Midsize BEVs (& PHEVs) in 2017 & 2018

BEVs > 200-miles (PHEVs > 50-miles-EV)

GAME CHANGERS!

L. David Roper

roperld@vt.edu

Terminology

ICE = Internal Combustion Engine car (gasoline or diesel).
mHEV = mild Hybrid car: large ICE + very small battery + small inline electric motor.
HEV = hybrid car: medium ICE + small battery + 1 or 2 electric motors.
PHEV = Plug-in Hybrid car: small ICE + larger battery + 1 or 2 electric motors + plug.
BEV = Battery Electric car: large battery + 1 or 2 powerful electric motors + plug.
EV = Electric Vehicle: PHEV or BEV.
Electrified Vehicle: all of the above except ICE.
Energy: kilowatt-hours (kWh), Power = Energy/time = kilowatts (kW)

tinyurl.com/BEVsPHEVs

My BEV Experience and Planned BEV Future

1. Owned a **2007 ZAP Xero PK** for 3 years (2007-2010) (**30-miles range**).
2. Leased a **2012 Nissan LEAF** for 3 years (2012-2015) (**73-miles range**).
3. Leased a **2015 Nissan LEAF** for 2 years (2015-2017) (**84-miles range**).
4. Bought a **2017 Chevrolet Bolt EV (CBEV)** (**238-miles range**).
5. **Future Plans:**
6. Lease/buy a **2018 Tesla Model-3** for 3 years (2018-2022)(**310-miles**).
    1. To use the many Tesla Superchargers for long-distance travel.
    2. Because it is so beautiful!
    3. Because it is a Tesla.
7. Lease/buy a 2022 ? for 3 years (2022-2025)(**>450-miles**)

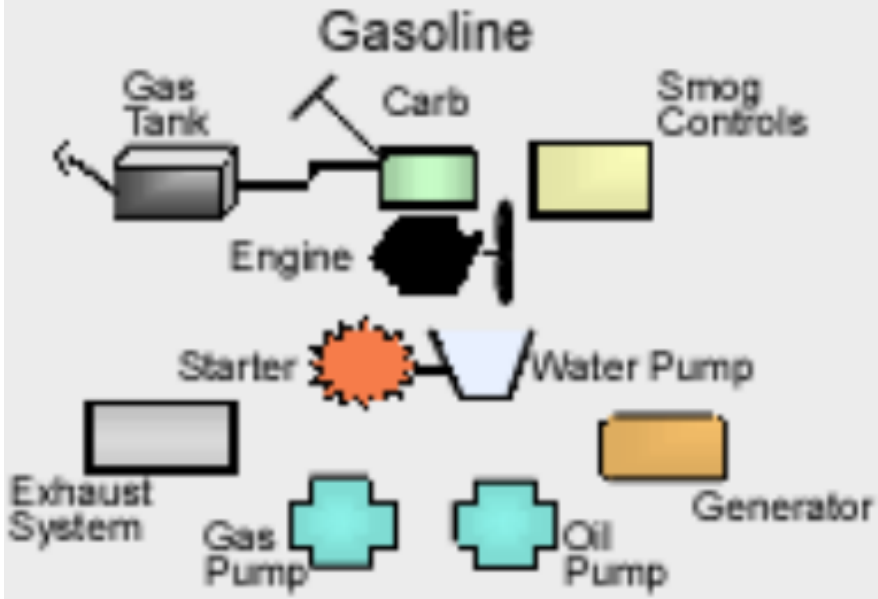
We own **2016 Toyota RAV4 AWD Hybrid** for long-distance trips (33 mpg).

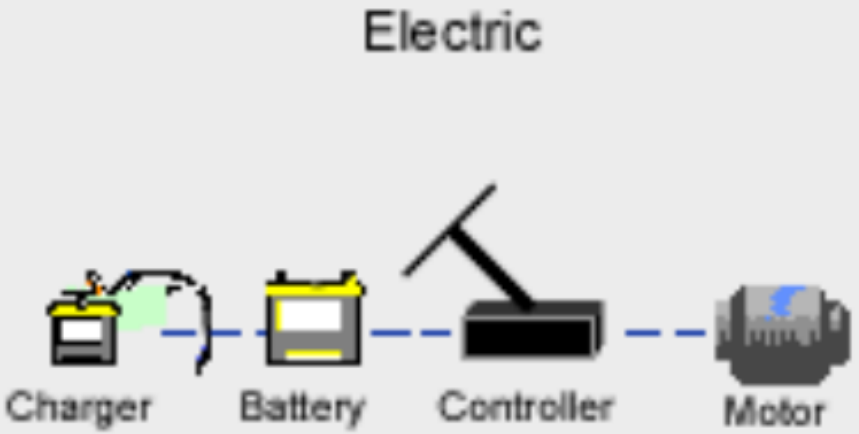
- 2007 Zap Xero PK 3-wheel pickup
- 8-kWh lead-acid gel batteries
- 5-kW (7 hp) DC motor
- 30-miles range, 40 mph top speed
- 0-30 mph in ~15 seconds
- 100-watts solar panel
- Dump bed
- Drove it >3000 miles.
- Poorly made in China.

- 2015 Nissan LEAF SV leased 2 years.
- 24-kWh lithium-ion battery
- 84-miles range, 94 mph top speed, 117MPGe
- 0-30 mph in ~4 seconds
- Drove 2012 SL & 2015 SV models >30,000 miles
- 2012: 73-miles range
- 2015: 84-miles range
- 2016: 107-miles range (30-kWh)
- Assembled in Tennessee.

Previously leased a red 2012 LEAF for 3 years.

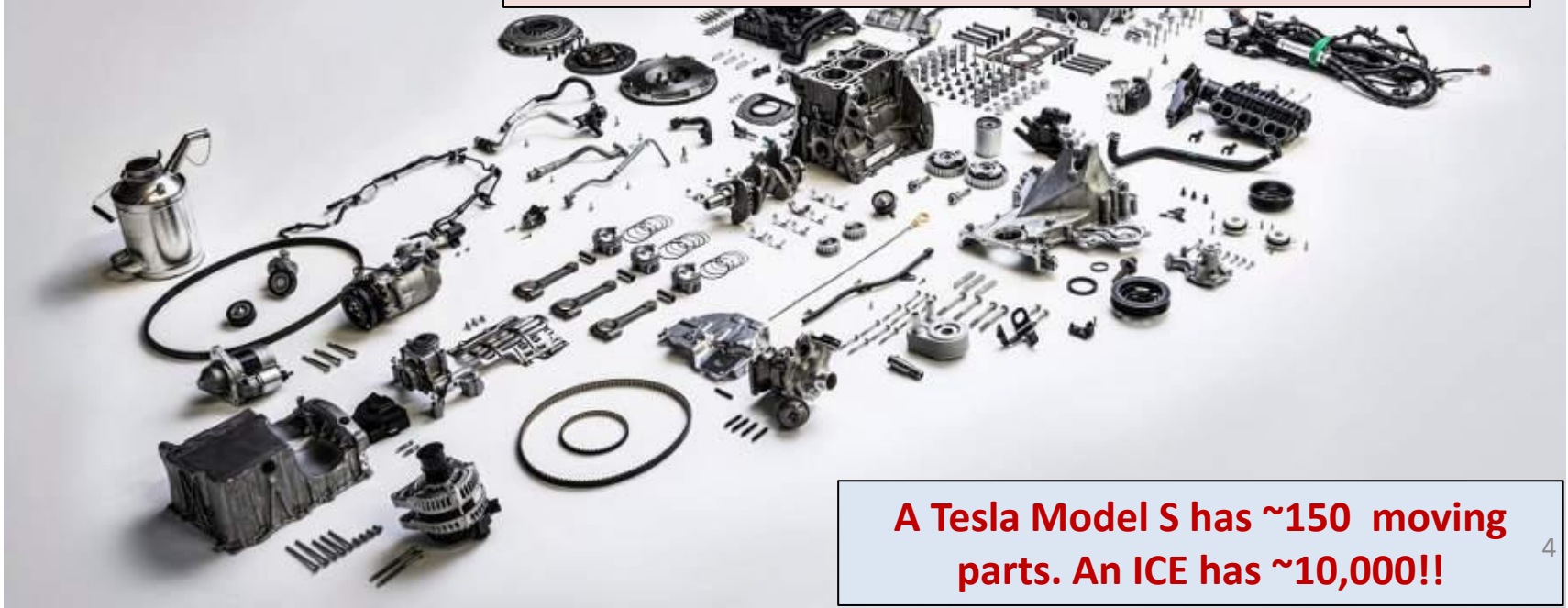
Vehicle Drive Components





Gasoline car parts!

How Cars Work: usmechanicedu.com

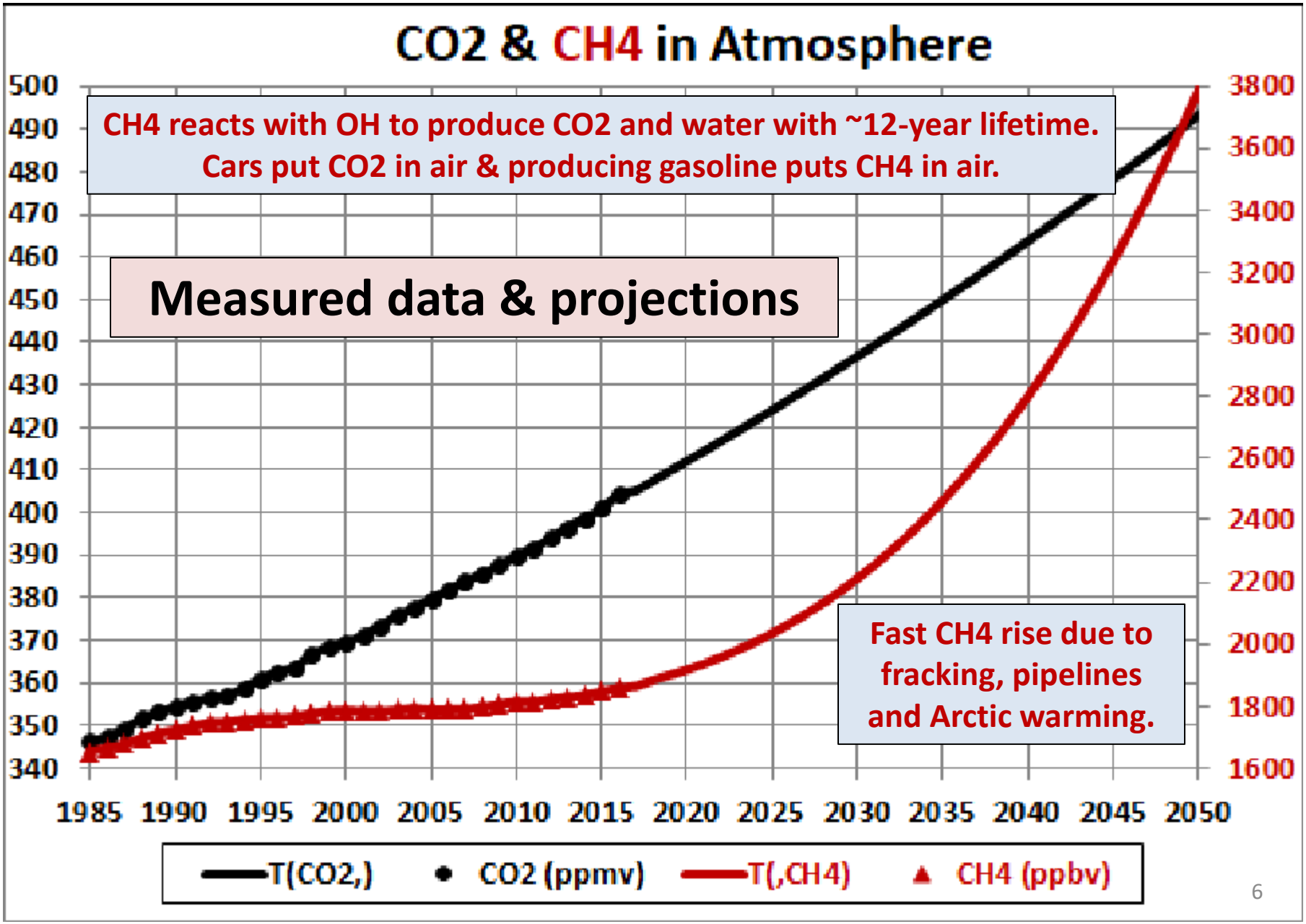


A Tesla Model S has ~150 moving parts. An ICE has ~10,000!!

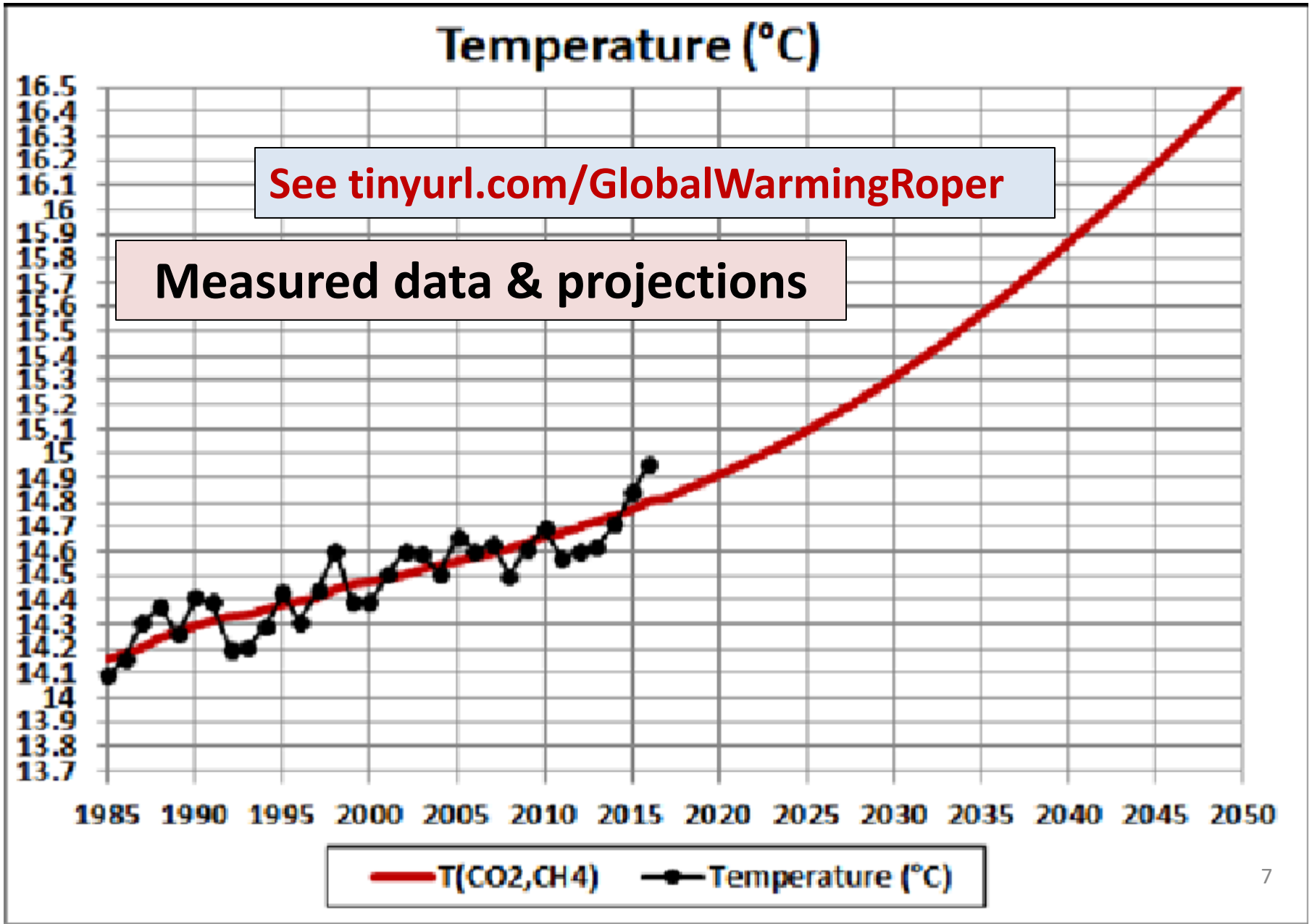
Why Drive an Electric Car?

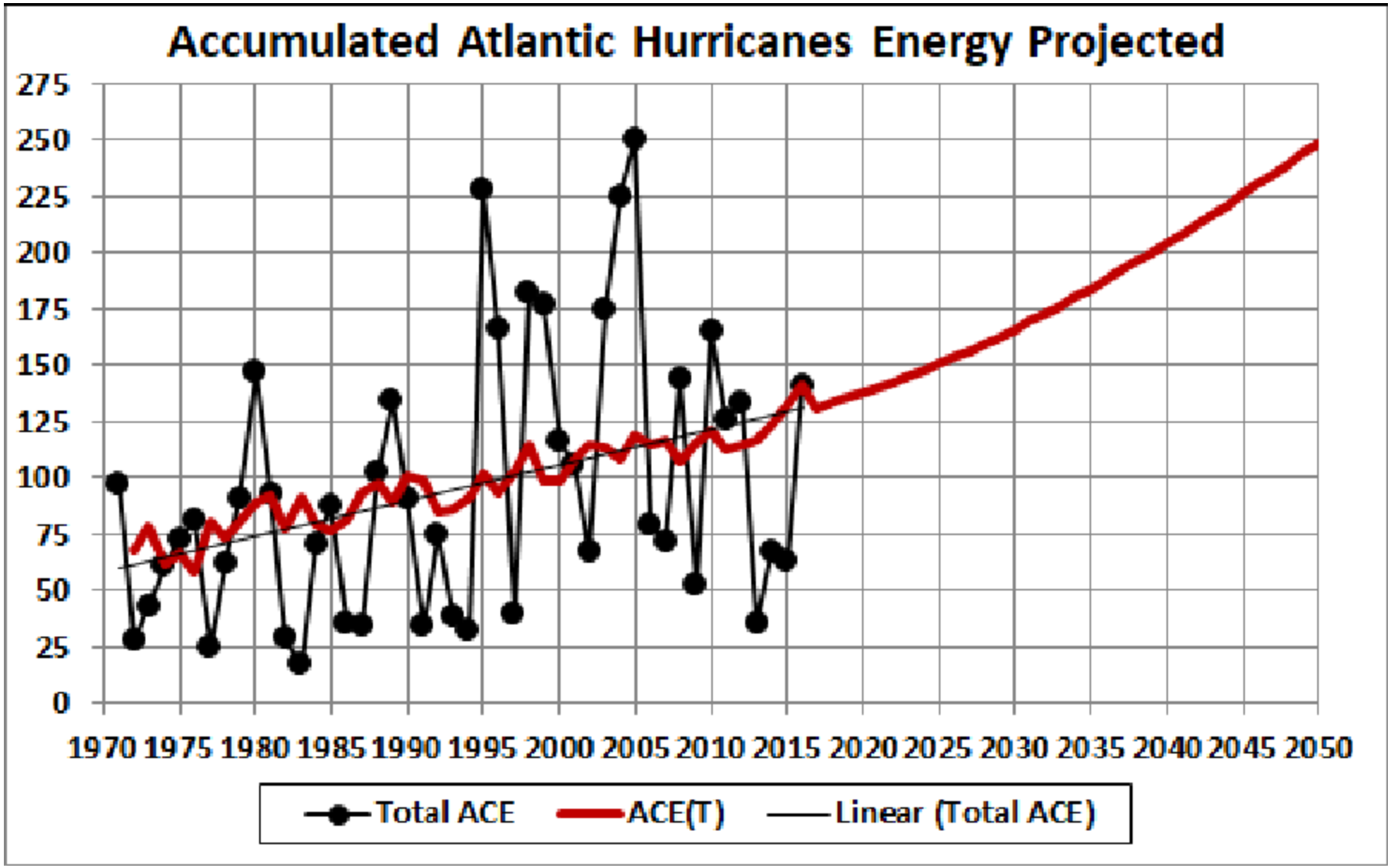
- **Zero vehicle emissions to reduce pollution and global warming**
- Greatly reduced noise & heat (Low noise added at low speeds.)
- High energy efficiency: ~90% (electric **motor**) vs ~30% (gasoline **engine**) and ~40% (diesel **engine**) (**Note terminology.**)
- Less total emissions than ICE car, even for 100% coal electricity. US average = 39% coal electricity.
  - >68-mpg ICE for same total emissions as a BEV in U.S.
- Most emissions are eliminated with solar and wind electricity. So, ultimate fuel source is solar, wind or other renewable electricity source.)
- Low "fuel" cost (~33% of equivalent gasoline car)
- Low maintenance cost (~25% of equivalent gasoline car)
- High performance: **high torque at low speed!**
- $7,500 federal tax credit (Some states have additional benefits.)

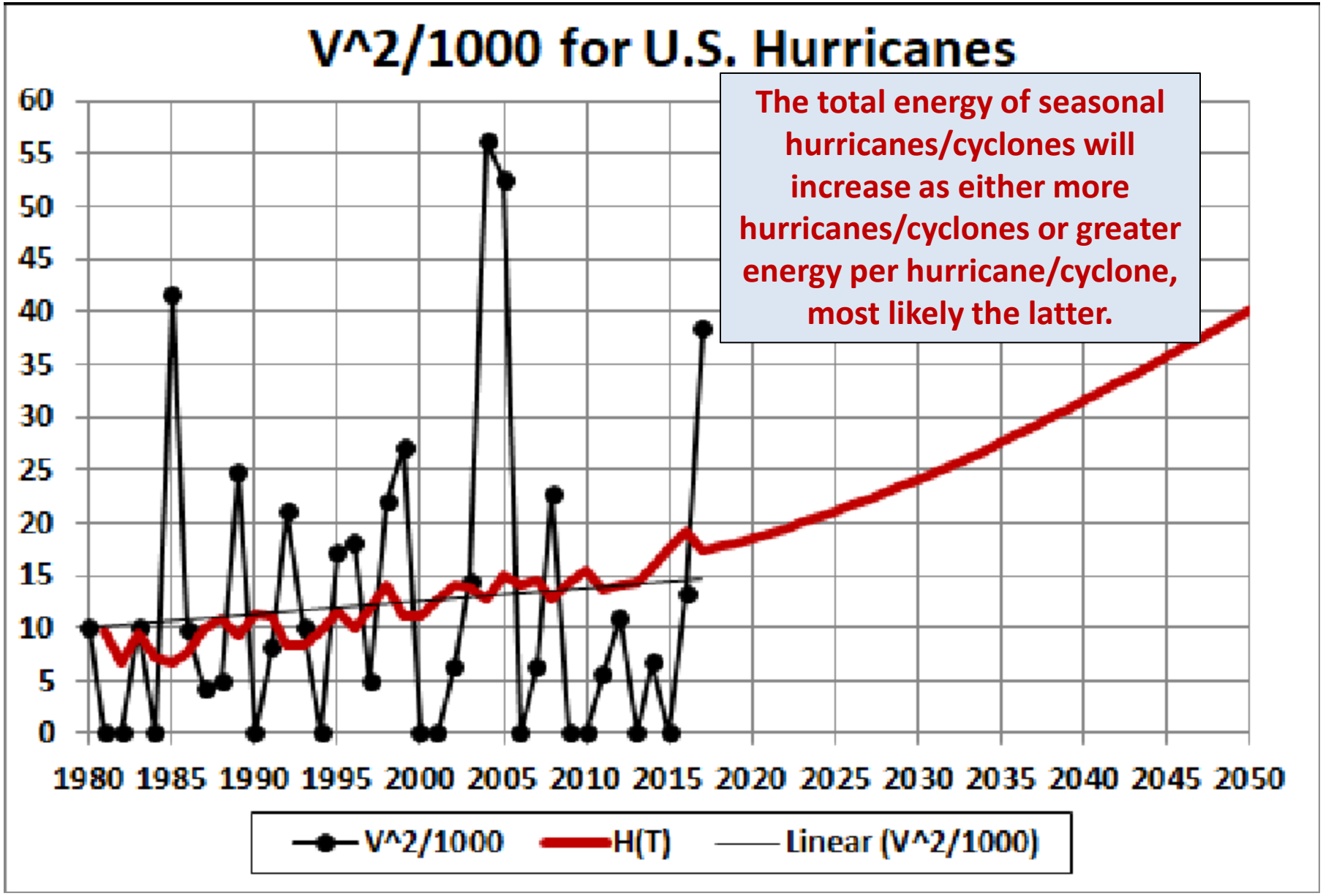
The Two Main Global-Warming Gases



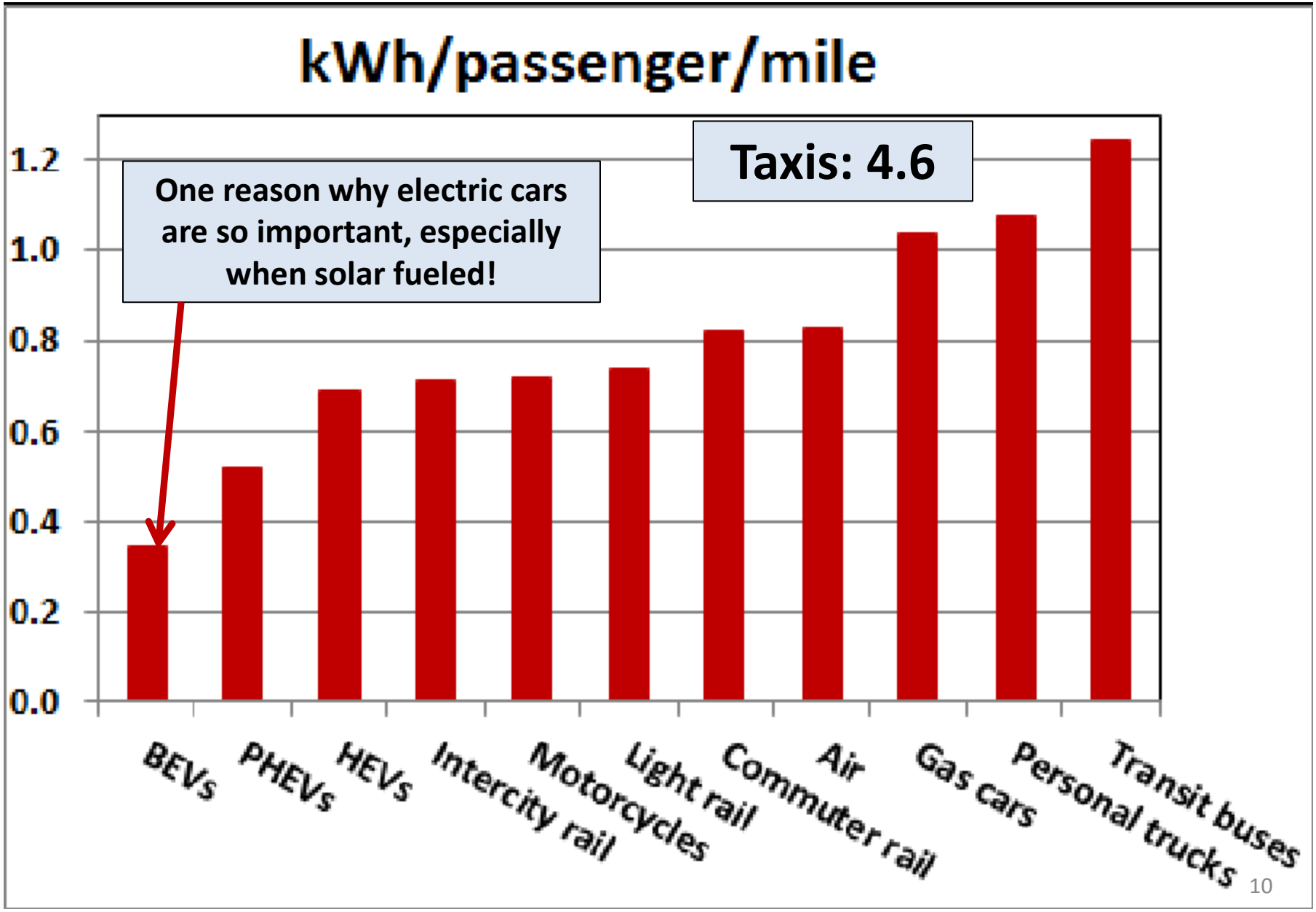
Global Temperature due to CO2 and CH4 Emissions Projected




Accumulated Atlantic Hurricanes Energy Projected
275
250
225
200
175
150
125
100
75
50
25
0
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
Total ACE
ACE(T)
Linear (Total ACE)

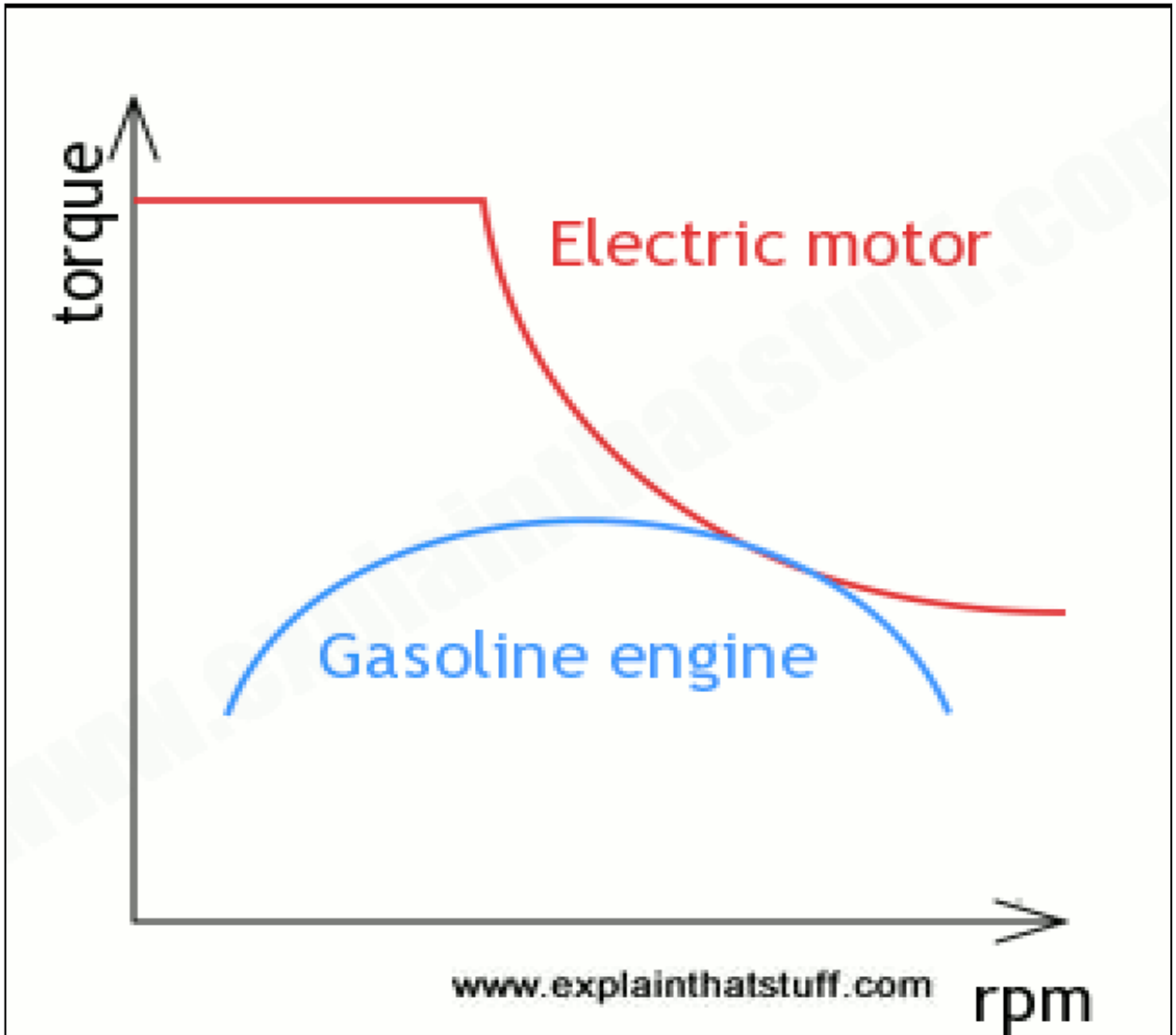

V^2/1000 for U.S. Hurricanes
The total energy of seasonal hurricanes/cyclones will increase as either more hurricanes/cyclones or greater energy per hurricane/cyclone, most likely the latter.
60
55
50
45
40
35
30
25
20
15
10
5
0
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
V^2/1000
H(T)
Linear (V^2/1000)

Passenger Travel Energy Use



0-30 mph Acceleration is a BIG DEAL!

