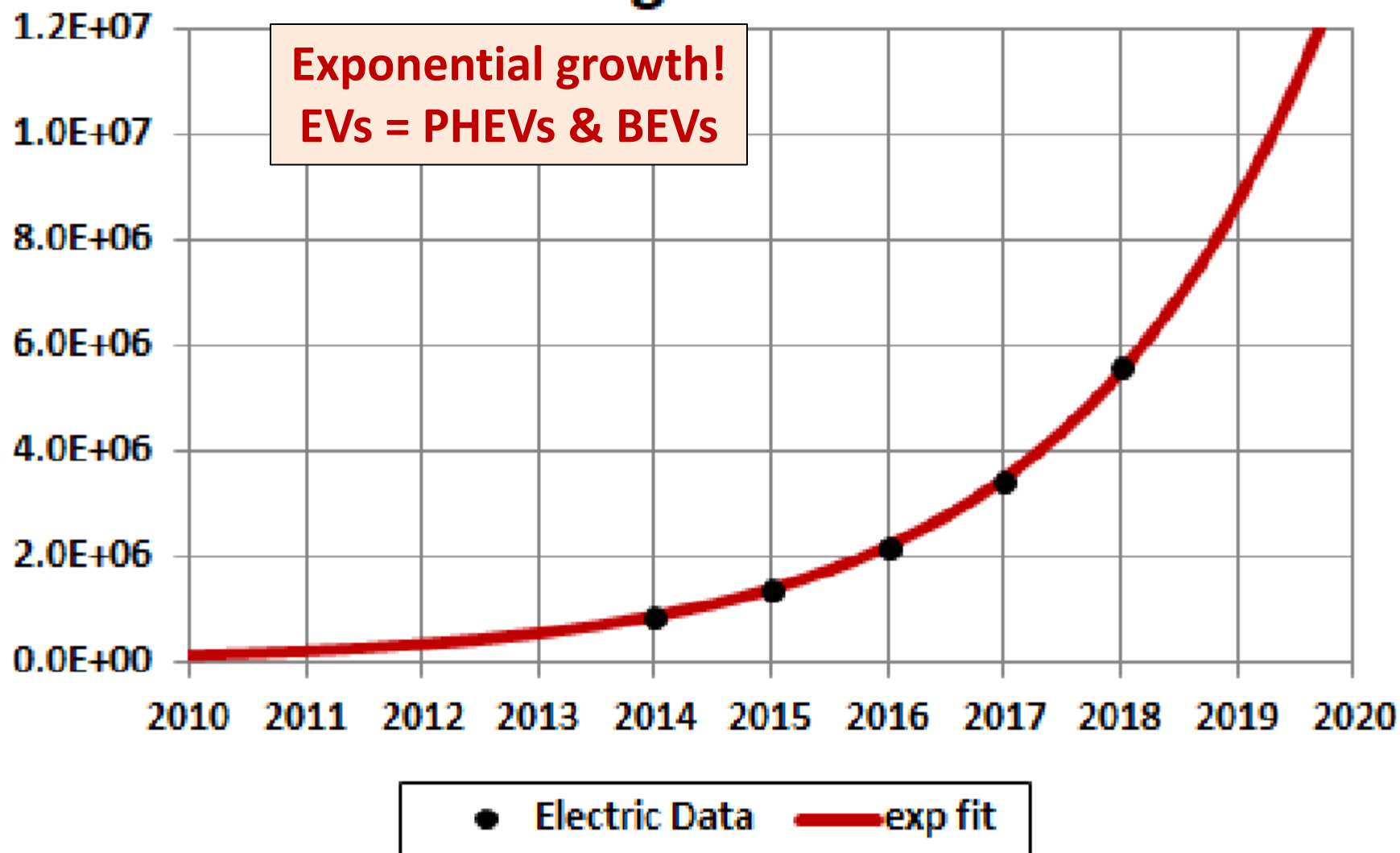
- Here is an estimate of 5-billion 120-V electrical outlets in the US: [How many electrical outlets exist in the United States?](#)
- Here is a survey of 186,000 gasoline stations in the US: [How many gas stations are there in the U.S?](#)



