Everything You Need To Know About EVs

Jim Weichel
Owner of an EV for 3+ Years

Background

- MSEE from Purdue & Business Training at Penn State, Harvard, & Northwestern
- Software Development and Management Bell Labs 1970-1999
- COO of Data Visualization Company, CTO of Energy Industry Data Supplier and Securities Brokerage
- Consultant to Fermi National Laboratory Open Science Grid
- Currently - Web Design & Developer for 2 non-profits

Outline

- Early History of EVs
- EV Market Status Worldwide
- EV vs ICE Characteristics
- EV Economics
- Batteries and Charging
- EV Driving Experience Locally and Long Distance
- Many EV Choices
- The Greatest Revolution in Autos Since the Model T
- The 21st Century Auto

Early History of EVs

- 1880-1894 – First Practical Electric Cars based on Lead-Acid battery (1859)
- 1890 – First Successful Electric built in US by Iowa chemist Oliver Fritchle
- 1895-1920 – Golden age of Electric Taxis, Vans, & EVs for Society Women
- By 1900, 30% of vehicles in NYC were electric
- 1900-1910 – Many EV brands, 90% of Taxis in NYC were EVs, Many Delivery Services Started using EV Delivery Wagons
- Electricity was in 35% of homes by 1920. Also people could install a power plant in their stable for charging.
- 1910 - NYC had 100s of public charging stations
- The wives of Edison, Ford, & Rockefeller all had Electric Cars

Early History of EVs

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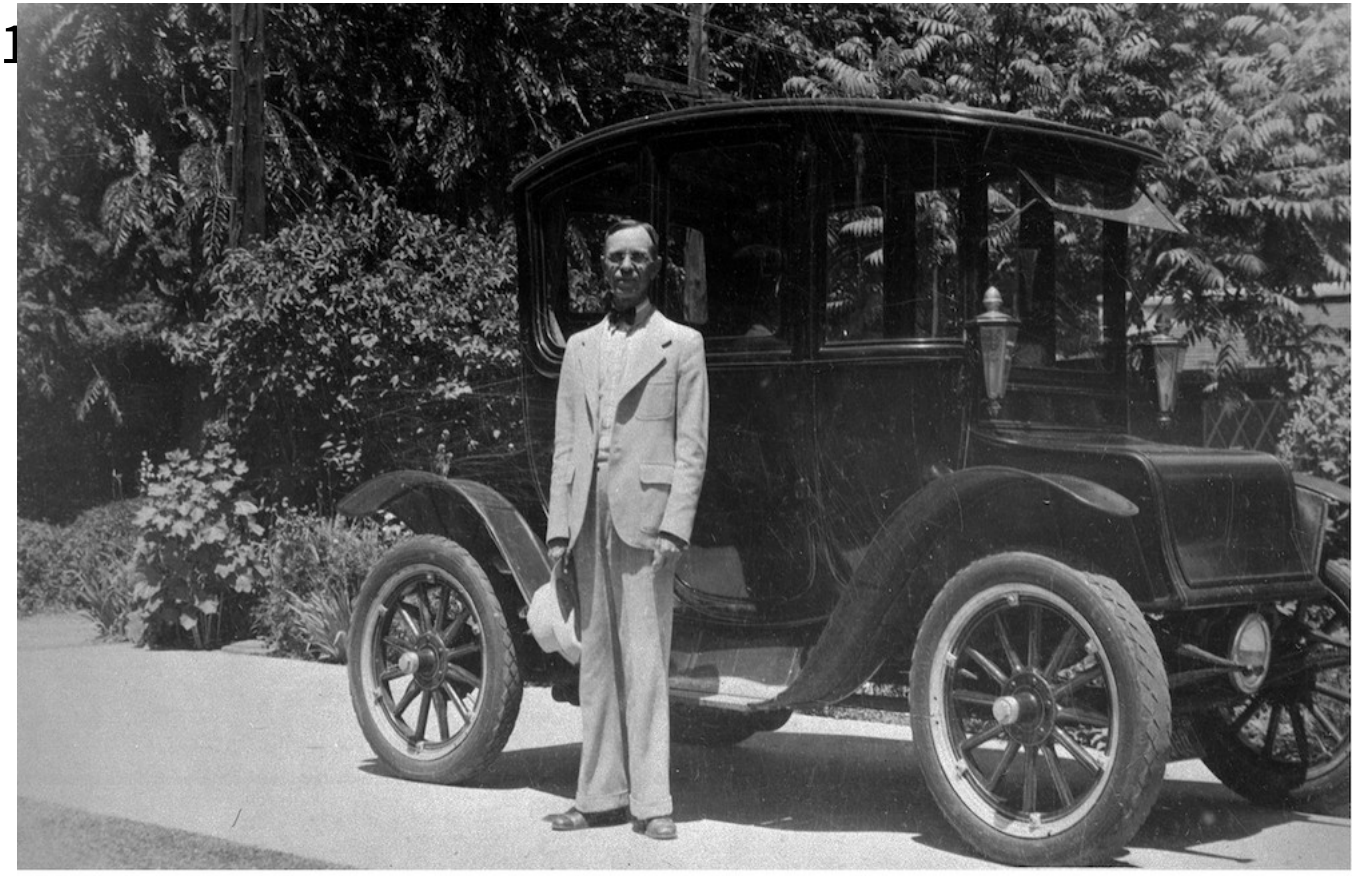


Oliver O. Fritchle stands in front of one of his cars. | 10025305, History Colorado

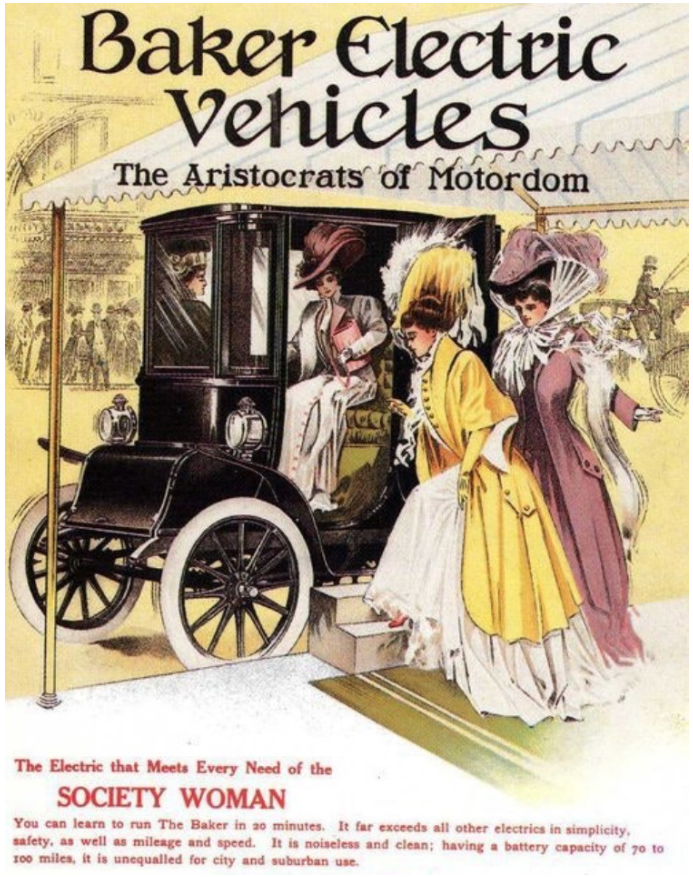
Early History of EVs

1906 Detroit – An Electric Wagon Delivering Beer

From: Detroit News

Early History of EVs

Electric Cars were marketed to Women (clean, quiet, no crank)



From: tumblr.com

Early History of EVs

What happened to this great start?

- Oil was discovered in Texas and gasoline became cheap
- Ford's production line produced a car for $650 while the average price of an Electric Car were $1750
- Marketing had cemented the view that an EV was a Woman's Car
- Electric Starters become common in the 1920s
- EVs at the time were only feasible in the city due to short range
- The Great Depression finished off the EV industry by 1935

Recent History of EVs

- New battery technology available (Lithium Ion)
- In the early 1990, the California Air Resources Board pushed for lower emissions vehicles
- In response, Honda, Chrysler, Ford, GM, Nissan, & Toyota developed EVs
- The largest program was GM's EV1 where cars were leased to customers
- Program ended after 2 years with GM forcing the cars to be returned (against the customers' wishes) and they were crushed
- Dealers sued CARB and got mandate neutered
- Public protests by EV drivers' groups upset by repossession of their cars caused Toyota to sell 328 RAV4 EVs until 2002. Toyota continues to support these cars.

Basically, automakers did not want to sell EVs and wanted it to look like there was no demand.

First Modern EV Company

Tesla - Created July 1, 2003 by Martin Eberhard and Marc Tarpenning

- Elon Musk invested $6.35M of $6.5M in 2006 to enable production of an expensive ($60K) sports car based on an electrified Lotus from the UK. Musk became CEO and hired J. B. Straubel from AC Propulsion (Li battery & electric motor expert).
- Tesla Roadster (~$60K) prototype shown in 2006 that changed the view of an EV. Won Time Magazine Best Inventions 2006: Transportation. Produced 2008-2012. Total ~2500
- Model S Large Luxury Sedan ($70K-$125K), with unheard of performance, features, and range. CR: "This car performs better than anything we've ever tested before. Let me repeat that: Not just the best electric car, but the best car. It does just about everything really, really well." Produced 2012-Present. Total through 2020: ~300,005
- Model X Large Luxury SUV ($80K-$125K) concept 2012. Only SUV to receive 5 star Safety Ratings in all Categories. Produced 2015-Present. Total through 2020: ~140,000
- Model 3 Small Sedan introduced 2016 with $35,000 ($40K - $50K) base price target. Produced 2017-Present
- Model Y Small SUV/CUV debuted 2018. Produced 2020-Present Total 3/Y through 3Q21: >1.5M

Tesla's mission is to accelerate the world's transition to sustainable energy

Aside from Tesla, breaking into the U.S. auto industry is so difficult that the last company to do so successfully was Chrysler - in 1925!