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

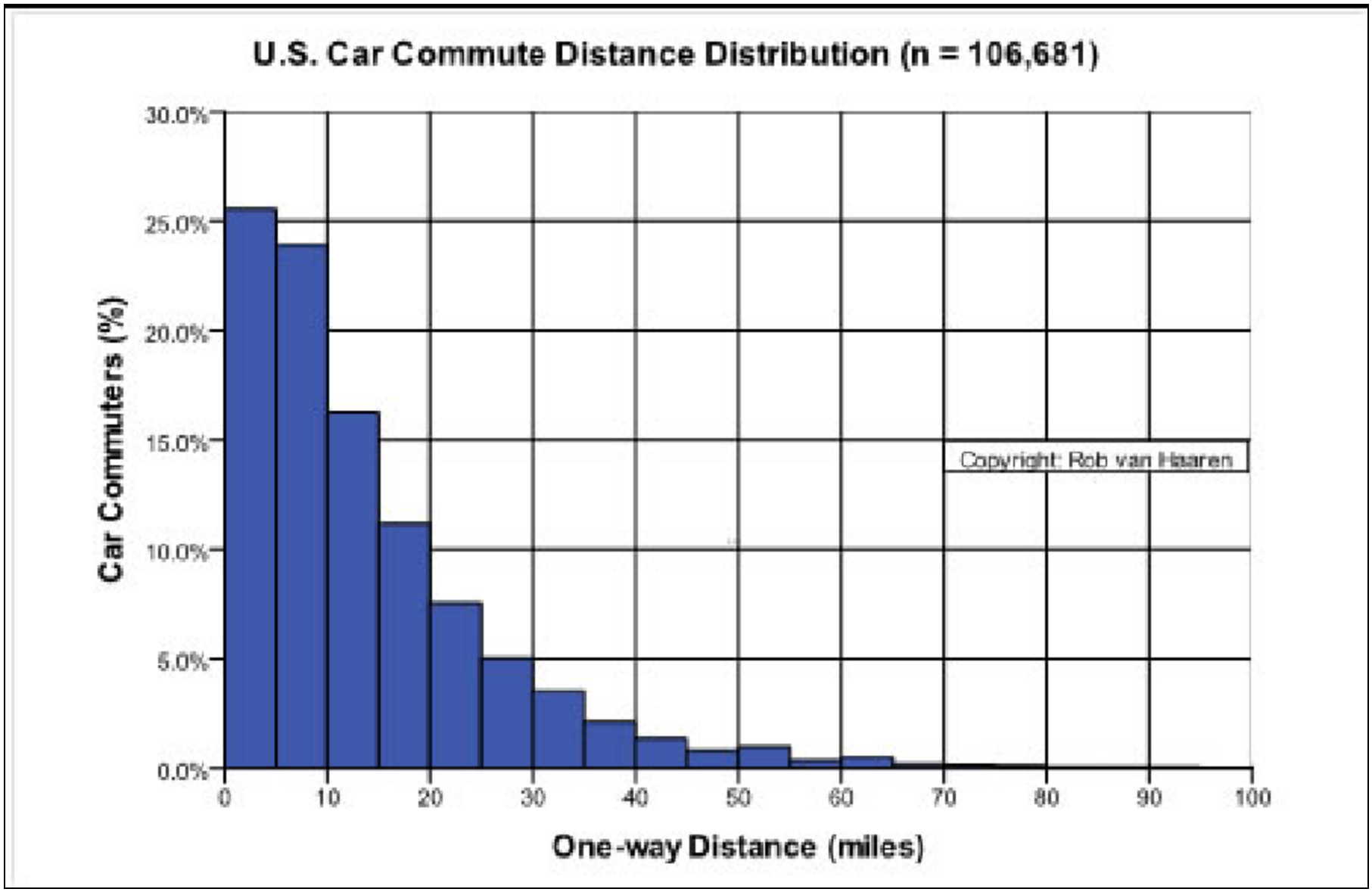


Why BEVs Have Only One Gear

- Electric motors have high maximum RPM (Chevy Bolt EV: 8,810 RPM)
- Electric motors have high efficiency over a broad RPM range.
- Electric motors produce high torque at low RPM.

Questions about BEVs

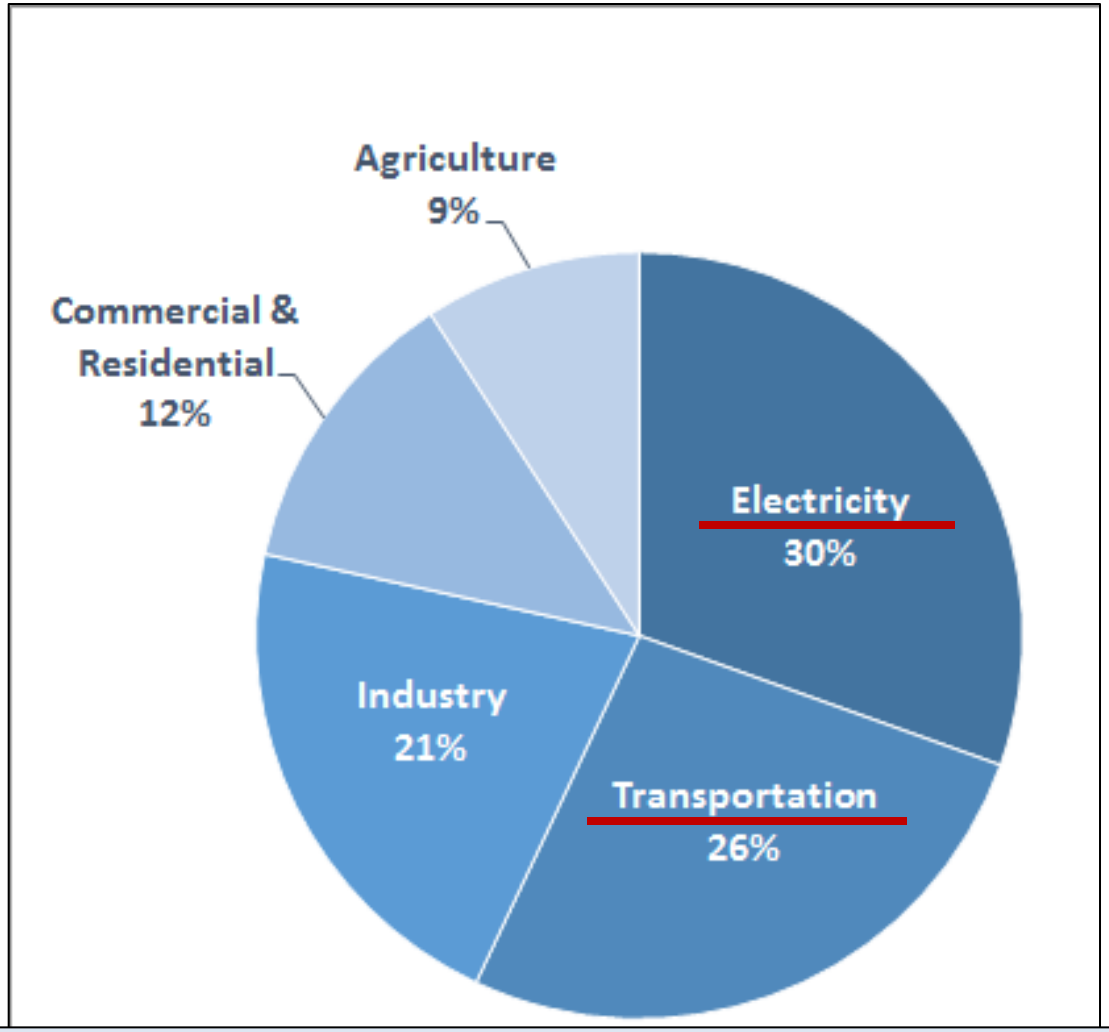
- Q: What do you do when you run out of electricity?
- **A: What do you do when you run out of gasoline? You don't, because you watch the fuel gauge. You fill it up when needed.**
- Q: Do you have "range anxiety" when you drive?
- **A: No, because I plan my trip.**
- Q: What do you do when you go up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



'Driving an Escalade to buy groceries is like hanging a picture with a sledge hammer!"

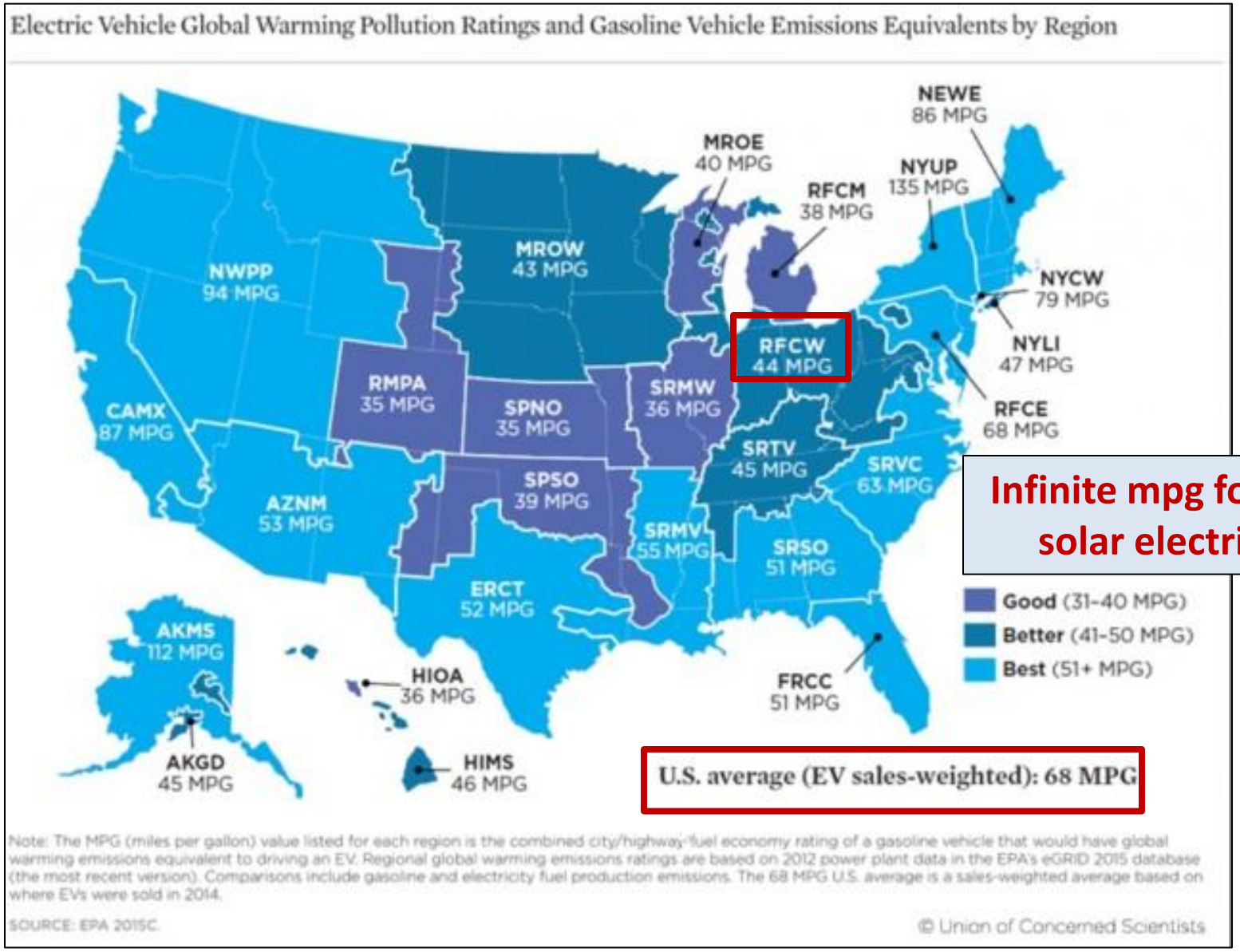
Causes of Global Warming

Too many people is basic cause!

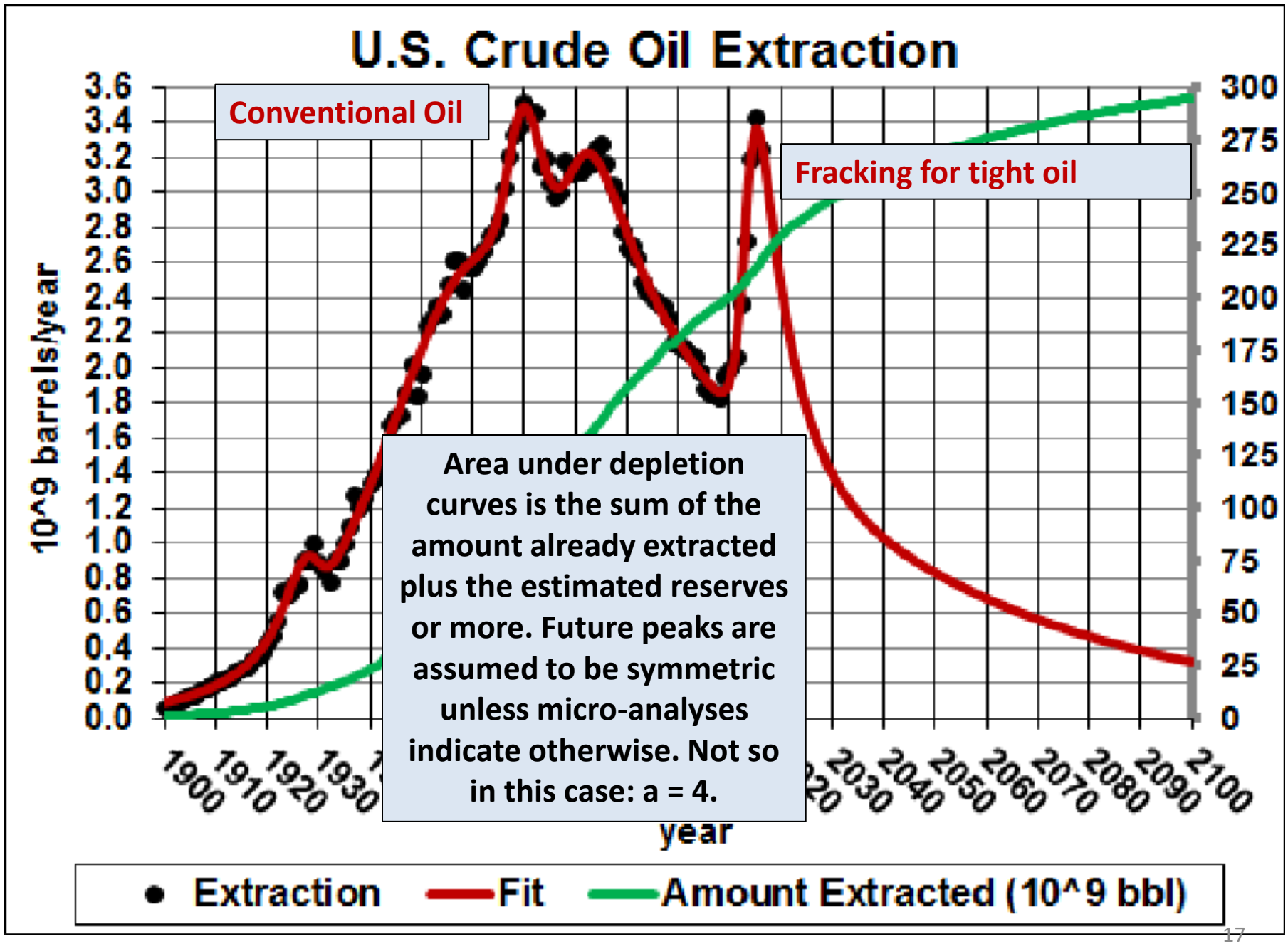


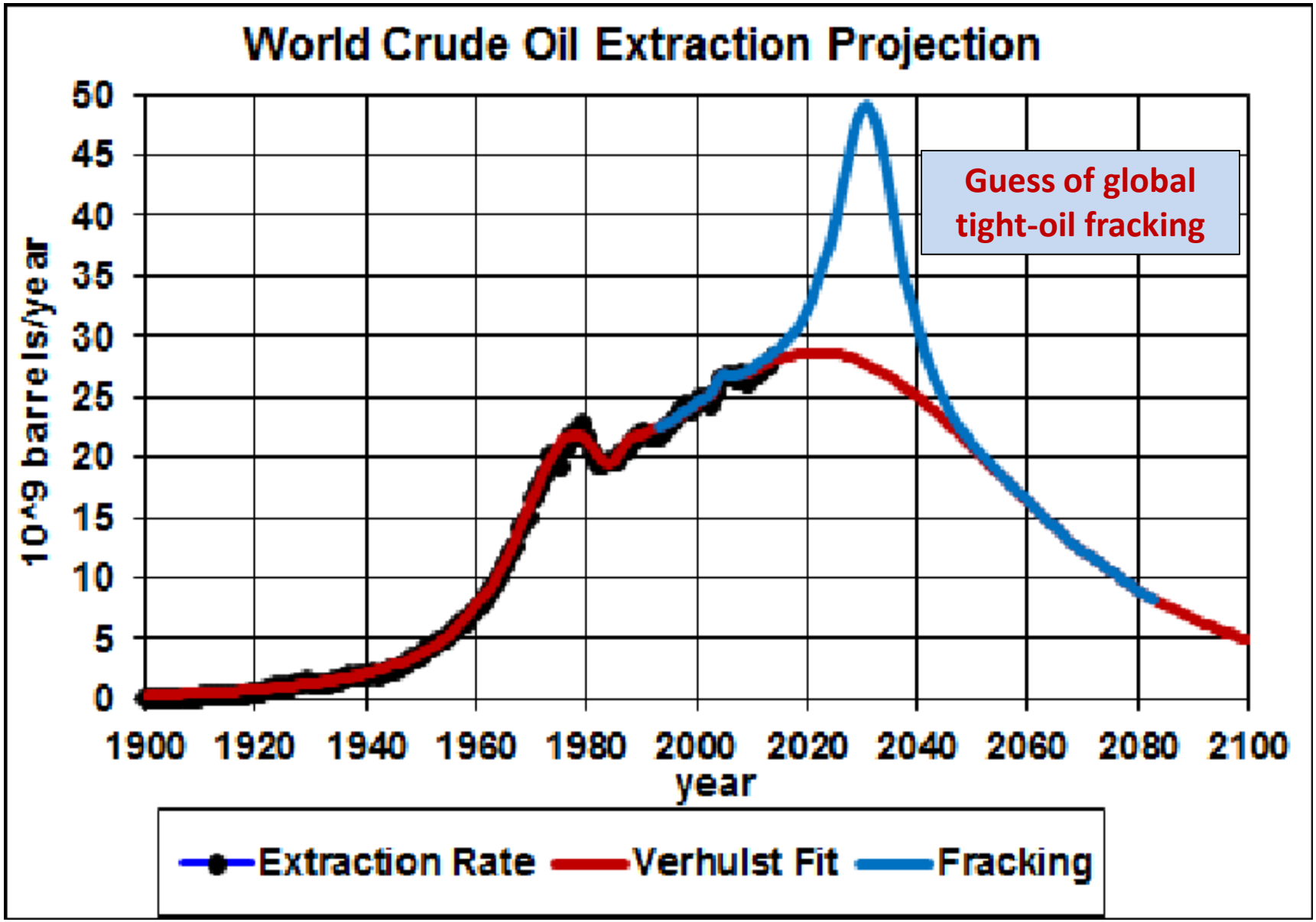
We need renewable electric energy & electric cars!

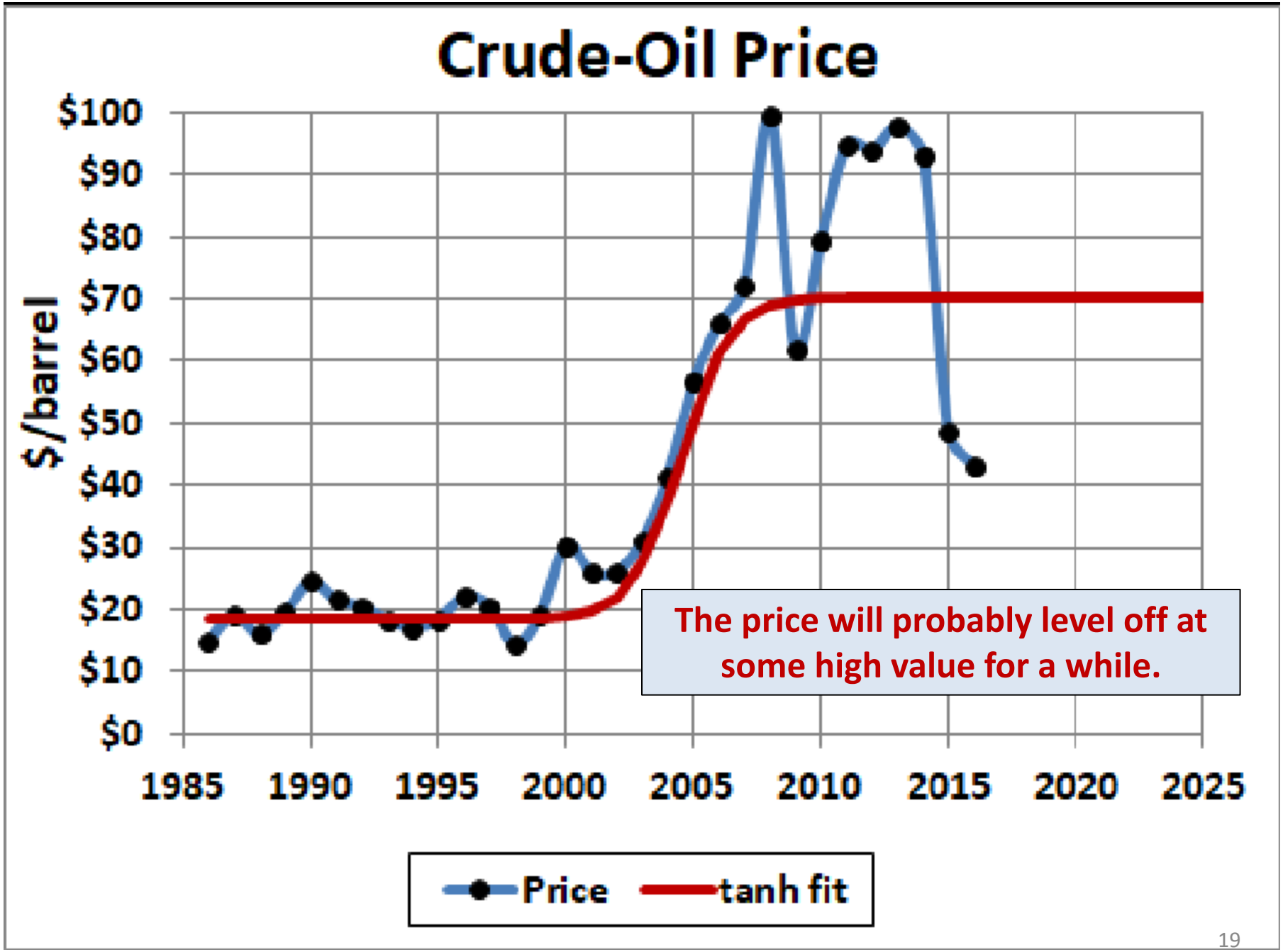
Equivalent ICE GW Emissions to BEVs Charged on Grid

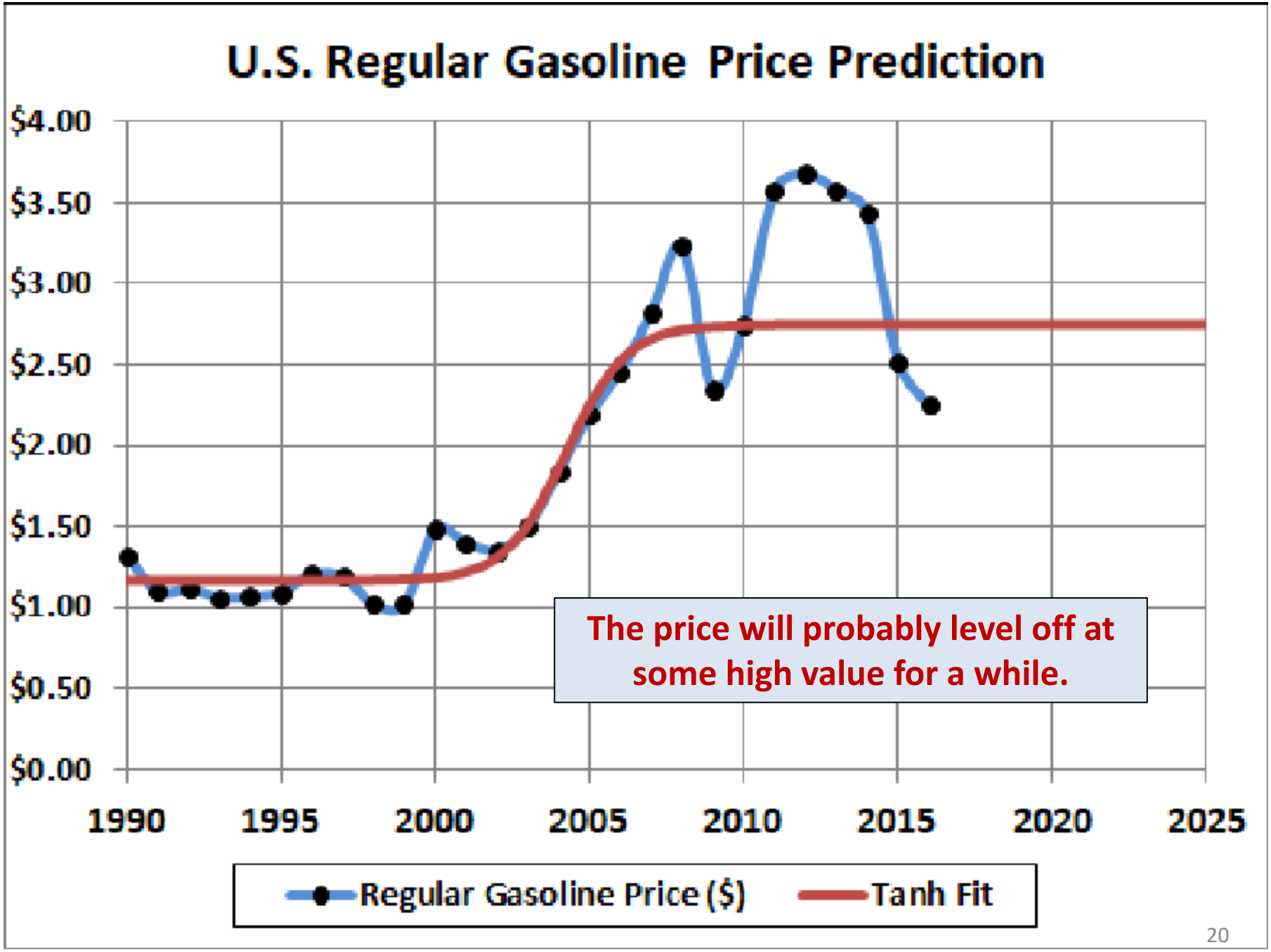


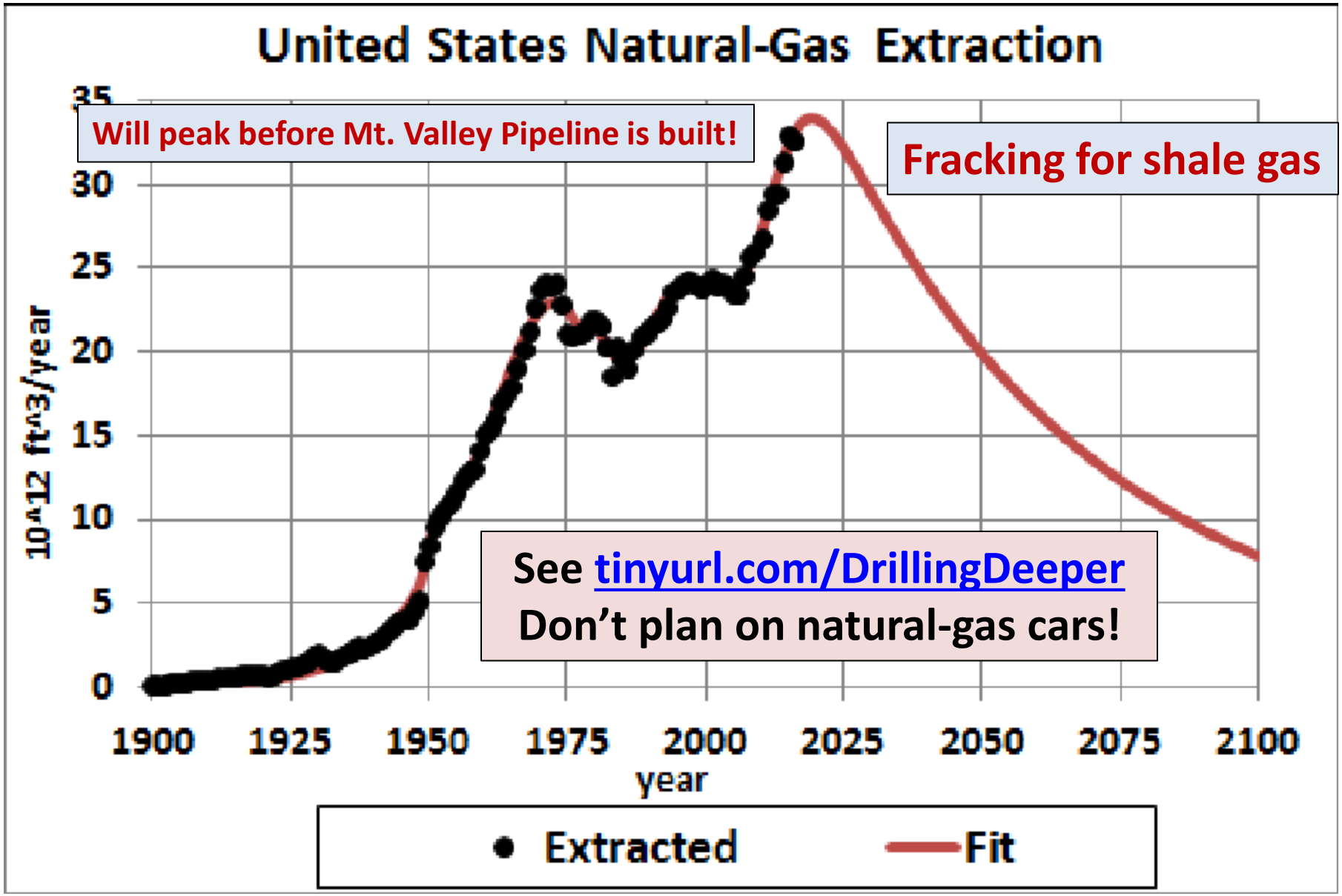
Infinite mpg for 100% solar electricity!


