ECE 398GG – ELECTRICAL VEHICLES

1. Introduction and Overview

George Gross

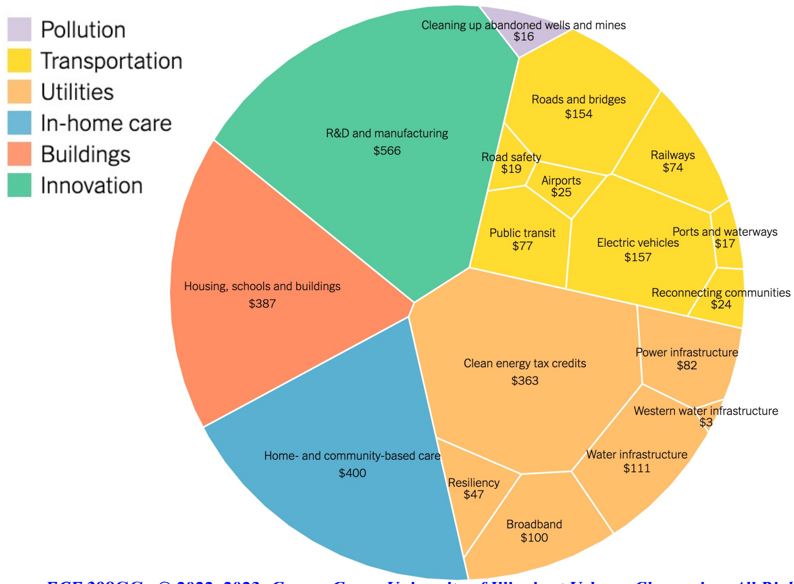
Department of Electrical and Computer Engineering

University of Illinois at Urbana–Champaign

BIDEN ADMINISTRATION'S CLIMATE GOALS

sector	goal for the year		
	2030	2035	2050
US economy 	*GHG* emission reduction by 50 %		net–zero *C*
transportation  	set up of 500,000 *EV* chargers	electrification of the transportation sector; growth of *US EV* manufacturing	
buildings 		*C* footprint reduction by 50 %	
power & energy  	80 % zero *C*	*C*–free electricity	

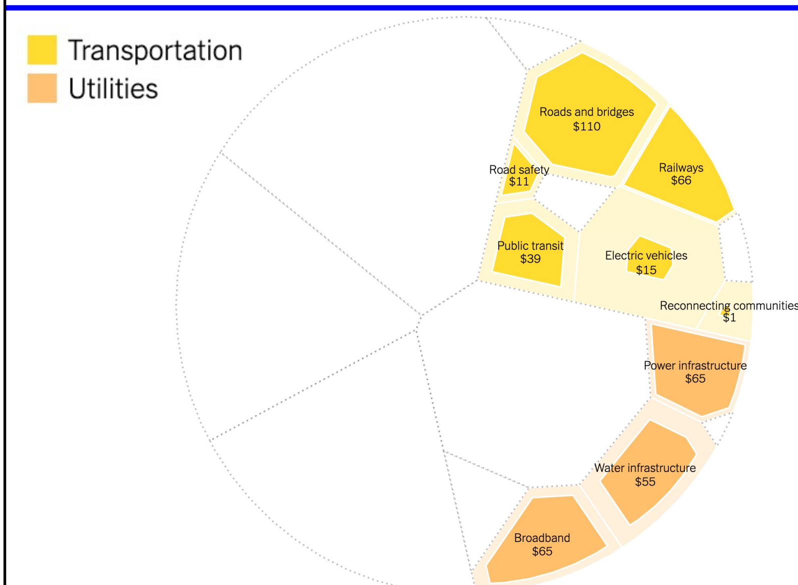
THE ORIGINAL BIDEN PLAN: *2.6 TRILLION $*



Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

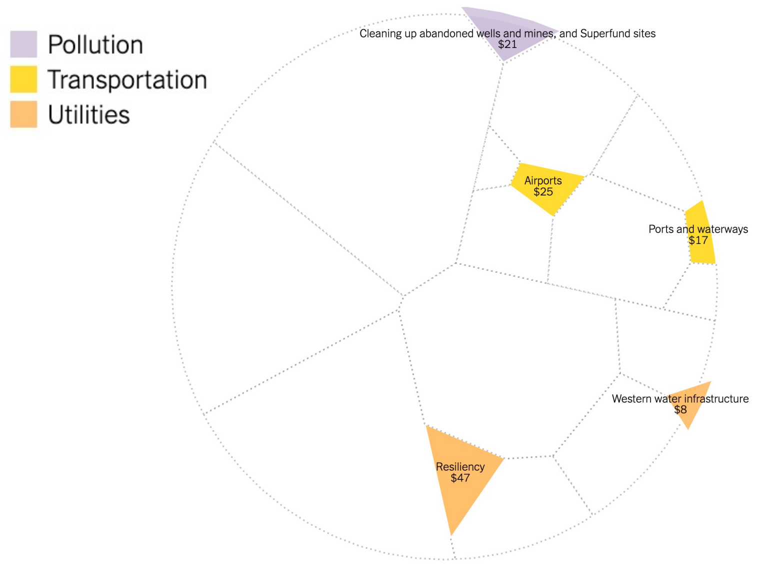
THE ELIMINATED AND THE SHRUNK PARTS OF THE BIDEN PLAN



Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

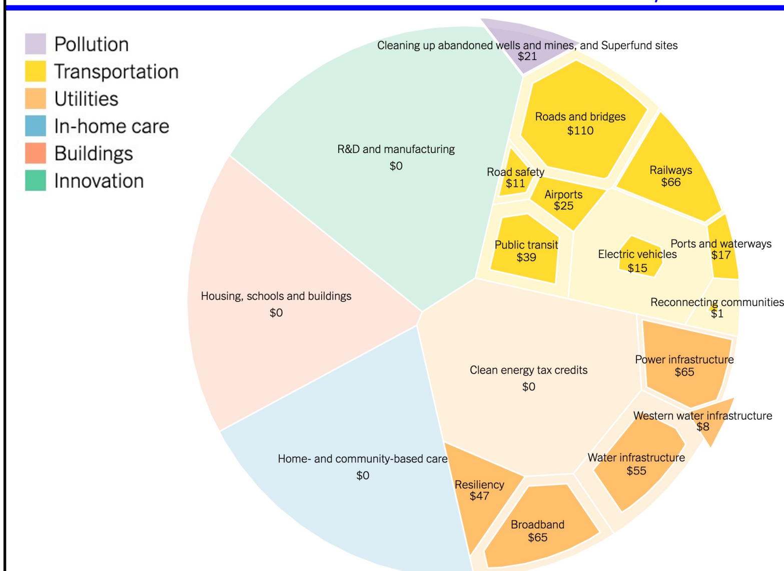
THE PARTS THAT REMAINED UNCHANGED OR INCREASED



Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

THE SENATE BIPARTISAN PLAN: *550 BILLION $*



Source: NY Times online; avalible online at https://www.nytimes.com/interactive/2021/07/28/upshot/infrastructure-breakdown.html?action=click&module=RelatedLinks&pgtype=Article

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

BIPARTISAN *INFRASTRUCTURE INVESTMENT AND JOBS ACT*: 2021

- A version of the *Senate Bill* was also passed by the *House of Representatives* and was enacted as the *Bipartisan Infrastructure Investment and Jobs Act* signed by *President Biden* on November 15, 2021
- The so-called *Bipartisan Infrastructure Law* provides funding opportunities for a wide range of conventional infrastructure projects to make significant improvements in the health, resilience and equity of American communities with funding of over a *trillion dollars* to help create good-paying jobs, and increase climate resilience

BIPARTISAN INFRASTRUCTURE INVESTMENT AND JOBS ACT: 2021

- The Law provides more than *$ 50 billion* to improve our nation's drinking water, wastewater, and stormwater infrastructure and $ 5.5 *billion* to clean up legacy pollution and to prevent pollution
- The Law also provides about *$ 65 billion* for energy resources and technology development, electric transmission/distribution grid additions, green resource deployment, hydrogen implementation, nuclear energy, *EV*s and their charging infrastructure, nuclear energy and cybersecurity

INFLATION REDUCTION ACT: 2022

- A close counterpart of the *Bipartisan Infrastructure Law* is the *Inflation Reduction Act* or *IRA*, which was signed into law on August 16, 2022
- The *IRA* authorizes *$ 369 billion* to fund climate-change-related and clean energy initiatives
- The *IRA* provides a broad range of incentives and tax credits for clean energy, storage, *EV*s, nuclear energy, clean hydrogen and direct consumer rebates for families to buy heat pumps or other energy efficient home appliances, aimed to decrease *US* CO_2 emissions by 40 % by 2030