Tesla Model S

Tesla Model X

Tesla Model 3

Tesla Model 3 Interior

Tesla Model Y

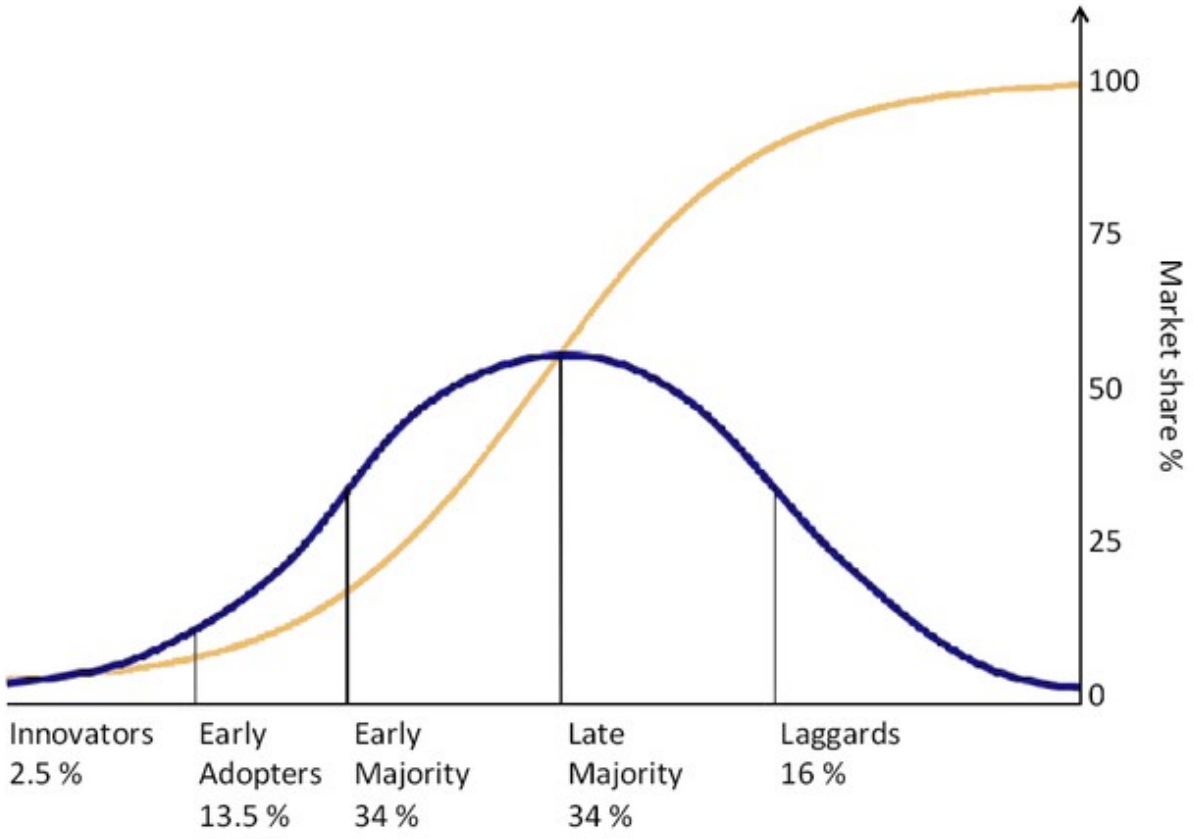
Definitions

- ICE – An Internal Combustion Engine powered vehicle
- EV or BEV – An electric vehicle powered only by batteries
- PHEV – A Plug-in Hybrid Electric Vehicle. An ICE vehicle with an Electric motor and batteries to provide all electric for ~50 miles for urban travel. Long distance travel reverts to a regular Hybrid.
- Hybrid (HEV) – An ICE vehicle with an Electric motor and some batteries (a few miles of range). Increases efficiency and mpg.
- MPGe – Miles per Gallon Equivalent for EVs - NHTSA & EPA standard 2013

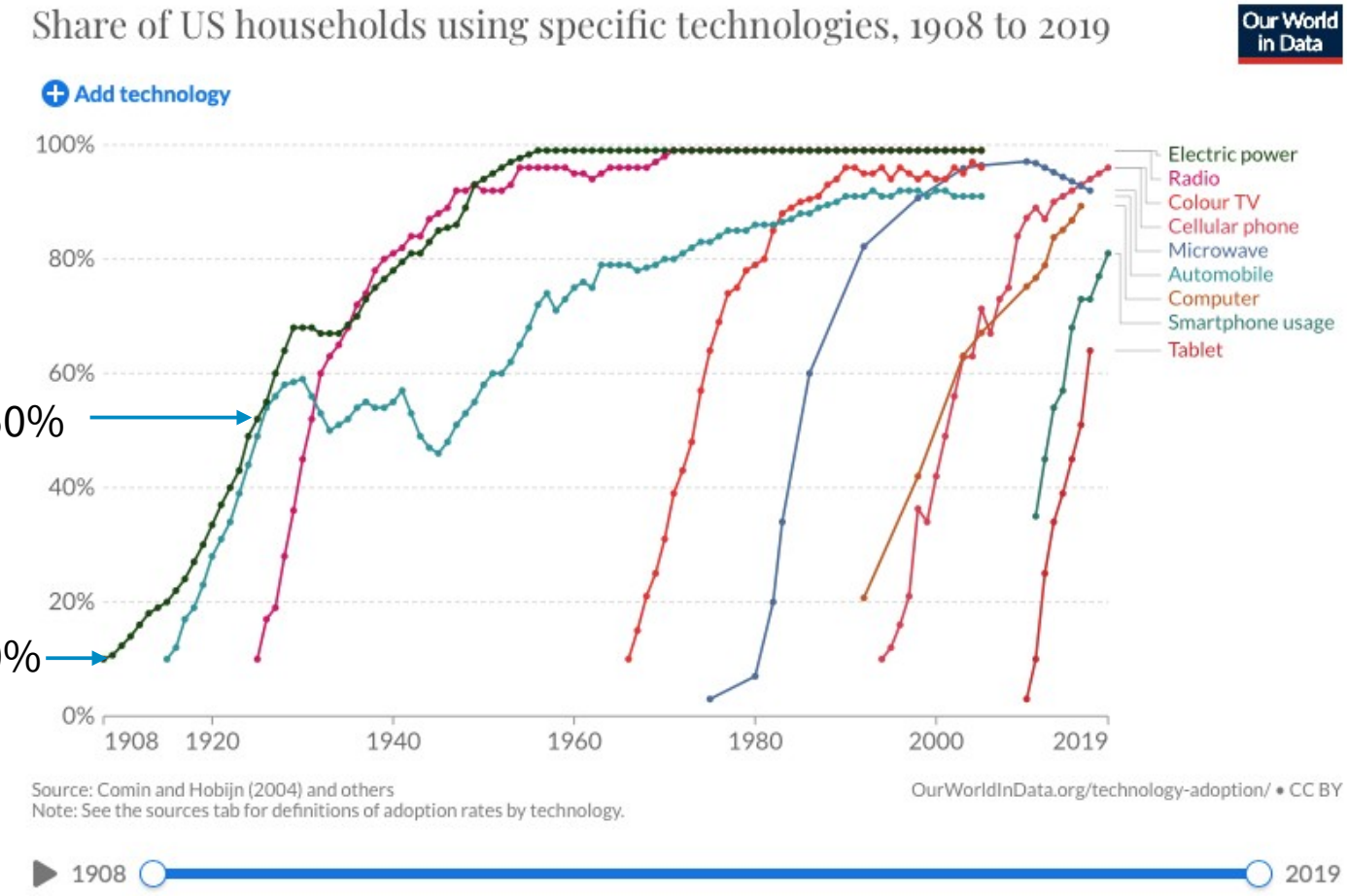
  Miles traveled * Energy in 1 gallon of gasoline)/Total Energy in Battery Used

