Battery Electric Vehicles (BEV): A guided history

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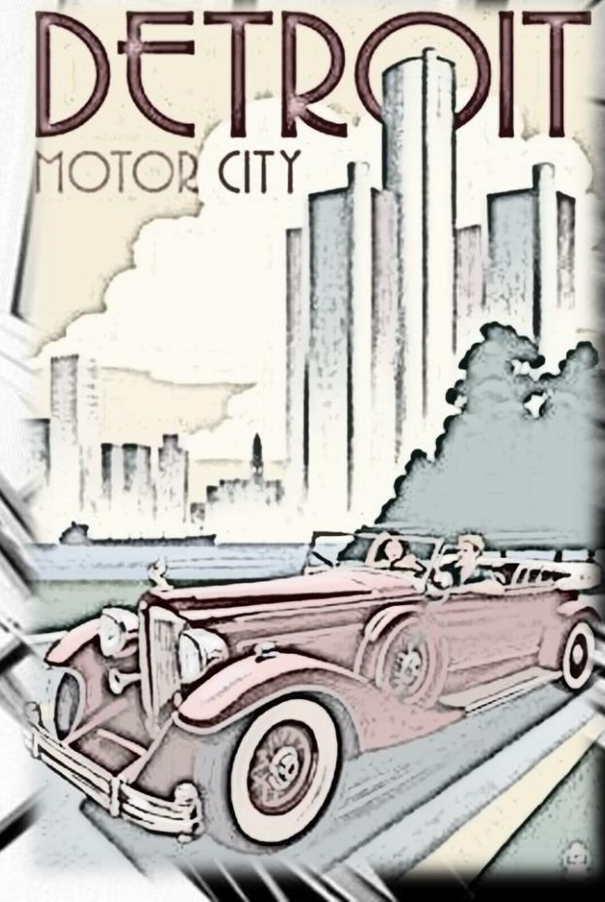
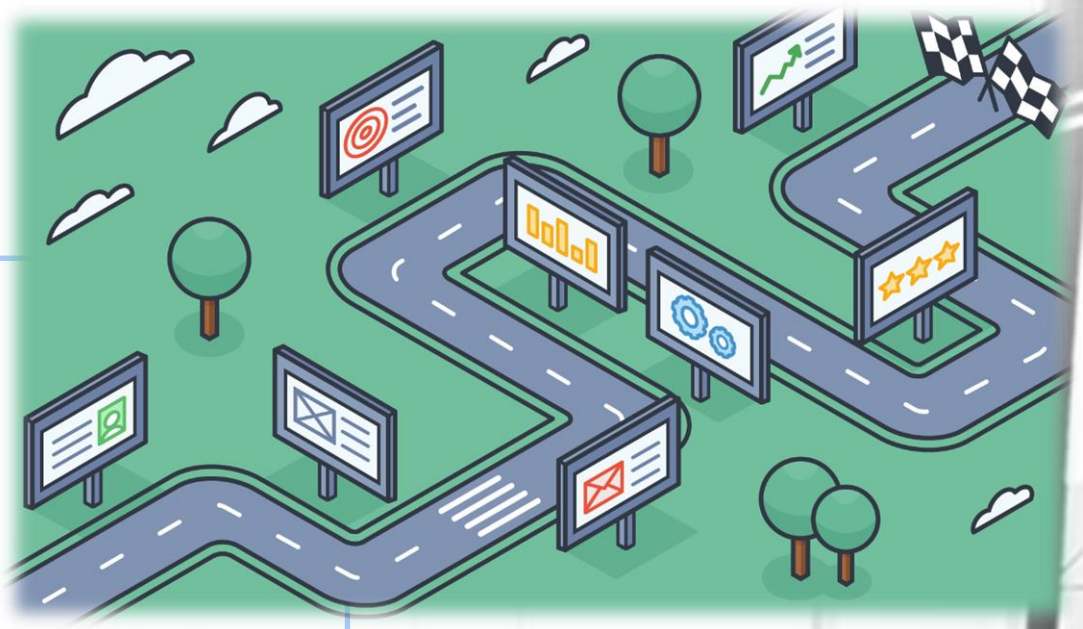


Outline

- Clarification/Terminology
- Early History
- Modern History, Factors
- Outlook

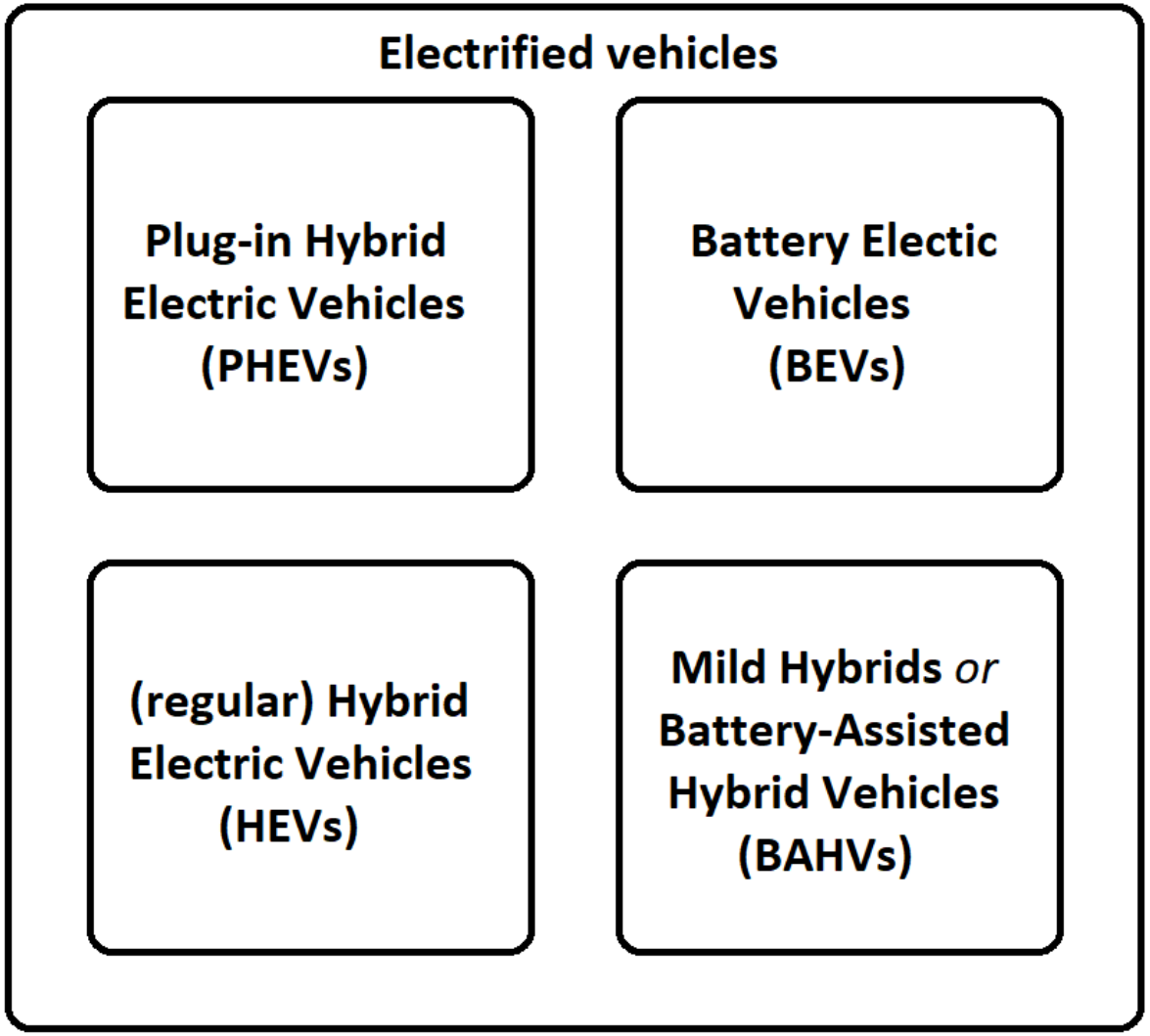


Backup Slides

- *Technologies:*
  - *Batteries*
  - *Energy Efficiency*
  - *Safety*
  - *Controls*
  - *Infrastructure*

Clarification/Taxonomy

- BEV (or pure EV or AEV), distinct from:
  - Hybrids (HEV),
  - mild Hybrids or Battery assisted (BAHV)
  - Plug-in Hybrids (PHEV)
- Low speed EVs, aka NEVs
- Solar Cars
- **NOT COVERED HERE:**
  - *Fuel Cell Vehicle (FCEV), etc.*



Credit: Nederlandse Leeuw

Thru the decades

- Mid-Late 1800s
- 1920s to 1950s
- 1960s to 1990s
- 2000: *Change*
- 2010: *Major milestones*
- 2020: *Present Day*

1830s

- In 1828, Ányos Jedlik invented an early type of electric motor, and created a small model car powered by his new motor.
- Between 1832 and 1839, Scottish inventor Robert Anderson also invented a crude electric carriage.
- In 1835, Professor Sibrandus Stratingh of Groningen, the Netherlands and his assistant Christopher Becker from Germany also created a small-scale electric car, powered by non-rechargeable primary cells

https://blog.upsbatterycenter.com/first-model-electric-car-1828/
http://inventors.about.com/library/weekly/aacarselectrica.htm
https://www.rug.nl/museum/collections/collection-stories/wagentje-van-stratingh

Invention of the Lead-Acid Battery

- 1859 – *Gaston Plante*, later *Camille Alphonse Faure*!
- 1880-1881, *Gustave Trouve*
- 1884-1895: *Thomas Parker*, first production electric car in Wolverhampton
- 1888, German engineer *Andreas Flocken*
- *1891, William Morrison* (Des Moines, Iowa), 6-passenger wagon, top speed of 14 mph