U.S. Crude Oil Extraction
Conventional Oil
Fracking for tight oil
Area under depletion curves is the sum of the amount already extracted plus the estimated reserves or more. Future peaks are assumed to be symmetric unless micro-analyses indicate otherwise. Not so in this case: a = 4.
10^9 barrels/year
year
Extraction
Fit
Amount Extracted (10^9 bbl)


World Crude Oil Extraction Projection
10^9 barrels/year
50
45
40
35
30
25
20
15
10
5
0
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
year
Guess of global tight-oil fracking
Extraction Rate
Verhulst Fit
Fracking

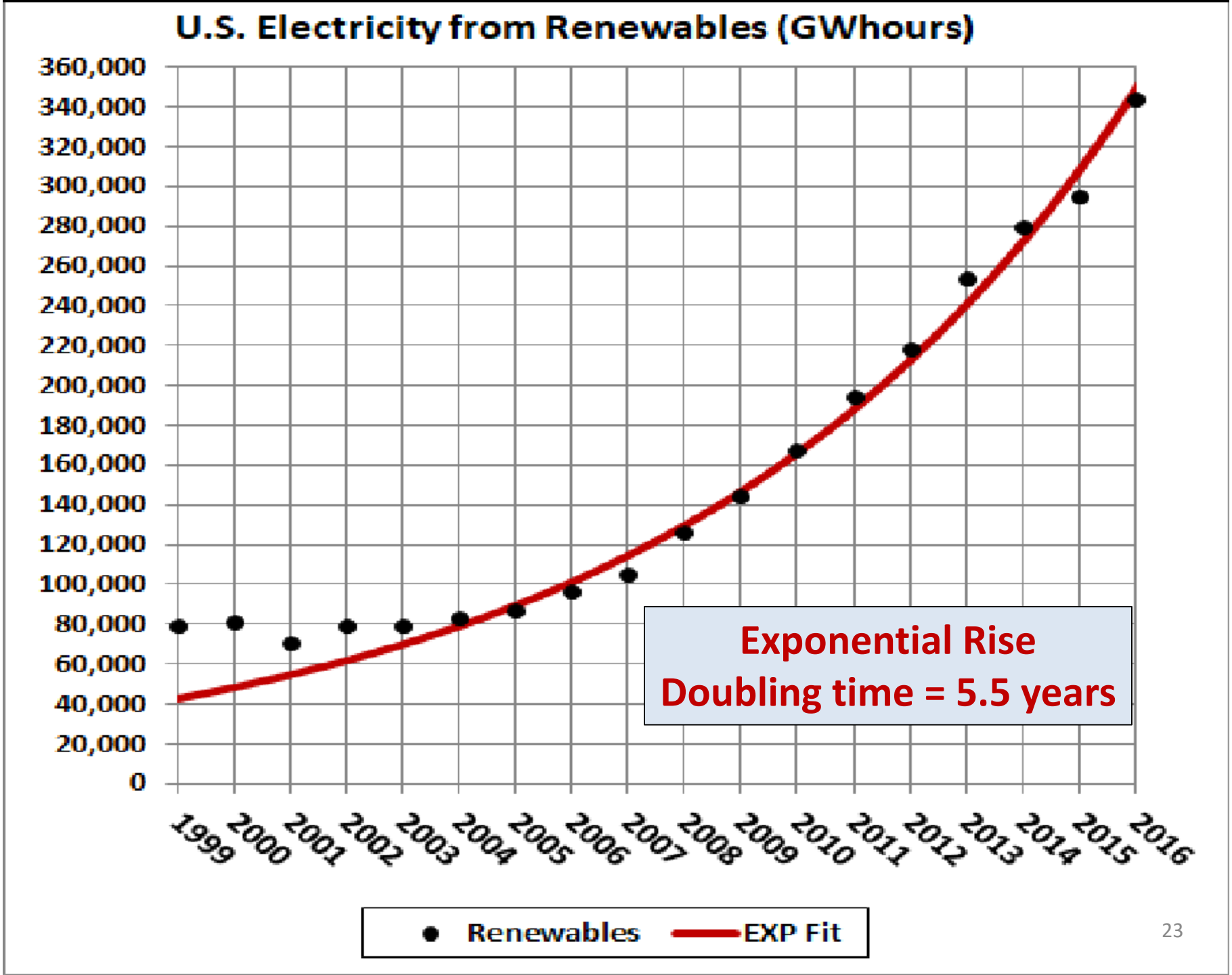

Crude-Oil Price
$/barrel
$100
$90
$80
$70
$60
$50
$40
$30
$20
$10
$0
1985
1990
1995
2000
2005
2010
2015
2020
2025
The price will probably level off at some high value for a while.
Price
tanh fit

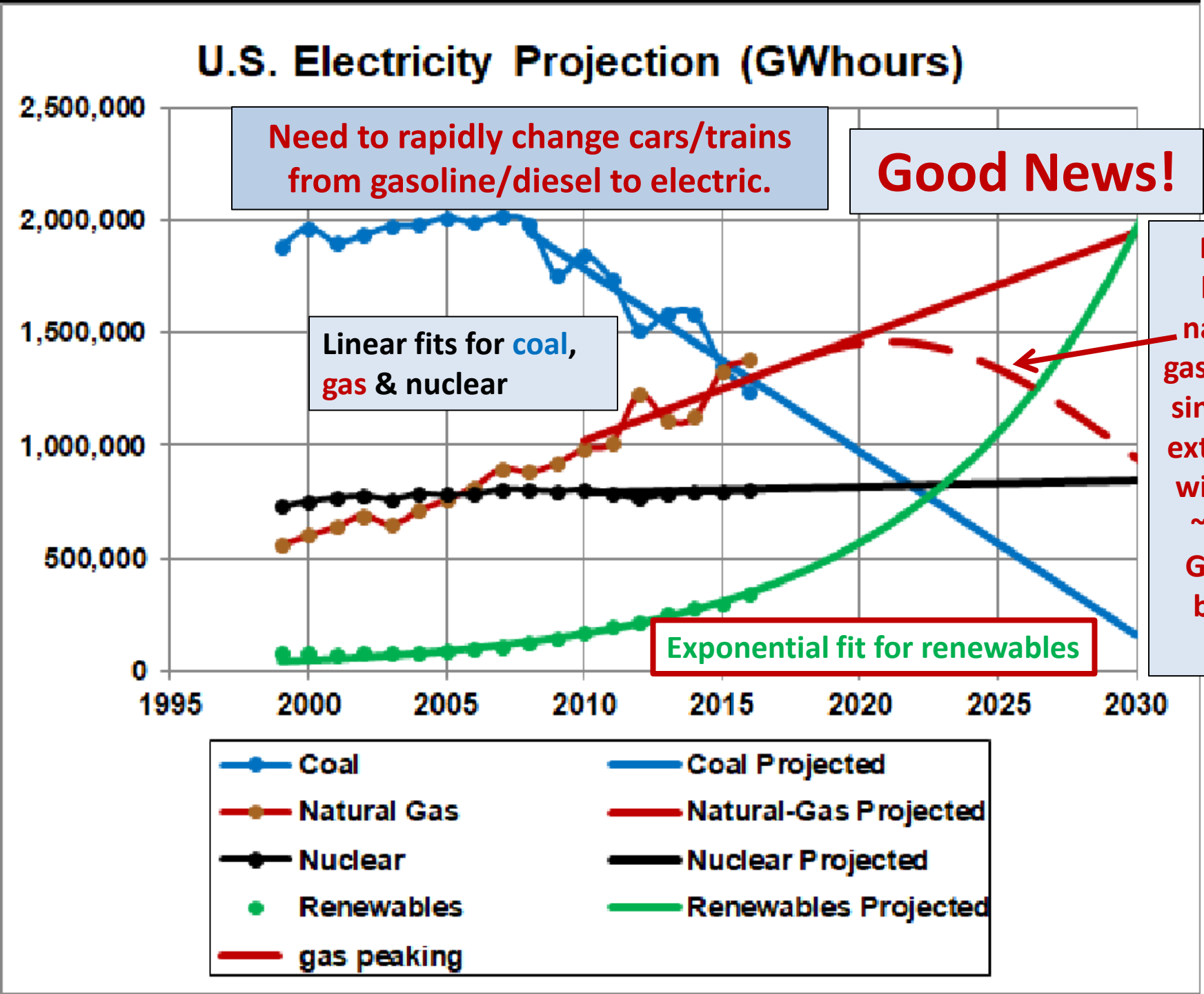

U.S. Regular Gasoline Price Prediction
$4.00
$3.50
$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$0.00
1990
1995
2000
2005
2010
2015
2020
2025
The price will probably level off at some high value for a while.
Regular Gasoline Price ($)
Tanh Fit


United States Natural-Gas Extraction
Will peak before Mt. Valley Pipeline is built!
Fracking for shale gas
See tinyurl.com/DrillingDeeper
Don't plan on natural-gas cars!
10^12 ft^3/year
35
30
25
20
15
10
5
0
1900
1925
1950
1975
2000
2025
2050
2075
2100
year
Extracted
Fit

BEVs and Petroleum

- Plastic components made from petrochemicals (PCs)
- Synthetic-rubber partly made from PCs
- Metals mined using machines powered by fossil fuels
- Metal parts produced using fossil fuels
- Auto plants powered by fossil fuels
- Transport of materials and BEV using fossil fuels


U.S. Electricity from Renewables (GWhours)
360,000
340,000
320,000
300,000
280,000
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Exponential Rise
Doubling time = 5.5 years
Renewables
EXP Fit


U.S. Electricity Projection (GWhours)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1995
2000
2005
2010
2015
2020
2025
2030
Need to rapidly change cars/trains from gasoline/diesel to electric.
Good News!
Linear fits for coal, gas & nuclear
More likely natural-gas future, since U.S. extraction will peak ~2018. Gas is a bridge fuel.
Exponential fit for renewables
Coal
Natural Gas
Nuclear
Renewables
gas peaking
Coal Projected
Natural-Gas Projected
Nuclear Projected
Renewables Projected

BEV versus ICE Driving Costs

- Assumptions
  - **Lease/buy cost is same for ICE & >200-miles-BEV**
  - Efficiency: ICE = 30-mpg; BEV = 3.8-miles/kWh
  - Both travel 75,000 miles in 5 years
  - Gasoline cost = $3/gallon; Electricity cost = $0.15/kWh
- Costs (Rough Calculation)
  - **Fuel:** ICE = $7,500; BEV = $2,960
  - **Maintenance:** ICE = $2000; BEV = $500
  - Cost difference: ICE – BEV = ($7,500 + $2000) – ($2,960 + $500) = **$6,040**.
  - If electricity is from **renewable sources**, CO_2 emissions cost @ $220/ton yields **~$650** (discounted 100 years @ 4%) for ICE and **$0** for BEV.

Average Annual U.S. Home Electricity Costs
U.S. DOE Study

- Electric heating: 11,300 kWh
- Electric hot water: 4,700 kWh
- Electric car: 2,800 kWh
- Mileage cost
  - Gasoline: $0.13/mile @ 35 MPG
  - Electric: $0.038/Mile @ 115 MPGe

150,000 miles

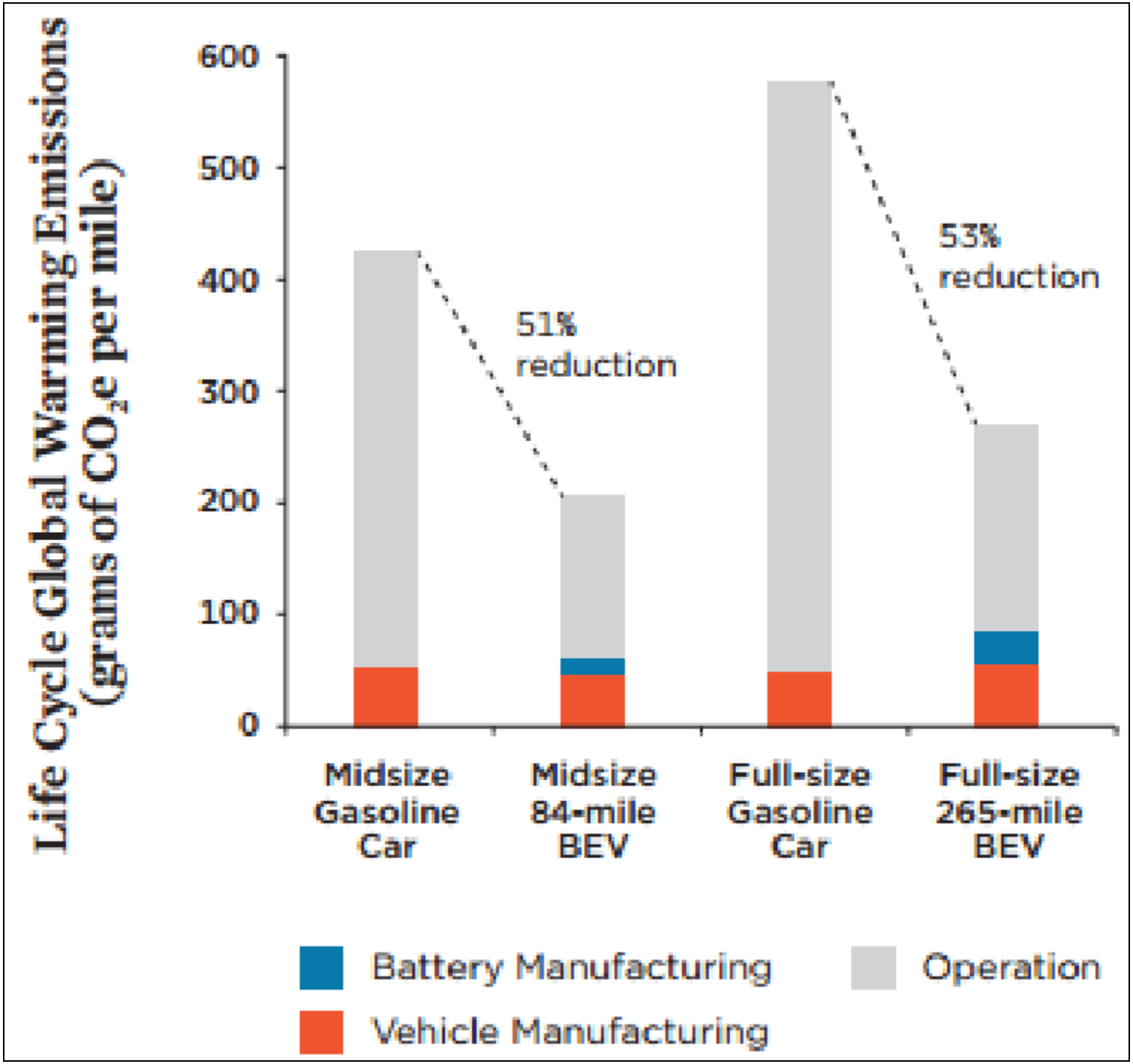
Maintenance Schedule for your 2017 Chevrolet Bolt EV

Certified Service	7,500 miles	15,000 miles	22,500 miles	30,000 miles	37,500 miles	45,000 miles	52,500 miles	60,000 miles	67,500 miles	75,000 miles	82,500 miles	90,000 miles	97,500 miles	105,000 miles	112,500 miles	120,000 miles	127,500 miles	135,000 miles	142,500 miles	150,000 miles
Rotate tires, if recommended for the vehicle, and perform Required Services.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Replace passenger compartment air filter (or 2 years, whichever comes first).			✓			✓			✓			✓			✓			✓		
Drain and fill vehicle coolant circuits.																				✓

150,000 miles

Maintenance Schedule for your 2016 Chevrolet Cruze Limited

Certified Service	7,500 miles	15,000 miles	22,500 miles	30,000 miles	37,500 miles	45,000 miles	52,500 miles	60,000 miles	67,500 miles	75,000 miles	82,500 miles	90,000 miles	97,500 miles	105,000 miles	112,500 miles	120,000 miles	127,500 miles	135,000 miles	142,500 miles	150,000 miles
Rotate tires, if recommended for the vehicle, and perform Required Services. Check engine oil level and oil life percentage. Change engine oil and filter, if needed.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Replace passenger compartment air filter (or 2 years, whichever comes first).			✓			✓			✓			✓			✓			✓		
Replace engine air cleaner filter (or every 4 years, whichever occurs first).						✓						✓						✓		
Replace spark plugs and inspect spark plug wires.													✓							
Replace spark plugs. Inspect ignition coils boots. (Applies to: 1.4 L)								✓								✓				
1.8L Engine Only: Rplace timing belt, idler pulley, and timing belt tensioner (or every 3 years, whichever comes first). (Applies to: 1.8 L)													✓							
Change automatic transmission fluid, if equipped. If filter is serviceable, change filter. (Applies to: Severe)						✓						✓						✓		
Change manual transmission fluid. (Applies to: Manual, Severe)						✓						✓						✓		
Drain and fill engine cooling system (or every 5 years, whichever comes first).																				✓
Change brake fluid (or every 3 years, whichever occurs first).						✓						✓						✓		
Change clutch fluid (or every 3 years, whichever occurs first). (Applies to: Manual)						✓						✓						✓		
Inspect evaporative control system.						✓						✓						✓		
Inspect engine accessory drive belts for fraying, excessive cracks or obvious damage (or every 10 years, whichever occurs first).																				✓


Life Cycle Global Warming Emissions (grams of CO_2e per mile)
600
500
400
300
200
100
0
51% reduction
53% reduction
Midsize Gasoline Car
Midsize 84-mile BEV
Full-size Gasoline Car
Full-size 265-mile BEV
Battery Manufacturing
Operation
Vehicle Manufacturing

Electric-Car Components

- **Large DC battery** (2018 LEAF: 40-kWh; CBEV: 60-kWh; Tesla Model 3 Long Range: 75-kWh)
- **Powerful AC electric motor** (LEAF-II: 110-kW =147-hp; CBE[illegible]8-hp)
- **Reg[illegible]ergy** (Motor is a generator, also. Same for hybrids, e.g., Prius.)
- **Chargers** (120V AC, 240V AC, 480V DC) (LEAF: 6.6 kW AC)
- **DC to/from AC inverter** (battery to/from motor)
- **Auxiliary 12V battery** & DC-HV to DC-12V converter
- **Cooling systems** for motor powered by 12V battery
- Possibly **heating system for battery**
- Electric steering, brakes and climate control
- In-cab driver information about battery level, energy used and location of charging stations

Many BEVs have an option of one-pedal driving, using only the accelerator.

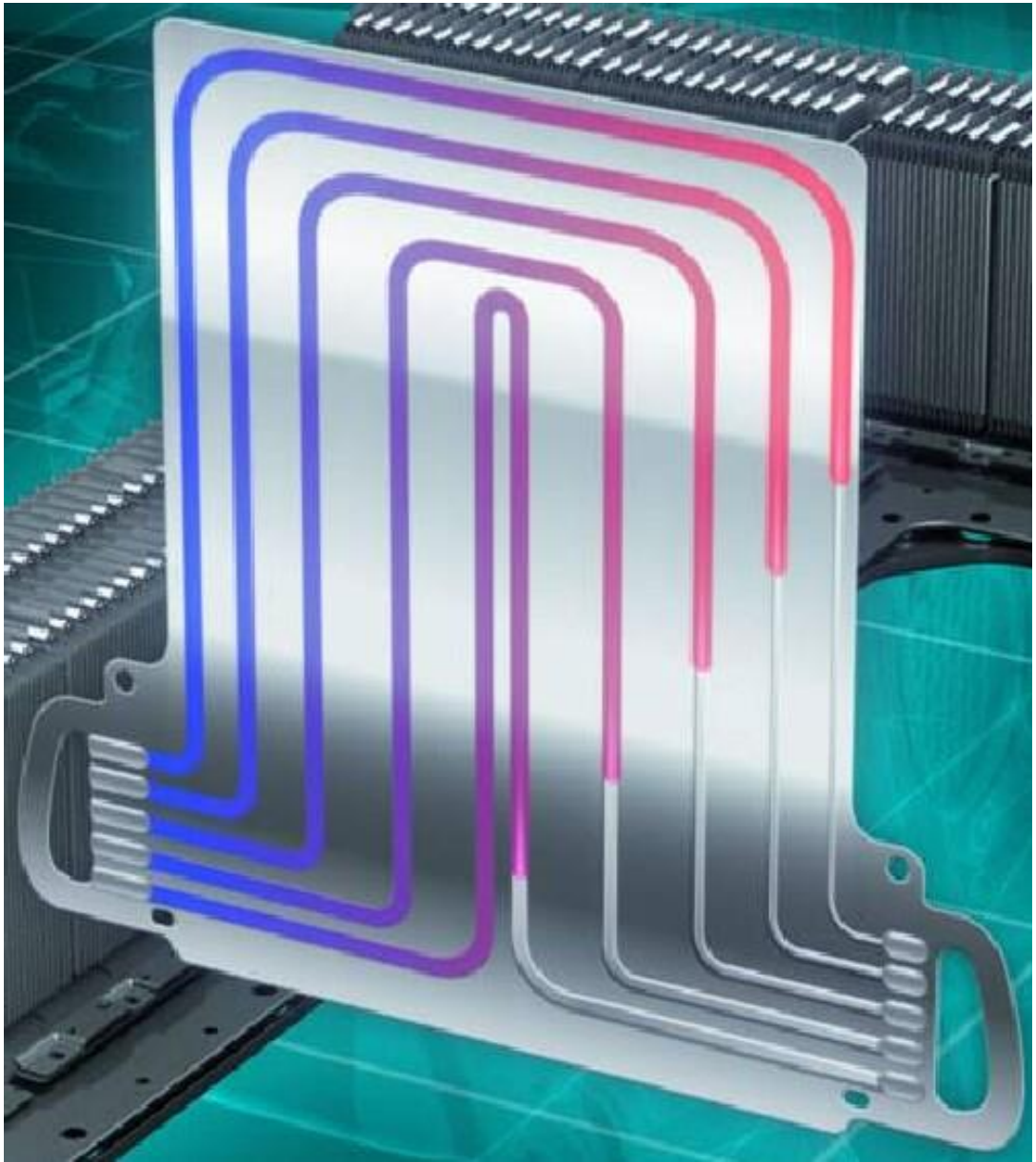
Lithium Batteries' Materials

- Lithium compounds
- Battery separators: plastics
- Current collectors: nickel, copper & aluminum
- Cathode materials: cobalt, iron, phosphate, manganese, nickel
- Anode materials: porous carbon; e.g., graphite
- Electrolyte solutions: lithium salts & flame retardant
- Packaging: steel, aluminum and titanium

Lithium “Mining” at Salt Flats

Battery Thermal Management

Chevrolet Volt/Bolt-EV Method



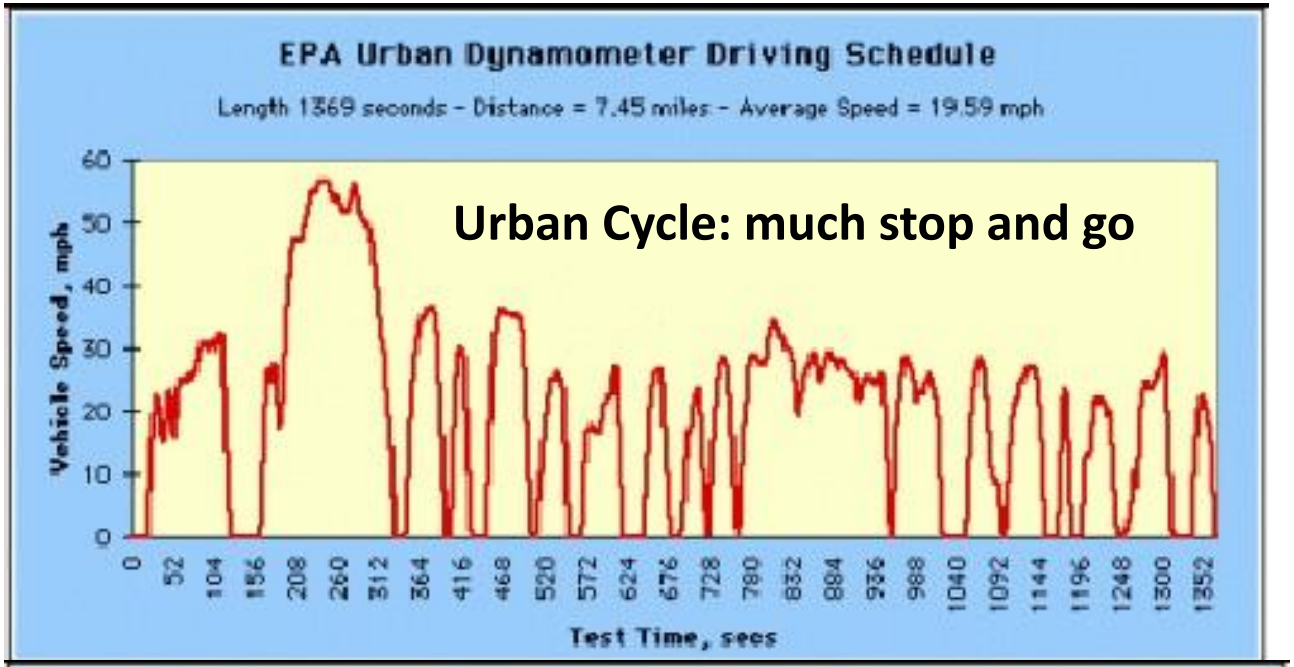
Refrigeration for cooling and resistance heating of glycol flowing in parallel tubes.