  20 * 34 kWh / 5 kWh = 116 MPGe

Technology Adoption Curve



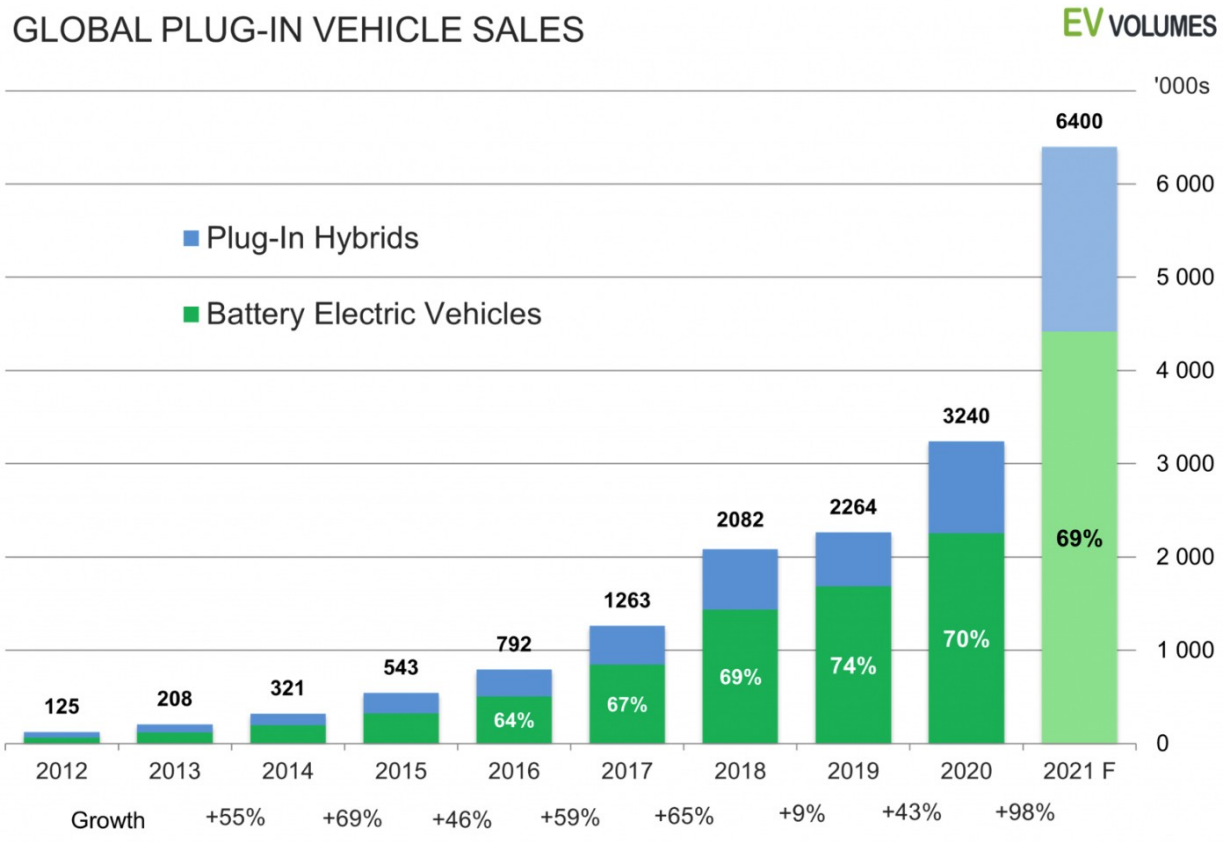
Past Technology Adoption Curves



Autos 1925 >50%

Autos 1910 10%

EV Adoption



Note: The Auto Industry wants to include PHEVs (and sometimes even Hybrids) with BEVs, so BEV only data is hard to find.

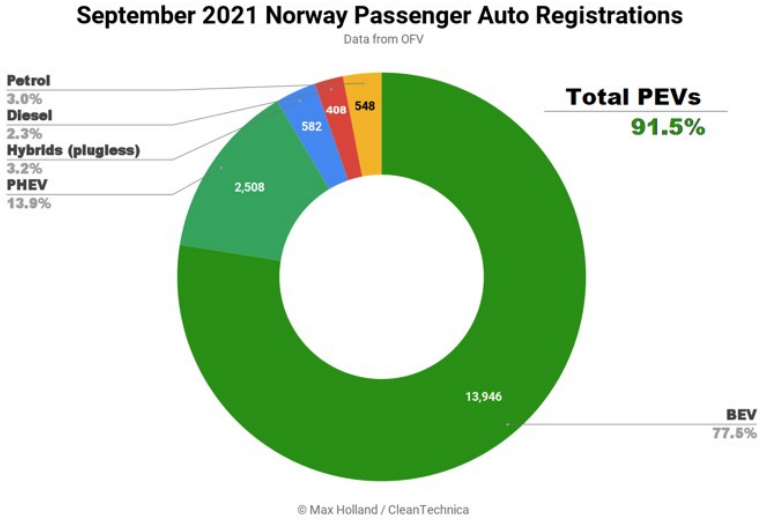
EV Adoption

EV Adoption Rate is Exponential and limited by Manufacturing Capacity

Europe

- 3Q21 BEVs were 9.8% of all cars sold in the EU
- 09/21 the Tesla Model 3 was the best selling car (of any type) in the EU
- 9/21 BEVs were 15% of all cars sold in England

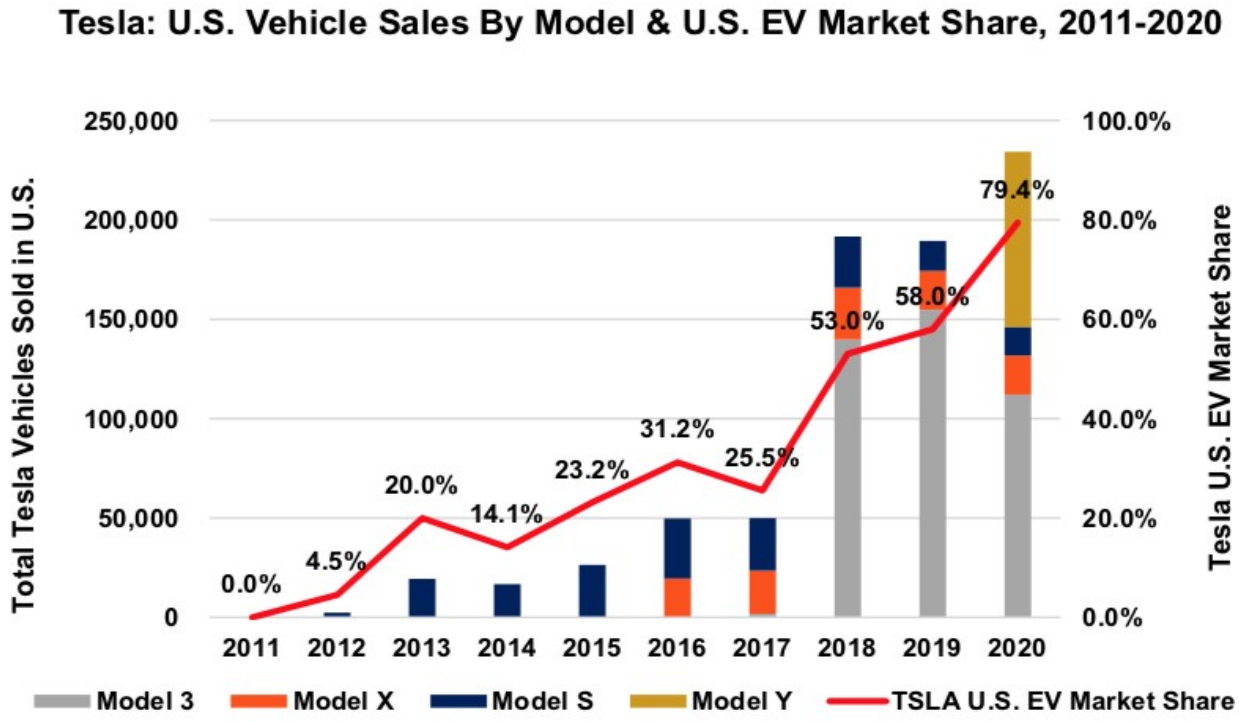
Norway hit the 10% EV market share in 2014



In China, BEVs are 4.6% of the Market (statista.com)

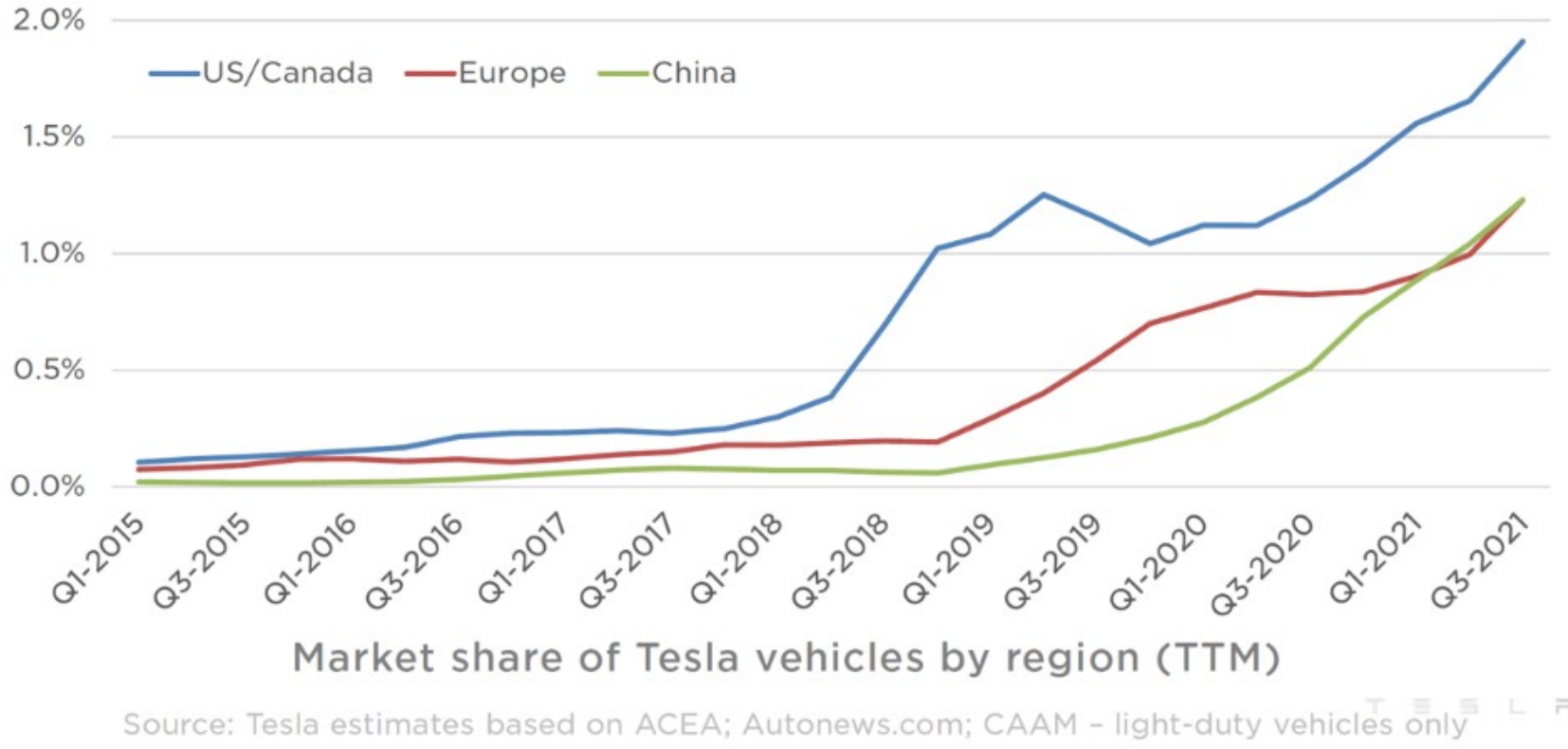
EV Adoption

US: Since Tesla has sold the vast majority of EVs in the US, it is a good representation of the current US market.
9/21; EVs were 2.6% of all vehicles sold in US. For all of 2021, EVs will be about 2% market share