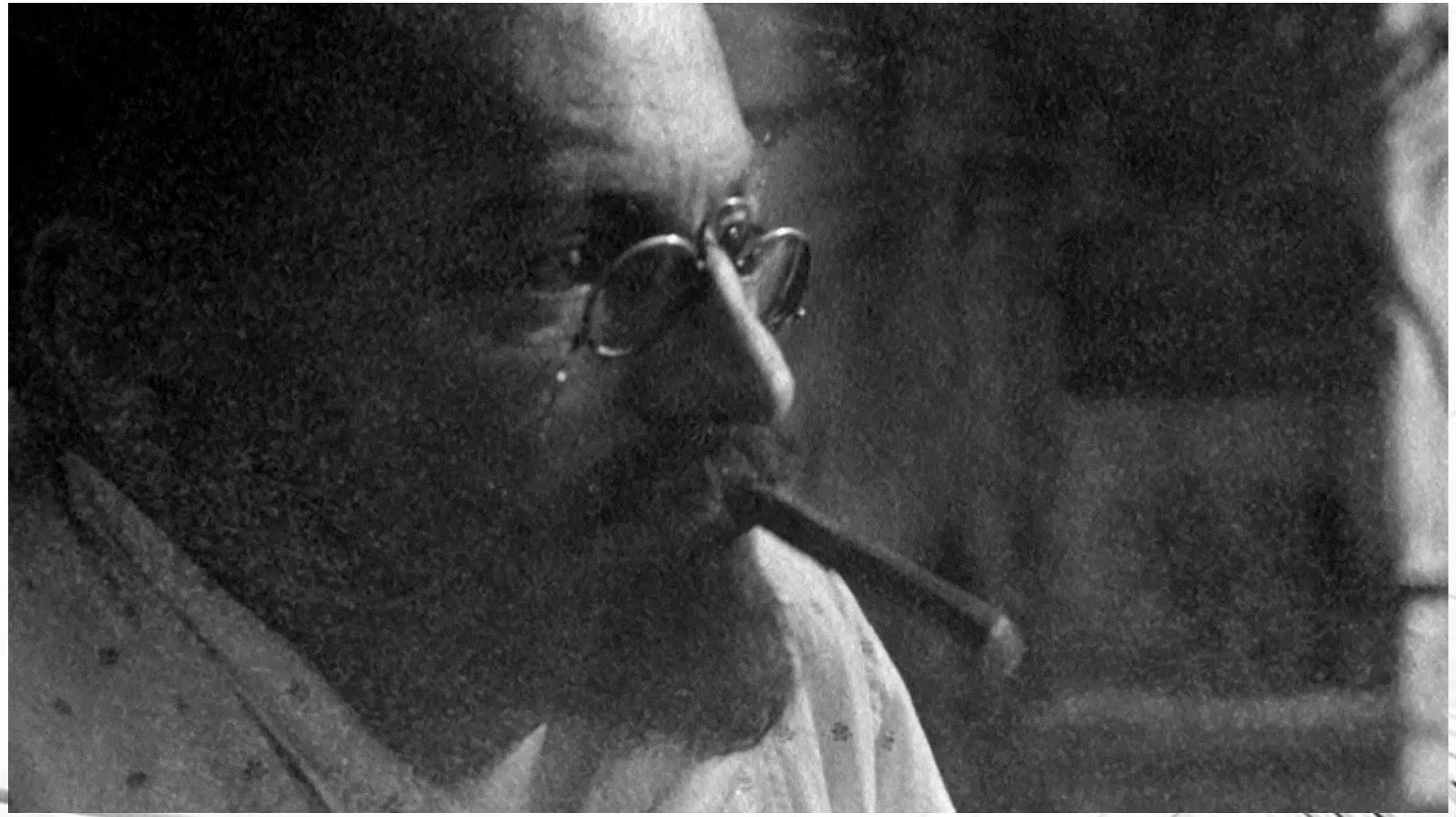
Early Lead of BEV, ….

- Held many speed records
- Advantages:
  - Did not have vibration, smell & noise
  - No gear changes
  - Instant starts
- Electric taxis (London 1897) *"Hummingbirds"*
- Steinmetz video

Thomas Edison and an electric car in 1913

1912: *Detroit Electric* advertisement

Steinmetz video



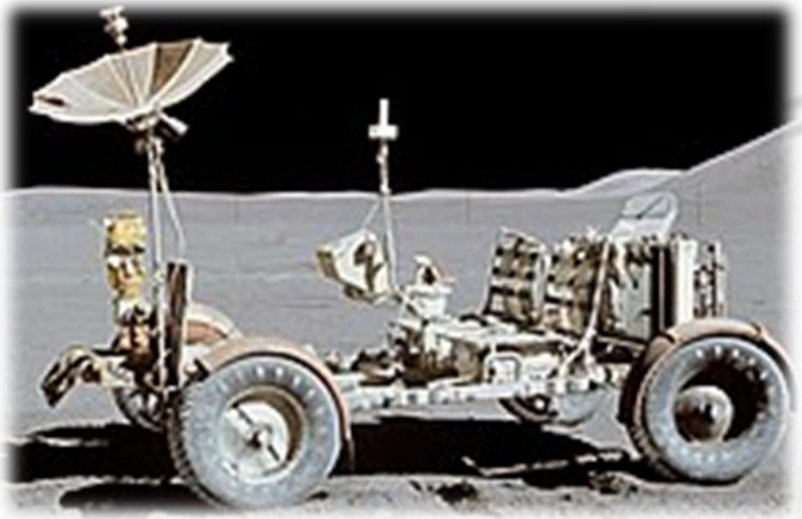
Early Lead of BEV, but ICE jumps ahead

- Disadvantages of ICE were:
  - Hand cranking, considered dangerous
  - Noisy
  - Price of gasoline
  - Manufacturing costs
- All that changed!
  - ***Charles Kettering: invented the electric starter (1912)***
  - ***Milton & Marshall Reeves: invented the muffler (1897)***
  - ***World-wide discovery of petroleum reserves***
  - ***Henry Ford: mass production*** **– Model T**

1920s to 1950s

- Limited to things like:
  - *Forklifts (1923)*
  - *Milk Floats (England)*
  - *Golf carts (Lektro, 1954)*
  - *Postal vans (Germany, 1953)*
  - *Other range-constrained applications*

1970s to 1990s



- Lunar Roving Vehicle
  - Apollo 15 mission
  - Aka “Moon Buggy”,
  - Developed by Boeing+GM Delco Electronics (co-founded by Kettering)
  - DC drive motor in each wheel,
  - 36V Ag-Zn Potassium Hydroxide non-rechargeable battery
- 1990 LA Auto Show, GM unveils the “Impact” electric concept car
- *Electric & Hybrid Vehicle Act of 1976*
- California Air Resources Board *(CARB), changed things!*

1990s to 2000s

- California Air Resources Board *(CARB), ZEV* (zero emissions vehicle)
- GM *EV1, S10 EV pickup,* Chrysler *TEVan,* Ford *Ranger EV pickup,*
- Honda *EV Plus,* Toyota *RAV4 EV,*
- Nissan Lithium-battery *Altra EV mini-wagon*
- *Too many lawsuits, bad taste w/ consumers, oil lobbyists, issues with battery tech, low sales, only some NEV barely survived or were wiped out financially.*

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1990s to 2000s

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- *Too many lawsuits, bad* with battery *tech, low sales, only* wiped out *financially.*

The General Motors EV1, one of the cars introduced due to the California Air Resources Board mandate, had a range of 260 km (160 miles) with NiMH batteries in 1999.

2000s: Major Advances (1)

- *MOSFET* (1959 Bell Labs, Mohamed Atalla & Dawon Kahng), *Power MOSFET* (1969 Hitachi), Single Chip Microprocessor or micro-controllers (1971 Intel)
- The power MOSFET with microcontrollers, led to significant advances in EV technology
- MOSFET power converters allowed operation at much higher switching frequencies, made it easier to drive, reduced power losses, and significantly reduced prices
- Microcontrollers managed all aspects of the drive control and had the capacity for battery management

https://ieeexplore.ieee.org/document/10194391
https://en.wikipedia.org/wiki/Power_MOSFET

2000s: Major Advances (2)

- Switch from Lead-acid, Ni-Cadmium to Lithium-Ion batteries!
- John Goodenough, Rachid Yazami & Akira Yoshino*, see

  "IEEE Medal for Environmental and Safety Technologies Recipients". IEEE Medal for Environmental and Safety Technologies. Institute of Electrical and Electronics Engineers.
- Sony Corporation w/ Asahi Kasei pioneered commercialization of the Lithium-Ion battery

2000s: Major Advances (2)

keyword01 **1991**

In 1991 Sony was the first in the world to commercialize a lithium-ion rechargeable battery, forever changing the history of mobile devices.

1991 was the year Sony lithium-ion rechargeable batteries were first used in mobile phones. By dramatically increasing the energy density from that of conventional rechargeable batteries, Sony was able to solve issues such as the inability to use devices outdoors and the short operational life of dry cell batteries. This year, in turn, served as a turning point completely redefining the history of mobile devices.

Near 2010: EV landscape starts to change

- Tesla Motors (2004) began work on the Roadster (delivered in 2008)
  - Major milestone: 200 mile range per charge
- Mitsubishi i-MiEV (Japan 2009)

N starts to change

- n the Roadster (delivered in 2008)
- er charge

Tesla Roadster

Tesla Roadster Sport 2.5

Overview	
Manufacturer	Tesla, Inc.
Also called	Code name: DarkStar[1]
Production	2008–2012
Assembly	Hethel, UK Menlo Park, California, U.S.

Near 2010: EV landscape starts to change

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Powertrain	
Electric motor	3-phase 4-pole AC induction motor **1.5** 185 kW (248 hp), 270 N·m (200 lb·ft) ***2.0, 2.5** 215 kW (288 hp), 380 N·m (280 lb·ft) ***2.5 Sport** 215 kW (288 hp), 400 N·m (295 lb·ft) (claimed)[4]
Transmission	Single speed BorgWarner fixed gear (8.27:1 ratio)
Battery	53 kWh (190 MJ) lithium-ion at the pack level: 117 Wh/kg and 370 Wh/L) CAC (Capacity) approx. 160 Ah when new

Near 2010: EV landsc

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The Mitsubishi i-MiEV was launched in Japan in 2009

2010s to 2020s: Everybody gets into the act……

- Nissan Leaf (December 2010)
- BYD e6 (October 2011)
- Smart electric drive, Volvo C30 Electric, Ford Focus Electric (2011)
- Tesla Model S (2012), Model X
- BMW ActiveE, Honda Fit EV, Mahindra e20, Chevy Spark EV, Fiat 500e, Mercedes-Benz SLS AMG Electrc Drive, BMW i3, Renault Zoe, Kia Soul EV, etc…
- Chevy Bolt EV concept (2015 NAAS)

2(gets into the act……

The first Nissan Leaf delivered in the U.S. went to a customer in the San Francisco Bay Area

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Retail deliveries of the BMW i3

2010s to 2 e act……

- Nissan Le
- BYD e6 (C
- Smart ele rd Focus Electric (2011)
- Tesla Mod
- BMW Act Chevy Spark EV, Fiat 500e, Drive, BMW i3, Renault Z
- Chevy Bo

The first Chevrolet Bolt EVs were delivered to customers in the San Francisco Bay Area in December 2016[1]

2010s to 2020s: Ev

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- BYD e6 (October 20
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- Tesla Model S (2012
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The Tesla Model S was the top-selling plug-in electric car worldwide in