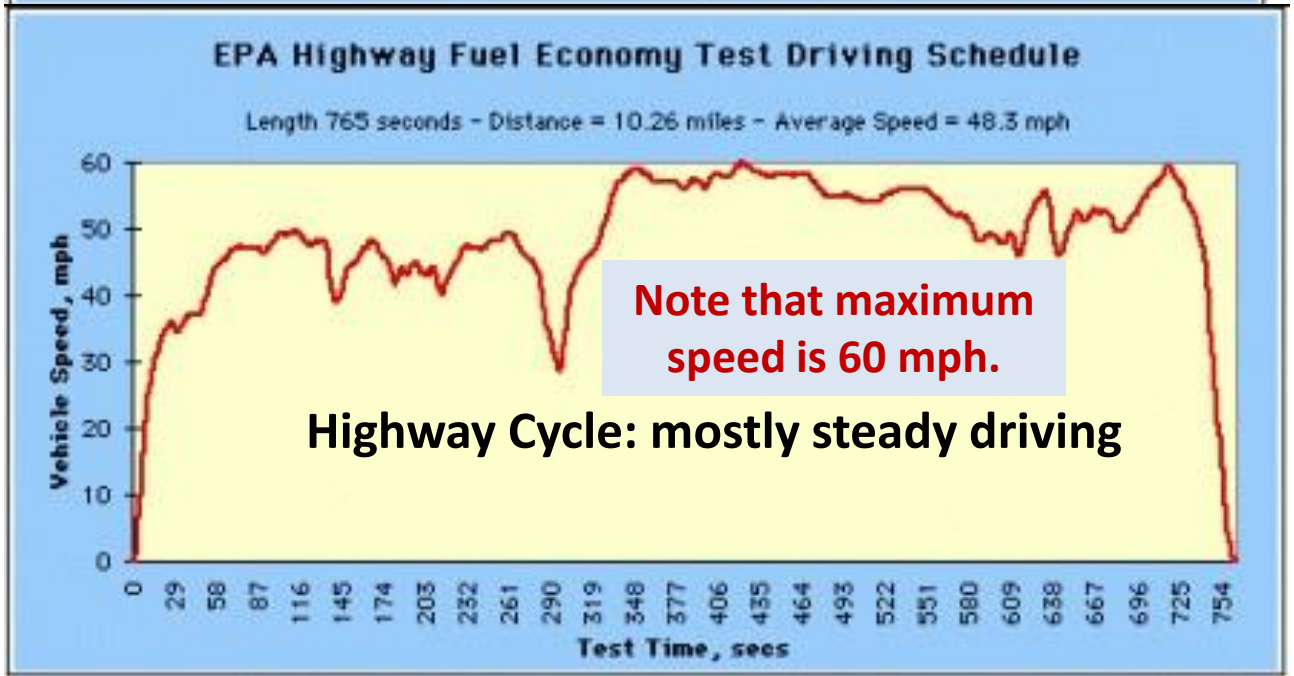
Keep battery plugged in after charging in cold or hot weather.

Safety of Electric Cars

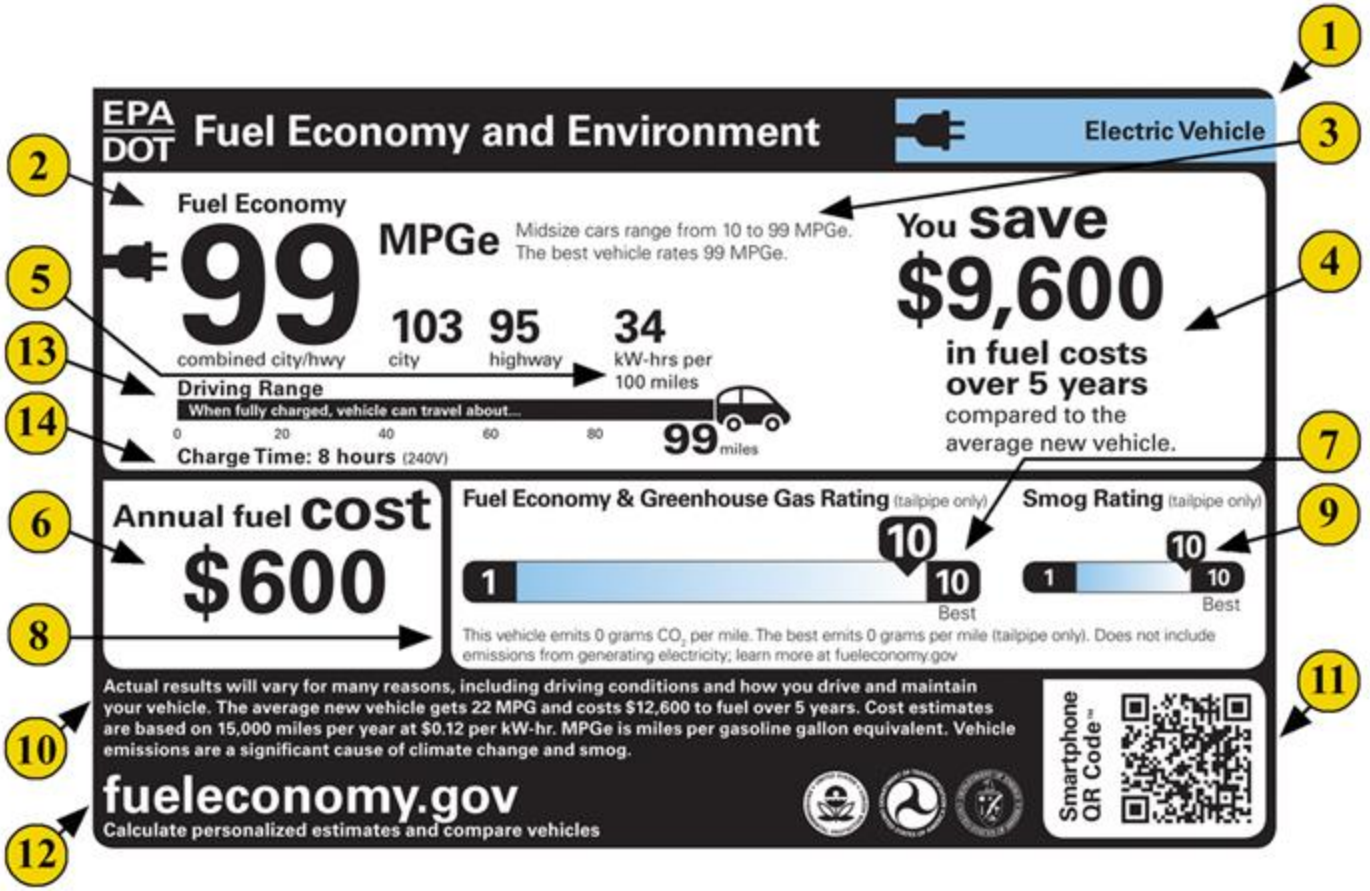
- Nissan LEAF, Chevrolet Volt and Tesla Model S have top safety ratings.
- Battery was left intact in a burned out Nissan LEAF.
- Two Tesla-S sedans have been burned somewhat by a fire in the battery due to massive metal in road puncturing the battery case. Drivers unharmed. More under-battery deflector and titanium protection was added.
- **~250,000 gasoline car fires/year in U.S. with ~400 deaths & ~1200 injuries.** Full gasoline tank has ~10 times the combustible energy that a Tesla battery has. Batteries are made of modules separated by firewalls.
- Battery is automatically disconnected in a collision.
- Manual battery disconnect is easily done.
- EMS manuals and training are available.

EPA Driving Cycles



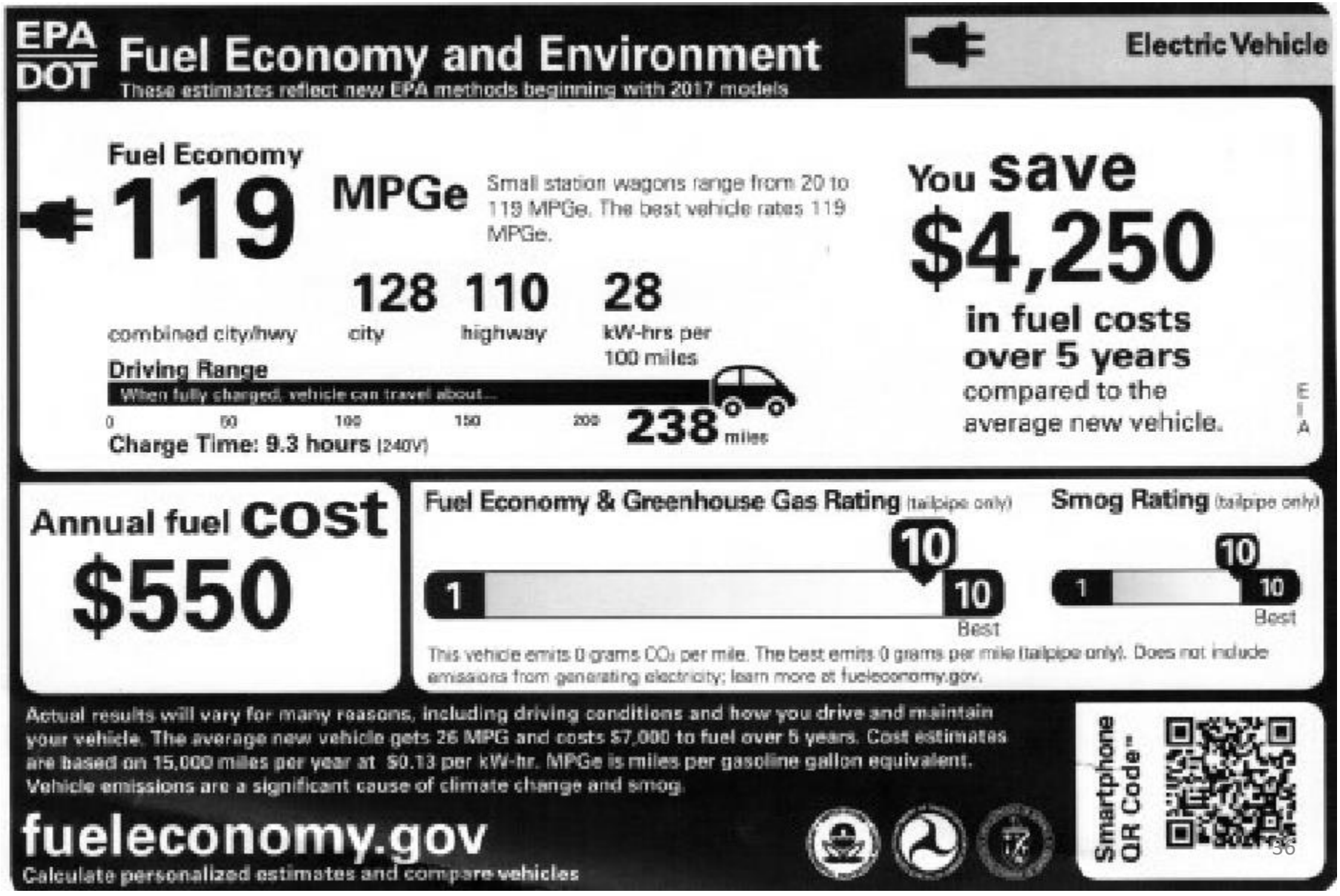


BEV Monroney Label



1: Vehicle Technology & Fuel. 2: Fuel Economy. 3: Comparing to Other Vehicles
4: Save/Spend More of 5 Years Compared. 5: Fuel Consumption Rate.
6: Estimated Annual Fuel Cost. 7: Fuel Economy & Greenhouse Gas Rating.
8: **CO_2** Emissions. 9: Smog Rating. 10: Details 11: QR Code. 12: Web page.
13: Driving Range. 14: Charge Time

Chevrolet Bolt EV Monroney Sticker



100-miles<Range<200-Miles BEVs

- **Nissan LEAF 2018**
  - Range: 150 miles
  - Efficiency: ? MPGe
  - Battery Capacity: 40 kWh
  - MSRP: $30,065
  - Optional 240-volts portable CS
- **BMW i3**
  - Range: 114 miles
  - Efficiency: 118 MPGe
  - Battery Capacity: 33.2 kWh
  - MSRP: $37,945
- **Ford Focus Electric**
  - Range: 115 miles
  - Efficiency: 107 MPGe
  - Battery Capacity: 33.5 kWh
  - MSRP: $22,495

>200-miles option next year

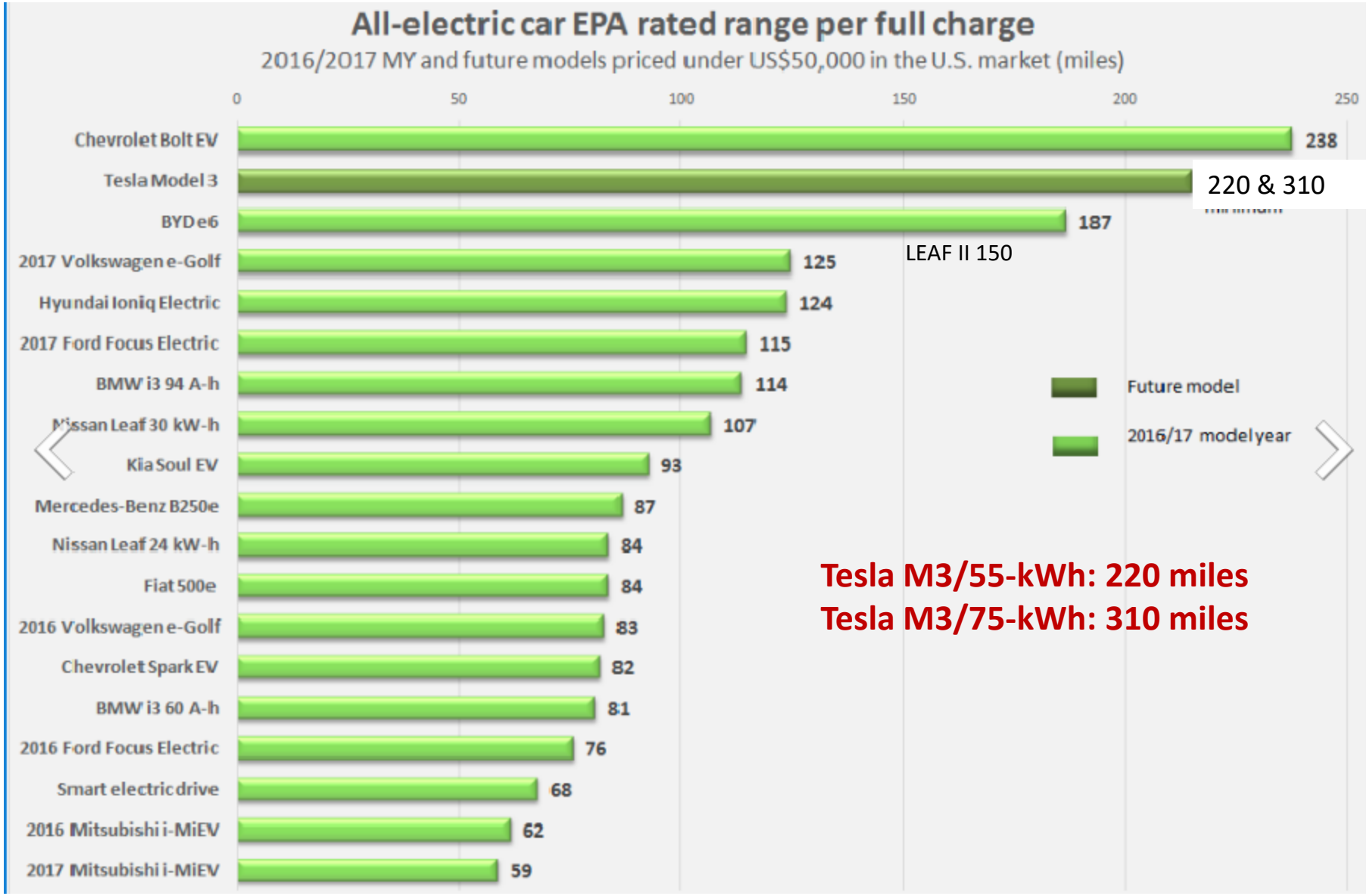
Local test drive: https://allnewleafdrive.com/

Sport i3s option

100-miles<Range<200-Miles BEVs

- **Volkswagen e-Golf**
  - Range: 125 miles
  - Efficiency: 106 MPGe
  - Battery Capacity: 35.8 kWh
  - MSRP: $30,495
- **Hyundai IONIQ**
  - Range: 124 miles
  - Efficiency: **136 MPGe**
  - Battery Capacity: 28 kWh
  - MSRP: $22,835

Range of Mid-size BEVs



220 & 310

LEAF II 150

Tesla M3/55-kWh: 220 miles
Tesla M3/75-kWh: 310 miles

Midsize >200-Miles BEVs in 2017-8

tinyurl.com/BoltEVManual

Chevrolet Bolt EV (**238-miles**)($37,495-$7,500)

60-kWh battery

119 MPGe EPA

Sport Mode

Don't confuse the Chevy Bolt EV, a BEV, with the Chevy Volt, a PHEV, which will be briefly discuss later.

LT: $37,500
Premier: $41,780
DC CCS Fast Charging: $750

Midsize >200-Miles BEVs in 2017-8

Tesla Model 3 (220 miles EPA range)($35,000)

Often called Model ≡

55-kWh battery

- **15” horizontal screen only**
- **Superchargers**
- **Destination Chargers**
- **DC CHAdeMO fast-charging**

Options:

- **75-kWh battery: 310 miles EPA range; $44,000 (126 MPGe)**
- **AWD**
- **Autopilot $5,000, Enhanced Autopilot (autonomous ready) $3,000**
- **Glass roof**
- **Colors other than black: $1000**

Chevy Bolt EV

US design
Korean EV system
Assembled in MI.
New safety features
CCS fast charger

How many here have ordered the Tesla Model 3?

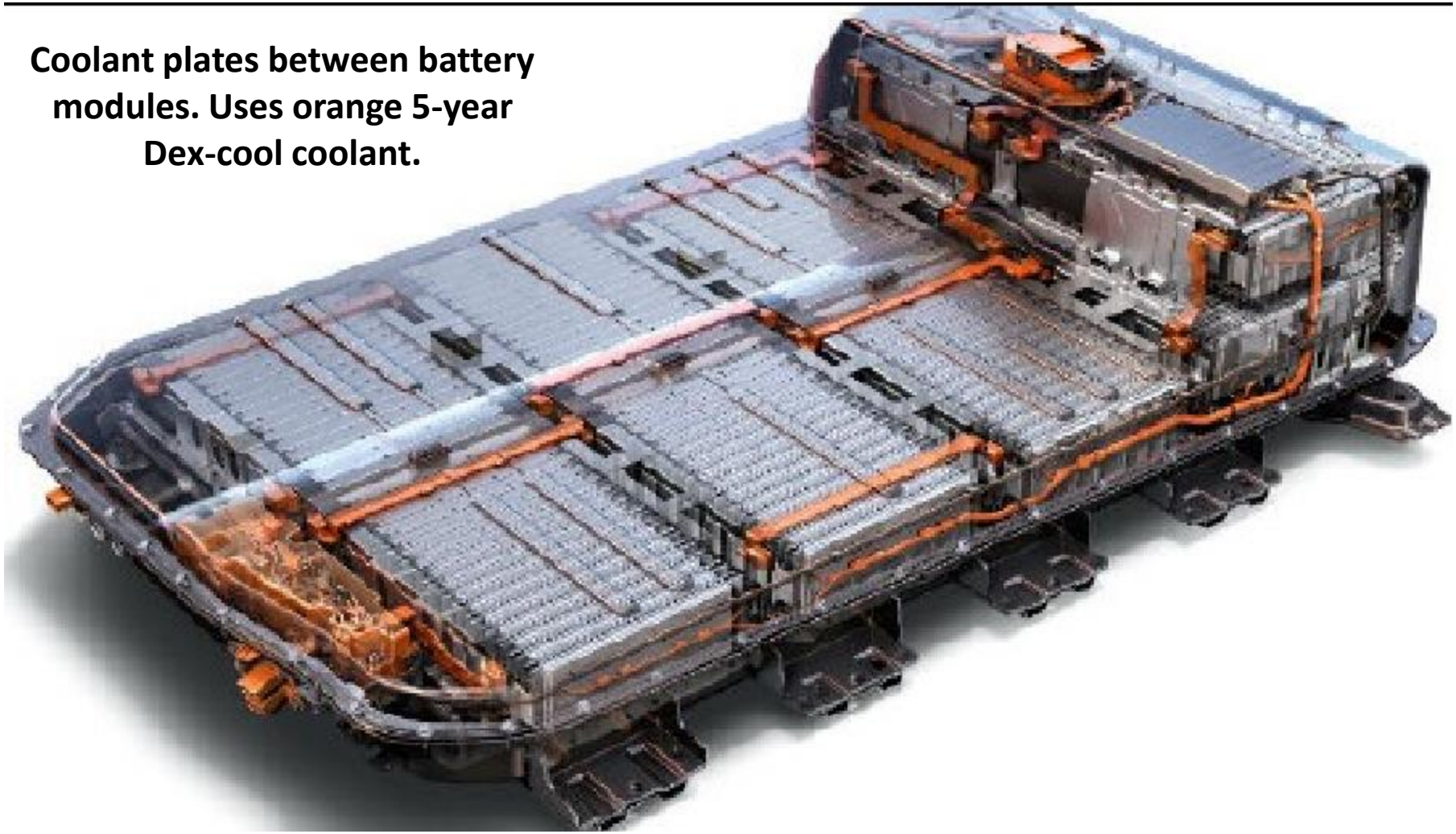
Tesla Model 3

US design & made
Autopilot available
Superchargers capable

15” horizontal display

Chevrolet Bolt EV 60-kWh Battery

Coolant plates between battery modules. Uses orange 5-year Dex-cool coolant.



288 flat landscape cells of 3.75 volts each

96 groups in series of 3 cells in parallel (96 x 3.75V = 360V)

Chevy Bolt EV Motor & Gear Box

Drive Shaft passes through center of motor. Tesla is similar.

Chevrolet Bolt EV Awards

- 2017 Motor Trend Car of the Year
- 2017 North American Car of the Year
- 2017 AutoGuide.com Reader's Choice Green Car of the Year
- 2017 Green Car Reports Best Car to Buy
- 2017 Car & Driver '10 Best Cars' List
- 2017 Green Car Journal Green Car of the Year
- 2016 Time Magazine 25 Best Inventions of Year
- 2016 Popular Science 10 Greatest Automotive Innovations. **Plus 4 more awards!**

Roper Chevy-Bolt-EV >200-miles Trips

- 278 miles first trip from Sterling VA to Blacksburg Va. Probably could have made trip without charging.
- 310 miles Blacksburg to Charlottesville and back. Charged twice for 30 minutes at fast charging station in downtown Staunton.
- 265 miles Blacksburg to Pipestem and Hawks-Nest Resort State Parks WV. Charged at both.
- 218 miles Blacksburg to Grayson Highlands State park and back. Had ~25% charge left for ~291-miles range.

Roper Chevy-Bolt-EV >200-miles Trips

- 441 miles Blacksburg to Shenandoah National Park to Front Royal and back. Charged at Staunton both directions.
- 427 miles Blacksburg to Raleigh NC and back. Charged at Greensboro NC both directions.

Midsize >200-Miles BEVs

Volkswagen I.D. BUZZ

- 111-kWh battery
- 270-miles EPA range
- AWD
- 369 hp
- Heads-up display
- 16’ length
- Autonomous capable
- Available in 2022

VW I.D. Crozz Sedan

>200-Miles BEVs in 2018-2019

- **Nissan LEAF II** (~235 miles)(2018)

- **Hyundai Kona SUV** (~217 miles)(2018)
- **Volkswagen** (~215 miles)(2018)
- Ford Model E (~200 miles)(2019)
- **Volvo** (~200 miles)(2019)
- Audi eTron Quattro SUV (~250 miles)(2018)

- Jaguar i-Pace Crossover

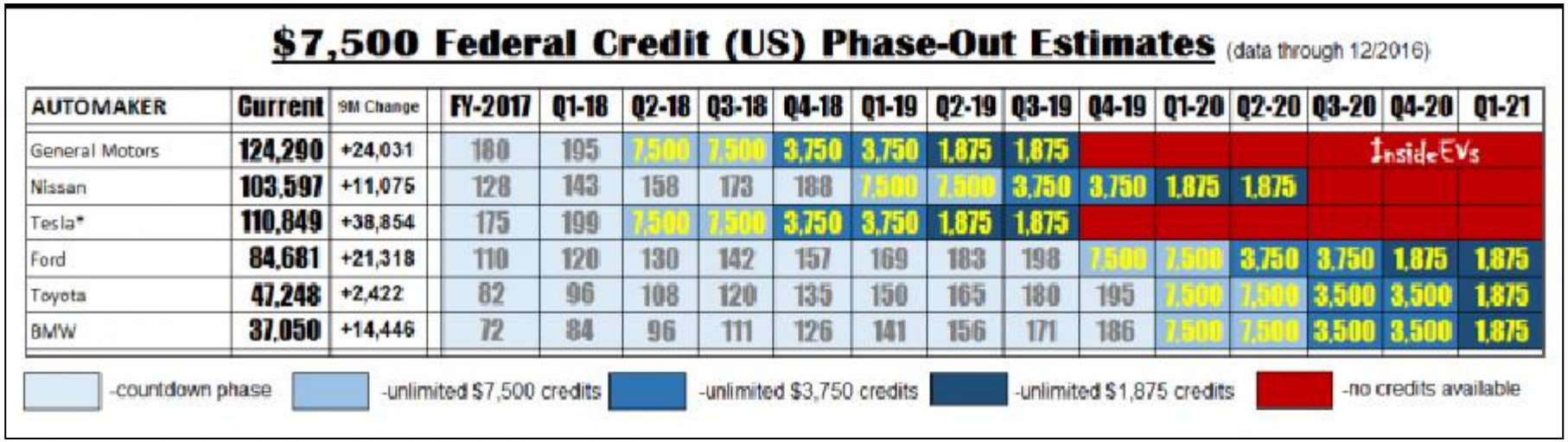
- **BMW 3 Series**
- Hyundai IONIQ II (~200 miles)(2018)
- Mercedes-Benz EQ
- Porsche Mission E (~300 miles)($85,000)

Possible Tesla Model Y AWD SUV

Possible Tesla Pickup Truck

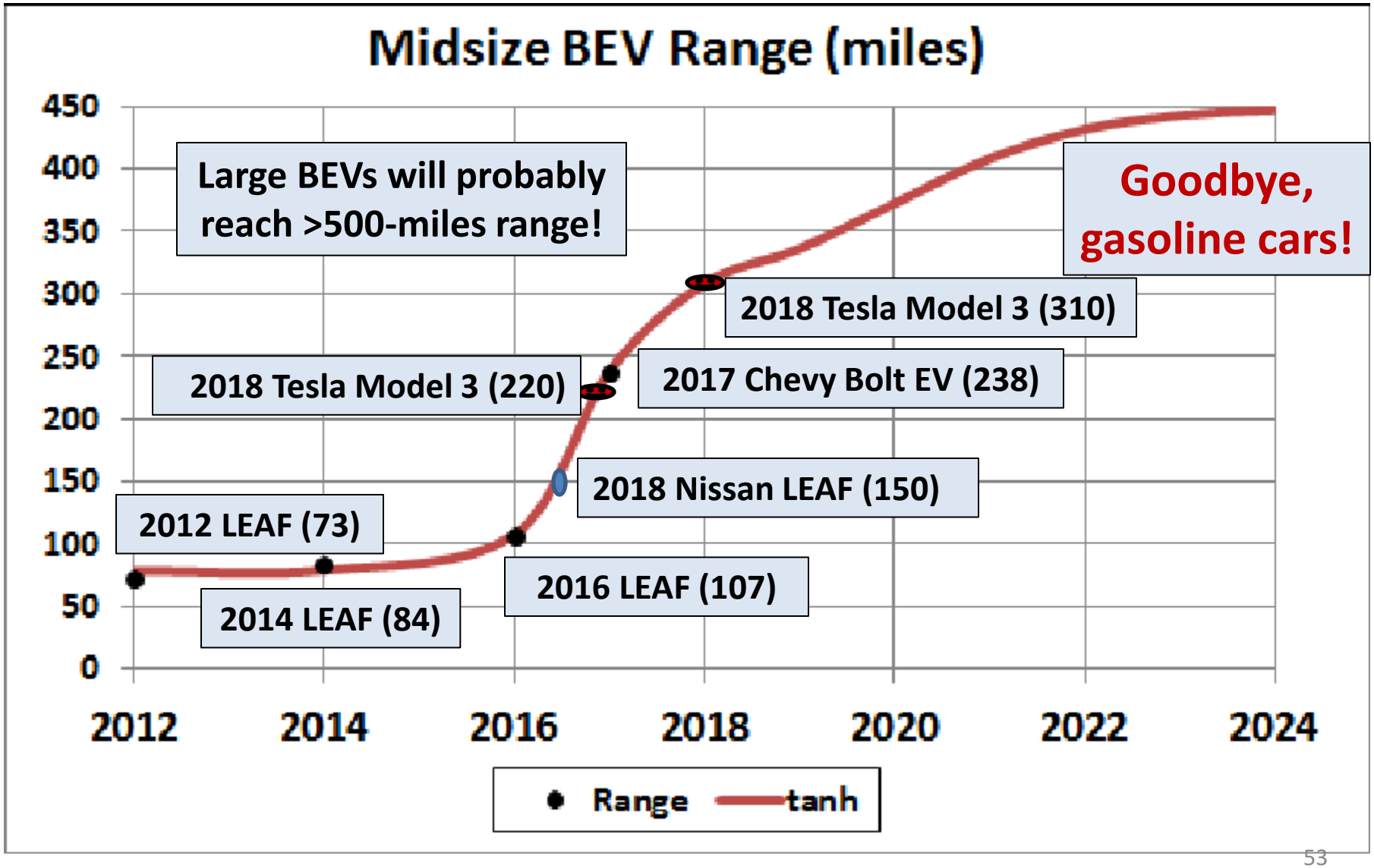
Expiration of BEV Tax Credits

Tax credit: $7,500 until 200,000 BEVs/brand
Qualifying vehicles made by that manufacturer are eligible for 50 percent of the credit if acquired in the first two quarters of the phase-out period and 25 percent of the credit if acquired in the third or fourth quarter of the phase-out year.