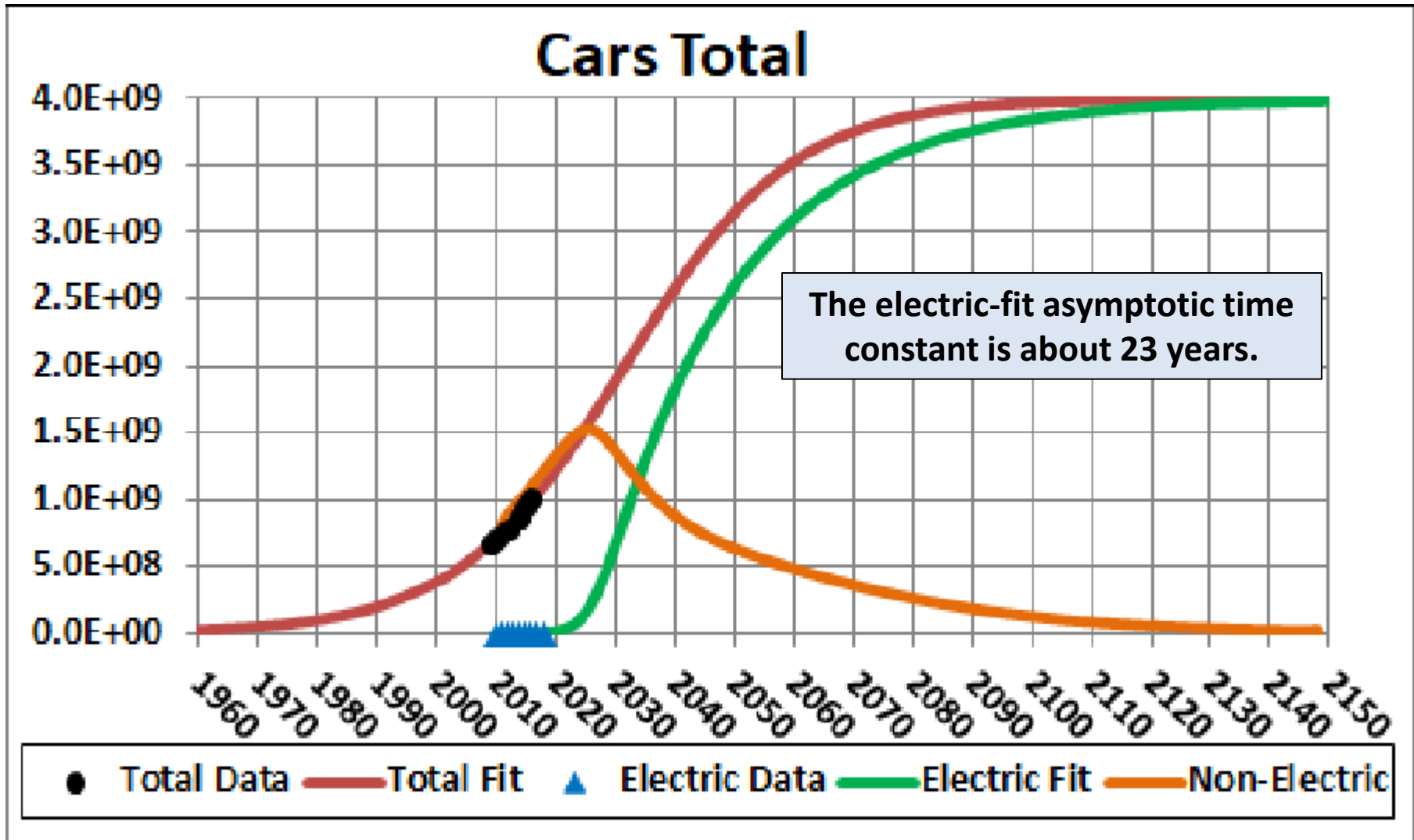
Plug-In Hybrids (PHEV)