2010s to 2020s: Everybody gets into the act……

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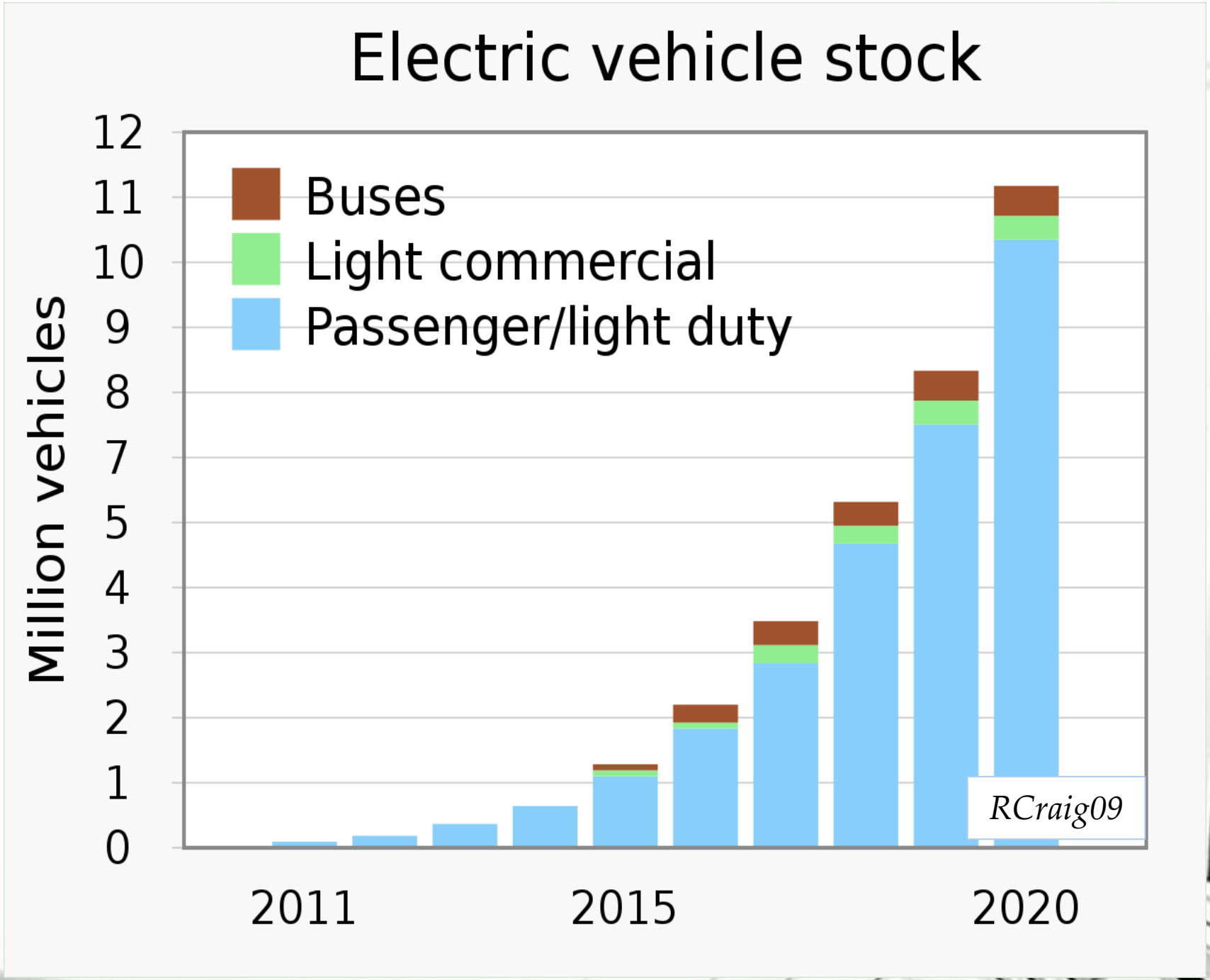
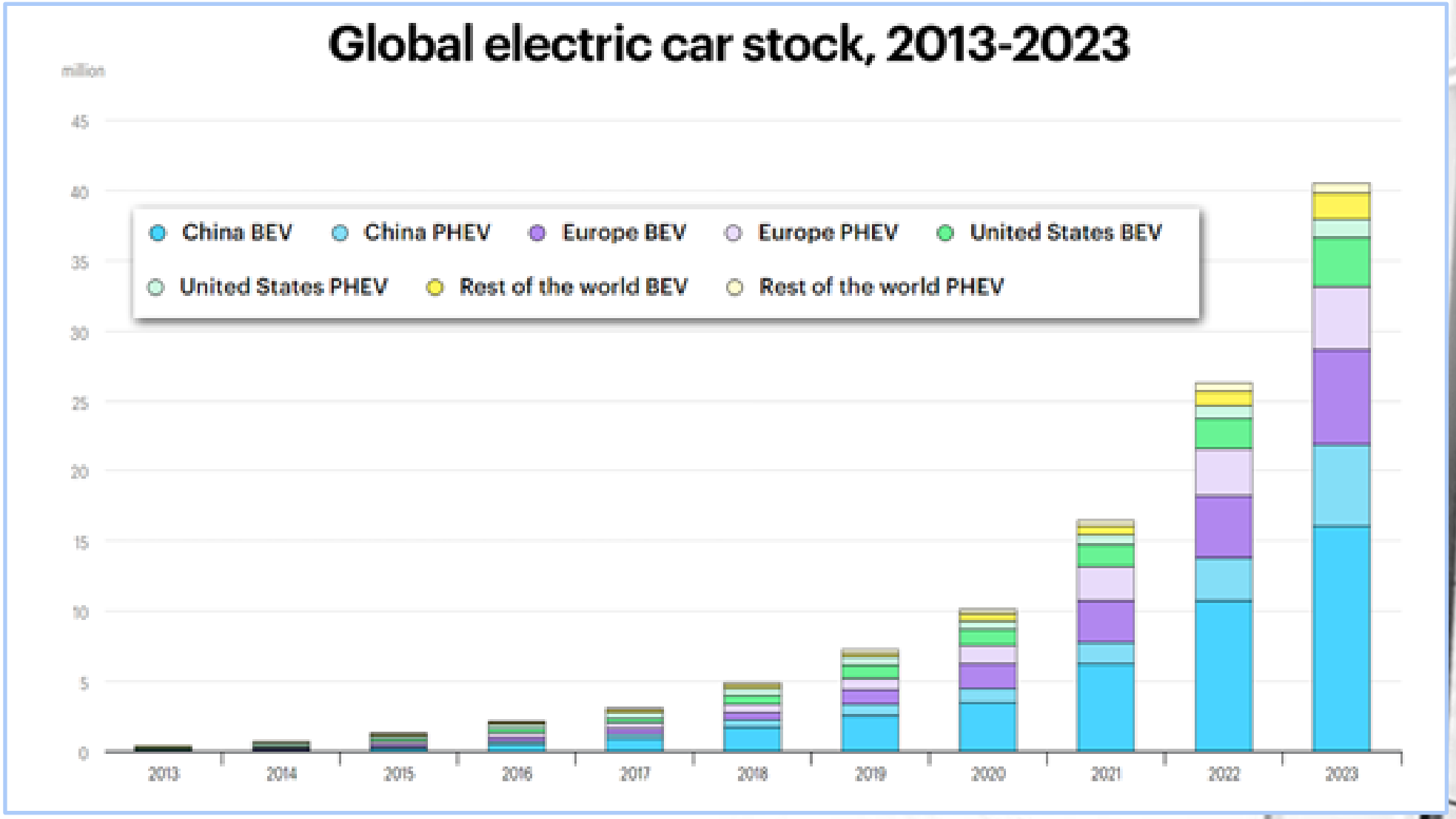
Global sales of the Renault Zoe,

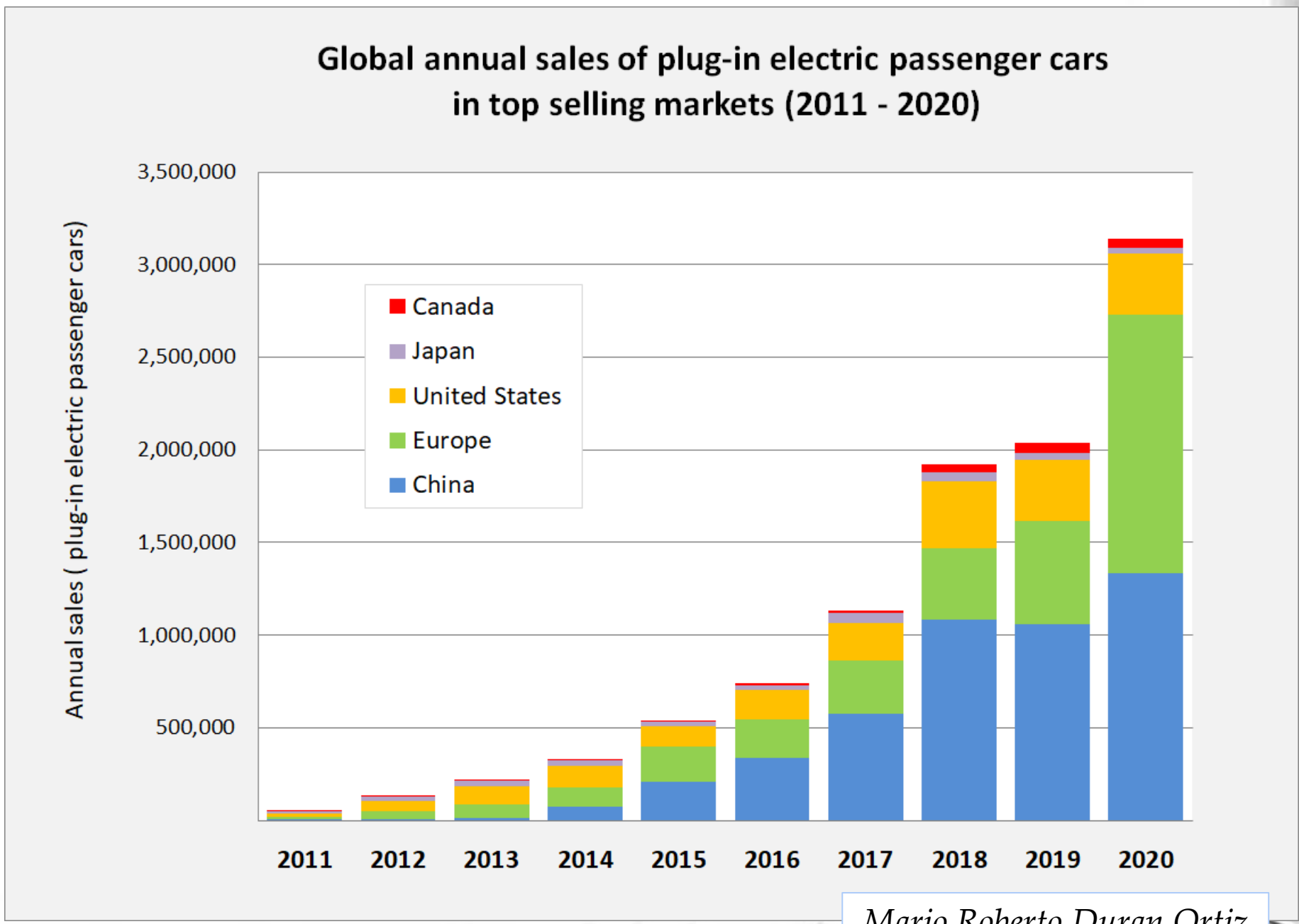
Early-2020s: Outlook.....



Mid-2020s: Outlook.....