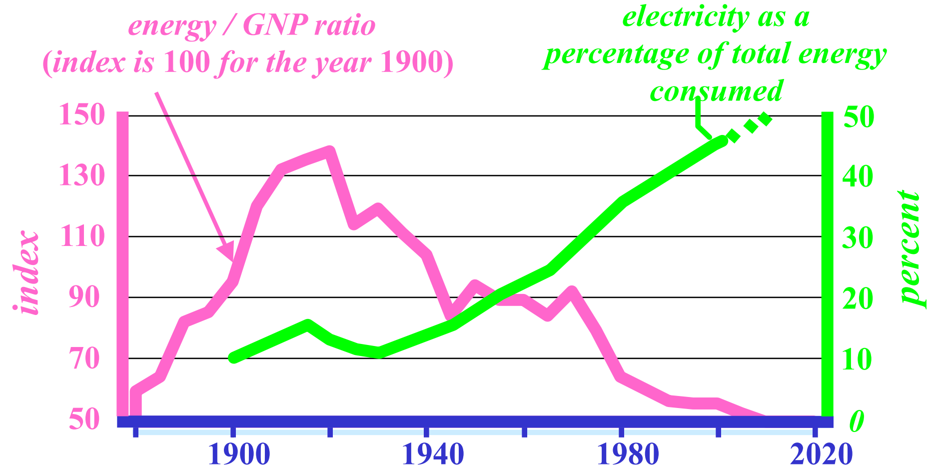
 © 2022–2023 *George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.*

CRITICAL IMPORTANCE OF ELECTRICITY

- Energy is the *lifeblood* of modern society
- The importance of electricity is on the rise
- Efficient and environmentally sensitive electricity services are key requirements for the nation's global competitiveness
- The *US* power industry valued above *$ 2.3 trillion* is among the world's largest industrial sectors; 2021 retail sales revenues rose above 400 *billion $*

 © 2022–2023 *George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.*

US ENERGY CONSUMPTION AND ELECTRICITY USE

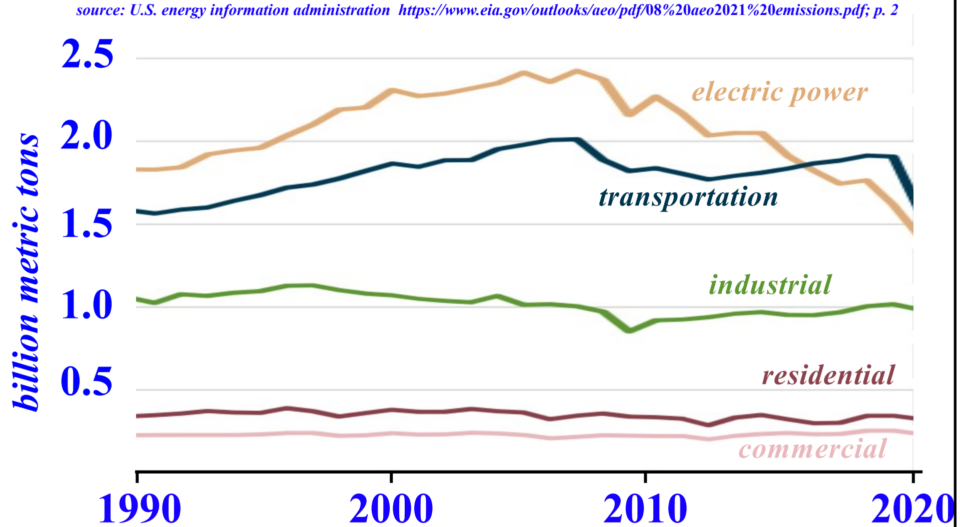


electricity will continue to substitute for less efficient and less productive energy forms

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

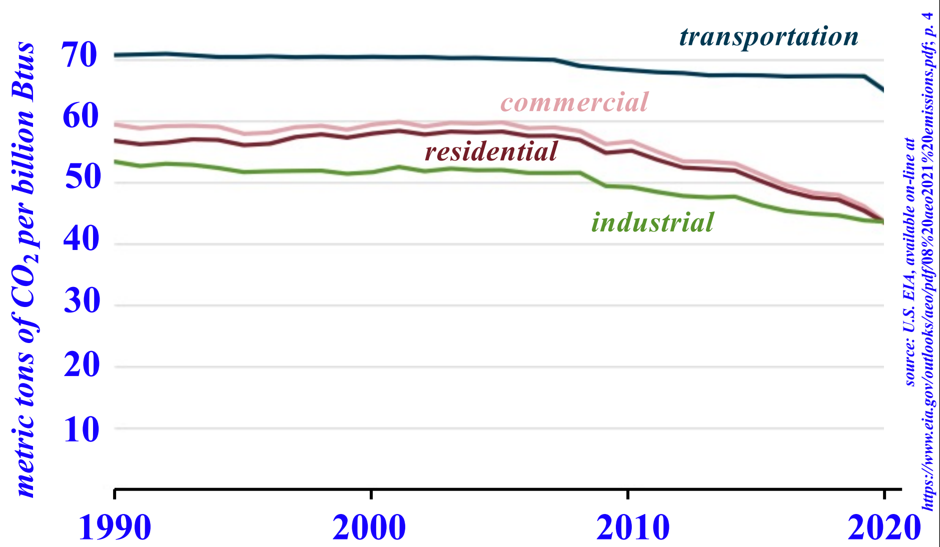
US ENERGY – RELATED CO_2 EMISSIONS BY SECTORS: 1990 – 2020