1.1M BEVs were sold in China in 2020

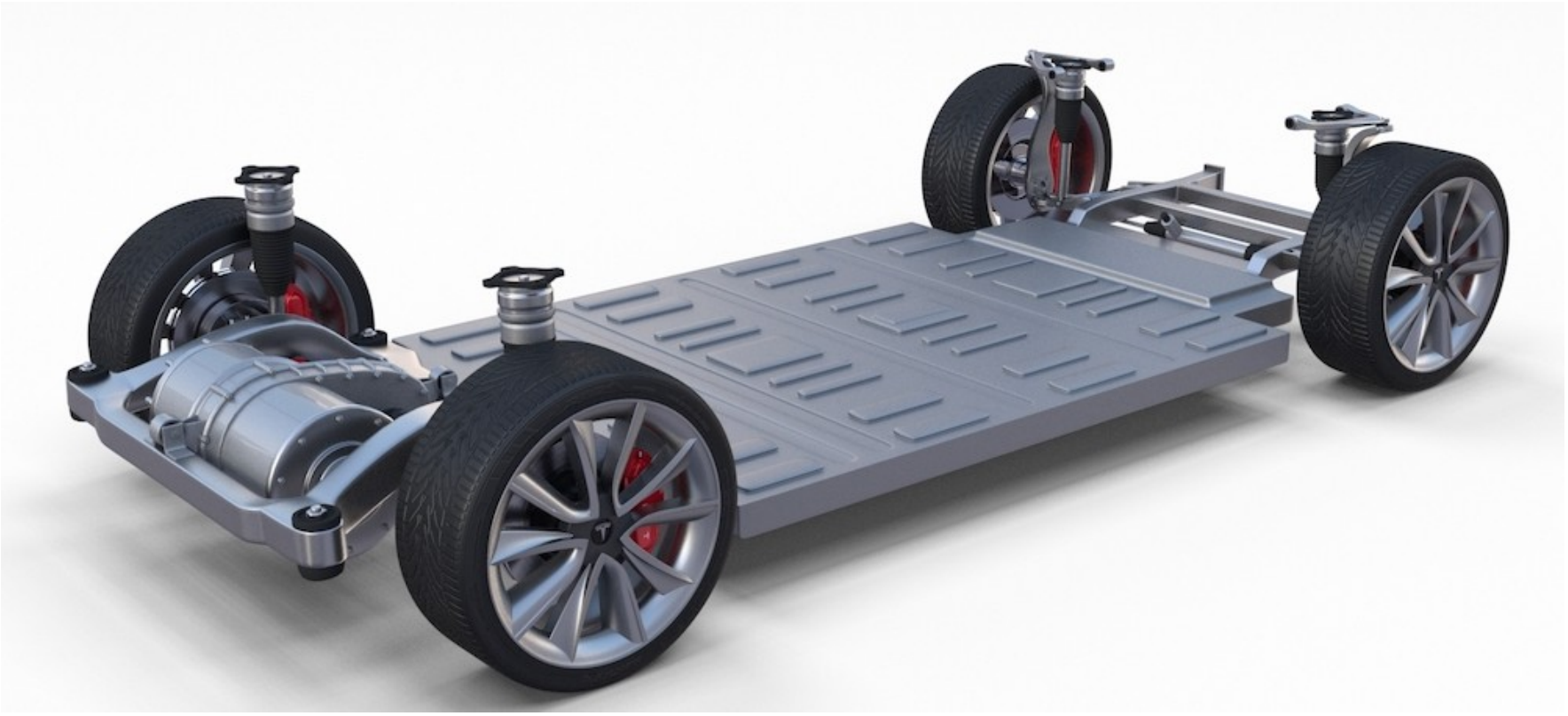
EV Adoption – Just Tesla



EV vs ICE

Measure	EV	ICE
Acceleration	Excellent - Fastest production car	Mediocre at best unless gas mileage is low
Energy Efficiency	~80%	~20%
Cornering	Little/No body roll	Noticeable body roll
Emergency Handling	Excellent (>50 mph) Moose Test	Fair (35 mph) to Good (45 mph)
Noise	Only wind & tire noise	Same plus engine noise
Winter/Summer Comfort	Excellent, heated/cooled in garage	Fair, car must be outside & running to heat/cool cabin
Maintenance Effort/Cost	Excellent, only tires, wipers, cabin filter (2 yrs)	Poor, requires 6 mo oil/filter change, brake pads, air cleaner. Emission Inspections Service ~3 times in 2 yrs
Convenience	Refuel in garage	Find gas station
Range	Most ~300 miles, a few ~500 miles; Limited fast charging (Except Tesla)	Most >400 miles: Gas ~everywhere
Refuel Time	12 Min – 8 Hours	8 Min

EV Mechanics



Range

For EVs, Range needs to be viewed from a different perspective

- US drivers average only 30 miles driven per day
- Only 10% average more than 60 miles per day
- Only 1% average more than 100 miles per day

But an EV can easily begin every day with a full battery, so 200 miles of range is sufficient for almost all normal use.

Long distance travel is most easily done with ~300 miles of Range.

EV Economics

Factors

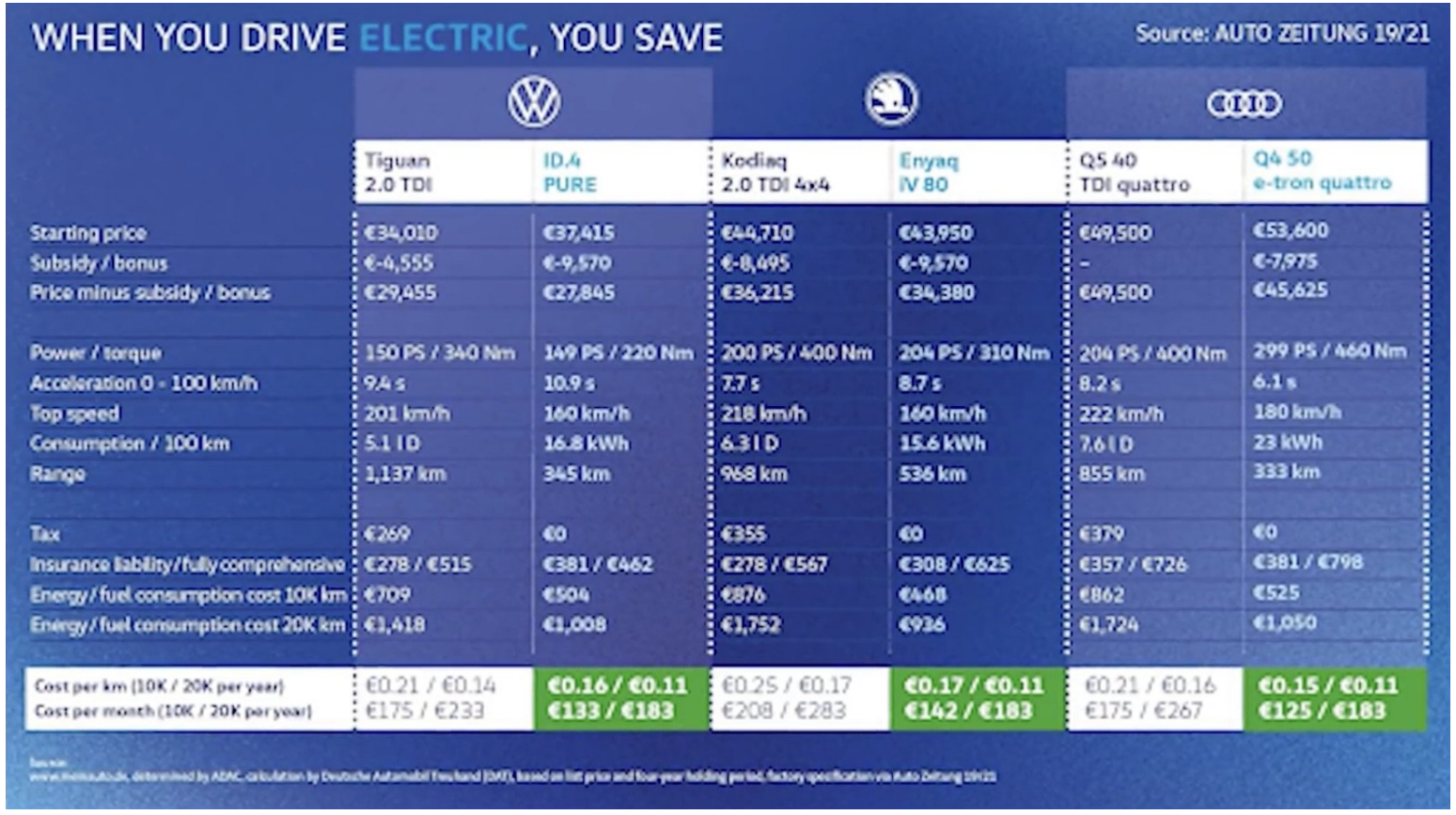
- EV Purchase Price exceeds competing ICE cars by $5,000 - $15,000
- Fuel costs for an EV are 25%-35% of ICE fuel costs ($0.03 vs $0.12 / mile)
- Maintenance costs are significantly less for EVs over 5 years (no oil/filter changes, air filter, brake pads, engine maintenance, etc.)
- Resale values currently are much higher for EVs

Fuel: Assume 15,000 miles/year @ 30 mpg for ICE car
ICE Fuel: 15,000/30 * $3.50 = $1750 ($0.11.7/mile)
EV Fuel: 15,000/4 (mi/kWh) * $0.11 = $412 ($0.027/mile)

Most analyses show that a Tesla Model 3 is economically equivalent to a similarly equipped Toyota Camry or Honda Accord after 5 years.