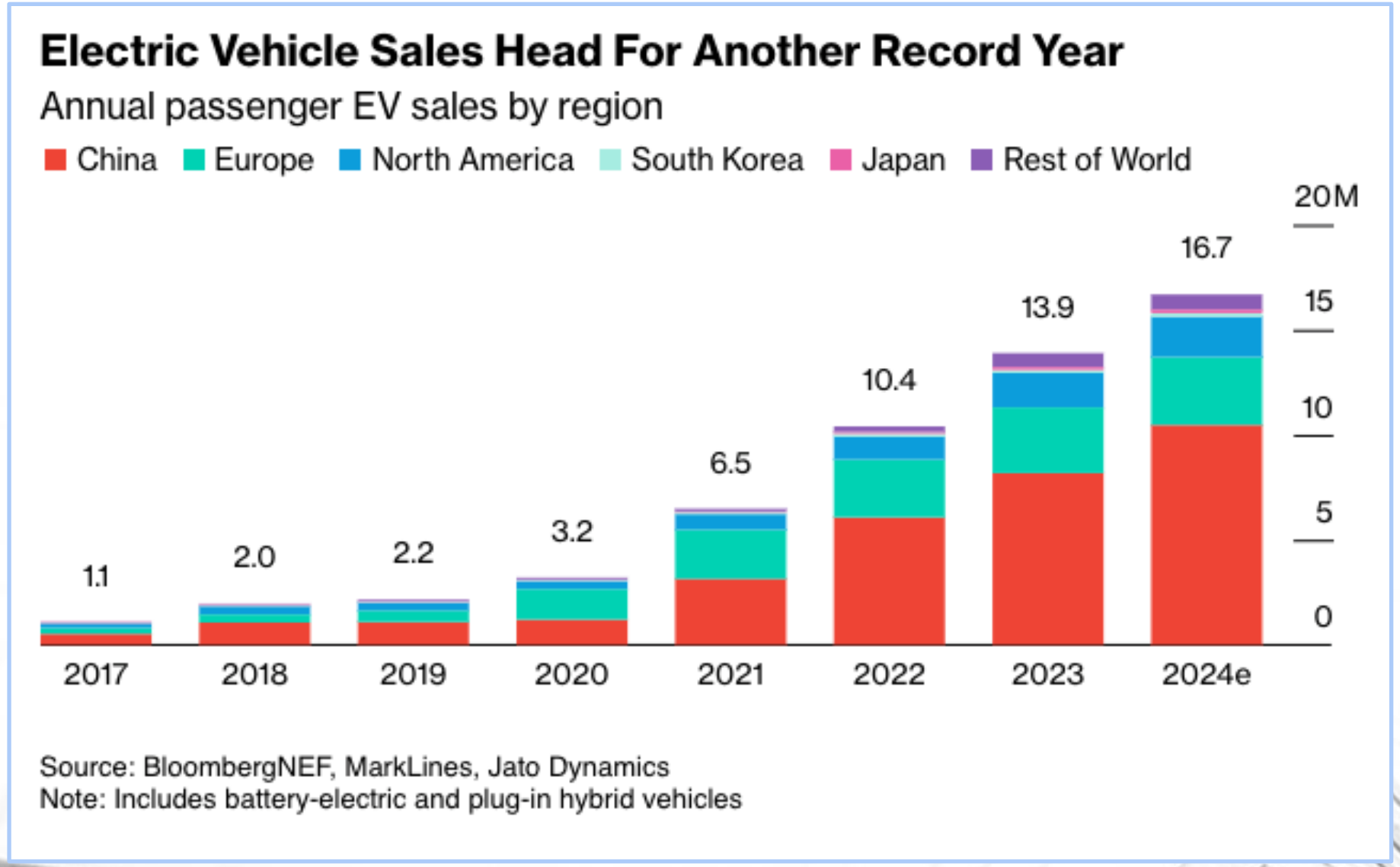


Early-2020s: Outlook.....



Mario Roberto Duran Ortiz

Mid-2020s: Revised Outlook.....



2020s: Outlook…..country targets

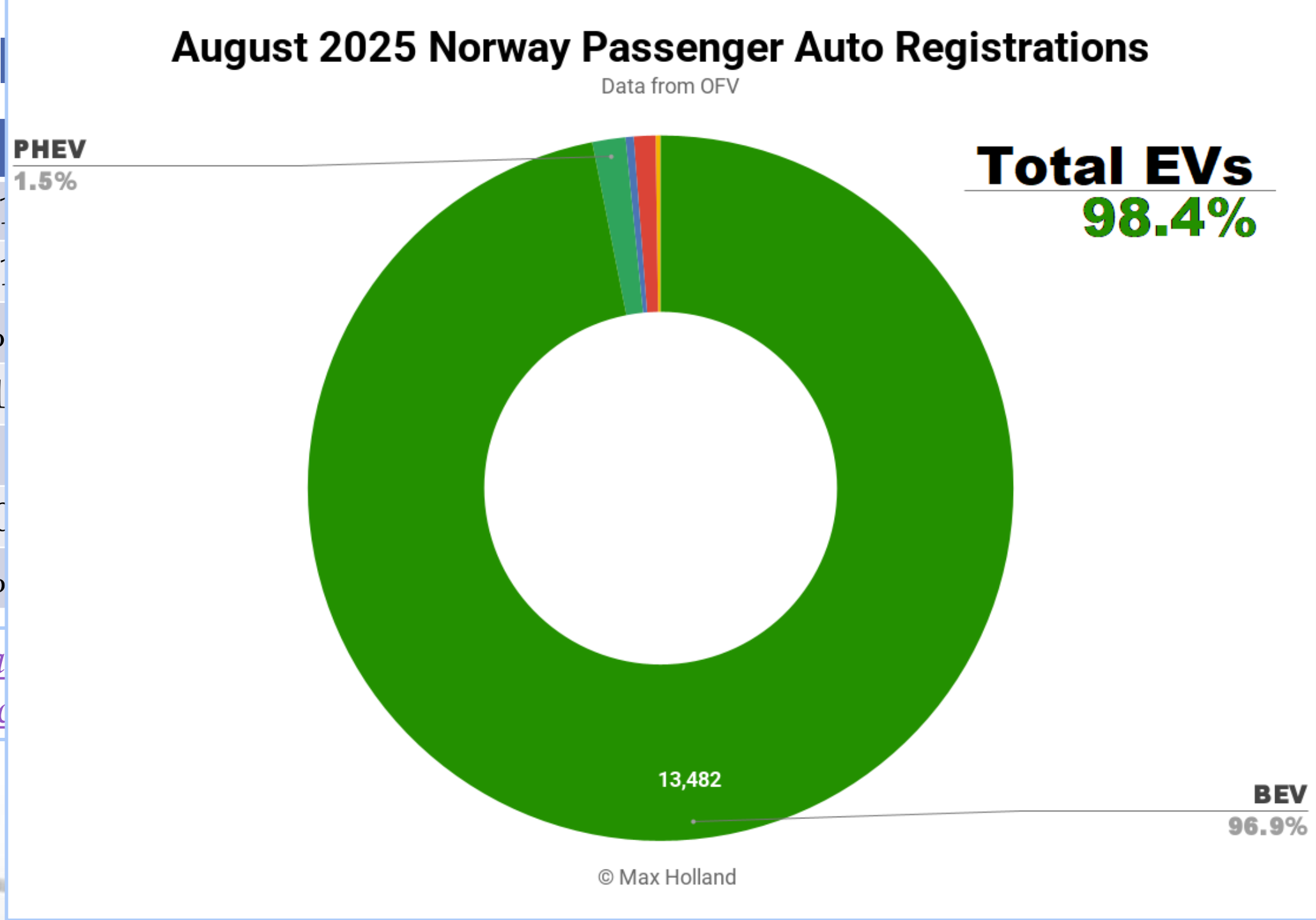
Countries	Year
Norway (100% ZEV sales)	2025
Holland (100% ZEV sales)	2030
UK (100% ZEV sale)	2035
Canada (100% ZEV sales)	2040
Germany (100% ZEV sales)	2050
Japan (100% ZEV/PHEV/HEV sales)	2050
USA (10% ZEV sales)	2050

https://www.iea.org/reports/global-ev-outlook-2020 (*)
https://awaken.com/2025/09/evs-at-a-record-98-4-share-in-norway-kgm-musso-arrives/

2020s: Outl

Norway (1
Holland (1
UK (100%
Canada (1
Germany
Japan (10(
USA (10%

https://www.iea
https://awaken.c



Ethical/Environmental/Practical concerns

- What happens to old batteries??
- Current electric generation infrastructure ***cannot*** support global emissions limits
  - If 100% of vehicles sold per year in the US were BEVs (approximately 16 million), it would require the construction of ~ 10 additional full size 1000 MW power plants *every year*. ***Restated:*** for every 10% of US vehicle sales that are BEVs, another 1000 MW power plant will be required per year.
  - Morgan Stanley estimates that if all US vehicles were BEVs, it would require 1/3 of the entire US generating capacity just to power them
- Doug Patton's presentation: *Why ICE won't disappear overnight…..*

Some recent thoughts (8/3/2022 and 9/17/2025)

- Legislation ($7500 credit) ◀◀ Recent changes!!
- *SAE Smart Brief articles (see slide #67 onwards)*
- *Recent survey claims to show why America buys EVs*
- *New sources of rare earth minerals (South Africa discovery, USA: California, others)*
- *Research Work on Silicon-Carbide battery, other tech*
- *PBS China EV report (video)*

For further reading….

An Extensive Electric Vehicle History

History And Directory Of Electric Cars From 1834 to 1987

The Electric Vehicle and the Burden of History: Kirsch, David A

Taking Charge: The Electric Automobile in America

https://www.energy.gov/timeline/timeline-history-electric-car

https://www.energy.gov/articles/history-electric-car

https://www.smithsonianmag.com/science-nature/the-death-of-the-ev-1-118595941/

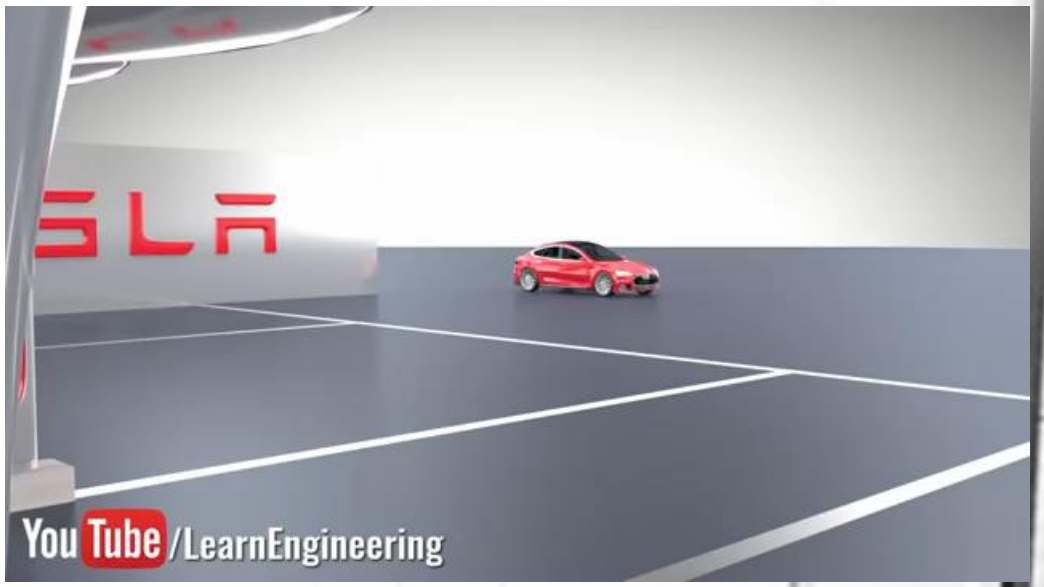
https://www.cnn.com/interactive/2019/07/business/electric-car-timeline/index.html

Post-2021: In case you are interested….

- https://www.pbs.org/video/how-china-is-driving-the-future-of-electric-cars-1570054491/
- http://www.pbs.org/independentlens/revenge-of-the-electric-car/
-

For the impatient ones: (remember to skip ads!)

- Youtube on TESLA (~10 minutes), https://www.youtube.com/watch?v=3SAxXUIre28



- Youtube (UK BEV review site) (~2 minutes), https://www.youtube.com/watch?v=cK4SRldpd8U
- Youtube (TU Delft, academic version), https://www.youtube.com/watch?v=d6B-4cIOGAA

Thank you!