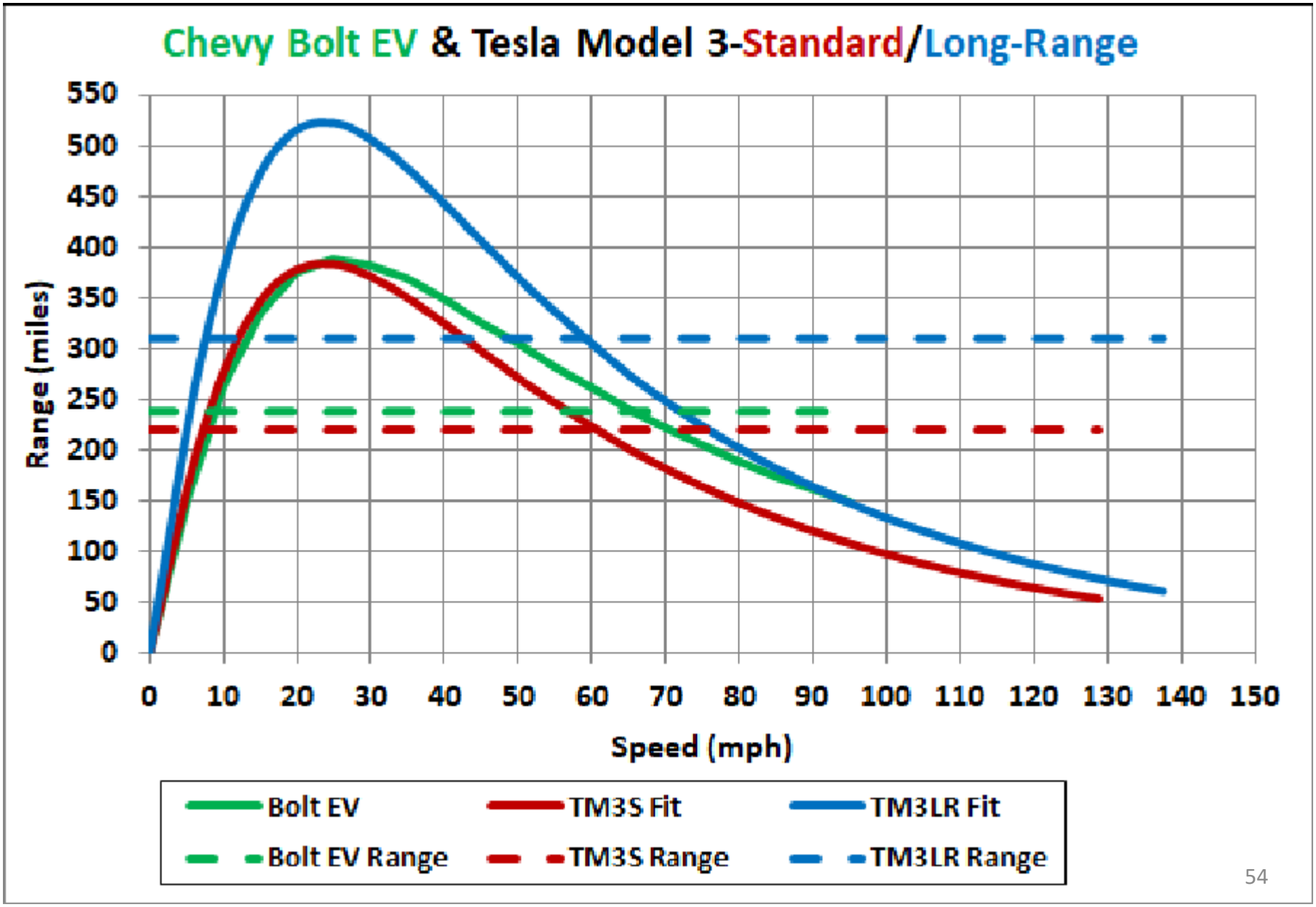


Current Expectations For $7,500 Federal Credit Phase-Out For Major US EV Makers. Grey shaded areas are expected cumulative future sales in 000s. Colored blocks indicate stage of the Federal credit a particular OEM is at.

BEV Range Increasing



Chevy-Bolt-EV & Tesla-Model-3 Ranges at Constant Speed



These will be “Game Changers”!

- **Apartment dwellers can charge once or twice a week at a fast public charging station and/or top the battery up at work each day.**
- **Long distance travel is possible!**
- **Chevrolet expects to make 25,000 Bolts in 2017.**
- **Tesla has >500,000 $1000 orders for Model 3.**
  - **Tesla plans to build 500,000 Model-3s in 2018.**
- Almost all car companies, except Chrysler, are planning to have >200-miles BEVs by 2020.

Vehicle to Grid (V2G)

- **Millions of electric cars connected to the national grid.**
- **Charge at early morning low-grid-load times and drive to work; finish by 6-7 AM.**
- **Recharge at work 8 AM to 2 PM.**
- **Discharge into grid in evening at high-grid-load times 6 PM to 11 PM. (~$3000/year profit)**

Electric Cars' Batteries as Backup Power (V2H)

- **Backup power for the grid at high-load times. Estimates of $3000/year earnings for electric-car owners.**
- **Old batteries from electric cars in locations for grid storage.**
- **Backup power for homes when the grid is down. Nissan may market this soon. Requires a house circuit with needed devices on it.**

Leasing or Buying BEVs

- BEV technology is changing rapidly!
- Batteries lose capacity ~0.035%/charging cycle. (This may reduce for new battery chemistries.)
- Federal tax credit of $7,500 for first 200,000 BEVs/brand. (Tesla may be out for Model 3.)
- Battery replacement? (~$6,000 for LEAF)
- **Leasers/buyers organize for bulk buying discount.**
- I recommend leasing new BEVs. **Tax credit off lease price, not at tax time as when buying.**
- Buying used BEVs at low prices ($8000- LEAFs)

Buying a Used Nissan LEAF

- 2011-2: SV & SL models, 73-miles range
  - 24-kWh battery subject to capacity loss due to extreme heat
  - No SOC digital meter.
- 2013: 84-miles range.
  - New less expensive S model.
  - Digital SOC meter
- 2015: New battery less heat sensitive
- 2016: 30-kWh battery option
- Prices: $9,000-$12,000

EV Buying Experience

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

My Ideal Cars

- An AWD electric car with 400-miles range.
- An AWD biodiesel-electric plug-in hybrid with at least a 20-kWh battery.

Charging BEVs

- **Level-1**: 120-volts AC, **1.12-kW**, for all BEVs & PHEVs (Everywhere!) (**SAE-J1772 cord that comes with the PHEV**)
- **Level-2**: 240-volts AC, **3.3-kW** & **6.6-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 - 120-kW**, only for BEVs (Blacksburg Town Hall 35-kW)
  - **CHAdeMO** standard (**Asian**) (150-kW in 2017)
  - **SAE CCS** standard (**USA & Europe**) (Level-2/3 one plug)

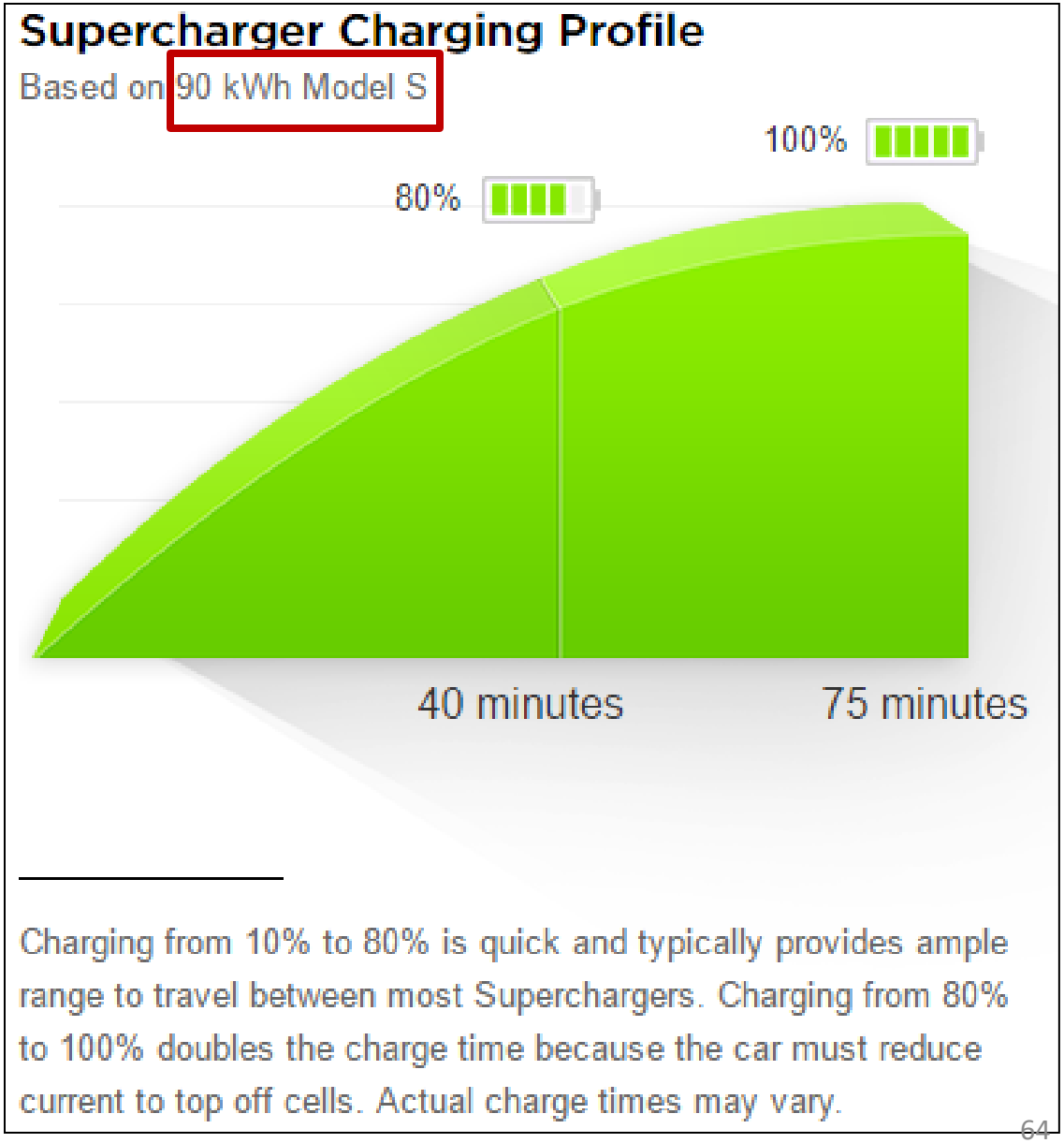
Most charging will occur at home in a garage, driveway or parking space.

Charging BEVs

- **SAE-J1772 cord that comes with the PHEV** can have a pigtail that allows level-2 charging with a standard 240-volts outlet.
- An adaptor is available to allow level-2 SAE-J1772-plug charging at Tesla Wall Connectors version 1.
- 350-kW under study Installed 4 stations in Calif.
- Tesla Wall Connector: 240-volts AC, **20-kW** for Tesla BEVs, but adaptor can allow other BEVs.
- Tesla Superchargers: 480-volts DC, **120-kW** only for Tesla BEVs (planning for **170-kW**)(City: **72-kW**)

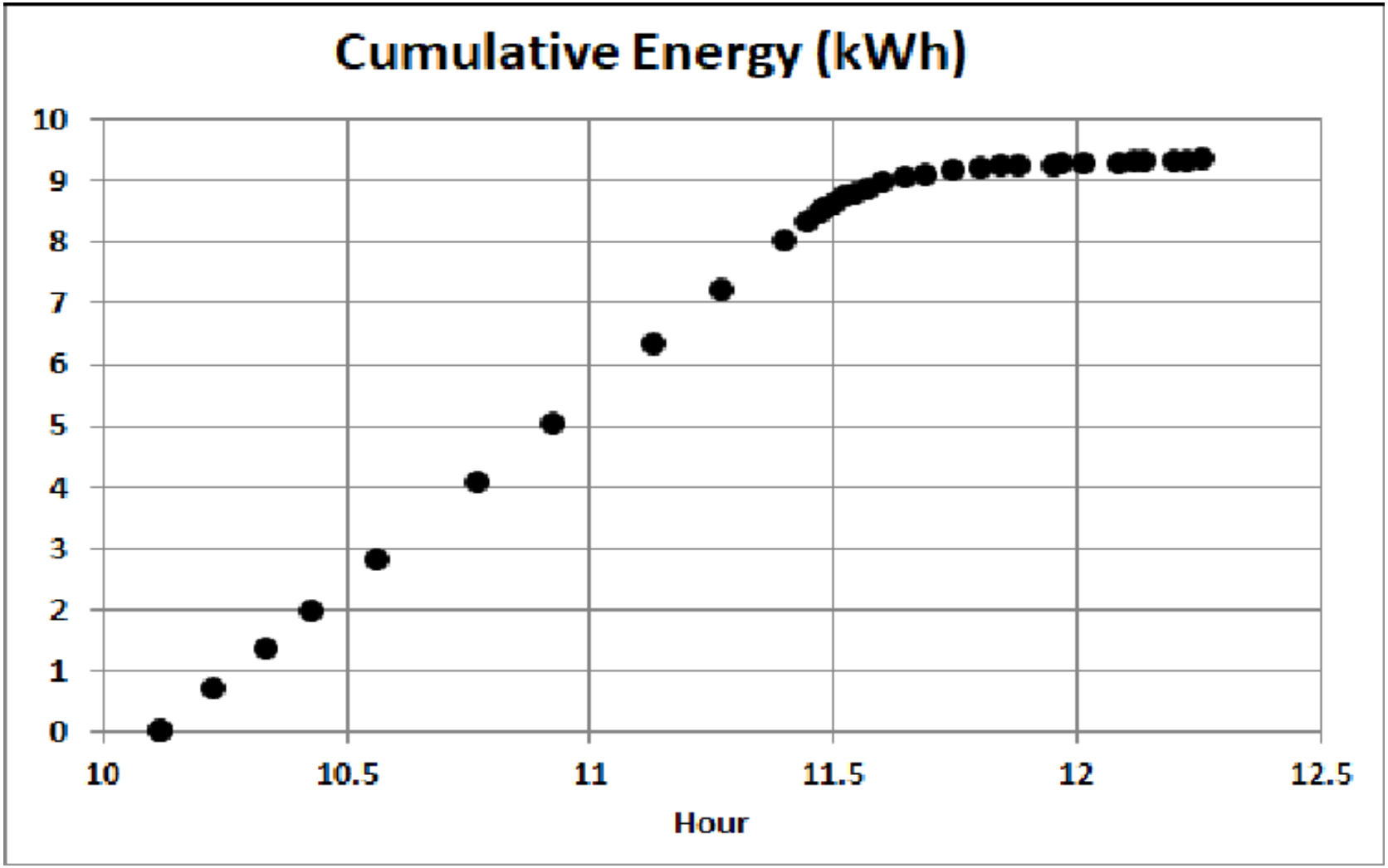
Charging Times

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



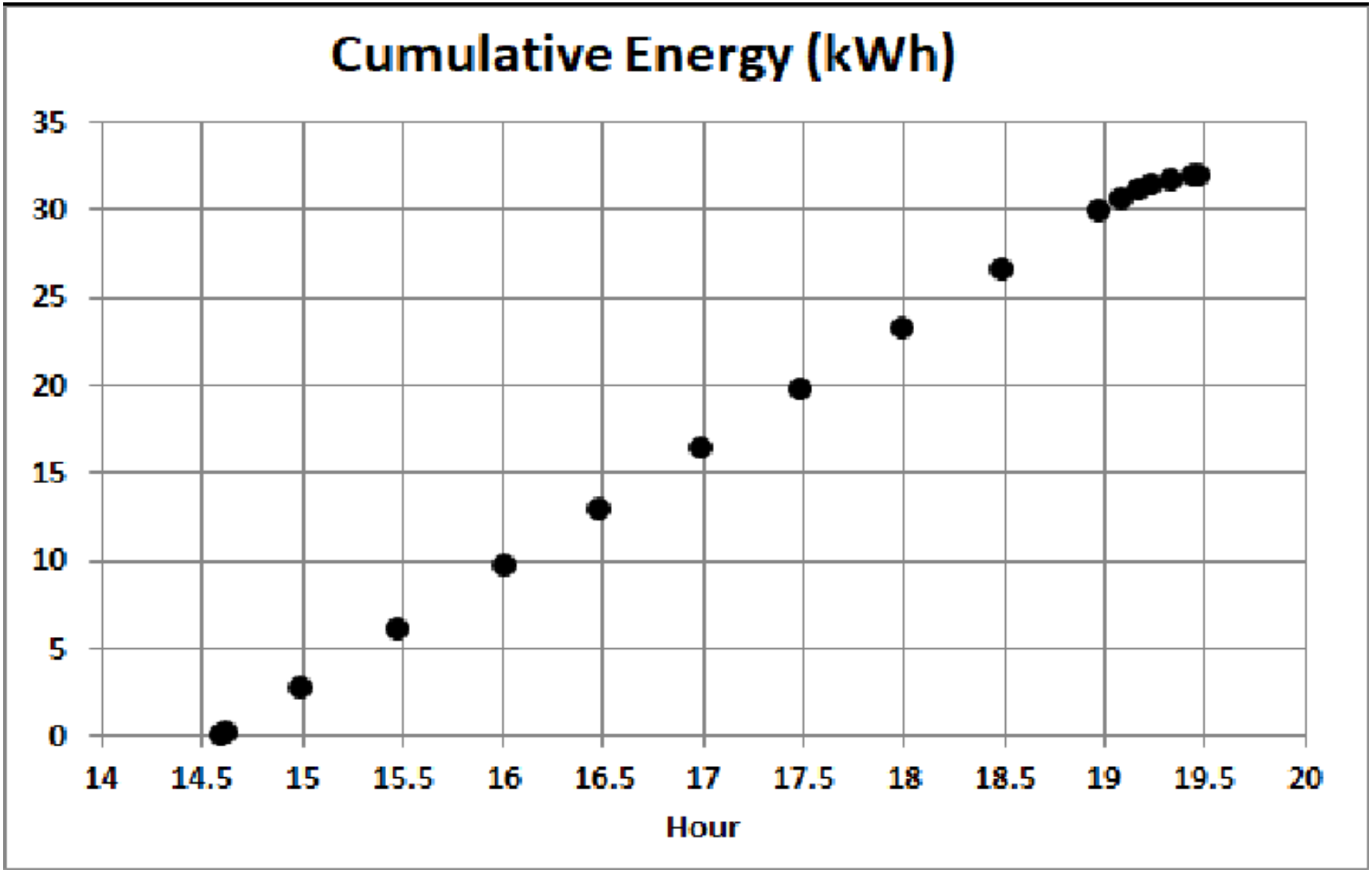
Charging Time (LEAF)

50%->100%



Charging Time (CBEV)

50%->100%



Charging BEVs

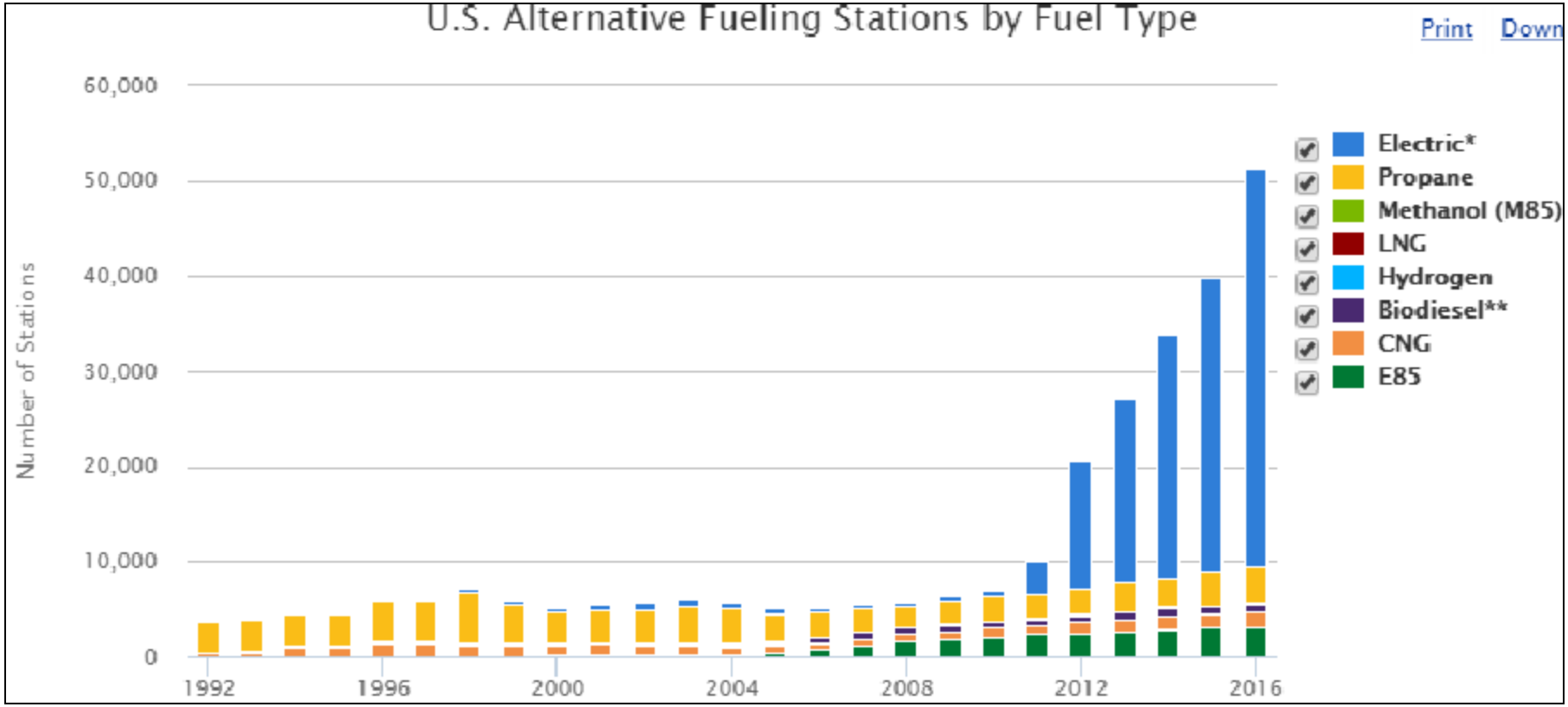
- **Most charging will occur at home in a garage, driveway or parking space.**
- Charging at work doubles the range.
- I probably will charge my >200-miles BEV to **60% every night**, except for long trips the next day.
- I like to have **>20 miles left** when I get home.
- **ICE'd**! Leave firm polite note on windshield of ICE.
- 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.

Light-Pole Charging Stations

Laundromats & Gas Stations

- **Laundromats were mostly replaced by home washers/dryers.**
- **Gas stations will be mostly replaced by home charging stations and fast public charging stations.**

Roper LEAF being charged ~98% of time in Roper garage.


U.S. Alternative Fueling Stations by Fuel Type
Print
Down
Number of Stations
60,000
50,000
40,000
30,000
20,000
10,000
0
1992
1996
2000
2004
2008
2012
2016
Electric*
Propane
Methanol (M85)
LNG
Hydrogen
Biodiesel**
CNG
E85

Charging Times for Empty 60-kWh Battery

- Level 1, 1.12 kW: ~54 hours (**60-kWh/1.12-kW**)
- Level 2, 3.3 kW: ~18 hours (2010-2012 LEAFs)
- **Level 2, 6.6 kW**: ~9 hours (2013-2016 LEAFs)
- **Level 3, 35 kW**: ~1.75 hours (BB Town Hall)
- Tesla Wall Charger, 20 kW: ~3 hours
- Tesla Supercharger, 120 kW: ~0.5 hours
- 150 kW: ~0.4 hours
- 170 kW: ~0.35 hours
- 350-kw: ~0.17 hours

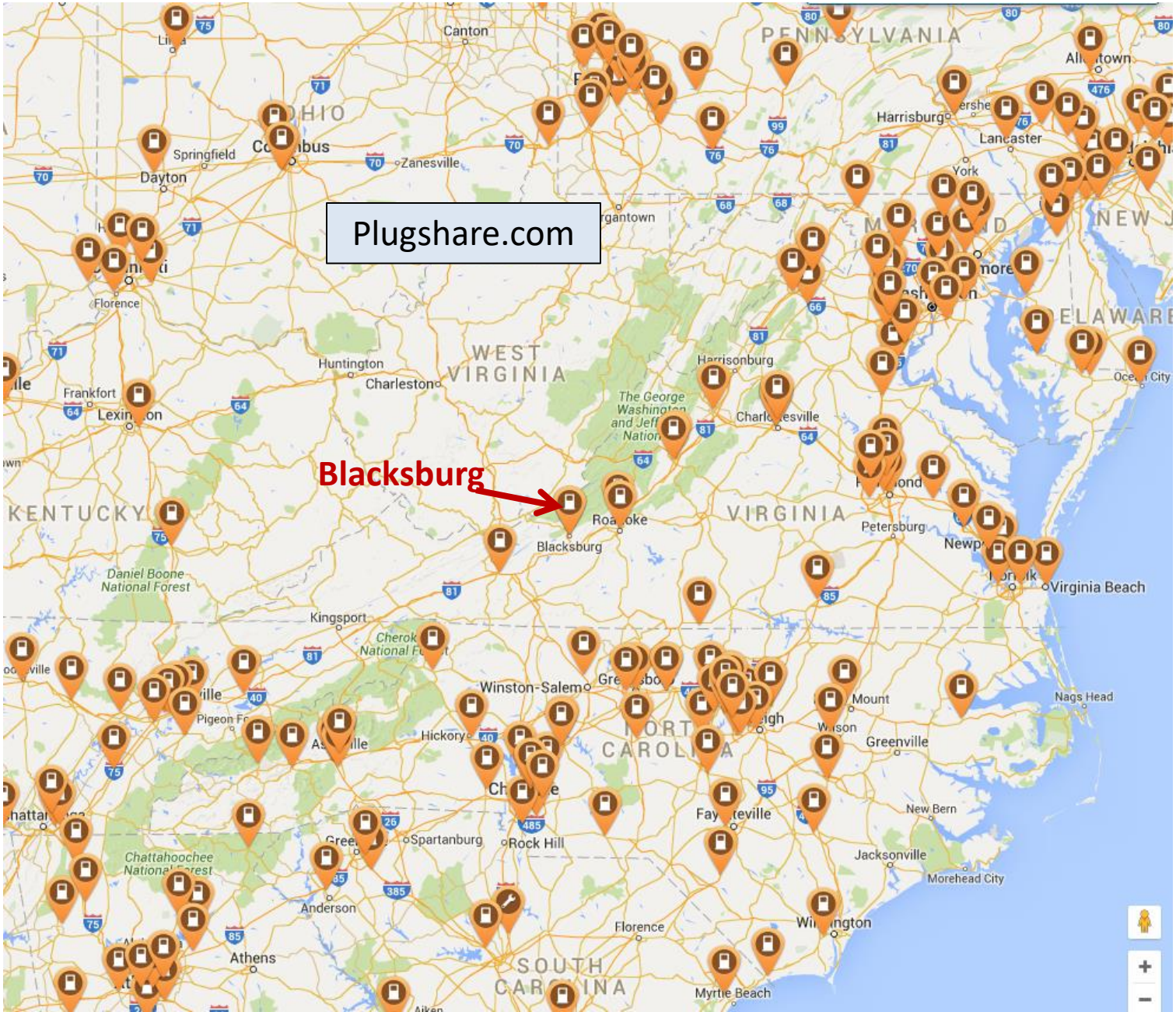
Battery is seldom empty. Daily charging time is usually ~half. I set my LEAF timer to have full charge by 6 AM every day.

These times are too short, because power decreases while charging.

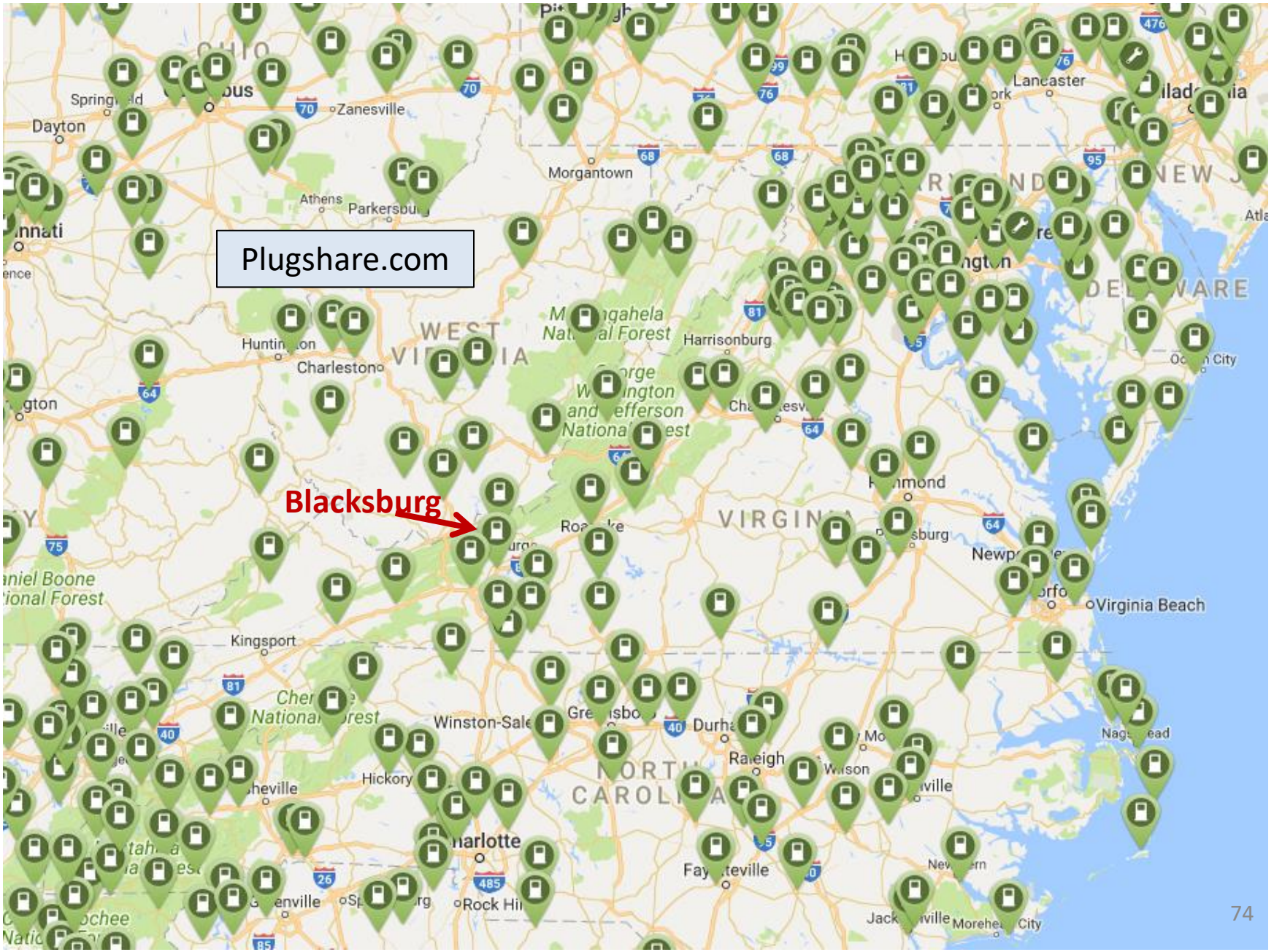
Charging BEVs

- **Plugshare.com** to locate charging stations.
- BEVs have charging-stations locator in navigation.
- Some stations have a fixed fee ($3 at **Roanoke Quick Charge downtown**) & some have an hourly charge ($1/hr at **Virginia Museum of Transportation**).
- **ChargePoint.com** stations (Phone app & RFID) (**Salem Veterans Medical Center**) (free or automatic fee)
- **Greenlots.com** stations (Phone app & RFID) (**Blacksburg Town Hall**) (free or automatic fee)
- **GEWattstations.com** (Phone app & RFID) (**Roanoke River House**) (free or automatic fee)
- Independent RFID (**Hotel Floyd**)
- Free Plug In (**2 Krogers, InnVT & Campus Automotive**)

High-Power (L3) Charging Stations



240-Volts (L2) Charging Stations



Tesla Superchargers by End of 2017

Teslamotors.com/supercharger

Building about 1 a day!