EV Economics

Herbert Diess, CEO of VW, has shown owner 5 year costs of VW's EVs vs their corresponding VW ICE vehicles for Germany.



WHEN YOU DRIVE ELECTRIC, YOU SAVE

Source: AUTO ZEITUNG 19/21

	Tiguan 2.0 TDI	ID.4 PURE	Kodiaq 2.0 TDI 4x4	Enyaq iV 80	Q5 40 TDI quattro	Q4 50 e-tron quattro
Starting price	€34,010	€37,415	€44,710	€43,950	€49,500	€53,600
Subsidy / bonus	€-4,555	€-9,570	€-8,495	€-9,570	-	€-7,975
Price minus subsidy / bonus	€29,455	€27,845	€36,215	€34,380	€49,500	€45,625
Power / torque	150 PS / 340 Nm	149 PS / 220 Nm	200 PS / 400 Nm	204 PS / 310 Nm	204 PS / 400 Nm	299 PS / 460 Nm
Acceleration 0 - 100 km/h	9.4 s	10.9 s	7.7 s	8.7 s	8.2 s	6.1 s
Top speed	201 km/h	160 km/h	218 km/h	160 km/h	222 km/h	180 km/h
Consumption / 100 km	5.1 l D	16.8 kWh	6.3 l D	15.6 kWh	7.6 l D	23 kWh
Range	1,137 km	345 km	968 km	536 km	855 km	333 km
Tax	€269	€0	€355	€0	€379	€0
Insurance liability / fully comprehensive	€278 / €515	€381 / €462	€278 / €567	€308 / €625	€357 / €726	€381 / €798
Energy / fuel consumption cost 10K km	€709	€504	€876	€468	€862	€525
Energy / fuel consumption cost 20K km	€1,418	€1,008	€1,752	€936	€1,724	€1,050
Cost per km (10K / 20K per year)	€0.21 / €0.14	**€0.16 / €0.11**	€0.25 / €0.17	**€0.17 / €0.11**	€0.21 / €0.16	**€0.15 / €0.11**
Cost per month (10K / 20K per year)	€175 / €233	**€133 / €183**	€208 / €283	**€142 / €183**	€175 / €267	**€125 / €183**

EV Economics

Diess also said that their new ID.4 factory requires 30 hours to build a car, while the Berlin Tesla factory will be able to build a car in 10 hours. So, the legacy automakers may not be as good as one might expect.

Manufacturing of new designs is hard, even for the big automakers. For example: Tesla Model S & X have had many problems over time – especially the Falcon Wing doors on the X.

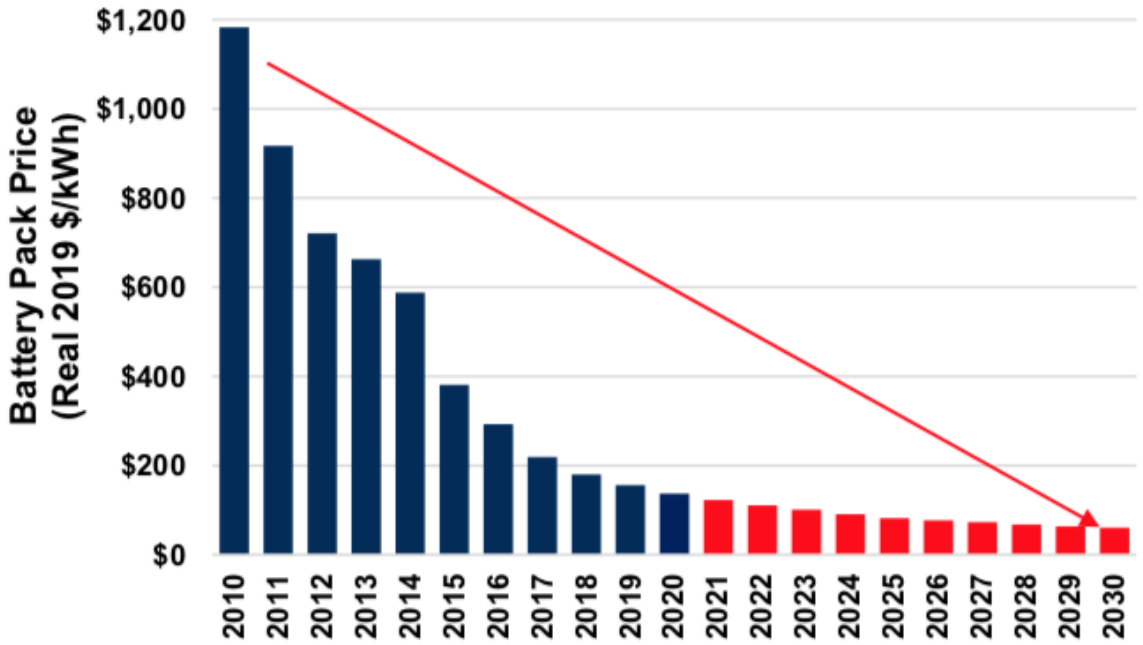
Ford Mustang Mach-E has recalls for lack of adhesive on windshield & sunroof.

Chevy Bolt has a major recall on battery packs causing spontaneous fires.

All manufacturers have had software problems – software expertise at legacy automakers is not very strong; but it has become a the key requirement for cars.

EV Economics

The big driver of EV costs is the cost of the batteries.



Credit: CFRA

Charging: AC

There are many misunderstandings about EV Charging.
There are 2 basic charging methods:

AC: Charging from an AC source. EVs have an onboard AC (120V-220V) to DC (400V-800V) Converter to charge batteries at relatively slow rates.

- Plug into a outlets anywhere from 120V 15A - 20A to 220V 30A – 60A
- 120V chargers charge at 2-3 miles added per hour (1.4 – 1.9 kW)
- 240V chargers charge at up to 18-35 miles added per hour (5.7 – 11.5 kW)
- 240V chargers are also called L2 (for Level 2)
- Use L2 Destination chargers at stores, restaurants, & hotels (all are 240V)

There are 2 plug types: Tesla and J1772 with simple adapters between them
Charging is fully automated: Car indicates time required to charge depending on the % of full charge you have set and kW available from the source.

Charging: AC

Charging: DC

DC: High speed charging from an DC source. Directly charges the battery after car communicates with charger to negotiate Voltage needed and Maximum Current.

Tesla calls them Superchargers. Charging rates are typically between 100 kW and 350 kW depending on the charger and the car. Tesla has the most extensive network.

The other largest companies are Electrify America, ChargePoint, EVgo, & EV Connect. Many of these provide many more L2 chargers than DC.

- Mostly used for long distance travel or for commercial vehicles (e.g. taxis)
- Charging rates depend on battery level and battery cooling
- Miles added per hour can be as high as 1000 (for ~10 min)
  All this is automated: Car will tell you how long the charge will take depending on the % of full charge you have set.

There are 2 plug standards: Tesla & CCS with adapters between them
All this is automated: Car will tell you how long the charge will take depending on the % of full charge you have set.