Sharan dot Kalwani @ ieee dot org

If you liked this, feel free to leave some feedback on my Linked page:

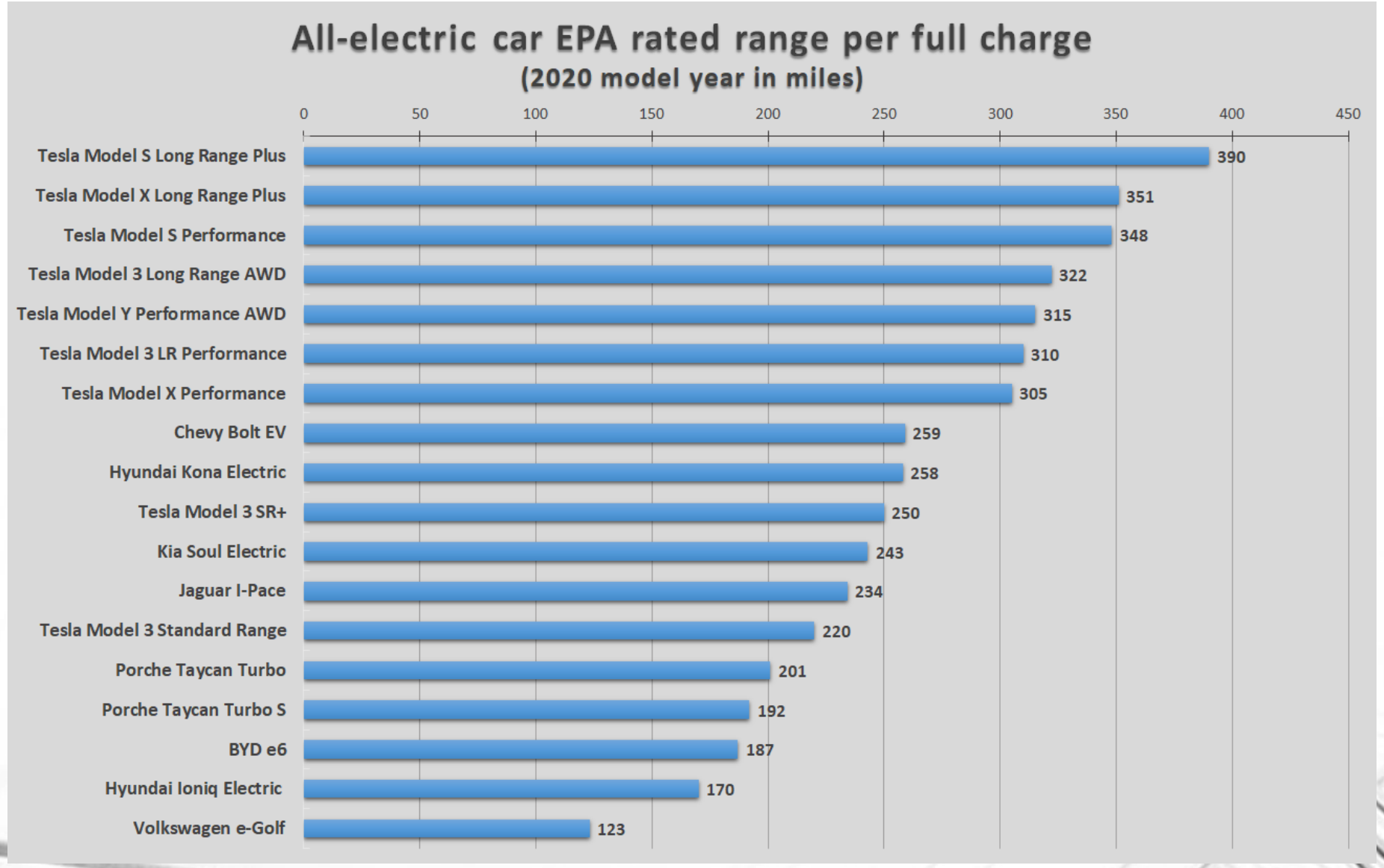
https://www.linkedin.com/in/sharankalwani

Backup Slides (some updates needed!)

Technologies: Battery

- Today: Lithium-Ion dominate
- NiMH (Nickel Metal Hydride) while cheaper, have a poor power-tow-eight ratio
- Zinc-Air maybe lighter
- Many R&D efforts underway globally

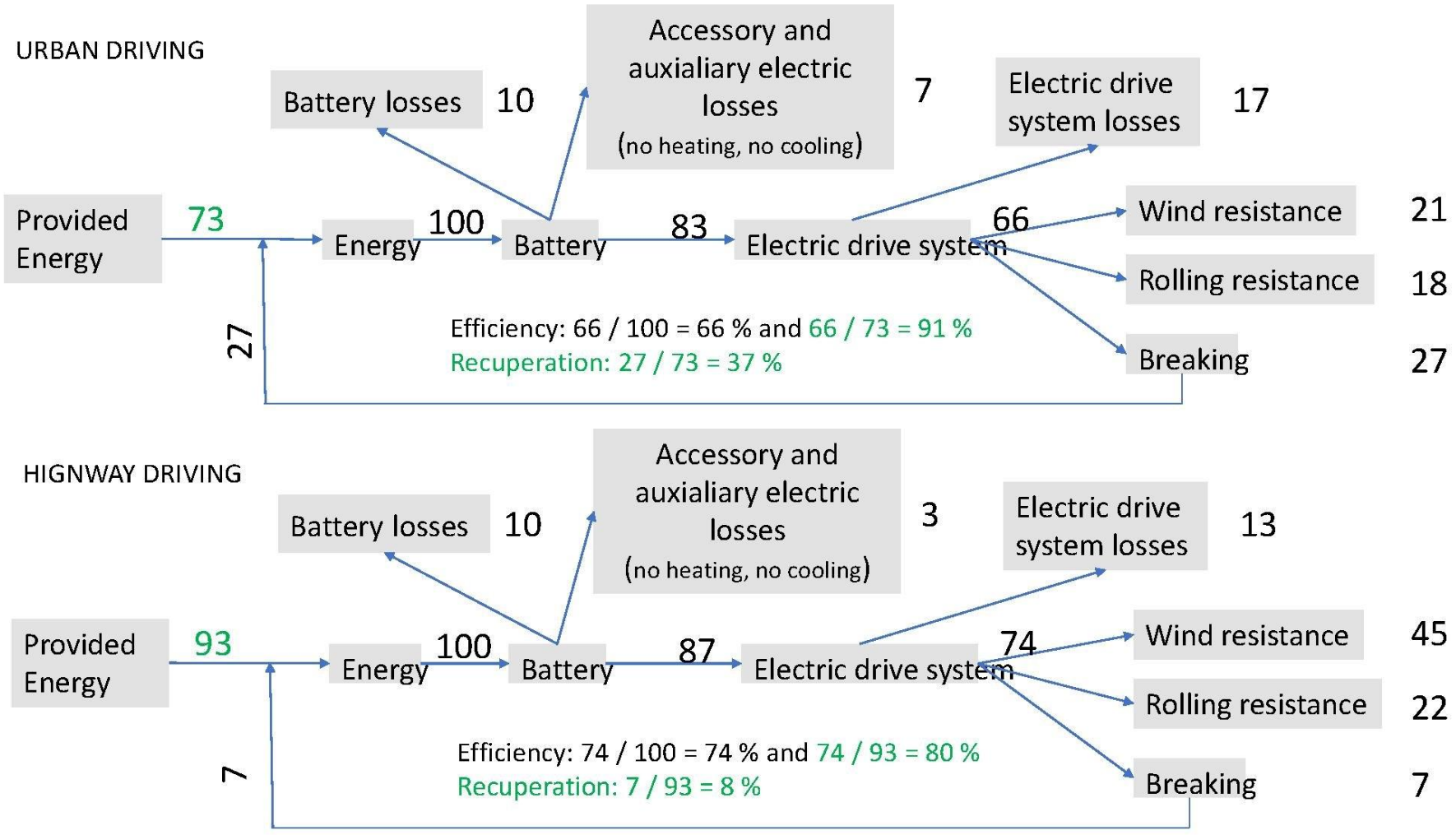
Technologies: Range (*fueleconomy.gov*)



Technologies: Energy Efficiency

- ICE depends on thermodynamic efficiency
  - Petrol/gasoline: ~ 15%
  - Diesel: ~ 20%
  - BEV: ~ 69 to 72% (chemical energy), 59 to 62% (incl. re-charge)
- Electric motors usually more efficient
- Regenerative braking is added tech advantage in BEVs

Technologies: Energy Efficiency



- https://www.fueleconomy.gov/feg/atv-ev.shtml

Technologies: Safety

- On-board electrical energy storage, i.e. battery fire
- Functional Safety, heavy battery weight, need for stronger body structures and light weighting
- Electrical hazards

Technologies: Charging Infrastructure

- Itself merits a full 1-hour discourse! (Gene Saltzberg event earlier in 2021)
- Charging stations have different speeds, connectors
- Vehicle to Grid (V2G) – also merits another session!

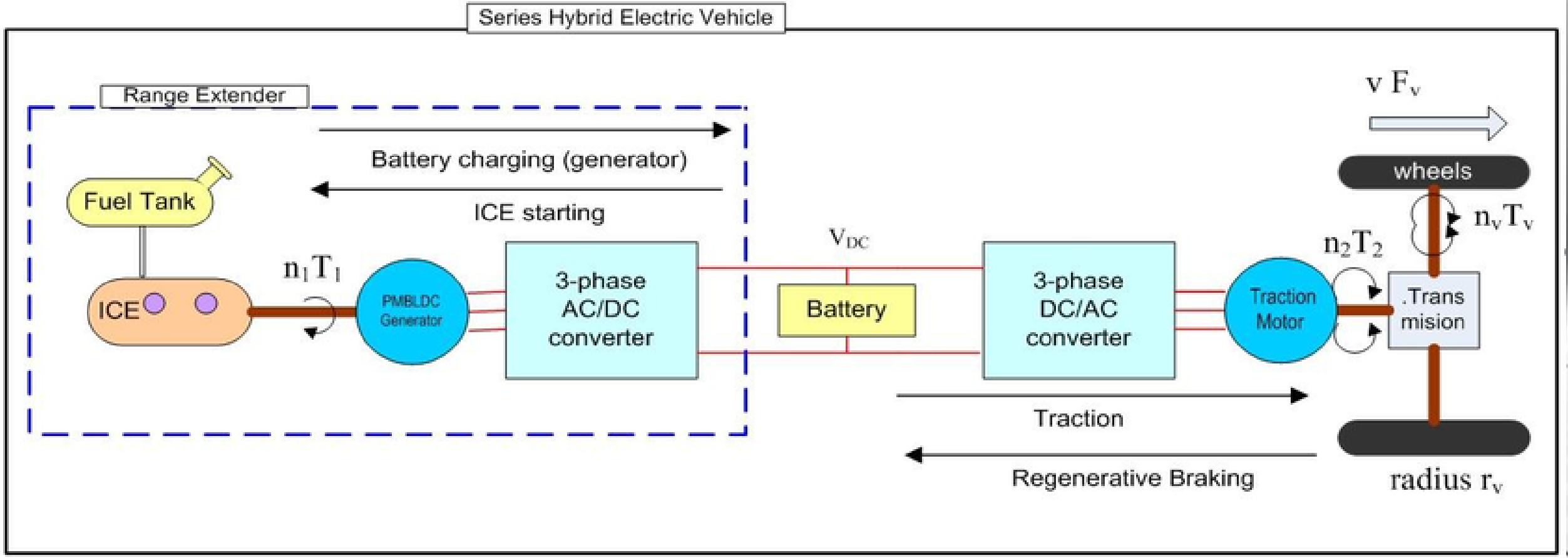
Technologies: Controls (remember to skip ads!)