- [Toyota Prius Prime](#): 25 miles EV @ **133 MPGe**
- [Toyota RAV4 Prime](#): 39 miles EV @ 90 MPGe, **AWD**
- [Mitsubishi Outlander](#): 22 miles EV @ 74 MPGe, **AWD**
- [Honda Clarity](#): 47 miles EV @ 110 MPGe
- [Chrysler Pacifica](#): 33 miles EV @ 82 MPGe, van
- [BMW Rex](#): 97 miles EV, 111 MPGe, **2.4-gal. gas tank**
- [Ford Fusion PHEV](#): 21 miles EV @ 103 MPGe
- [Hyundai Ioniq PHEV](#): 29 miles EV @ 119 MPGe
- [Kia Niro PHEV](#): 28 miles EV @ 105 MPGe
- Several more expensive (Cadillac, Porsche, Volvo, etc.)

Plug-In Cars



World Light Vehicles (Assume 4-billion leveling off.)



If this analysis is approximately correct, about half of the cars in the world will be electric by about year 2035 and almost all cars will be electric by 2100. Probably by 2100 almost all electric cars will be BEVs with few PHEVs.

Autonomous Vehicles

- **Level 0:** All major systems are controlled by humans.
- **Level 1:** Certain systems, such as cruise control or automatic braking, may be controlled by the car, one at a time.
- **Level 2:** The car offers at least two simultaneous automated functions, like acceleration and steering, but requires humans for safe operation; e.g. [Autopilot](#).
- **Level 3:** The car can manage all safety-critical functions under certain conditions, but the driver is expected to take over when alerted.
- **Level 4:** The car is fully-autonomous in some driving scenarios, though not all.
- **Level 5:** The car is completely capable of self-driving in every situation.