source: U.S. energy information administration https://www.eia.gov/outlooks/aeo/pdf/08%20aeo2021%20emissions.pdf; p. 2



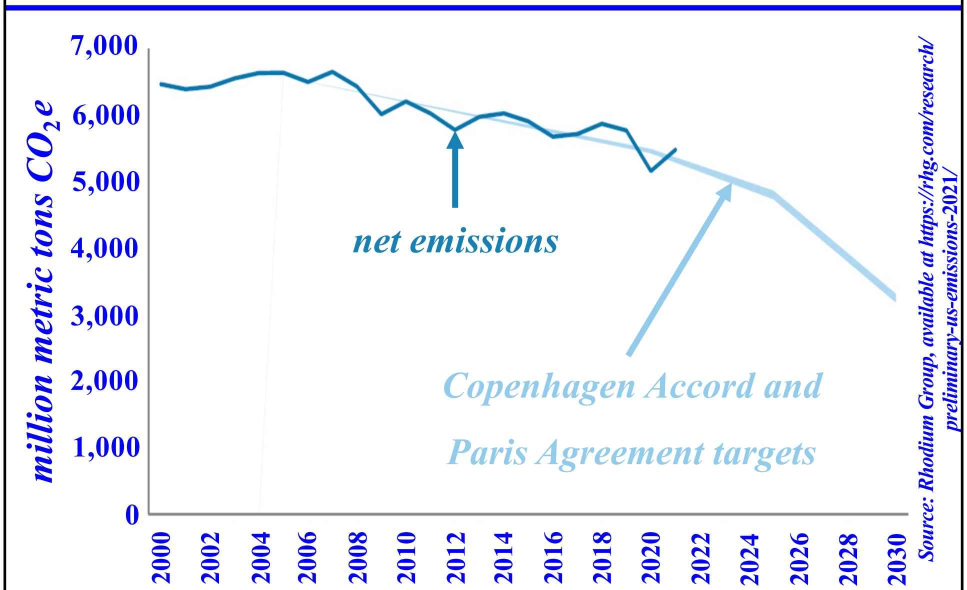
ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