- Youtube (~10 minutes), https://www.youtube.com/watch?v=3SAxXUIre28
- Youtube (~2 minutes), https://www.youtube.com/watch?v=cK4SRldpd8U
- Youtube (academic version), https://www.youtube.com/watch?v=d6B-4cIOGAA

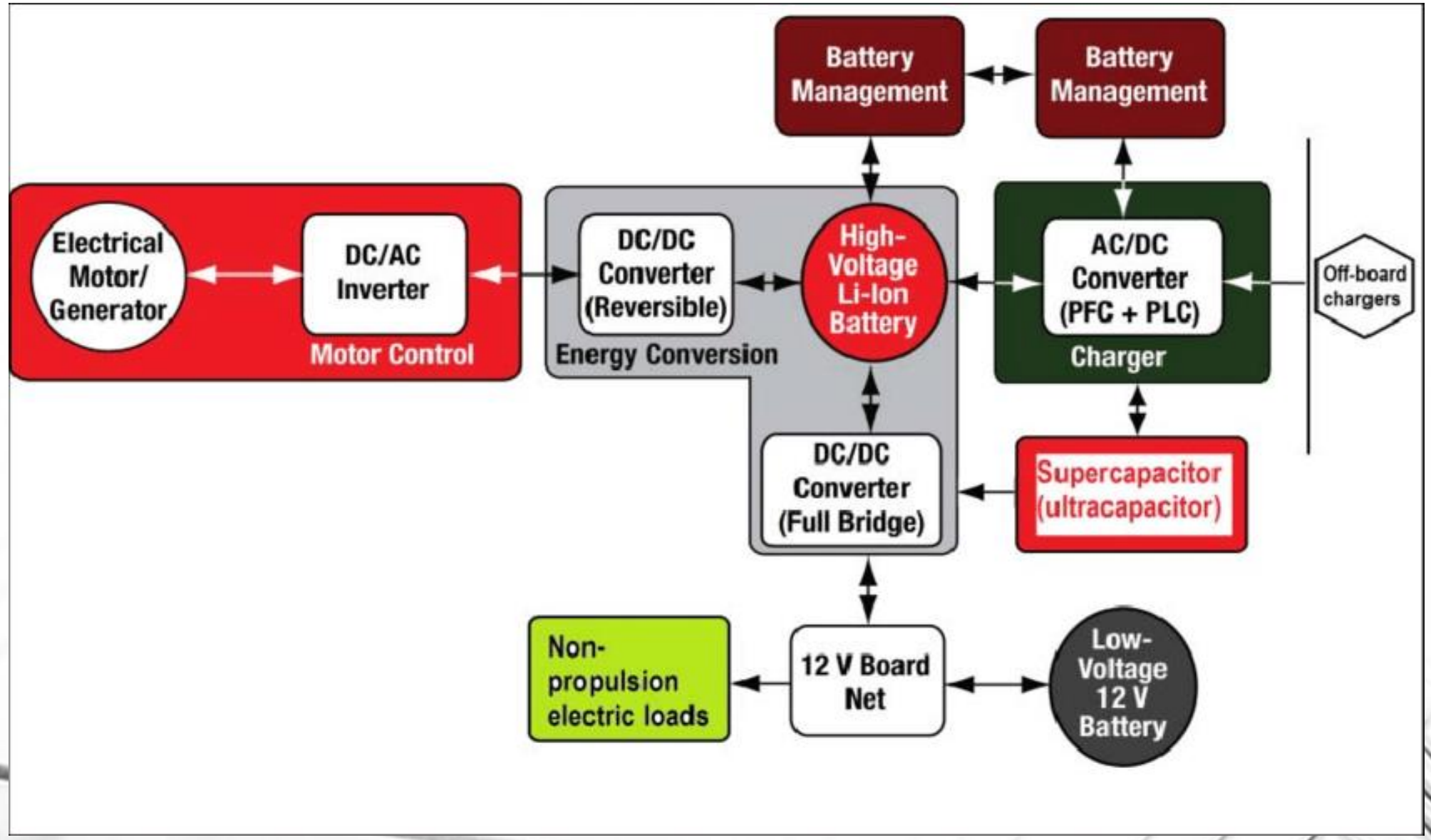
- An **electric** powered **car** has **three primary components**. These are the **electric** engine, motor controller, and battery.
- There are two basic **types of EVs**: all-**electric vehicles** (AEVs) and plug-in hybrid **electric vehicles** (PHEVs). AEVs include Battery **Electric Vehicles** (BEVs) and Fuel Cell **Electric Vehicles** (FCEVs).
- **Electric cars** function by plugging into a charge point and taking **electricity** from the grid. They store the **electricity** in rechargeable batteries that power an **electric motor**, which turns the wheels. **Electric cars** accelerate faster than **vehicles** with traditional fuel engines – so they feel lighter to drive.

- There are three **main types of hybrid vehicle**; full **hybrids**, mild **hybrids** and plug-in **hybrids**. A full **hybrid** (FHEV) can run on just the combustion engine (i.e. diesel/petrol), the electric engine (i.e. power from batteries), or a combination. The Toyota Prius is the most commonly known example of this.

Series Hybrid EV



Power systems architecture



To calculate the **cost per mile** of an **EV**, the **cost** of **electricity** (in dollars **per** kWh) and the efficiency of the **vehicle** (how much **electricity** is used to travel 100 **miles**) must be known.

If **electricity costs** $0.13 **per** kWh and the **vehicle** consumes 33 kWh to travel 100 **miles**, the **cost per mile** is about $0.04.

Ref: https://avt.inl.gov/sites/default/files/pdf/fsev/costs.pdf

Comparing Energy Costs per Mile for Electric and Gasoline-Fueled Vehicles The fuel cost of driving an electric vehicle depends on the cost of electricity per kilowatt-hour (kWh) and the energy efficiency of the vehicle. For example, to determine the energy cost per mile of an electric vehicle, select the location on the left axis (Electricity Cost per kWh) at 10 cents in the graph below. Draw a horizontal line to the right until you bisect the EV 3 mi/kWh line. Now draw a vertical line down until you bisect the bottom axis (Energy Cost per Mile). This tells you that the fuel for an electric vehicle with an energy efficiency of 3 miles per kWh costs about 3.3 cents per mile when electricity costs 10 cents per kWh. The national average cost for electricity in the U.S. is about 10 cents per kWh, while the average residential rate is about 11.7 cents per kWh. Some electric utilities have historically had electric vehicle charging rates that vary by time of use, day, and season. In the past, these rates have ranged from 3 cents to as high as 50 cents per kWh. Older electric vehicles have energy efficiencies of about 2 miles per kWh. Some electric vehicles, such as the EV1 from General Motors, had energy efficiencies of over 6 miles per kWh under some testing.

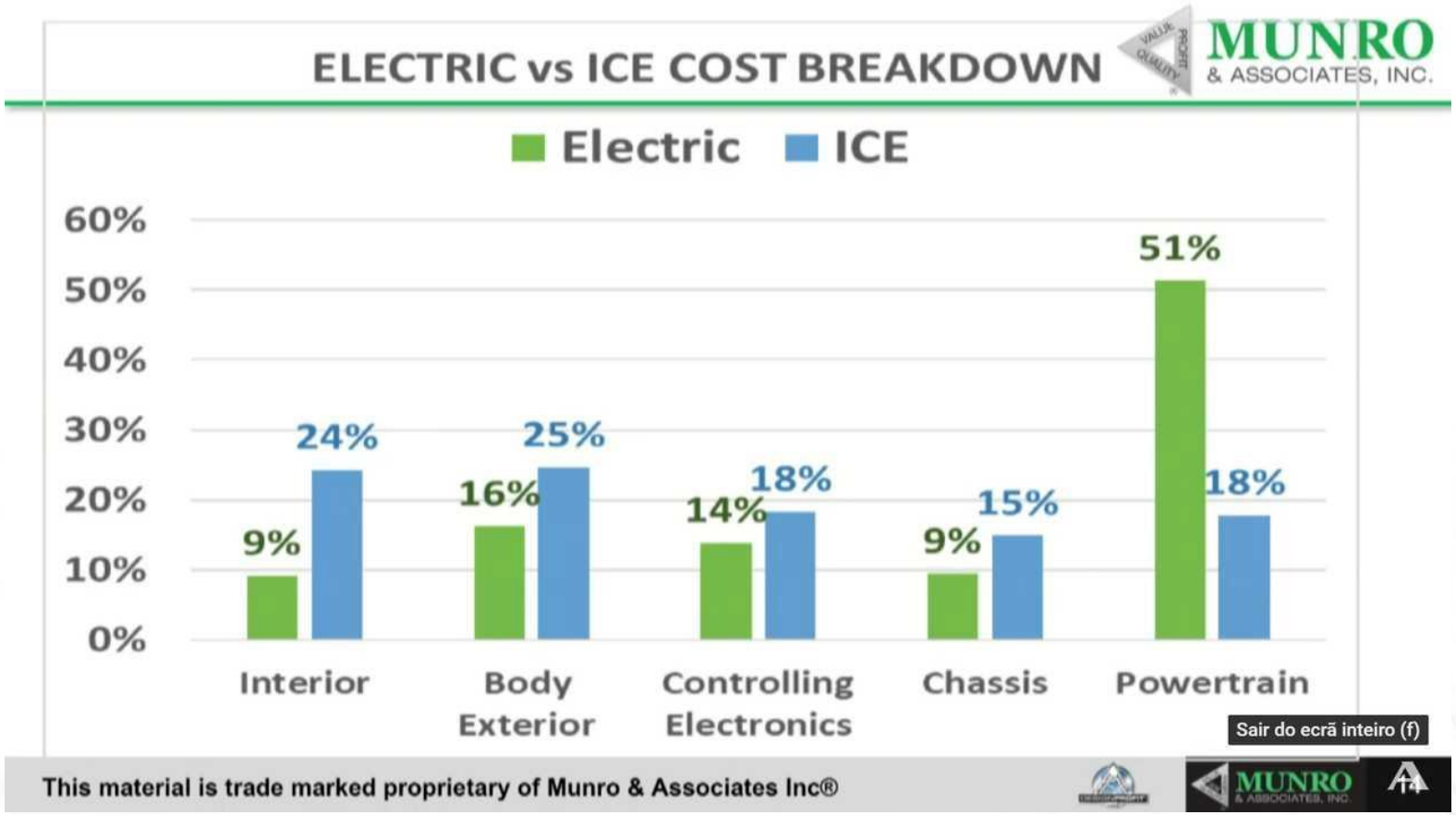
Lifetime costs

EVs have lower lifetime maintenance costs—and lower costs overall—compared to comparable gas-powered vehicles.

BEVs and PHEVs have similar lifetime costs. The cost savings of EV ownership are only expected to increase with new models and battery cost reductions

Consumer Reports Study Finds Electric Vehicle Maintenance Costs Are 50% Less Than Gas-Powered Cars, *November 2020*

Ref: https://leandesign.com/ev-vs-ice-cost-breakdown-and-its-effects-on-ev-adoption/



Sandy's cost breakdown shows 51% of the cost of an EV is in its powertrain, compared to only 18% for an ICE vehicle. To which Ruffo states, "Munro clarifies that battery packs, inverters, and controllers are as much part of the EV powertrain as are the motors and any transmission an EV decides to use, such as the Porsche Taycan's. Anyway, if he broke down the powertrain components' share in the total cost, the battery pack would undoubtedly be responsible for most of it."