Will double in 2017!

6-12 charging stations per Supercharger.

A 6-station Supercharger costs ~$250,000; a gasoline station cost ~$2,000,000.

Nearby High-Power Stations

- CHAdeMO 35-kW (**CM**) (Asian BEVs)
  - Blacksburg VA (Not available on home football days.)
  - Roanoke VA (2 locations)(Downtown one often out!)
  - Staunton VA
  - Charlottesville VA (3 locations)
  - Harrisonburg VA
  - Front Royal Visitors Center (I81-I66 intersection)
- CCS 35-kW (**CS**) (US & Europe BEVs)
  - Blacksburg VA (Not available on home football days.)
  - Staunton VA
  - Charlottesville VA (2 locations)
  - Harrisonburg VA
  - Front Royal Visitors Center (I81-I66 intersection)

Nearby Tesla Charging Stations

- Tesla Superchargers 120-kW (**TS**)(worldwide)
  - Wytheville VA (6 stations)
  - Lexington VA (8 stations)
  - Strasburg VA (6 stations) (I81-I66 intersection)
  - Charlottesville VA (8 stations)
  - Glen Allen VA (8 stations) (near Richmond)
  - Bristol TN (8 stations)
  - Burlington NC (8 stations)
  - Charleston WV (8 stations)
- Tesla Wall Chargers 20 kW (**TW**)(worldwide)
  - Courtyard Marriot, Blacksburg
  - Holiday Inn, Christiansburg
  - Hotel Floyd, Floyd
  - Hotel Roanoke, Roanoke
  - Hampton Inn, Salem
  - Inn at Riverbend, Pearisburg
  - Claiborne House B&B, Rocky Mount
  - Foxfield Inn, Charlottesville
  - Hyatt Place, Charlottesville
  - Oakhurst Inn, Charlottesville
  - Iris Inn B&B, Waynesboro
  - Primland, Meadows of Dan
  - Others added constantly

How Many Charging Stations (CS) Are Needed?

- 153,000 filling stations in U.S.
- Assume 4 pumps/station: 612,000 pumps
- 16,000 charging stations (CS) in U.S.
- 63% own home, so can install charging station
  - Assume 95% charging at home
- 612,000 x (0.37 + 0.05) = 257,000 CS needed
- Years to double needed CSs: 8 years
- Years to triple to needed CSs: 5 years
- Years to quadruple to needed CSs: 4 years

Long Trips in >200-miles BEV

- Blacksburg VA -> Richmond VA
  - Staunton 117 miles **L3 (Level 3)**
  - Richmond 108 miles **L3/TS (Tesla Supercharger)**
- Blacksburg VA -> Washington DC
  - Staunton 117 miles **L3**
  - Washington 153 miles **L3/TS** (or Strasburg TS)
- Blacksburg VA -> Burlington NC 173 miles **L3/TS**
- Blacksburg VA -> Atlanta GA
  - Charlotte NC 173 miles **L3/TS**
  - Greenville SC 101 miles **L3/TS**
  - Atlanta GA 145 miles **L3/TS**

Long Trips in >200-miles BEV

- Floyd VA -> Richmond VA
  - Staunton 130 miles CM (or Lexington 96 miles **CM/TS**)
  - Richmond 108 miles **CM/TS**
- Floyd VA -> Washington DC
  - Staunton 130 miles **CM** (or Lexington 96 miles **CM/TS**)
  - Washington 153 miles **CM/TS** (or Strasburg **TS**)
- Floyd VA-> Raleigh NC 158 miles **CM/TS**
- Floyd VA -> Atlanta GA
  - Charlotte NC 162 miles **CM/TS**
  - Greenville SC 101 miles **CM/TS**
  - Atlanta GA 145 miles **CM/TS**

BEV Efficiency

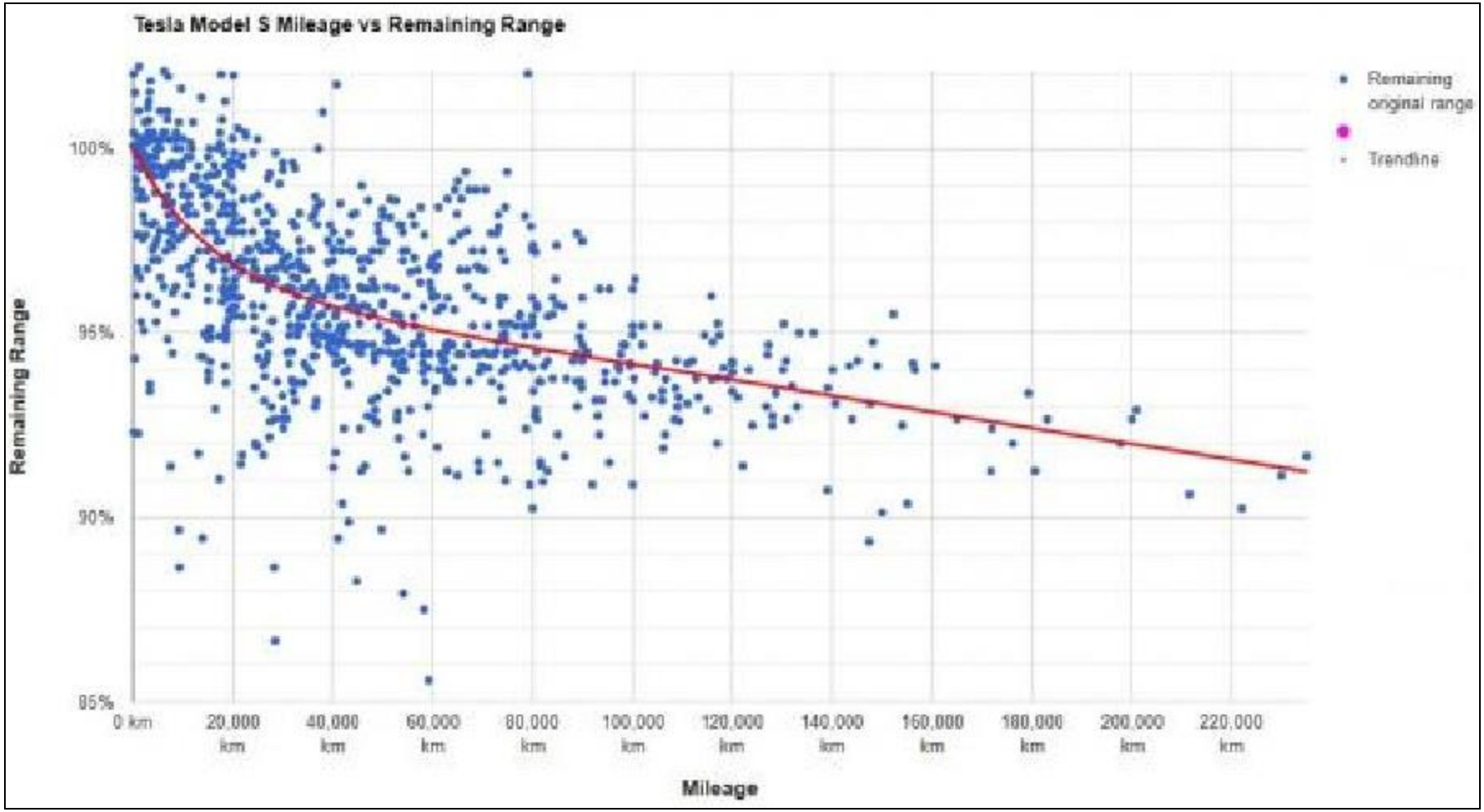
- Total battery capacity is not used.
  - ~1.5-kWh left when “empty”.
  - ~1.5-kWh less than capacity when “full”.
- Typical efficiency
  - **3.5-4.5 miles/kWh** depending on car, temperature and way driven (ECO mode)
  - Miles/gallon equivalent: **MPGe = 33.7 x miles/kWh**
    - 3.5-4.5 miles/kWh = 118-152 MPGe
- **Charging cycle** = from empty to full. Almost never the case.

Battery Capacity Loss with Time

- Capacity loss is ~0.035%/**charging-cycle**
- Lithium batteries lose ~20% of energy capacity in 5 years for typical driver.
- Lithium batteries lose ~30% of energy capacity in 10 years for typical driver.
- Drivers need to expect less range in later years; so buy larger than needed.
- At ~30% loss probably battery exchange with old battery used for renewable-energy storage.
- At ~50% loss probably recycled.

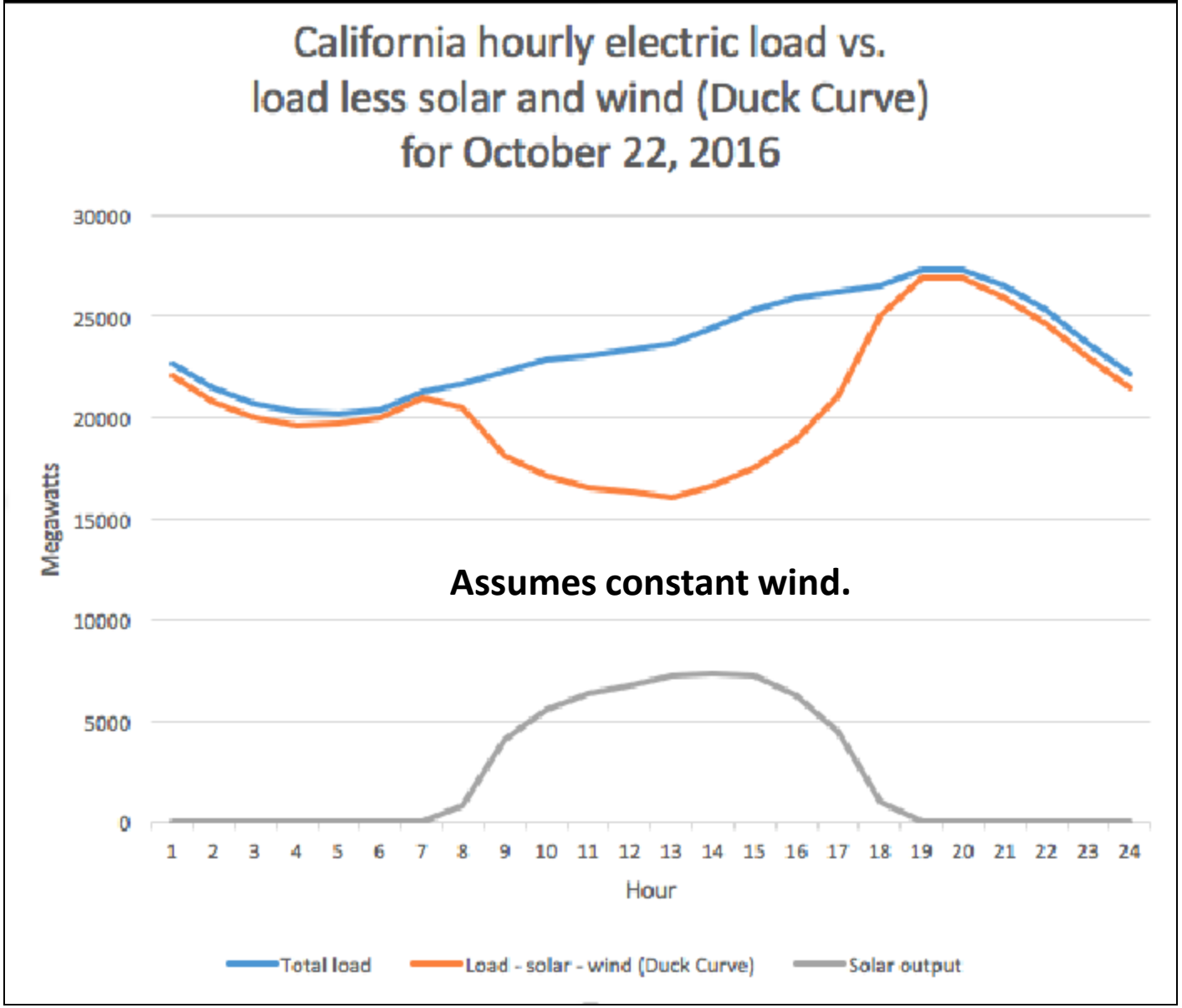
Capacity loss will reduce with new battery chemistries.

Tesla Model S Mileage vs Remaining Range



Planning for Green Housing

- **All plans for green houses should including wiring for current or future charging stations. In most cases the EVs will be charged over 95% of the time in the garage or driveway/parking-lot.**
- **All plans for green apartment houses should include conduit in the parking lots for current or future charging stations.**
- **All plans for green commercial buildings should include conduit in the parking lots for current or future charging stations.**



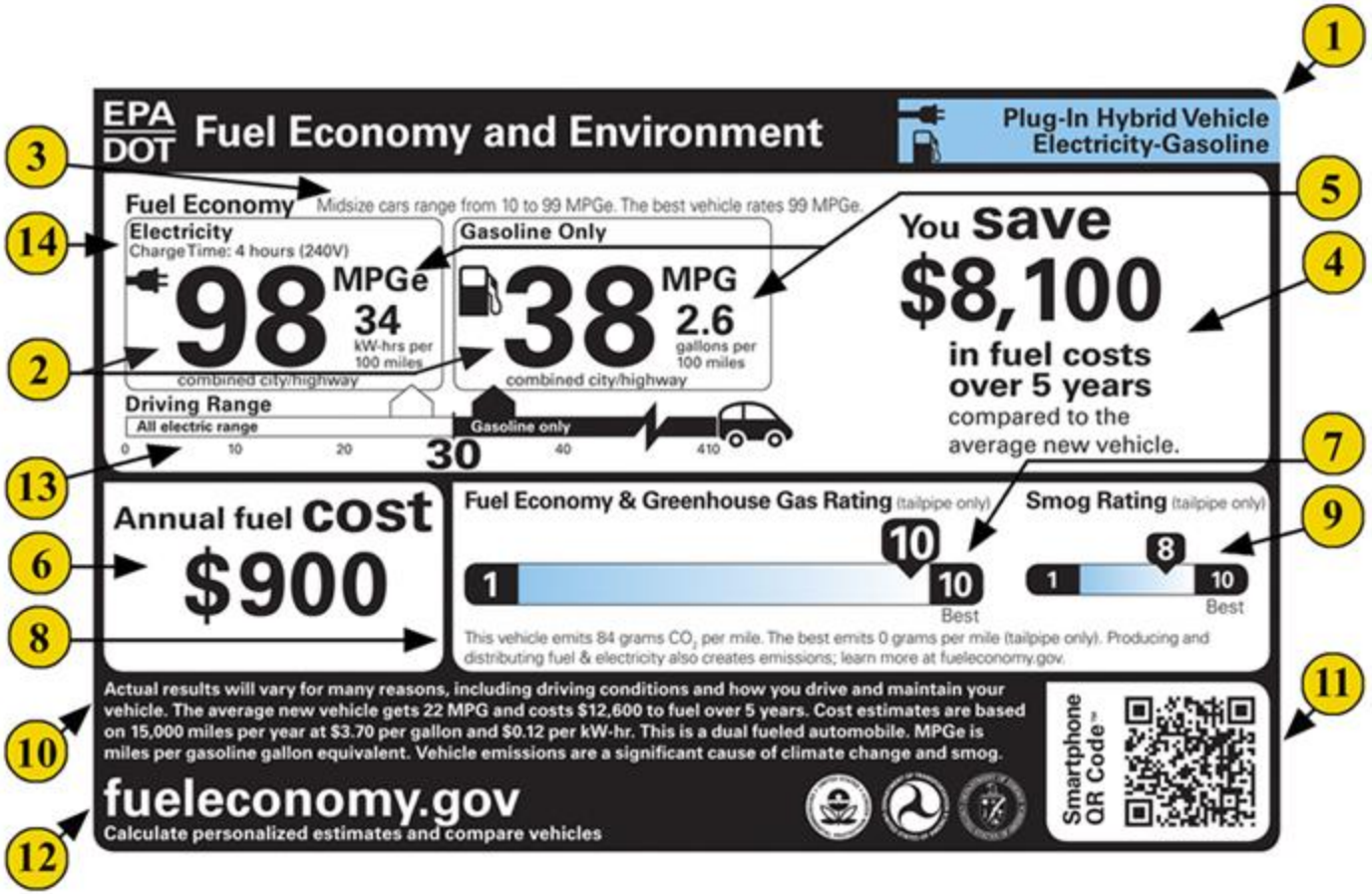
Parked electric cars could charge during the low point of the Duck Curve at a low $/kWh rate, then return power to the grid during evening peak time at a high $/kWh rate and then recharge during nights at a low $/kWh rate to even out the utility load.

Electric cars could pay for themselves over their lifetime!

PHEVs

- Hybrid car with a larger battery and a plug.
- Usually **two electric motors and a small gasoline engine connected by a Planetary Gear Set or two. (Prius one PGS, Highlander two PGS).** There is no standard transmission; the PGS and a computer serves as a continuous "transmission"! Toyota developed this system first. **Very ingenious!**
- **Mild hybrid** usually has an electric motor between the gasoline engine and the standard transmission.
- E.g., **Prius (1.31 kWh)** vs **Prius Prime (8.8 kWh + plug, 22 miles EV**). **RAV4 Hybrid** has motor in rear.
- **AWD PHEV** (e.g., Mitsubishi Outlander) has a third electric motor in the rear (no drive shaft).

PHEV Monroney Label



1: Vehicle Technology & Fuel. 2: Fuel Economy. 3: Comparing to Other Vehicles
4: Save/Spend More of 5 Years Compared. 5: Fuel Consumption Rate.
6: Estimated Annual Fuel Cost. 7: Fuel Economy & Greenhouse Gas Rating.
8: **CO_2** Emissions. 9: Smog Rating. 10: Details 11: QR Code. 12: Web page.
13: Driving Range. 14: Charge Time

Midsize >50-miles-EV PHEVs in 2017-8

Chevrolet Volt (~53 miles EV)(18.4 kWh)(2016)

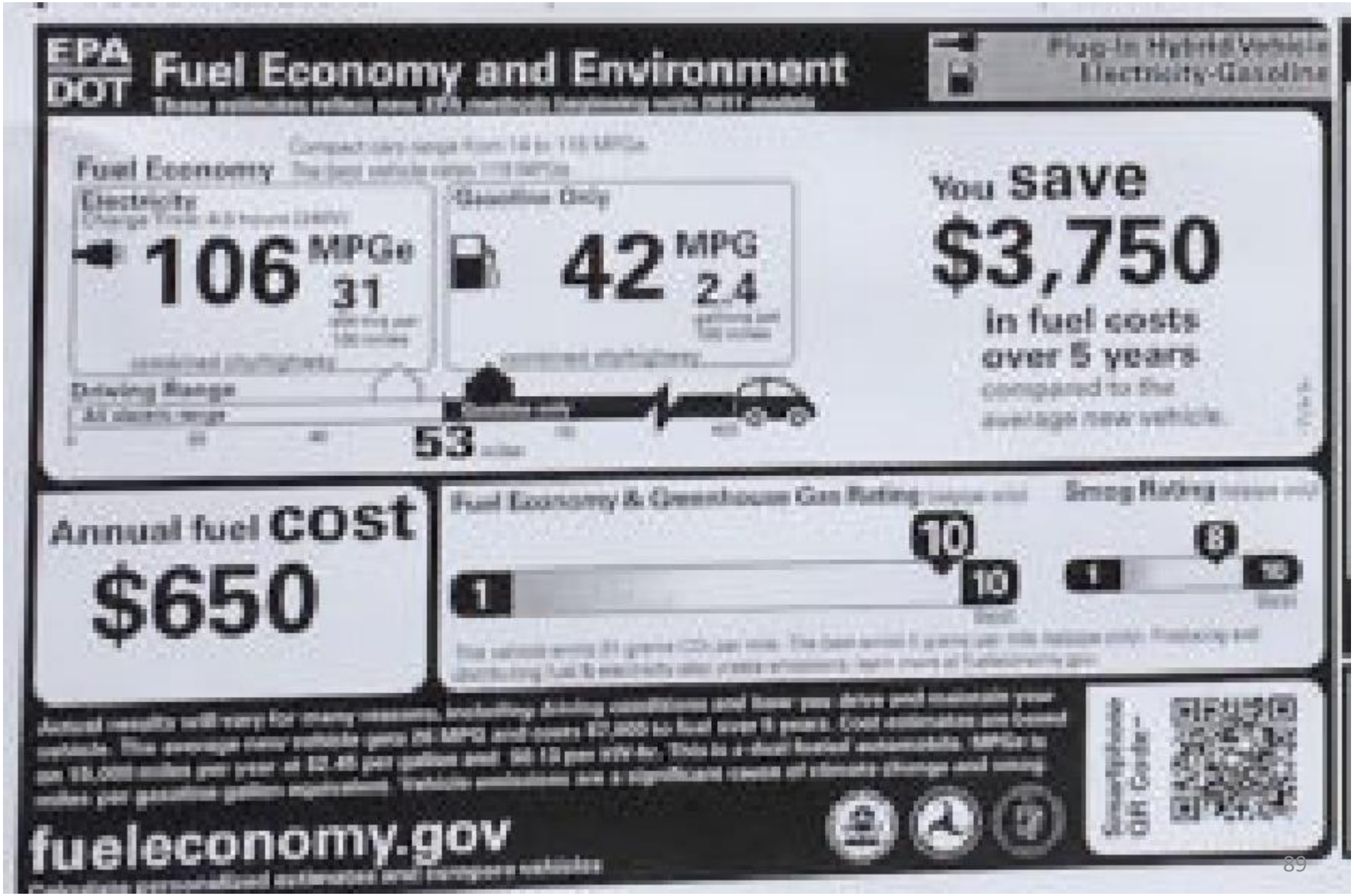
8.9-gallons gas tank.
~430-miles total range.

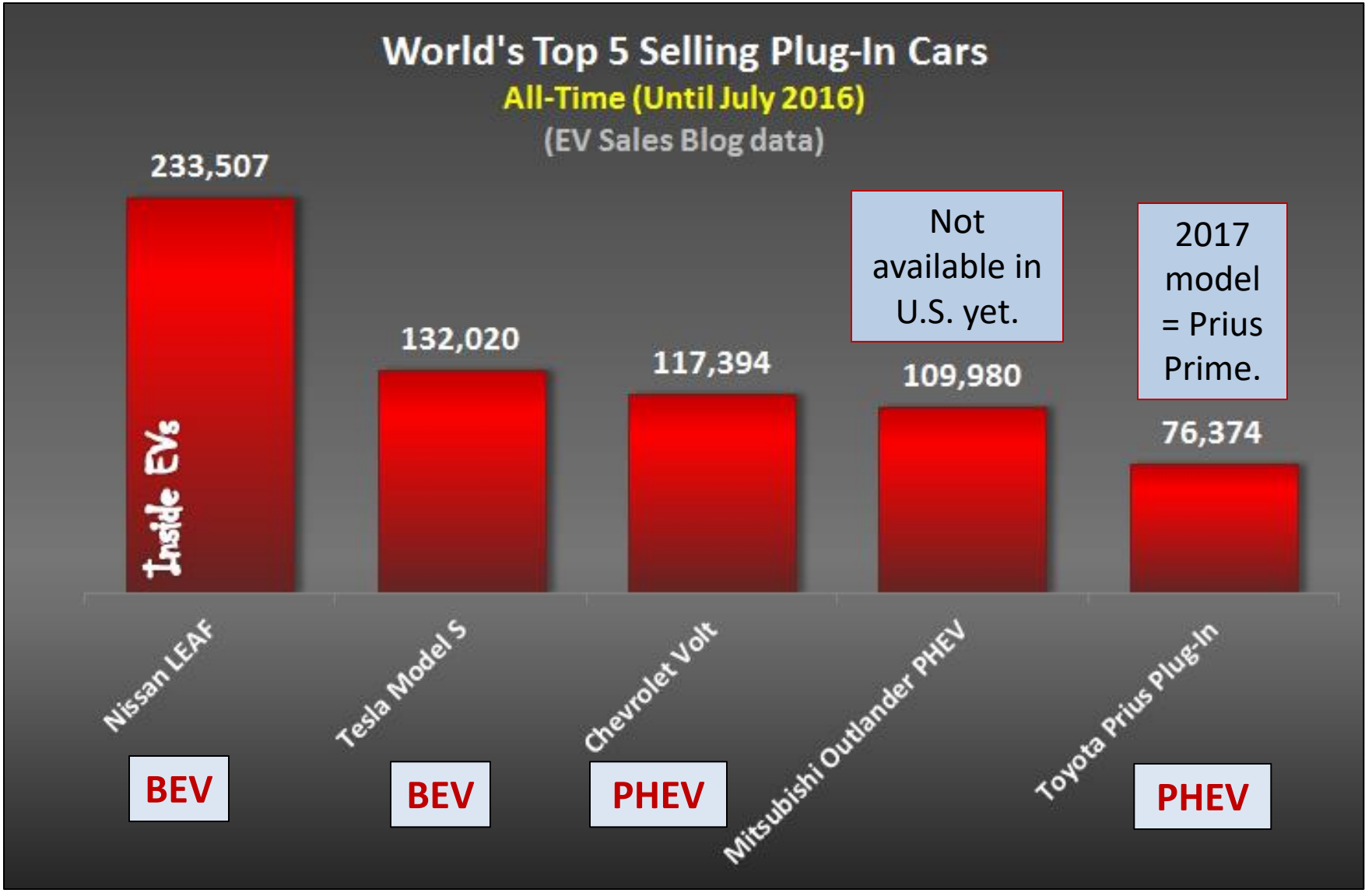
BMW i3 Rex (~97 miles EV)(33 kWh)(2017)

2.4-gallons gas tank.
~180-miles total range.

Federal tax credit:
5-kWh: $2,500
>5-kWh: $417/kWh
Max = $7,500
Both qualify max.

2017 Chevrolet Volt Monroney Label




World's Top 5 Selling Plug-In Cars
All-Time (Until July 2016)
(EV Sales Blog data)
233,507
132,020
117,394
109,980
76,374
Not available in U.S. yet.
2017 model = Prius Prime.
Inside EVs
Nissan LEAF
Tesla Model S
Chevrolet Volt
Mitsubishi Outlander PHEV
Toyota Prius Plug-In
BEV
BEV
PHEV
PHEV

Where Are EVs Taking Off?

While California remains the country's largest EV market in terms of cars on the road, it is no longer the fastest-growing. More states are encouraging EV driving by offering incentives such as tax credits, HOV lane access, utility rebates and special rate plans for EV charging.