Charging: DC

Charging: DC

A Typical Tesla Trip

A trip is started with a “full” battery (90% or above)
Enter (say) your destination and the car plans a route and suggests charging stops

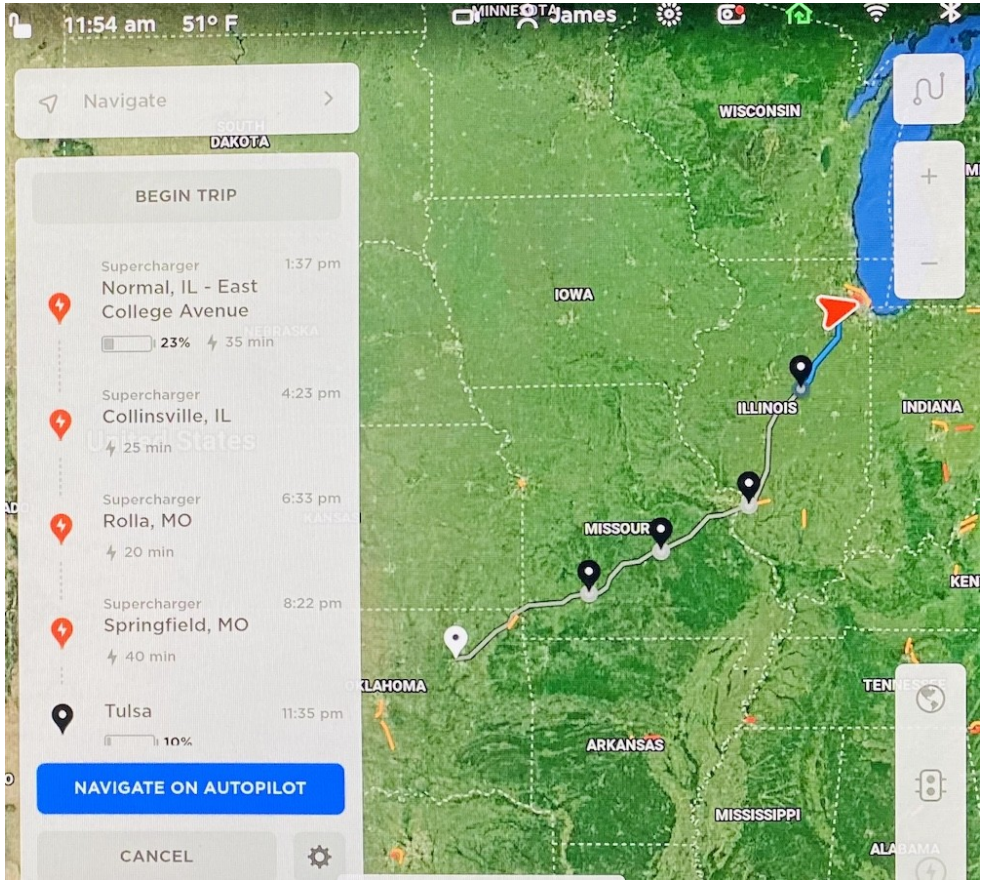
Mid morning: (2.5 – 3 hours maybe 150 – 200 miles). Stop at a Supercharger, plug in and take a rest stop with bathroom and coffee/snack. Car has enough charge to continue in 15 – 20 minutes (sometimes before I finish my coffee)

Lunch time: (after another 2 – 3 hours). Stop at Supercharger, plug in and go to lunch. Car is always charged enough before lunch is over. (Say 30 – 40 min)

Mid Afternoon: (2.5 – 3 hours maybe 150 – 200 miles). Stop at a Supercharger, plug in and take a rest stop with bathroom and drink. Car has enough charge to continue in 15 – 20 minutes

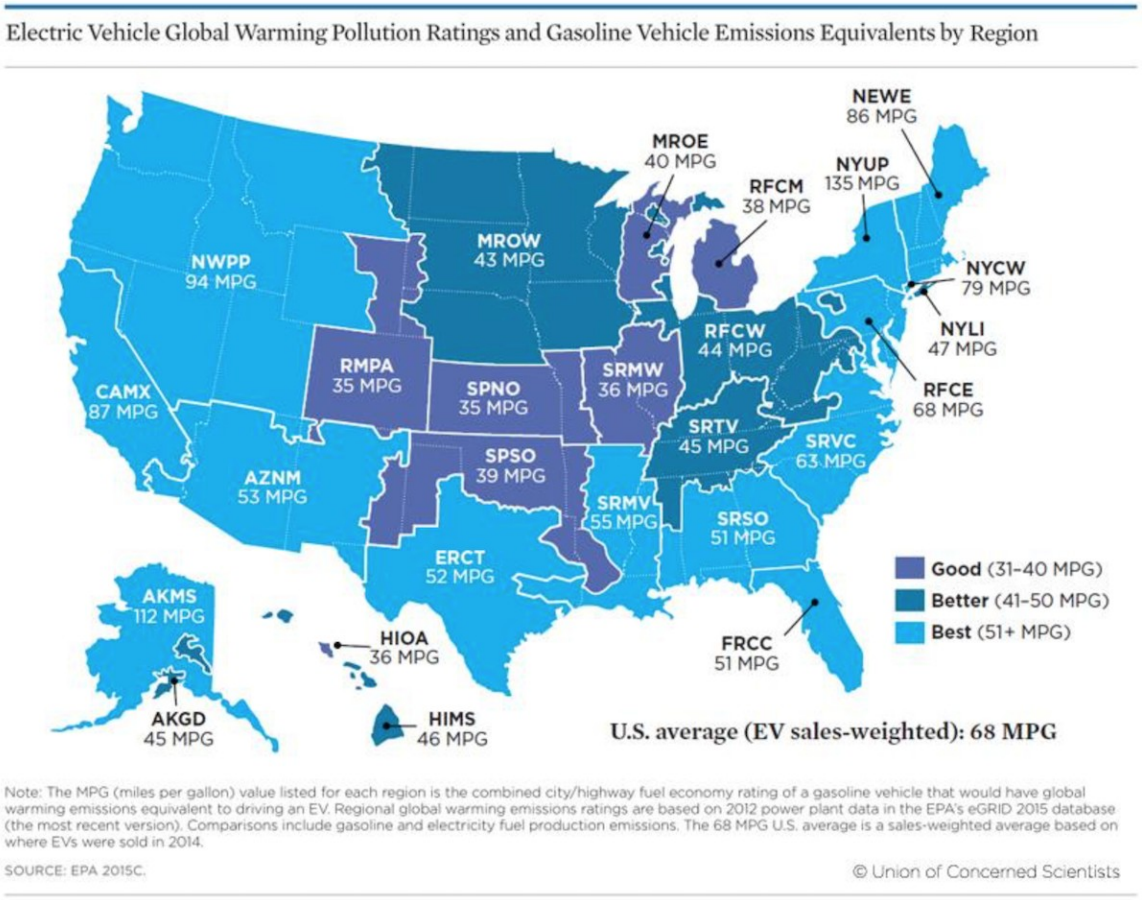
Arrive first day destination: (Total drive 500 – 600 miles). Stop at Hotel with Destination Charger. Plug in for overnight charge to restart next day at 90% charge.

Trip: Naperville to Tulsa



CO2 Emissions

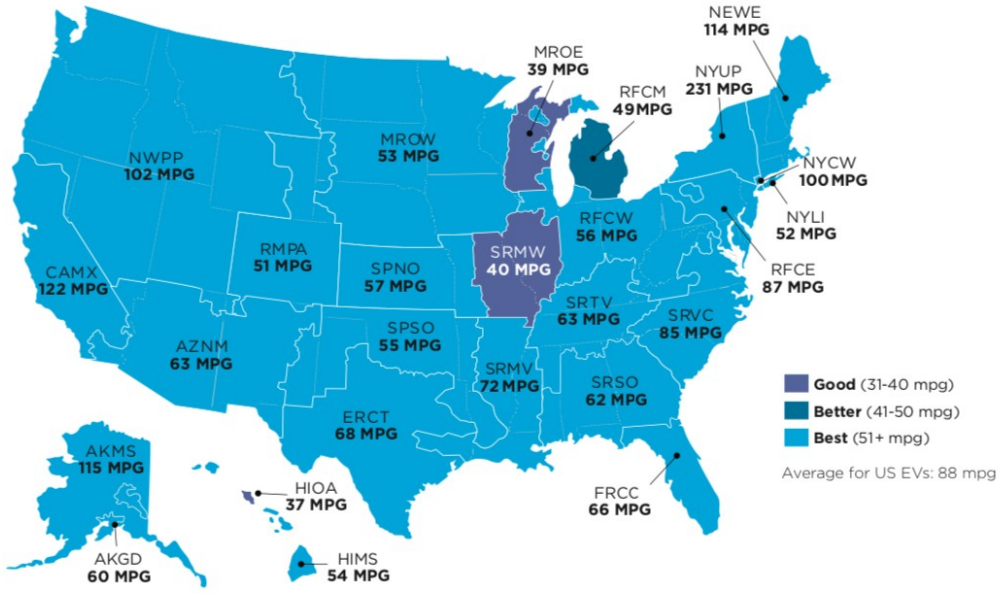
2015 Map of equivalent lifetime CO2 emissions of EVs in equivalent MPG.