US CO₂ INTENSITY BY END–USE SECTOR: 1990 – 2020



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 13

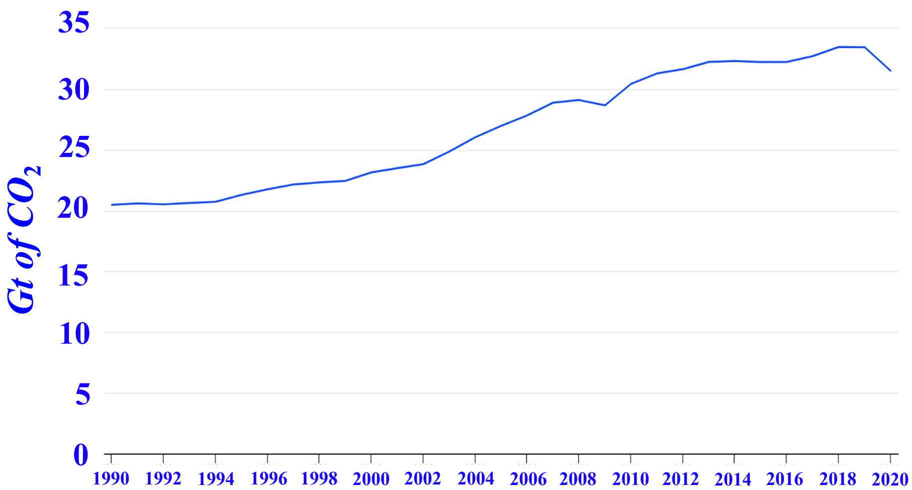
US GHG NET EMISSIONS AND INTERNATIONAL COMMITMENTS



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 14

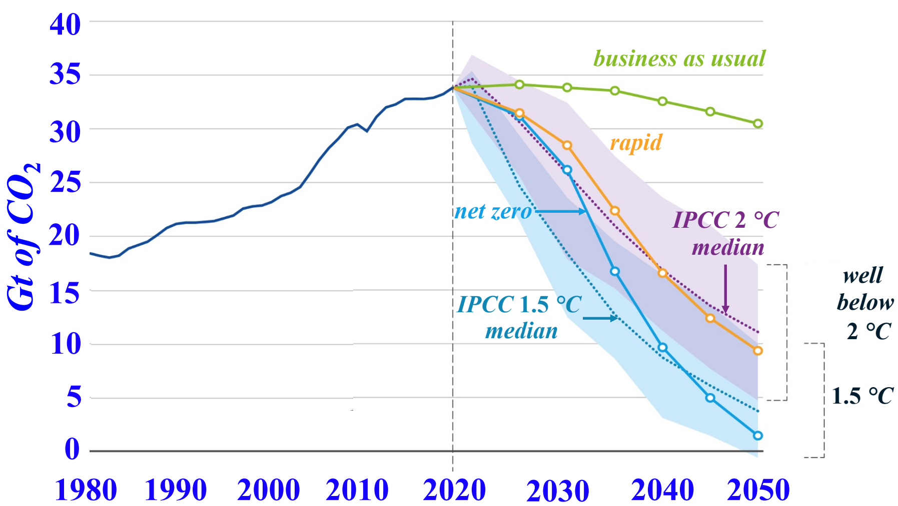
GLOBAL ENERGY–RELATED CO_2 EMISSIONS: 1990 – 2020

Source: International Energy Agency, Key Electricity Trends 2020, published in April 2021; available online at https://www.iea.org/data-and-statistics/charts/yearly-solar-production-in-oecd-countries-2010-2020



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

GLOBAL CO_2 EMISSIONS FROM FOSSIL FUELS



Source: BP, Energy Outlook 2020. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2020.pdf

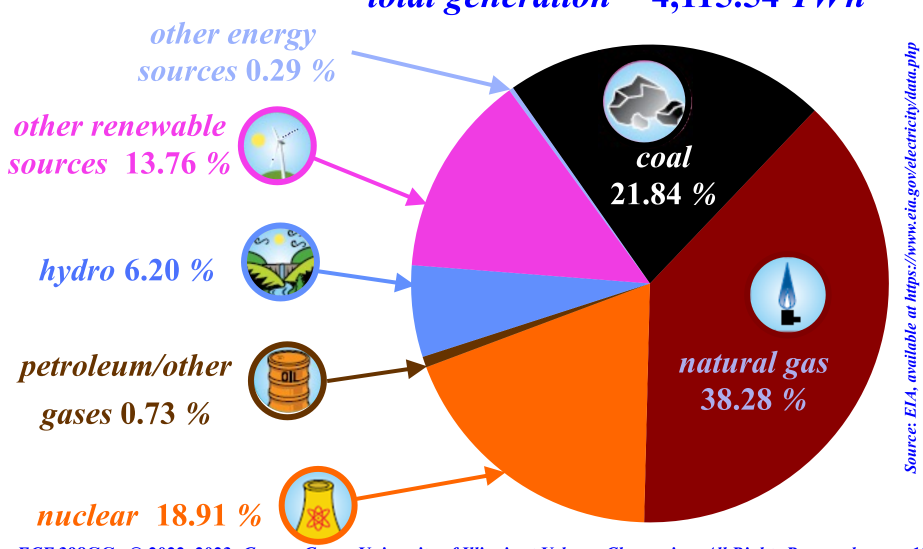
ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