Top 10 States

Total EVs in Operation

1. California
2. Georgia
3. Washington
4. Florida
5. Texas
6. New York
7. Michigan
8. Illinois
9. Oregon
10. New Jersey

EV Growth

1. Utah
2. Nevada
3. North Carolina
4. Colorado
5. Kansas
6. New Hampshire
7. Pennsylvania
8. Virginia
9. Florida
10. Arizona

Top 10 Metro Areas

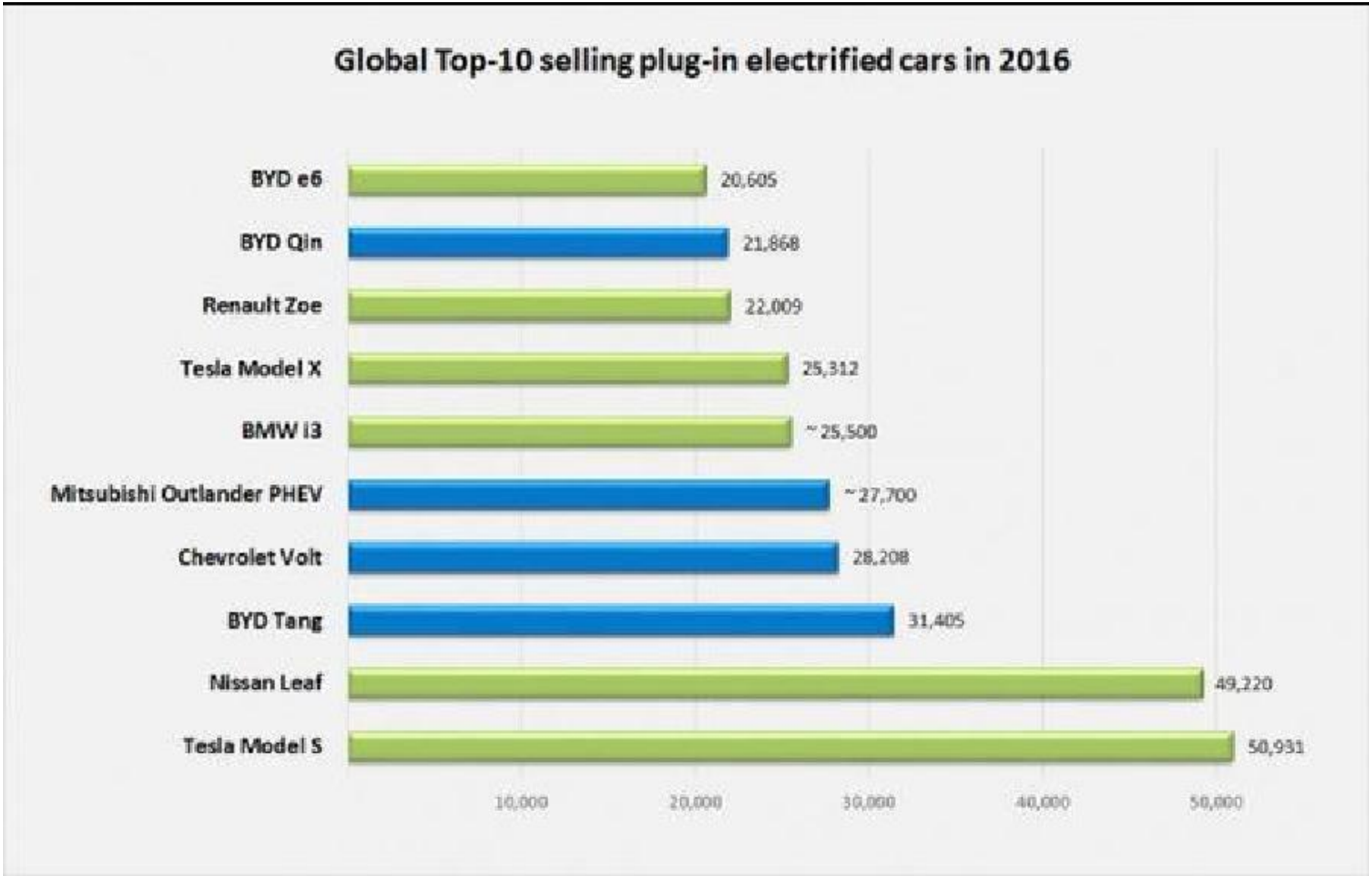
Total EVs in Operation

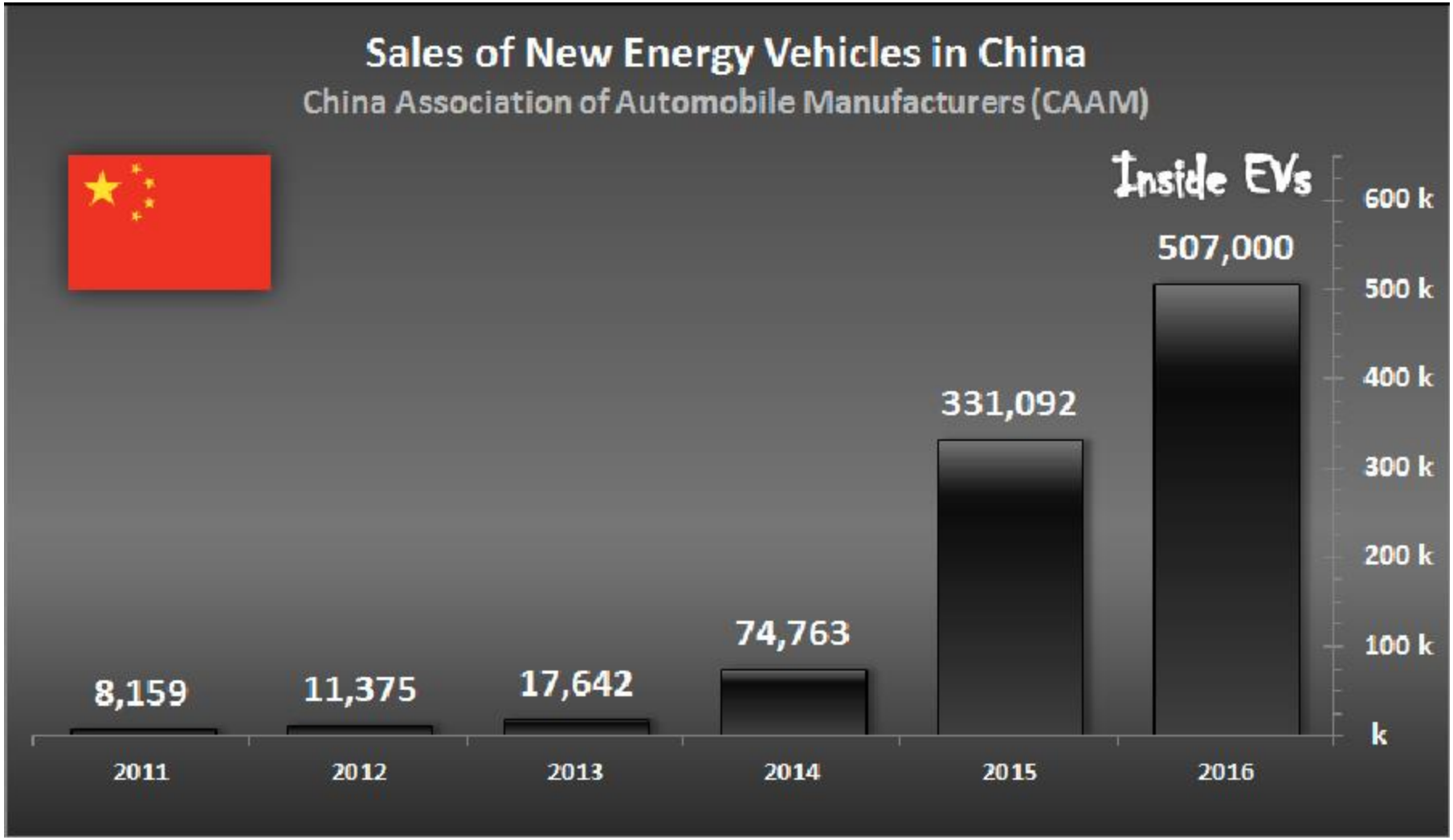
1. Los Angeles
2. Bay Area
3. New York Metro
4. Atlanta
5. San Diego
6. Seattle
7. Chicago
8. Washington, D.C.
9. Detroit
10. Portland

EV Growth

1. Las Vegas
2. Kansas City
3. Raleigh/Durham
4. Denver
5. Miami
6. Phoenix
7. Philadelphia
8. Portland
9. San Diego
10. Los Angeles

Top 10 states for total EVs in operation
Top 10 states for EV growth
Top 10 metro areas for total EVs in operation
Top 10 metro areas for EV growth


Global Top-10 selling plug-in electrified cars in 2016
BYD e6
20,605
BYD Qin
21,868
Renault Zoe
22,009
Tesla Model X
25,312
BMW i3
~25,500
Mitsubishi Outlander PHEV
~27,700
Chevrolet Volt
28,208
BYD Tang
31,405
Nissan Leaf
49,220
Tesla Model S
50,931
10,000
20,000
30,000
40,000
50,000


Sales of New Energy Vehicles in China
China Association of Automobile Manufacturers (CAAM)
Inside EVs
600 k
500 k
400 k
300 k
200 k
100 k
k
8,159
11,375
17,642
74,763
331,092
507,000
2011
2012
2013
2014
2015
2016

Auto Manufacturer Electric Vehicle Targets

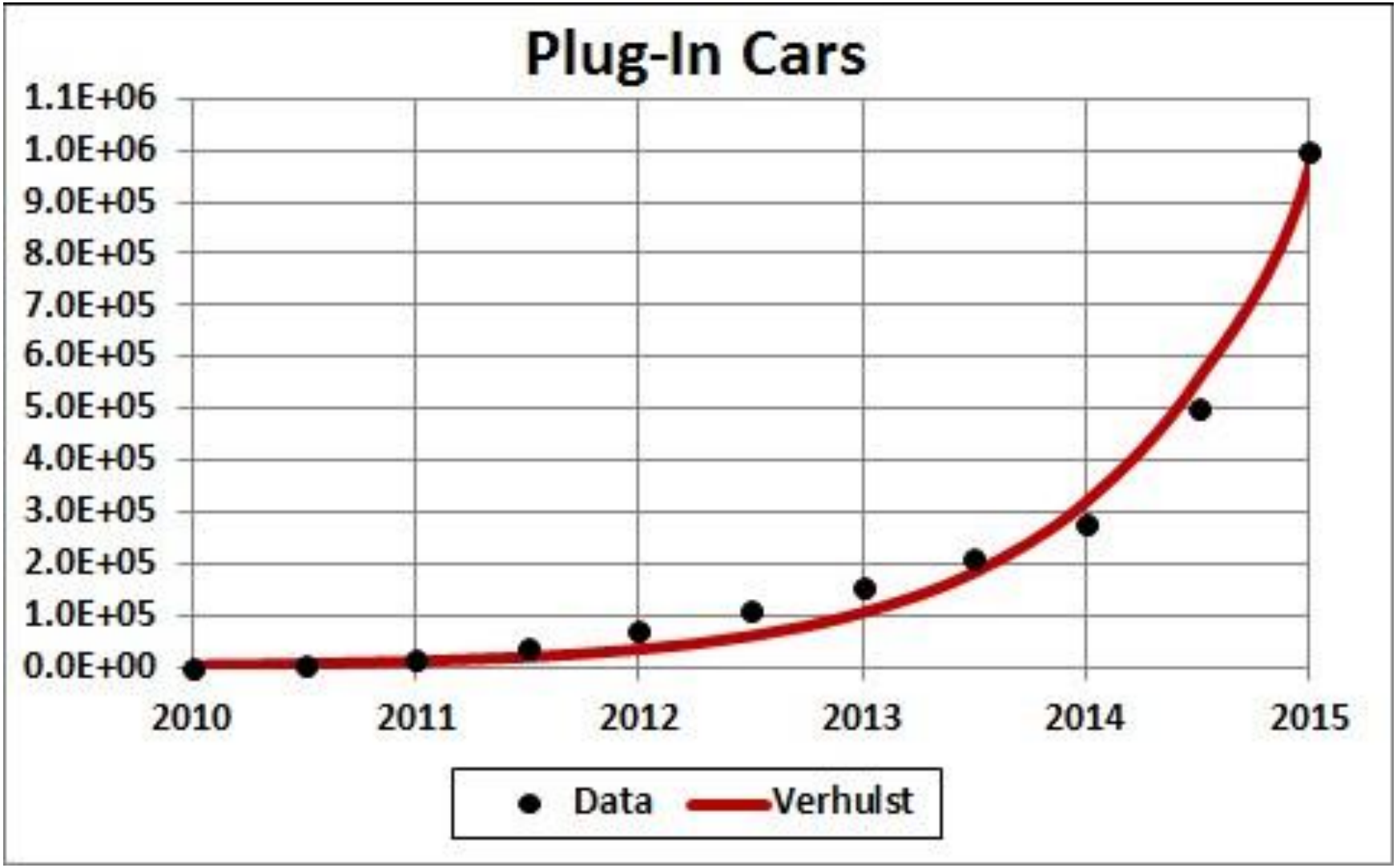
		Annual Sales Goal		
	Type	# Vehicles (m)	%	Year
Tesla	BEV	0.5	100%	2018
Geely	EV	na	90%	2020
JAC	EV	na	30%	2025
Volkswagen	EV	2 - 3	20-25%	2025
BMW	EV	~0.5	15-25%	2025
Mercedes-Benz	EV	~0.6	15-25%	2025
Renault-Nissan*	EV	Cumulative 1.5	~10-20% in	2020
Honda	BEV	~0.5	15%	2030
Toyota	FCV	0.03	~0.3%	2020

*Cumulative Sales Target; blue numbers derived approximations

Source: Company filings, news reports, Bloomberg Intelligence

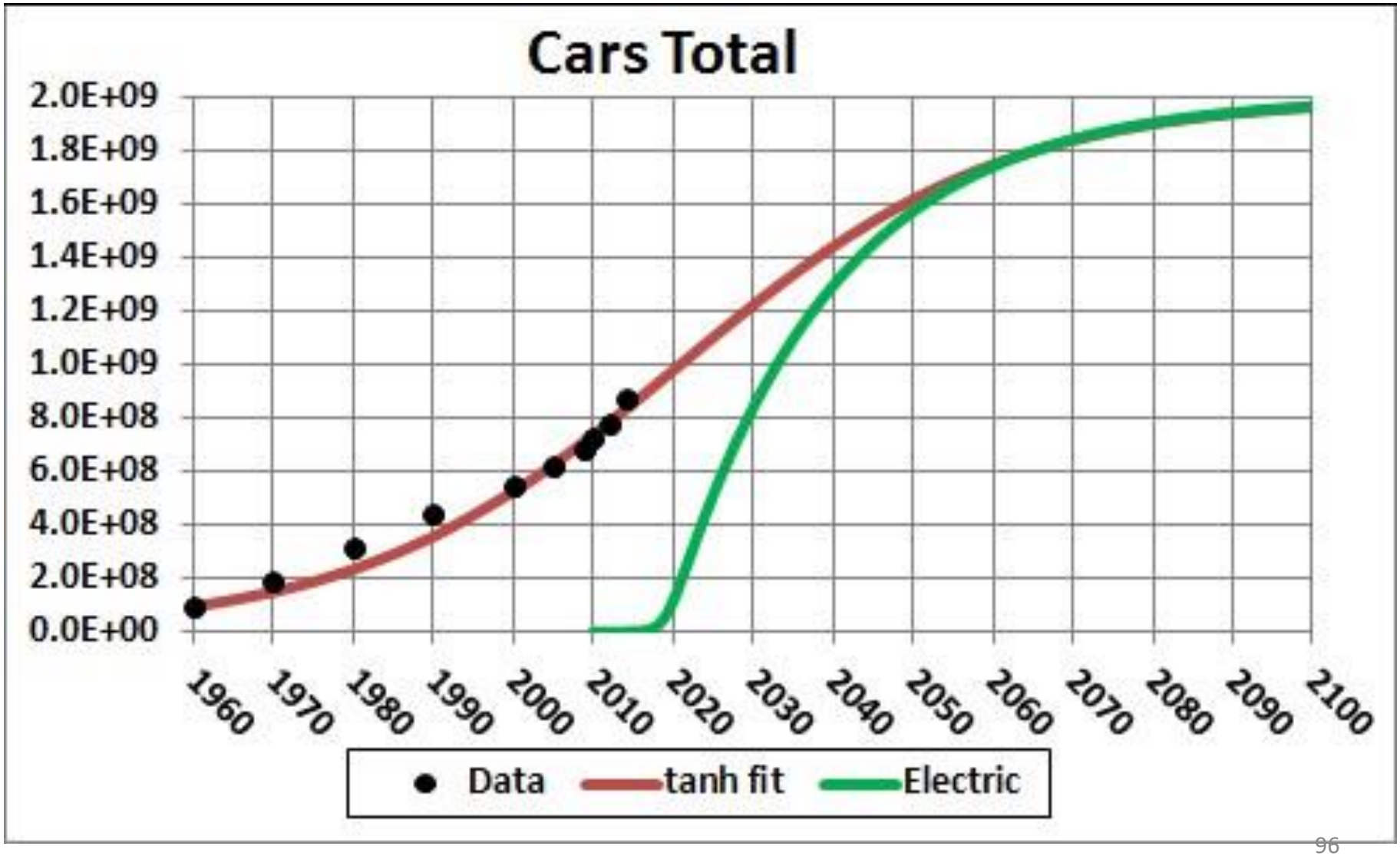
Exponential Rise of World Electric Cars

(BEV & PHEV)



When will all cars be electric?

(BEV & PHEV)



When will all cars be electric?

- All new cars are mandated to be electric in Germany by 2030.
- Britain and France will ban sales of fossil-fueled cars in 2040.
- India will ban sales of fossil-fueled cars by 2030.
- Norway will ban sales of fossil-fueled cars by 2025.
- China will spend $15-billion installing charging stations by 2020.
- Shell will install fast-charging stations at gas stations.
- BP will install fast-charging stations at gas stations.
- By 2030 over half of cars will be electric in U.S.
- All cars electric in India by 2030.

When will all cars be electric?

- Alliance (Nissan, Renault, Mitsubishi) plans for 12 BEVs by 2022
- Audi: 40% of luxury cars will be electric by 2030
- Audi: Electric cars will soon have 400-miles range, and eventually 500 miles.
- Volvo: All cars will be hybrids or battery cars by 2019
- VW will have 30 electric cars by 2025.
- Mercedes-Benz will have 4 electric cars by 2020.

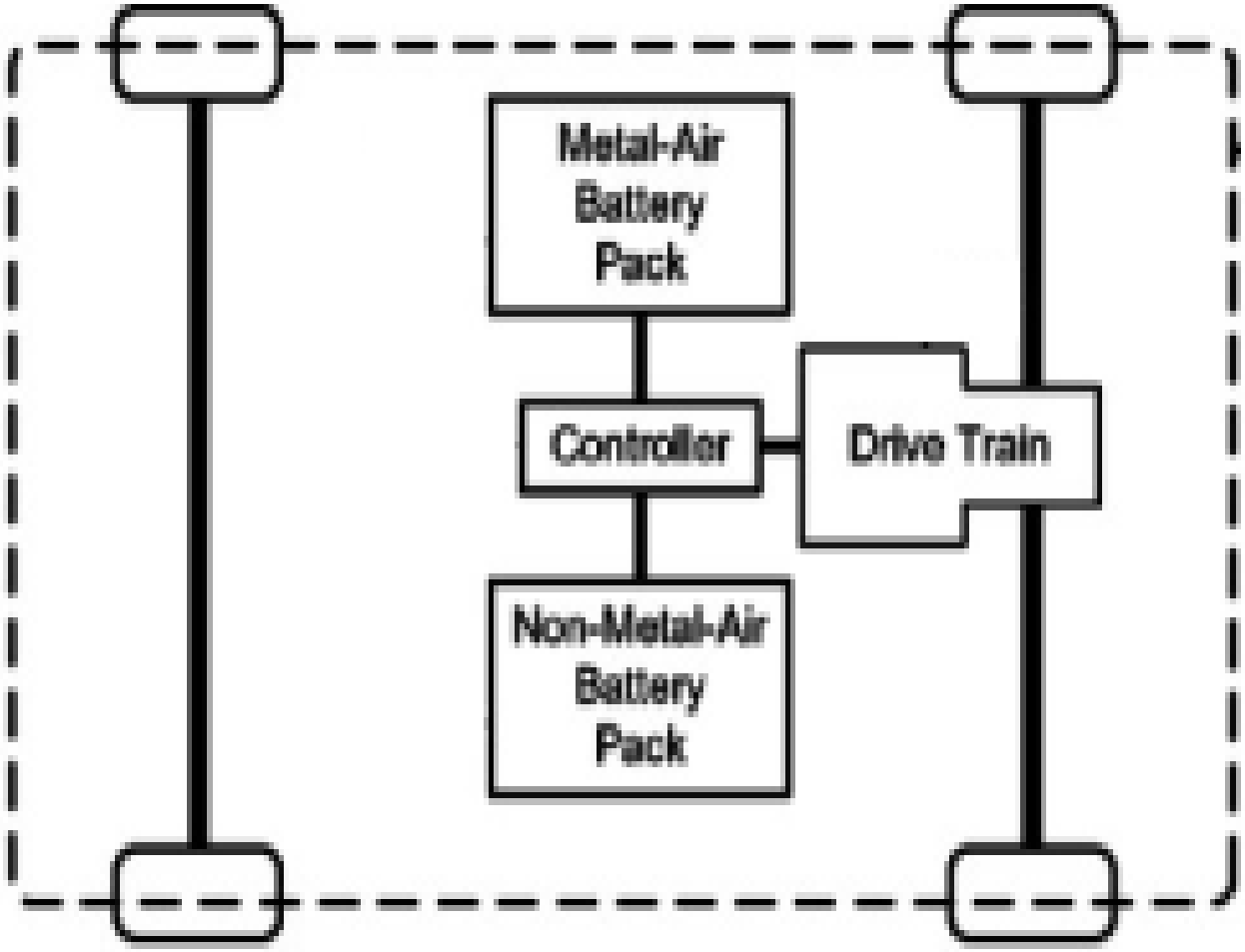
Electric Cars Future

- Tesla already has a >310-miles car (Model 3 Long Range) and promises a ~700-miles car (**Goodbye gas car!**).
- Autonomous cars fleet on fast call instead of individual ownership.
- Automatic charging in garages and parking lots.
- Number of fast-charging stations will exceed number of gas stations by 2020.
- Battery exchanges will become common and used batteries (capacity <80%) will be used for renewable-energy storage and then, when capacity <50%, will be recycled.
- BEVs will be used for **power backup in emergencies**

Battery/Battery Hybrid

- Tesla has patented the concept of using a lithium-ion (LI) battery (medium energy density and high power density) with a lithium-air (LA) battery (high energy density and medium power density).
- The Lithium battery would be used to provide energy during brief driving periods requiring high power (accelerating and climbing hills) and the LA battery would be used to provide energy during periods requiring low power (cruising).
- The LA battery also can recharge the LI battery.

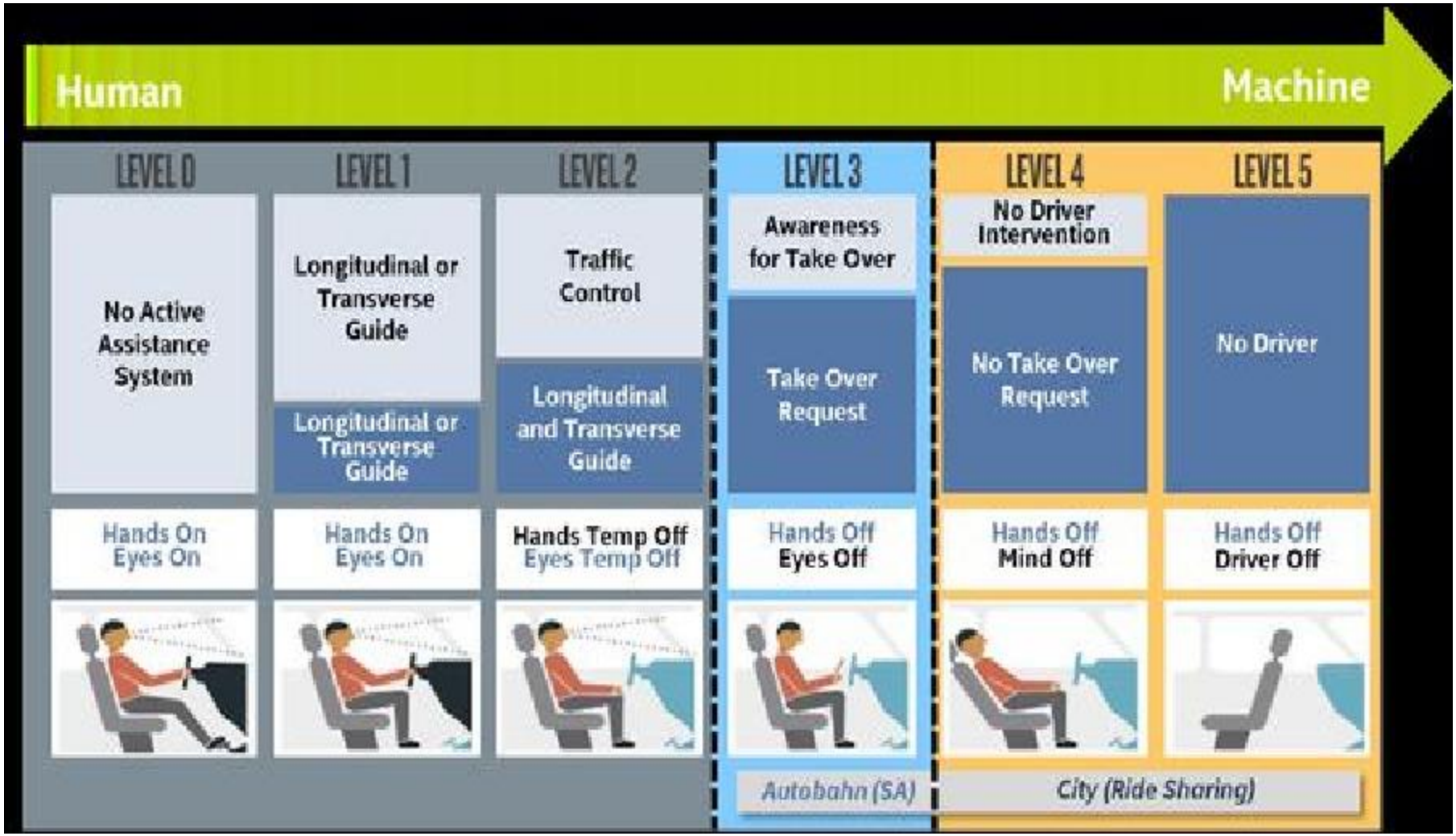
Battery/Battery Hybrid



Graphene Supercapacitors for BEVs

- Graphene: carbon atoms layer one atom thick charge bilayers
- Typically high power density but **low energy density**
- Very long lifetimes (high duty cycles)
- Rapid charge and discharge
- High efficiency
- Wide range of operating temperatures
- No maintenance or toxic materials
- Fisker Emotion BEV may have a supercapitor instead of a lithium-ion battery.

Autonomous Vehicles Levels

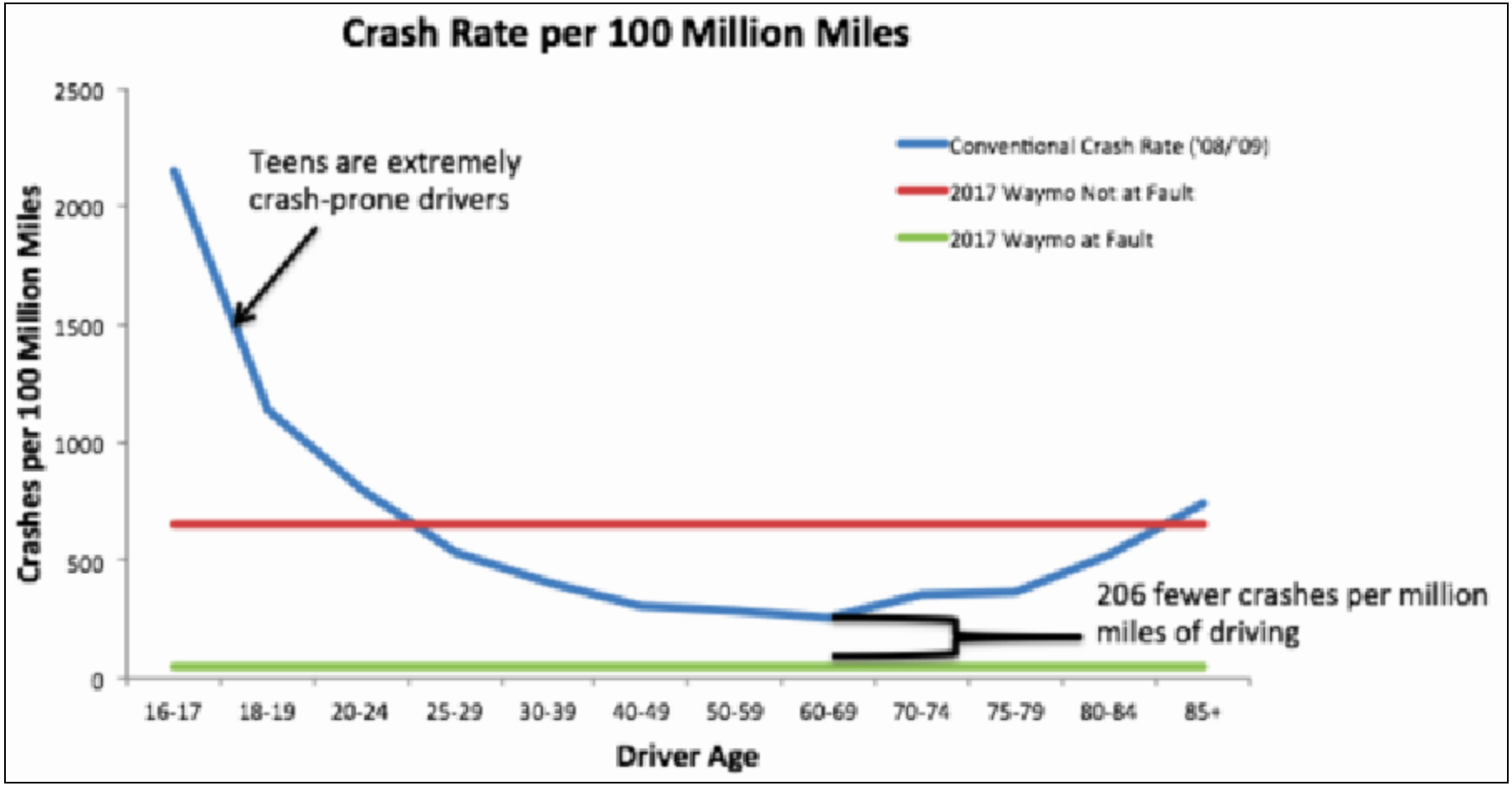


Tesla plans a 'shared autonomous fleet' for owners to make money off their Tesla.