CO2 Emissions

2020 Map of equivalent lifetime CO2 emissions of EVs in equivalent MPG.

FIGURE 1. EV Emissions Vary by Regional Electricity Supply

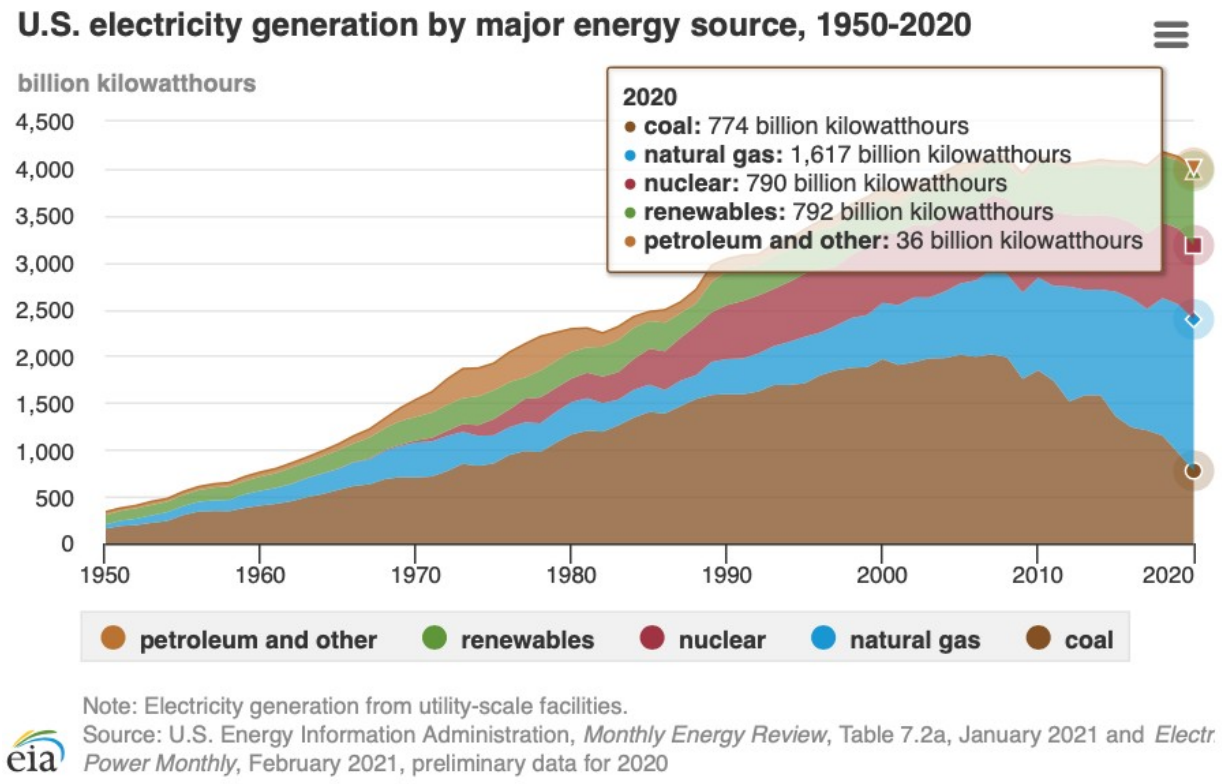


For each region of the US electricity grid, UCS calculated how the global warming emissions of charging and driving an average EV compare with those of a gasoline vehicle. The miles-per-gallon (mpg) value listed for each region is the combined city/highway fuel economy rating of a gasoline vehicle with emissions equivalent to the average EV. Nationally, the average EV is equivalent to a gasoline car that gets 88 mpg.

NOTES: Regional global warming emissions are based on 2018 power plant data in the eGRID2018 database (EPA 2020b). Comparison includes gasoline and electricity fuel production emissions estimates for processes including extraction, transportation, and refining, using the GREET 2019 model (ANL 2019). The 88 mpg US average is a sales-weighted average based on where EVs were sold from January 2011 through September 2019.

CO2 Emissions

Improvement due to cleaner Electricity Generation in the US.



Jim's Criteria For Selection

Here is a list of criteria I suggest for comparing EVs.
First decide if you want mostly an Urban car or you want to take Long Trips.
Cars are expensive, so I want a car I can use for everything.
Pick type of vehicle (Sedan, SUV/CUV, Pickup), then use these criteria:

1. Range must be >250 miles (if only Urban, 150-200 is OK)
2. You have to like the looks (you see it ~every day and should like it)
3. Efficiency (cheaper to operate and lighter car)
4. Features (especially those that affect comfort, easy of use, and your joy of driving)
5. Assistance driving long trips (makes a big difference on long trips)
6. Safety (only this low because most EVs have great safety scores)
7. Ease of interacting with Service and recommended Service frequency

Many Choices: Sedans

Sedans/Sports/Hatchbacks:

Large Luxury

- Tesla Model S - Std 375 mi $95K, Plaid 348 mi $130K
- Porche Taycan - Std 225 mi $82K, Cross Turismo 215 mi $153K
- Volvo Polestar 2 - FWD 265 mi $46K, AWD 249 mi $50K
- Mercedes EQS - 450 350 mi $103K, 580 340 mi, $120K
- Lucid Air - Grand Touring 516 mi $100K (not yet available)

Porche Taycan 4S

Volvo Polestar 2

Mercedes Benz EQS

Lucid Air Grand Touring

Lucid Air Interior

Many Choices: Sedans

Sedans/Sports/Hatchbacks:

Small/Medium

- Tesla Model 3 - Std 267 mi $45K, AWD 334 mi $51K
- BMW i4 - M40 300 mi $56K, M50 $67K
- Chevy Bolt - EV 2LT 259 mi $36K, EUV 2LT 247 mi $39K
- Hyundai Kona Electric - SEL 258 $34K, Limited 258 mi $43K (not avail in IL)
- Nissan Leaf - S 149 mi $28K, SL Plus 226 mi $38K
- MINI Electric Hardtop - SE 114 mi $30K (2 door)

BMW i4

Chevy Bolt

Nissan Leaf

MINI Electric Hardtop 2 door

Many Choices: SUV

SUV/CUV/Hatchback:

- Tesla Model Y - AWD 318 mi $60K
- Ford Mustang Mach-E - AWD 211 mi $48K, Extended Range 300 mi $53K
- Volkswagen ID.4 - RWD 260 mi $40K
- Kia Nero EV - EX 239 mi $41K, EX Premium 239 mi $46K
- BMW iX Sports - xDrive50 AWD 300 mi $85K
- Hyundai Kona Electric - SEL 258 mi $34K, Limited 258 mi $43K
- Audi E-Tron - Premium 198 mi $71K, Premium+ 250mi $77K
- Jaguar I-Pace - EV400 222 mi, $71K

Ford Mustang Mach-E

Volkswagon ID.4

Kia Nero EV

BMW iX Sport

Audi e-tron

Many Choices: Pickups

Pickup Trucks:

- Rivian R1T - Launch Edition 300 mi $74K (50 delivered)
- Tesla Cybertruck - 250-500 mi $40K-70K (late 2022?)
- Ford F150 Lightning - 230-300 mi $40K-$90k (2022?)
- Chevrolet Hummer - EV Edition 300 mi (2022+)

Rivian R1T

Tesla Cybertruck

Tesla Cybertruck

Ford F 150 Lightning

Hummer EV Pickup

EV Myths Dispelled

- EV are less “Green” than ICE cars (not true even including manufacturing)
- Charging EVs takes hours
- Fires – EVs often catch on Fire
  - Tesla has 10X fewer fires per billion miles driven than do ICE cars
  - Chevy Bolt EV does have more than ICE cars and has a recall
- EVs are very expensive (not over 5 years for comparable cars)
- EV batteries need replacement at great expense (Many now have about 400K miles without battery replacement, one with 750K miles!)
- Batteries will be a hazardous waste problem
  - Batteries will recycled, Tesla will recycle at their battery plants
- We don’t have enough minerals needed
  - Enough Lithium in 1 mine in Nevada to convert world to EVs
  - Some battery designs eliminate the Cobalt, a rare element

The 21st Century Car/Maker

Biggest Revolution in Automobile Since the Model T Ford!

- Electrification – advantages already discussed
- Connectivity – Feature delivery via network, data collection for autonomy
- Autonomy – Tremendous improvement in driving/safety, enjoyable trips

Auto Company in the 21st Century:

- Online Ordering with NO hassle (literally takes 10 min at Home or Showroom)
- Delivery to home or pick up at Service Center
- Most features implemented in Software
- New features/fixes delivered via network
- Service scheduled quickly via App and Mobile Service at your location
- Real world data collection for training neural net for autonomy

The 21st Century Car

Owner Perspective:

- Dramatic improvement in buying experience
- No Maintenance for 2 years (any less is for dealer benefit only)
- Refuel in garage or parking area
- Car features added ~monthly – customer choice
- Longer lifetime (500K to 1M miles for drivetrain)
- This results in better resale value
- Relaxing trips due to Autonomy features (before full autonomy)
- Actually driving that is Joyful (sports car like in a sedan) due to performance, handling, brakeless driving, etc.

The Only 21st Century Car

There are now many very good EVs; but only Tesla builds a 21st Century Car – As judged by the technology and features. It is the only EV that has all of:

- Improvements and New Features via WiFi (~2 updates per month)
- All solid state (e.g. no relays or fuses)
- Extensive Supercharger Network → Travel ~Anywhere
- Record Performance for production cars (including >$2.5M cars)
- Safest cars ever tested by NHTSA (all 4 models are 5 star in all tests)
- Self Driving (Interstate Now; Everywhere in Beta test)
- Energy efficiency of up to 4 miles/kWh
- Extensive Supercharging Network totally integrated with car

Tesla: The 21st Century Car

Technology Comparison by Sandy Munro & 3IS: Audi, Tesla, Ford

	ID.4	Model Y	Mach E
12 V Fuses	77	0	88
12 V Relays	7	0	22
Fuse Blocks	3	0	3

Tesla: The 21st Century Car

Efficiency Comparison

Model	Battery Size (kWh)	MPGe	Range
Tesla Model Y	75	125	326
Ford Mach-e	88	101	305
VW ID.4	82	97	260
Audi Q4 e-Tron	95	78	218

Tesla: The 21st Century Car

Sample Owner Perceived Technology/Features
CR: Tesla average owner satisfaction is 88, next highest brand is 79, Audi/BMW are 70:

- Car unlocks/locks automatically (no fob or key required)
- Car turns on/off automatically (no button)
- Car automatically opens/closes garage door
- Uses AI to operate rain sensing wipers
- Automatically heats/cools cabin at a specified time
- Looks on your calendar to set Navigation destination
- Many things can be controlled by voice – never had to type destination
- Records video all around car when parked (saves if a threat)
- Fully drives itself on limited access roads (requires monitoring)
- Summon car from parking lot to you
- Full Entertainment suite (Netflix, YouTube, Spotify, FM Radio etc.)