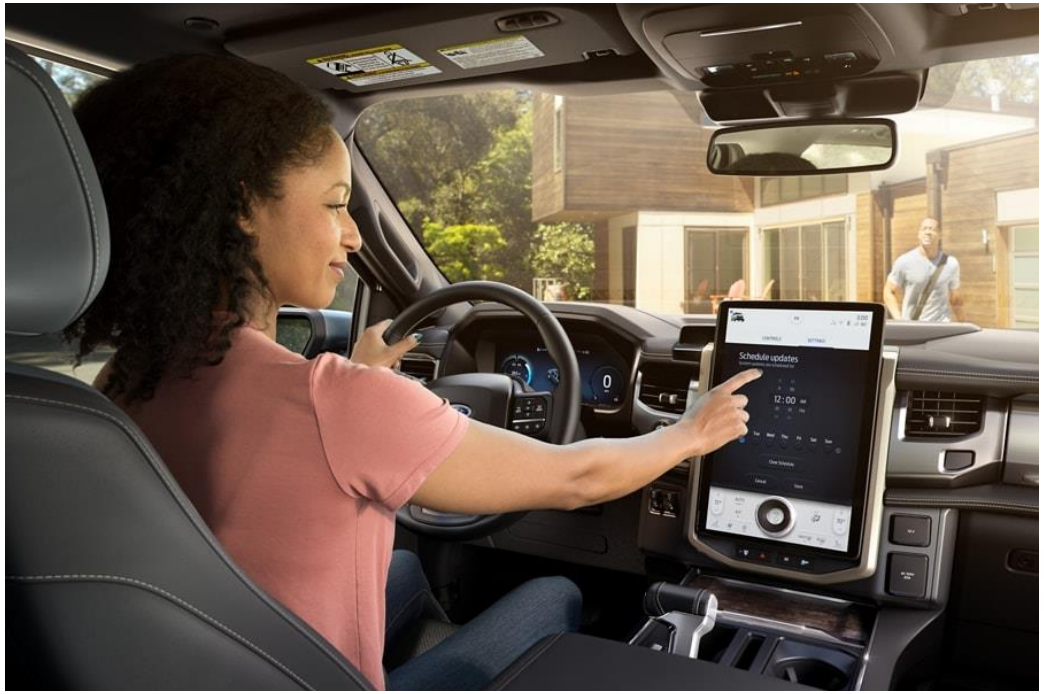
Currently, there are 8 electric cars on sale in India. Of these, the Strom Motors R3 is the cheapest EV while the Jaguar I-Pace is the most expensive electric car in India. Upcoming electric cars in India include BMW i3,Haima Bird Electric EV1 and Tata Altroz EV among others.

Cost Rs 5 Lakhs to 1.5 Crore

USA

F-series is America’s best-selling truck for 44 years* for a reason. And now, it’s charging into the future with the all-new, all-electric 2022 Ford F-150 Lightning. It’s the first ever F-Series that’s gas-free and offers more purposeful technology, an elevated driving experience and trusted Built Ford Tough capability. Offering an ingenious array of connected, intelligent features with over-the-air Software Updates to help ensure your truck can get even better over time.

F 150



Recent news

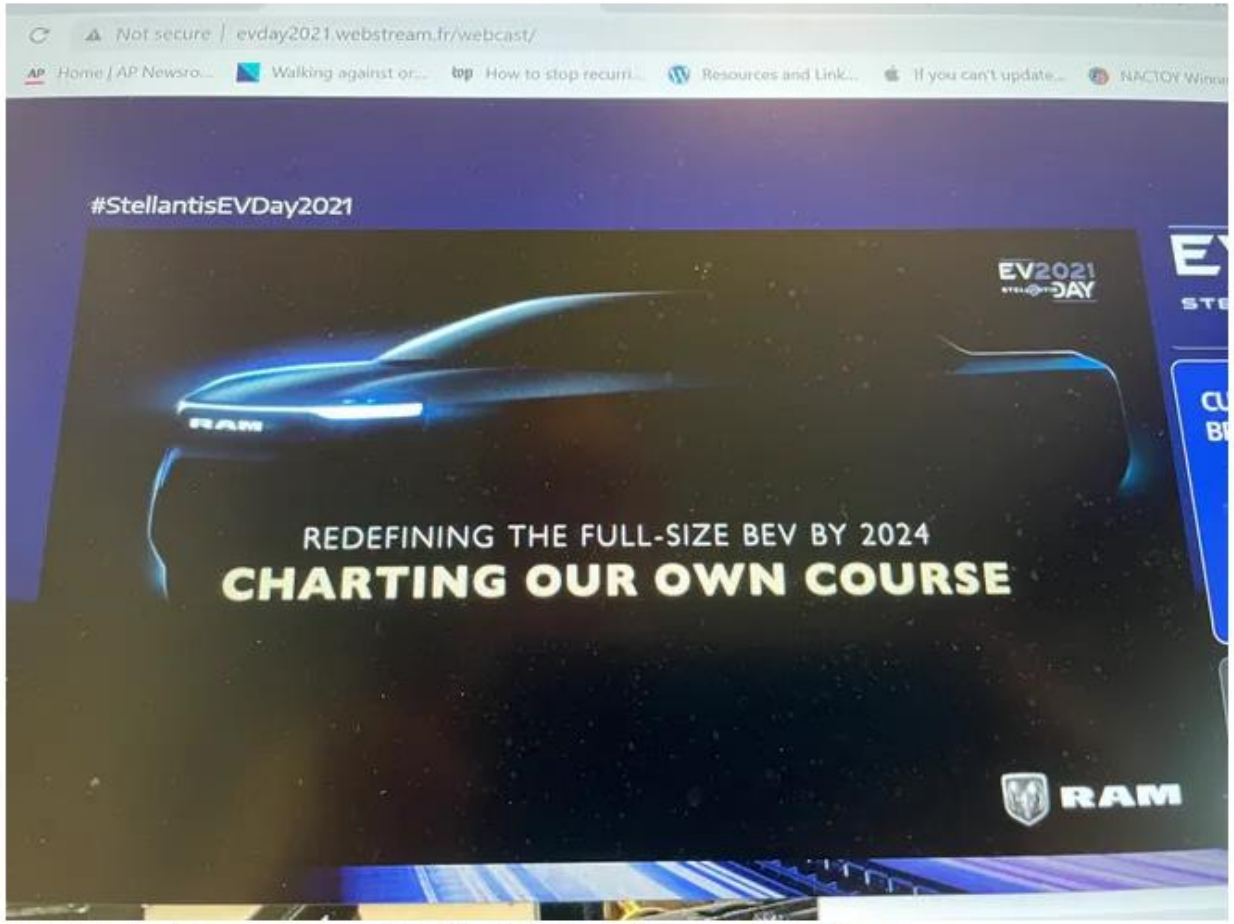
- Stellantis announces major thrust in BEVs, small/medium/large platforms
- https://www.freep.com/story/money/cars/chrysler/2021/07/08/stellantis-electric-ram-dodge-muscle/7899392002/

Recent news

- Stellantis announces major thrust in BEVs, s
- https://www.freep.com/story/money/cars/cl
  dodge-muscle/7899392002/

Stellantis announced Thursday that it would begin production on a battery-electric version of its popular pickup, one of its most profitable and important vehicles, in 2024.

Mike Koval Jr., Ram brand CEO, pledged that the "class-shattering" pickup would surpass the offerings of the brand's competitors, namely the electric versions of the Ford F-150 and the Chevrolet Silverado.



Stellantis is planning an electric Ram 1500 pickup in 2024. *Eric D. Lawrence/Detroit Free Press*

Recent news

- GM earlier announced aggressive EV plans
- https://www.reuters.com/business/sustainable-business/exclusive-gm-turns-supplier-build-initial-ev-vans-while-it-readies-plant-canada-2021-07-12/
- https://finance.yahoo.com/news/general-motors-preparing-shock-ev-125928234.html

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- https://www.reuters.com/business/sustainabl
  build-initial-ev-vans-while-it-readies-plant-ca
- https://finance.yahoo.com/news/general-mot

July 12, 2021
2:56 PM EDT
Last Updated 4 hours ago

Sustainable Business

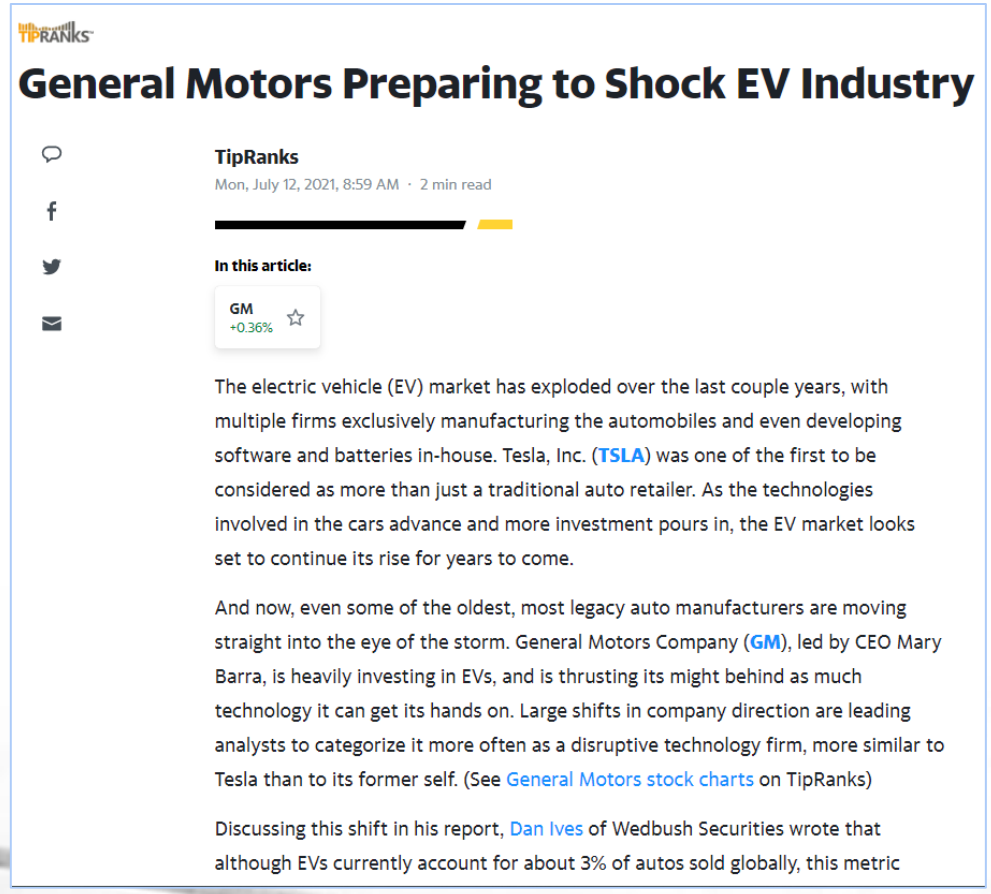
GM turns to supplier to build initial EV vans while it readies plant in Canada

5 minute read

Ben Klayman

Recent news

- GM earlier announced aggressive EV plans
- https://www.reuters.com/business/sustainable-business/exclusive-gm-turns-supplier-build-initial-ev-vans-while-it-readies-plant-canada-2021-07-12/
- https://finance.yahoo.com/news/general-motors-preparing-shock-ev-125928234.html



TIPRANKS

General Motors Preparing to Shock EV Industry

TipRanks

Mon, July 12, 2021, 8:59 AM · 2 min read

In this article:

GM
+0.36%

The electric vehicle (EV) market has exploded over the last couple years, with multiple firms exclusively manufacturing the automobiles and even developing software and batteries in-house. Tesla, Inc. (TSLA) was one of the first to be considered as more than just a traditional auto retailer. As the technologies involved in the cars advance and more investment pours in, the EV market looks set to continue its rise for years to come.