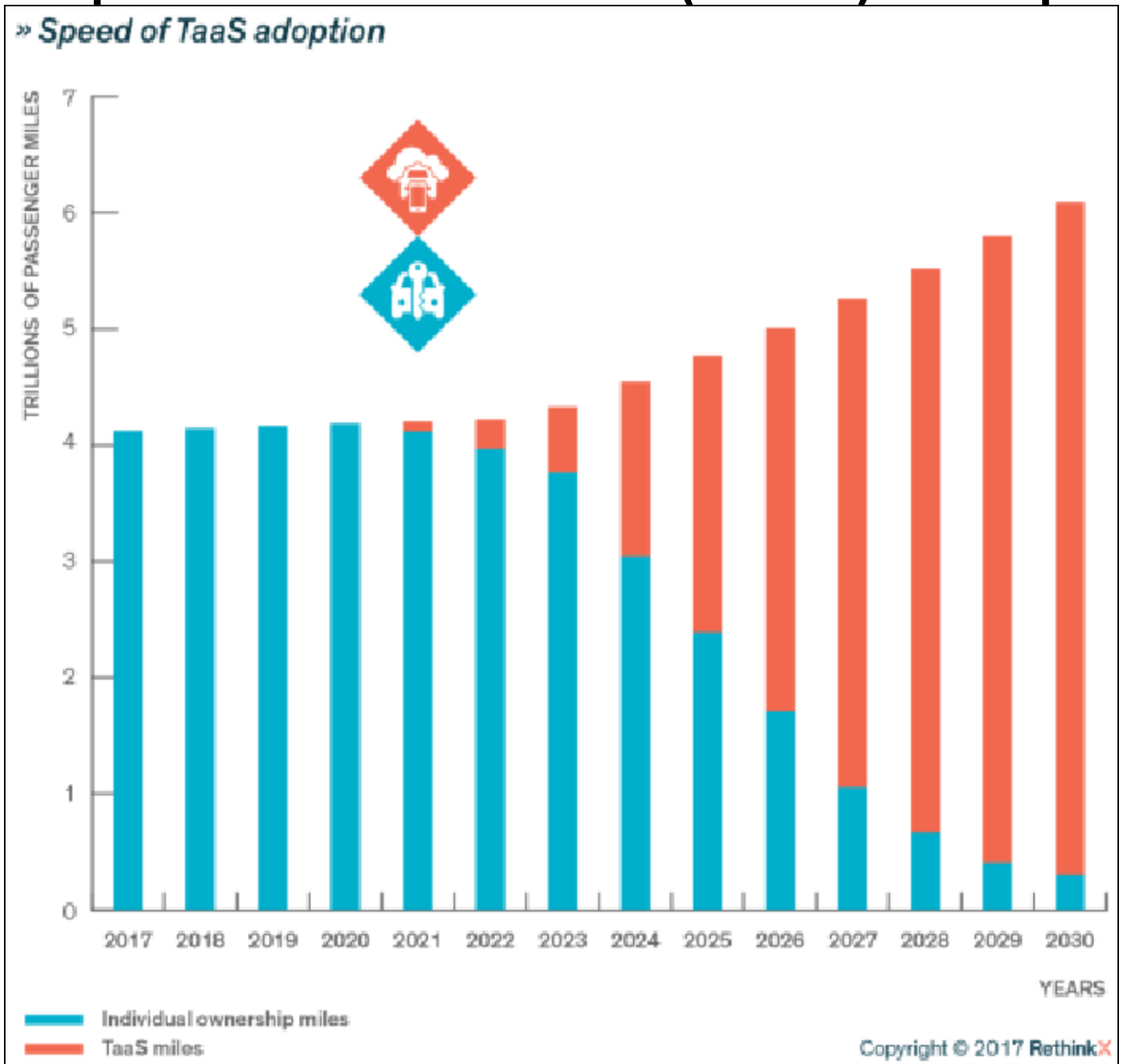
Autonomous Cars' Advantages

- Much safer; will save lives and injuries
- Less traffic congestion
- Less parking space; parked stacked in tall buildings when not in service
- Electric, so 1/4th less energy used
- Electric, so zero emissions
- More free time for passengers
- More convenient for passengers

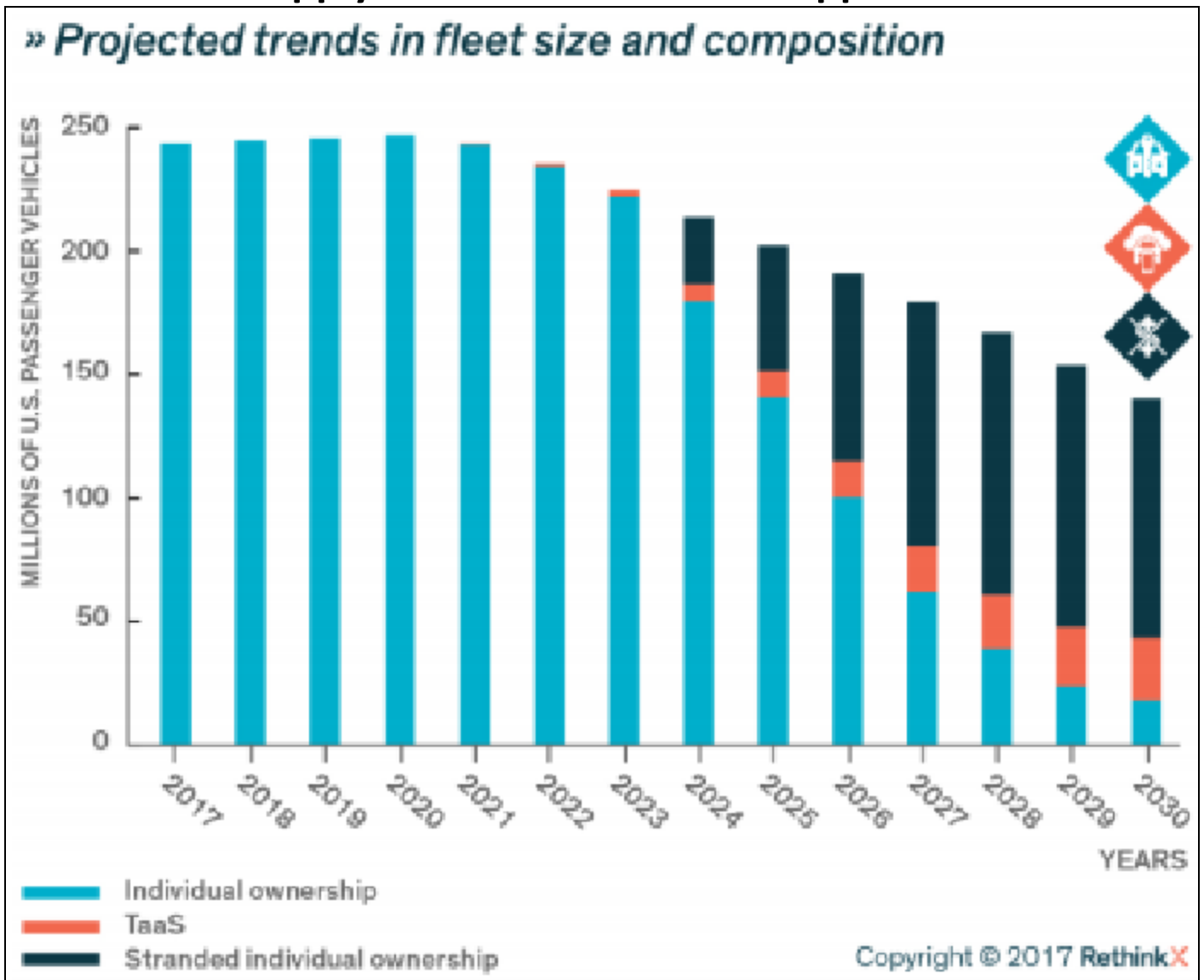
Autonomous Vehicles Safety



Transport as a Service (TaaS) Adoption



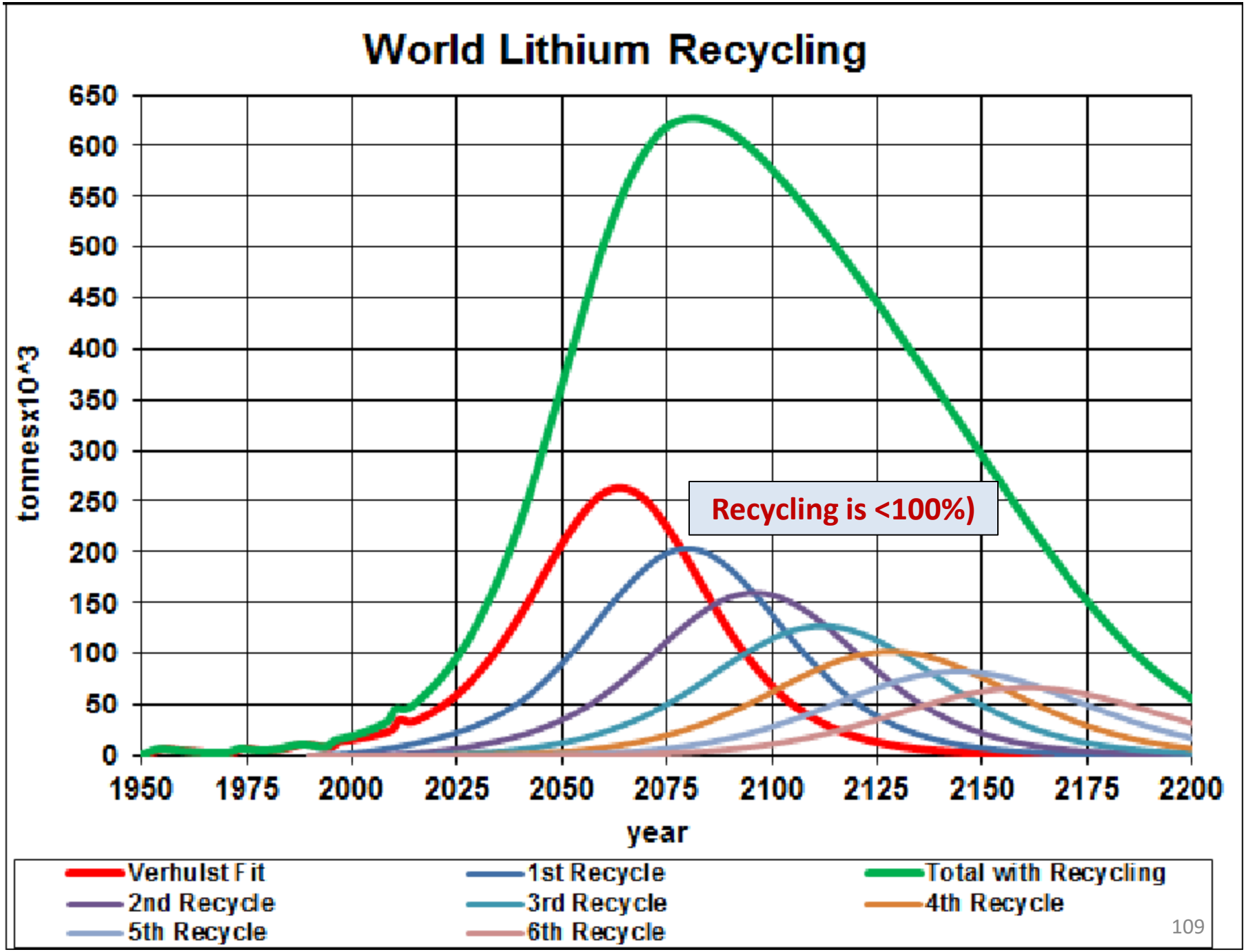
97 million ICE U.S. vehicles will be left stranded in 2030, representing the surplus that will be in the vehicle stock as consumers move to TaaS. These vehicles may eventually become entirely unsellable as used IO vehicle supply soars and demand disappears.

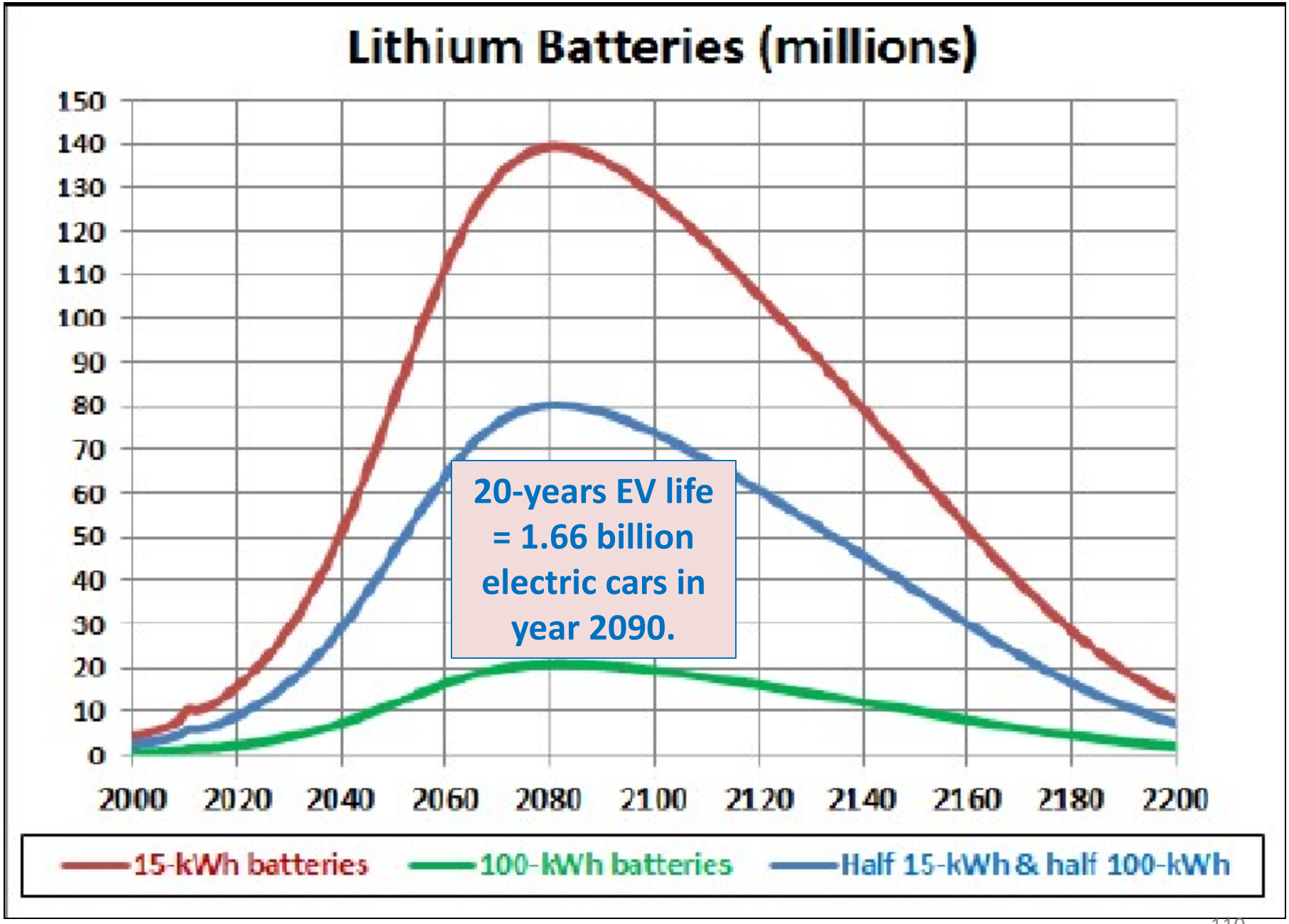


Autonomous Vehicles (AV)

- Audi: AV by 2017
- Tesla: AV by 2018
- Google: AV by 2018
- VW: AV by 2019
- Nissan: AV by 2020
- Ford: AV by 2020
- GM: AV by 2020
- Toyota: AV by 2020
- BMW: AV in 2021
- Worldwide: AV in 2025
- Uber: Driverless by 2030
- IEEE: 75% AV by 2040

Robots could replace 1.7 million American truckers in the next decade.

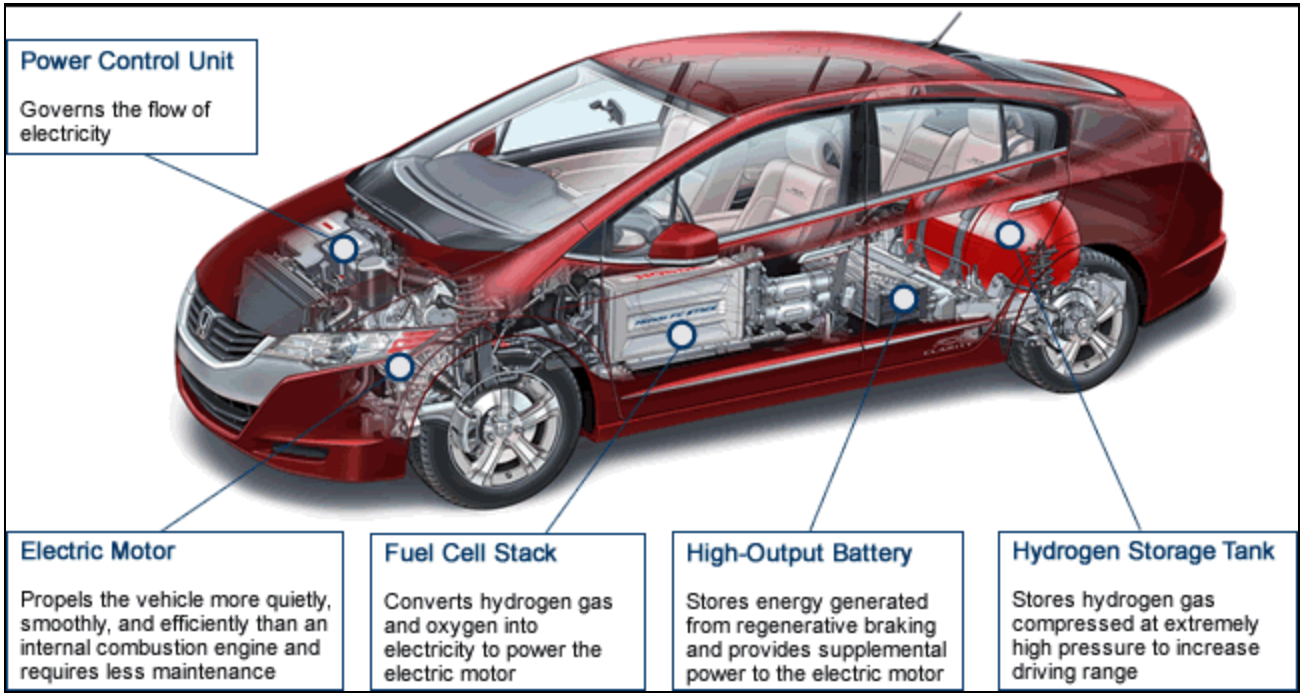

World Lithium Recycling
650
600
550
500
450
400
350
300
250
200
150
100
50
0
tonnesx10^3
1950
1975
2000
2025
2050
2075
2100
2125
2150
2175
2200
year
Recycling is <100%)
Verhulst Fit
1st Recycle
Total with Recycling
2nd Recycle
3rd Recycle
4th Recycle
5th Recycle
6th Recycle



In very-long term (>year 2100), must have grid-connected vehicle/trains and renewable energy.

Why Not Fuel-Cell Cars?

- They are very complicated:

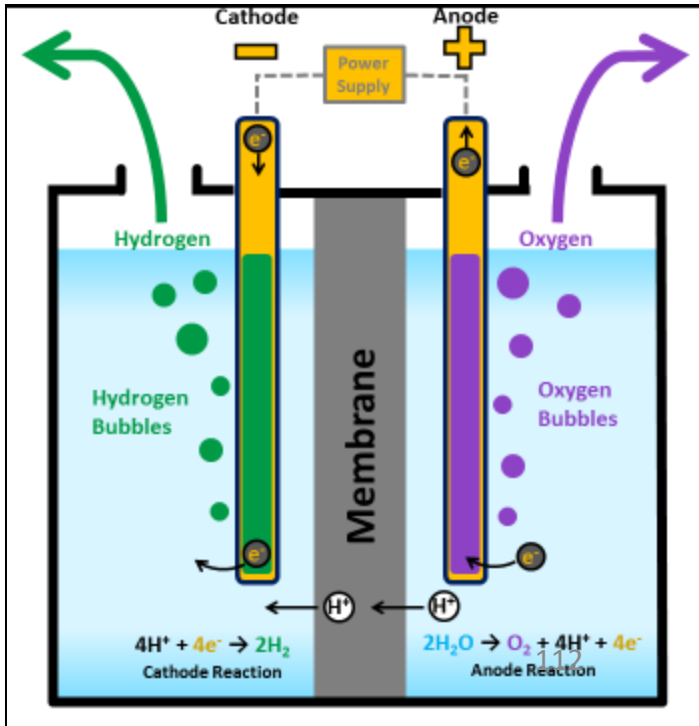


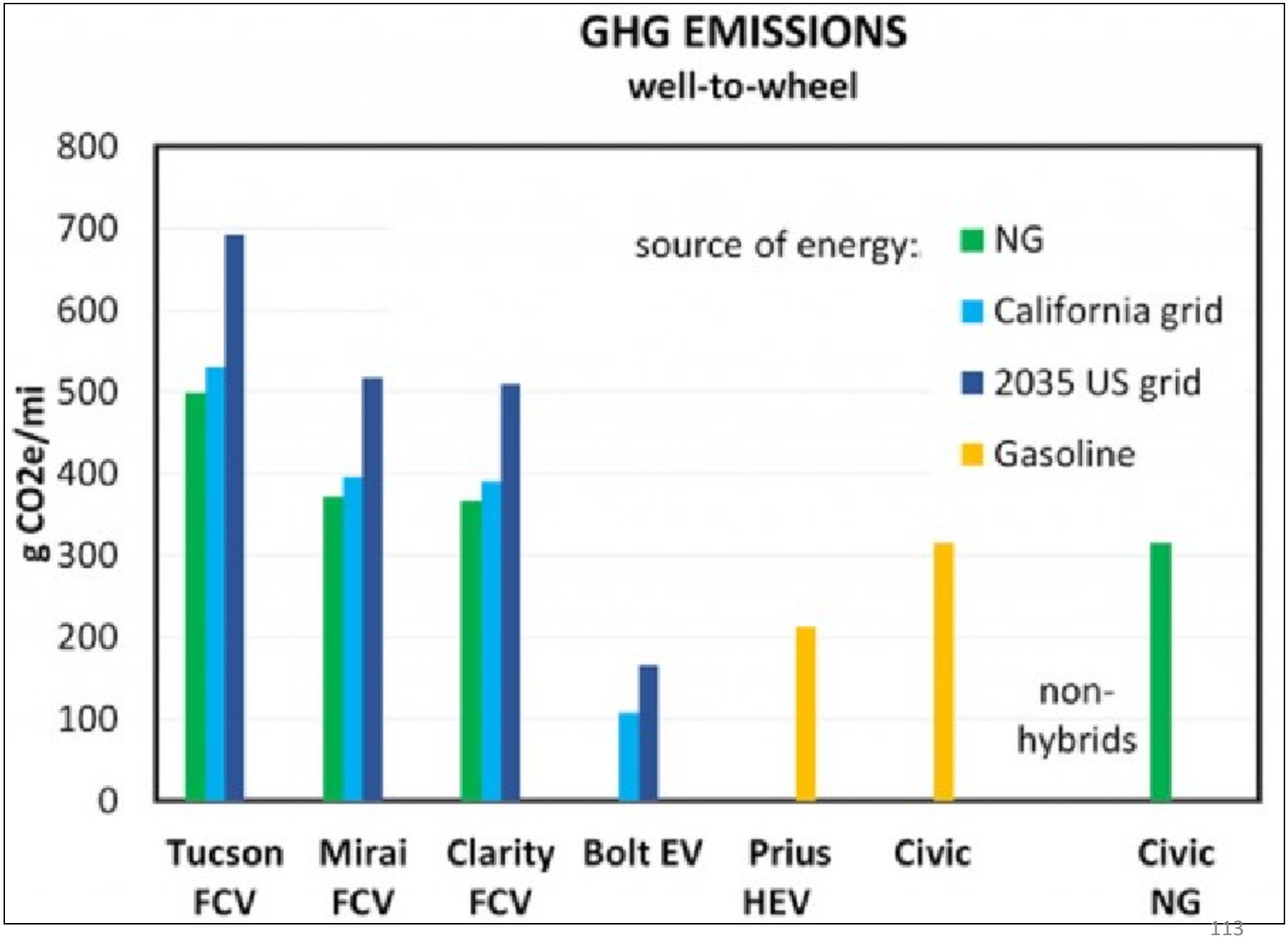
- Requires a lithium-ion battery similar to a PHEV!
- Hydrogen fuel is not easy to obtain. Most is made from methane and water, which produces carbon dioxide with the hydrogen! Should be made by solar!
- Better for heavy-duty vehicles, such as trucks.

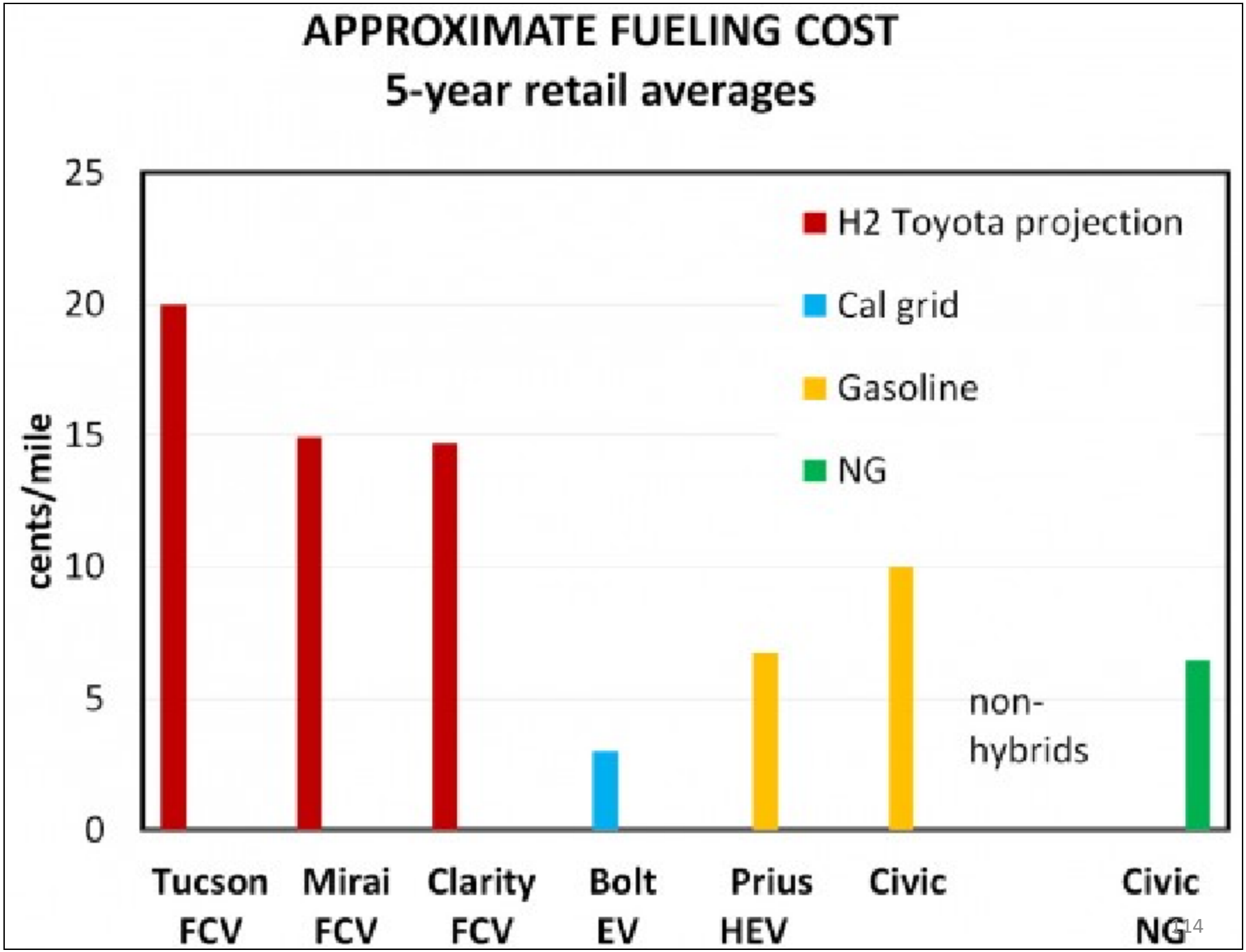
Making Hydrogen for Fuel-Cell Cars

- Steam-methane reforming:
  $CH_4 + H_2O$ (+ heat) → $CO + 3H_2$
- Partial oxidation of methane:
  $2CH_4 + O_2 \rightarrow 2CO + 4H_2$ (+ heat)
- Electrolysis of water
  $2H_20$ + electricity -> $4H + O_2$

The oxygen is released into the atmosphere.




GHG EMISSIONS
well-to-wheel
g CO2e/mi
800
700
600
500
400
300
200
100
0
source of energy:
NG
California grid
2035 US grid
Gasoline
non-hybrids
Tucson FCV
Mirai FCV
Clarity FCV
Bolt EV
Prius HEV
Civic
Civic NG


APPROXIMATE FUELING COST
5-year retail averages
cents/mile
25
20
15
10
5
0
H2 Toyota projection
Cal grid
Gasoline
NG
non-hybrids
Tucson FCV
Mirai FCV
Clarity FCV
Bolt EV
Prius HEV
Civic
Civic NG

DOE prize winning garage hydrogen creator from water and electricity. Stores 5 kg H_2 at 10,000 psi in a carbon-fiber tank, enough to run a fuel-cell car 312 miles.

Each kg takes 15 minutes to refuel a car.

Very Long Term Transportation

- Steady population size.
- Long-distance fast electric trains connected to a renewable-energy grid.
- Medium-distance electric trollies connected to a renewable grid.
- Short-distance buses inductively connected to an underground renewable powerline.
- Autonomous local BEVs for instant pickup.
- If not the above, back to horses & buggies!

References

- **Wall Street Journal:** Why Electric Cars Will Be Here Sooner Than You Think
- http://www.roperld.com/science/200_300mileselectriccars.htm
- http://www.roperld.com/science/BEVs_PHEVs2017.pdf (this talk)
- http://www.roperld.com/science/BEVvsICECost.htm
- tinyurl.com/ElectricCarsWorkshop
- US states with incentives for green cars