Tesla: The 21st Century Car

New Features Added Since Purchase (selected):

- 3% Efficiency Increase
- Increased charging rate from 100kW to 150kW to 250kW
- Automatic mirror folding/unfolding in garage & parking lot
- Automatic garage door closing/opening
- Dog mode – Keep cabin comfortable when unoccupied
- Schedule time to leave – charged and cabin comfortable
- Automatic routing to next appointment on calendar
- Automatic capture of last minute of video if horn is sounded or a crash
- Security mode with camera video automatically captured if threatened
- Live Security view remotely from Phone
- FSD – Summon car to you from parking lot; Navigate on Autopilot (highway; beta city)
- Joe Mode – Quiets notification gong (for sleeping children)
- Entertainment (parked) – Several video games, chess, backgammon & streaming movies from Netflix, Hulu, YouTube; (original driving) – FM radio, streaming music, podcasts, Spotify, TuneIn

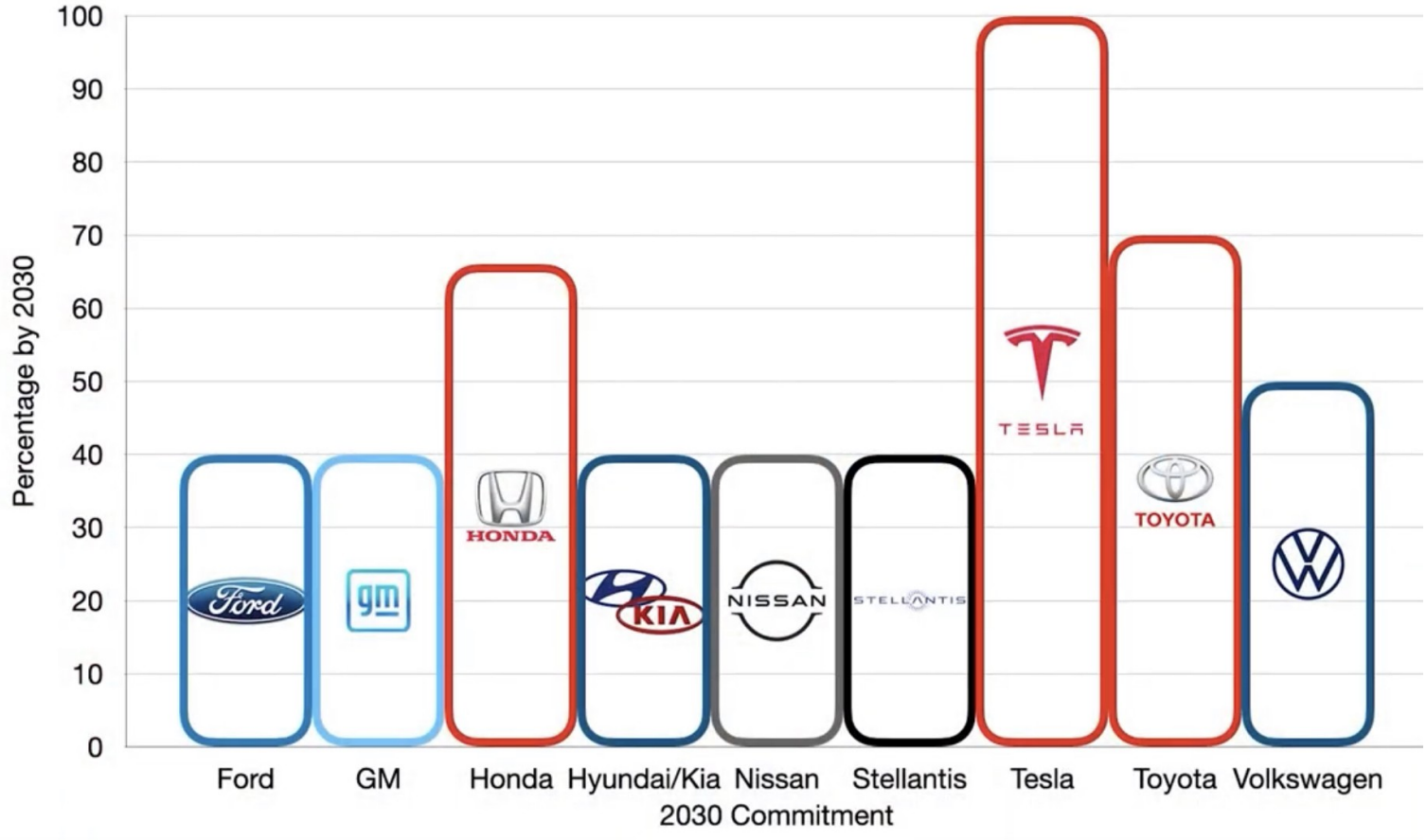
Example Technology: AC Vents

Tesla: The 21st Century Car

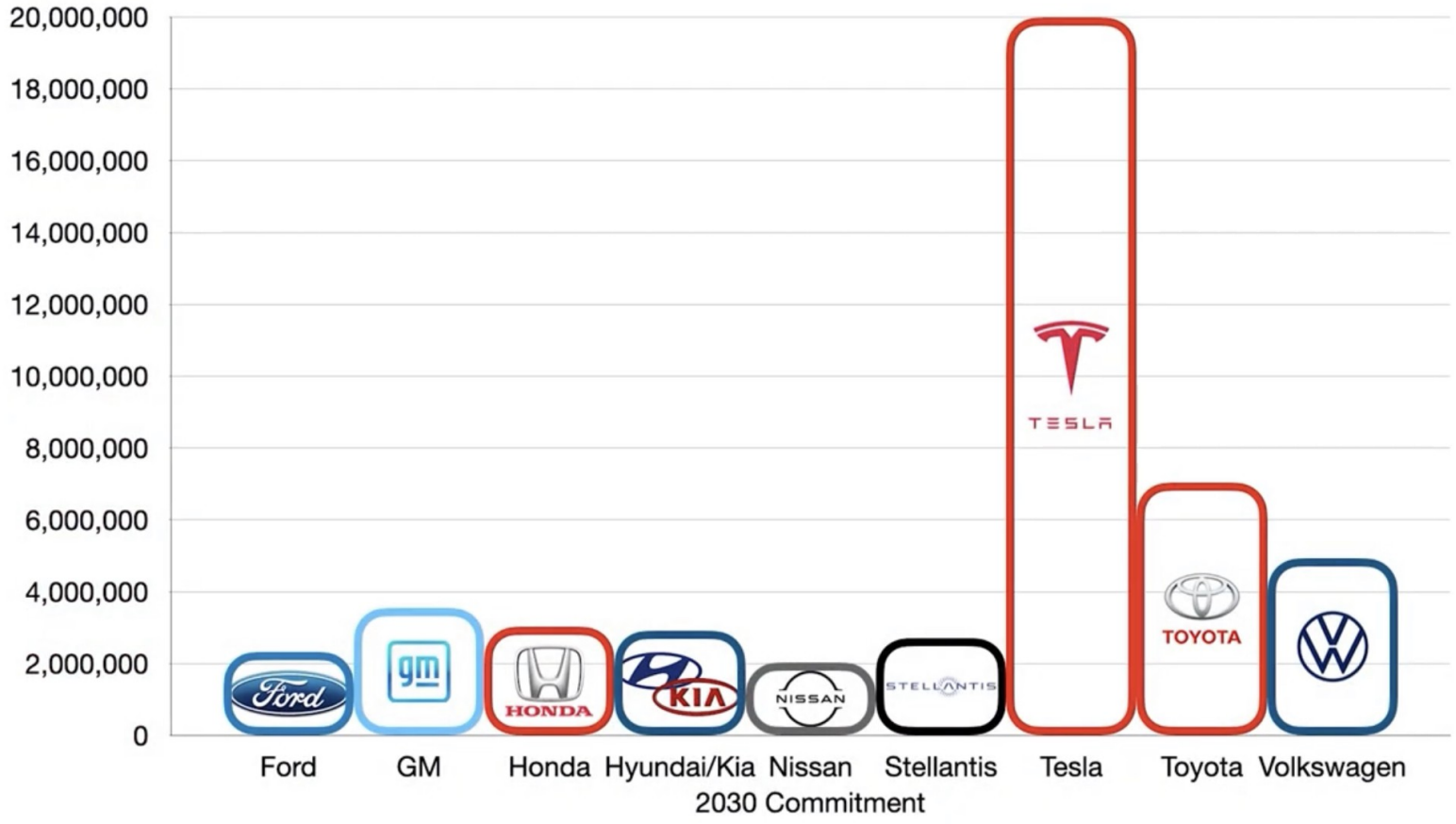
Sample Quality/Hardware Items:

- Most comfortable seats in any car I have driven
- Best car sound system I have heard (better than 5.1 home system)
- Very clean interior design (few buttons/switches, louvers, etc.)
- Roof is all glass (but no heat from sun & stronger than steel)
- Large display for info/map/self driving visualization of environment
- Ride is a bit harsh (tradeoff with handling and weight of 4000 lbs)
- Huge amount of storage for mid sized sedan or SUV

AutoMaker Goals %EV+Hybrid



AutoMaker Goals – Total EV+Hybrid



Useful Links to more Info

Charging

https://www.tesla.com/supercharger
https://www.electrifyamerica.com/locate-charger/
https://www.chargepoint.com/ (Requires registration)
https://www.evgo.com (Requires registration)

CO2 Info

https://www.ucsusa.org/sites/default/files/2020-05/evs-cleaner-than-gasoline.pdf
https://evtool.ucsusa.org (Find CO2 by specific car and location

2020 Tesla Impact Report

https://www.tesla.com/impact-report/2020
https://www.tesla.com/support/voice-commands

EVs are the Future

1000 Free Supercharging Miles for both of us
if you decide to order a Tesla and use this link:
https://ts.la/jamesd62050

Questions, and hopefully, Answers