And now, even some of the oldest, most legacy auto manufacturers are moving straight into the eye of the storm. General Motors Company (GM), led by CEO Mary Barra, is heavily investing in EVs, and is thrusting its might behind as much technology it can get its hands on. Large shifts in company direction are leading analysts to categorize it more often as a disruptive technology firm, more similar to Tesla than to its former self. (See General Motors stock charts on TipRanks)

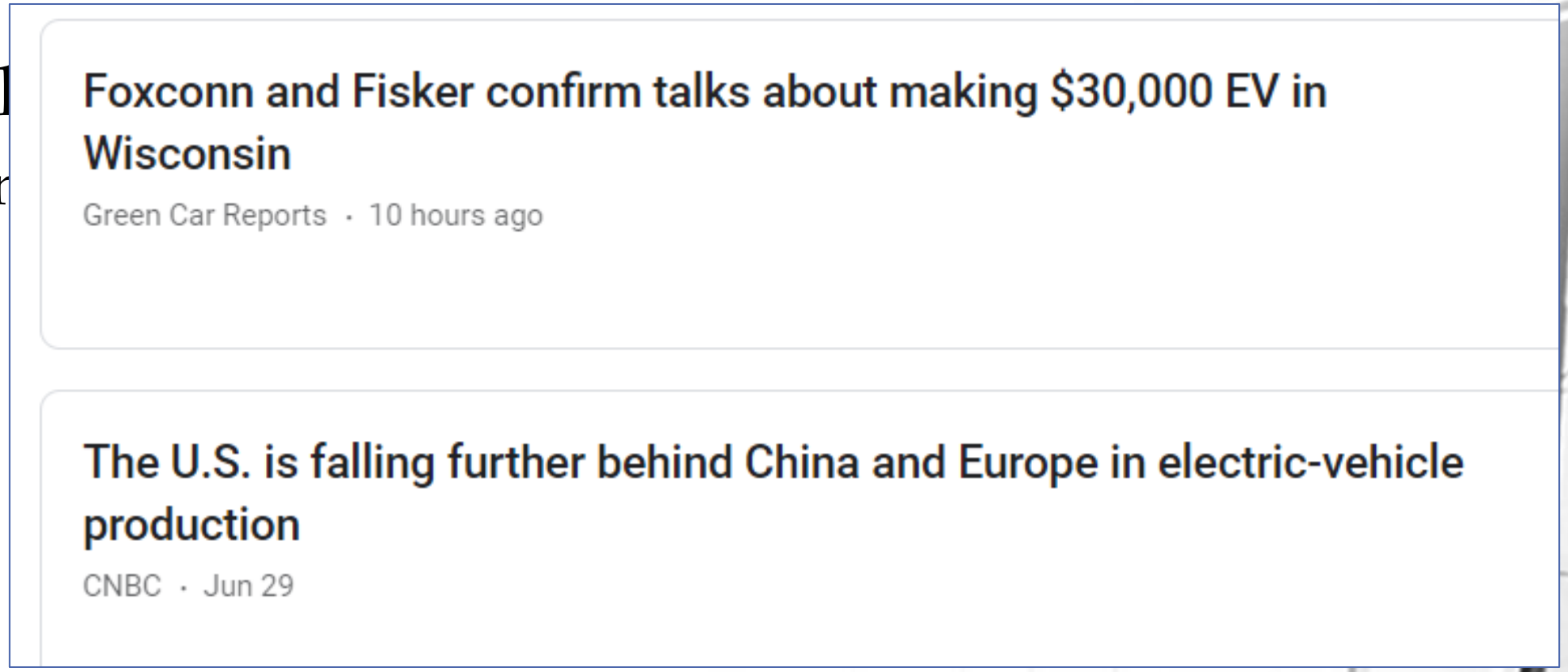
Discussing this shift in his report, Dan Ives of Wedbush Securities wrote that although EVs currently account for about 3% of autos sold globally, this metric

Recent news

- Everybody has firm EV plans:
  - Volkswagen: a ton of ***ID.4*** ads during the current Euro 2020
  - Mercedes
  - Ford
  - BMW
  - Hyundai
  - Toyota
  - Audi
  - *Long list of Chinese majors……*
  - A total of $300 billion being spent by 29 major automakers (2022 estimate)

Recent news

- Everybody l
  - Volkswager
  - Mercedes
  - Ford
  - BMW
  - Hyundai
  - Toyota
  - Audi
  - *Long list of Chinese majors……*
- A total of $300 billion being spent by 29 major automakers



Recent news (2022 vintage)

- Newer EVs that came to market and are popular (Lucid Air, Tesla Model X, Tesla Model Y, GMC Hummer, Rivian, Ford F-150 Lightning).
- DC fast charging is becoming more prevalent that makes charging much faster, many OEMs offer 150kW capability whereby we can charge the battery to provide 200-miles in about ~15 minutes

SAE Smart Brief

AUTOMOTIVE

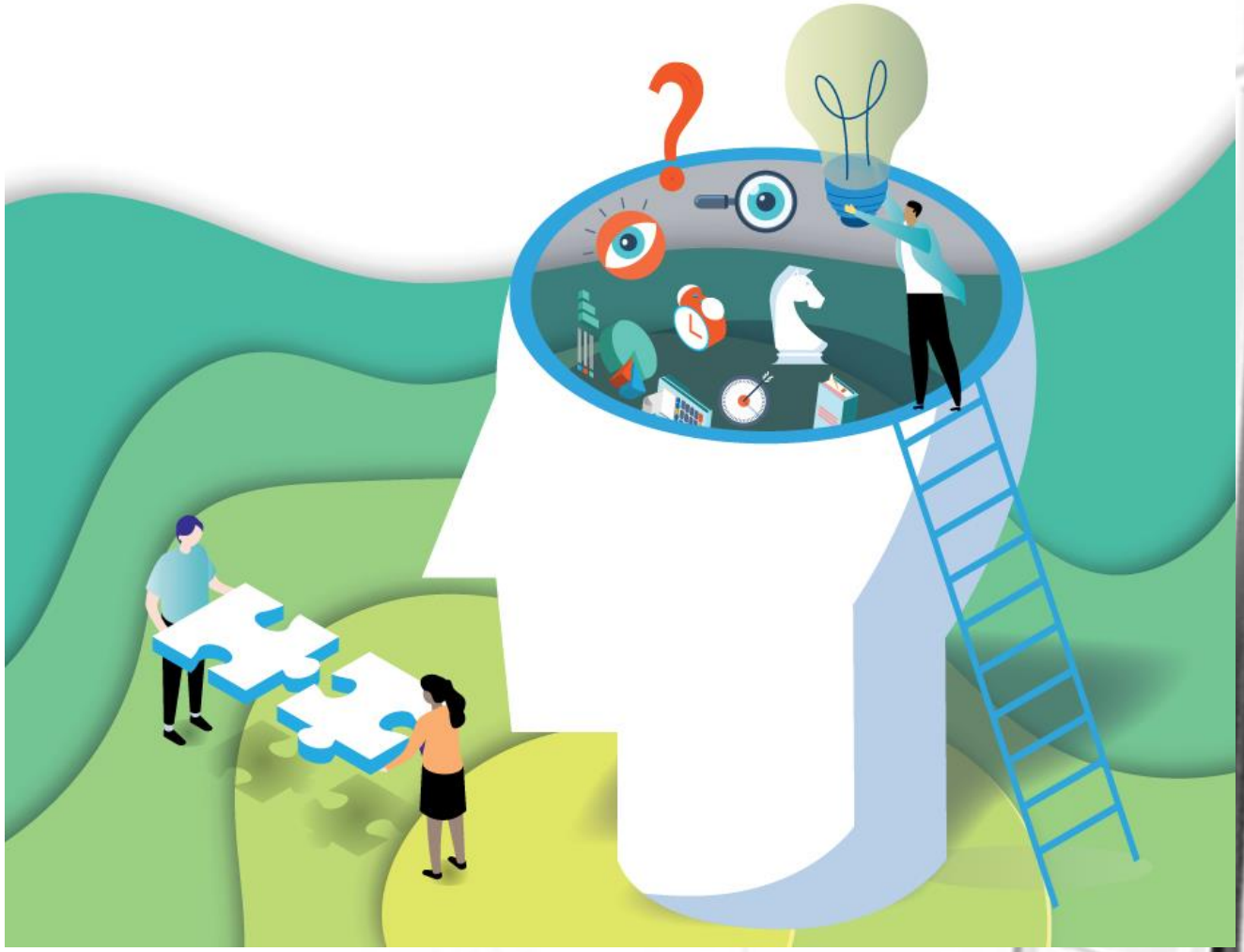
Ford CEO details plan to pivot toward EVs

Ford Motor Co. CEO Jim Farley provided more details on the automaker's plans to pivot to electric vehicles, including a projection to manufacture 600,000 EVs annually by the end of next year. "We have an opportunity as we go digital with these EVs, to simplify our body engineering and put the engineering where customers really care," Farley said.

Full Story: CNBC (7/31)

SAE Smart Brief

Quiz (from ASME)



Quiz (from ASME)

- **1.** The first crude electric vehicle was developed about 1832, but the first successful electric car debuted around 1890. It was basically and electrified wagon, but it spurred interest in EVs. What was its top speed?
    - A. 22 mph
    - B. 14 mph
    - C. 12 mph
    - D. 27 mph

Quiz (from ASME)

- **2.** By 1900, about one-third of all motor vehicles in the U.S. were electric and had strong sales for another 10 years. They were quiet and perfect for short drives in cities. What development furthered their popularity?
    A. Road construction
    B. Growth of electricity
    C. Battery chemistry
    D. Hybrid technology

Quiz (from ASME)

- **3.** The mass-produced Ford Model T stole sales and popularity from early electric vehicles. Its lower price, coupled with cheap and plentiful gasoline, and better roads, sent EV sales plummeting. They disappeared from the road by what year?
    - A. 1927
    - B. 1915
    - C. 1935
    - D. 1922

Quiz (from ASME)

- **4.** Fast-rising oil prices and the 1973 Arab oil embargo got people thinking about EVs again. It still took another 20 years for EVs to further develop. The 1992 Energy Policy Act and new California emissions regulations boosted interest. What was the first mass-produced electric car from a major automaker.
    A. Toyota Prius
    B. General Motors EV1
    C. Tesla
    D. Honda Insight

Quiz (from ASME)

- **5.** In 2012, only 120,000 electric cars were sold worldwide. How many were sold in 2021?
  - A. 6.6 million
  - B. 8.2 million
  - C. 3.5 million
  - D. 9.2 million