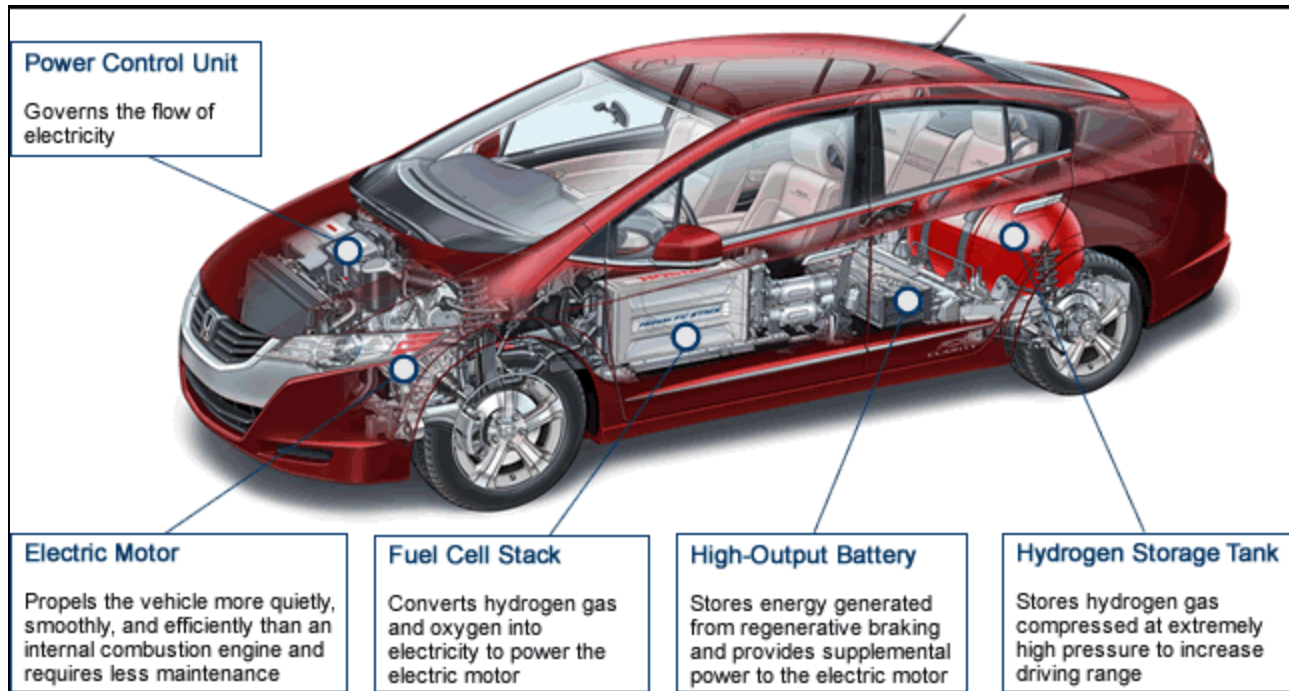
Auto Charging Autonomous Cars

Volkswagen concept; click to see movie.



Why Not Fuel-Cell Cars?

- They are very complicated:



- Requires a lithium-ion or NiMH battery similar to a PHEV!
- Hydrogen fuel is not easy to obtain. Most is made from methane and water, which produces carbon dioxide with the hydrogen! Should be made by solar!
- Better for heavy-duty vehicles, such as trucks.

Why Not Solar Cars?

- Lightyear One

- Extremely efficient: 253 MPGe (?)
- 450-miles range (?)
- Aluminum and carbon fiber body for low weight
- 1-kW high-efficiency solar panels



- Sion (Sono Motors)

- Totally covered with solar panels
- 140 miles range
- 118 MPGe



Conclusion

- If disasters due to global warming are to be mitigated we must **reduce carbon emissions!**
- All must do their part with their **influence** and **wealth** beyond necessities:
- Install **solar energy** on homes and businesses.
- Use **zero-carbon public transport** or **drive electric cars.**
- **Consume** food and materials that involve **low carbon emissions.**
- **Invest** only in companies that are committed to **low-carbon emissions.**
- **Vote** for politicians that will institute **mitigation programs.**

Volvo Polestar 2



Range (mi)	0-60 mph (s)	MPGe	Price
275	4.5	119	\$63,000

Volvo XC40 Recharge



Range (mi)	0-60 mph (s)	MPGe	Price	
221	4.8	96	\$55,000	AWD

Available 2021

BMW iX3



Range (mi)	MPGe	Price
223	100	\$?

Available 2020

Mercedes-Benz EQC



Range (mi)	0-60 mph (s)	MPGe	Price	
210	5.1	88	\$67,900	AWD

BEV Supercars: Tesla Roadster 2



Range (mi)	0-60 mph (s)	Top Speed (mph)	Price	
620	1.9	250	\$250,000	

Available 2021

Quotes about BEVs

- “After driving a BEV for 100 miles you will never want to drive an ICEV again.”
- “After driving a BEV for 100 miles with 1-pedal driving option, you will not want to go back to driving without it.”
- “Driving with Tesla’s driving options on a large screen makes ICEVs with multiple buttons and switches seem 20th century.”
- “Driving with Tesla’s Autopilot makes long-distance driving much easier.”

References to Follow EV Future

- Insideevs.com
- Electrek.co
- Cleantechnica.com (also renewable energy)
- Teslarati.com (also SpaceX)
- pluginamerica.org
- plugstar.com
- greencarreports.com (also HEVs)

Drive Electric Earth Day in Blacksburg Virginia

<https://driveelectricearthday.org/event.php?eventid=2346>

Saturday, 25 April 2020 1-3 PM

Virginia Tech Corporate Research Center, 1715 Pratt Drive, Blacksburg Virginia



EVs expected: Chevrolet Bolt EV, Chevrolet Volt, Nissan LEAF, Tesla Model S, Tesla Model 3

Other PHEVs and BEVs are invited to register to attend at <https://driveelectricearthday.org/event.php?eventid=2346>.