THE WORLD ECONOMIES RELY ON ABUNDANT AND AFFORDABLE ELECTRICITY

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 17

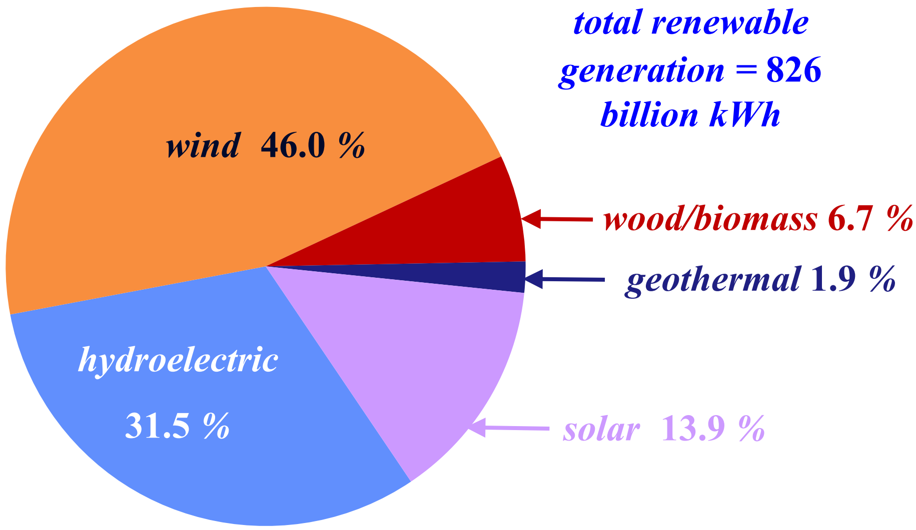
SOURCES OF 2021 *US* ELECTRICITY GENERATION

total generation = 4,115.54 *TWh*



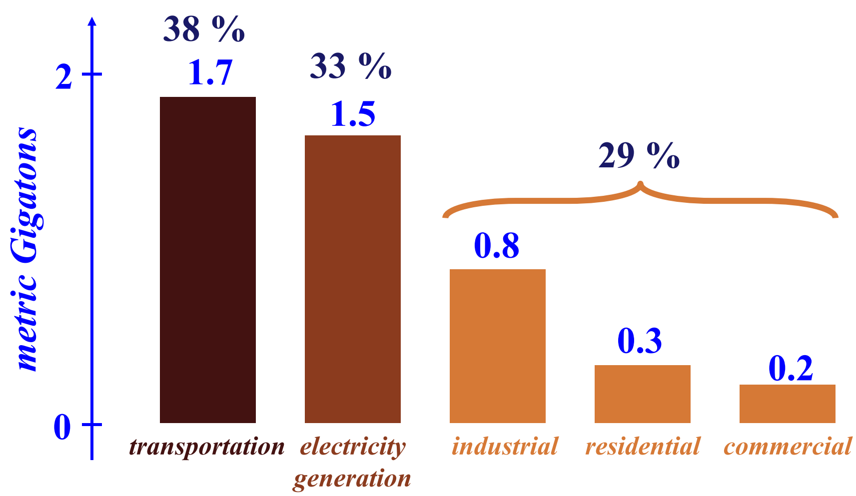
ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 18

NET 2021 *US* GENERATION BY RENEWABLE ENERGY RESOURCES



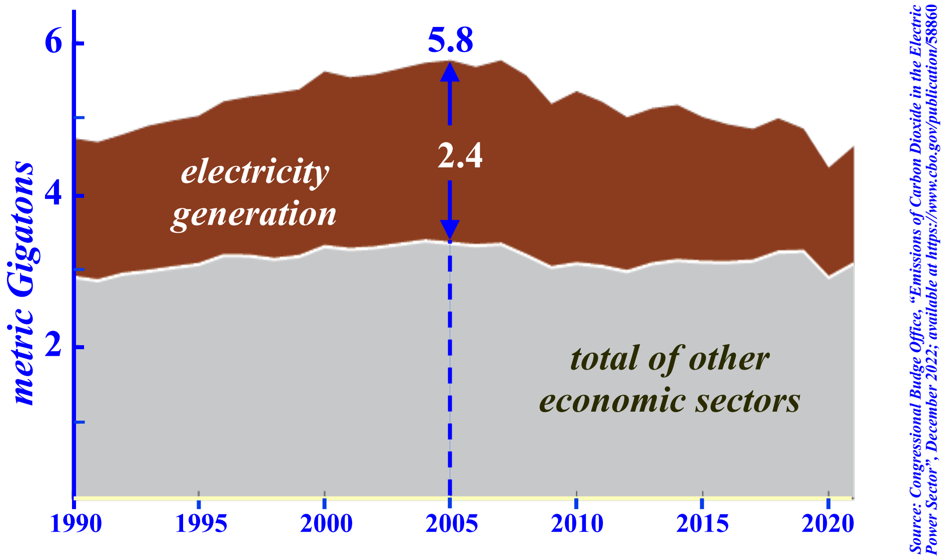
Source: EIA, June 2021, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

2021 *US* CO_2 EMISSIONS BY SECTOR



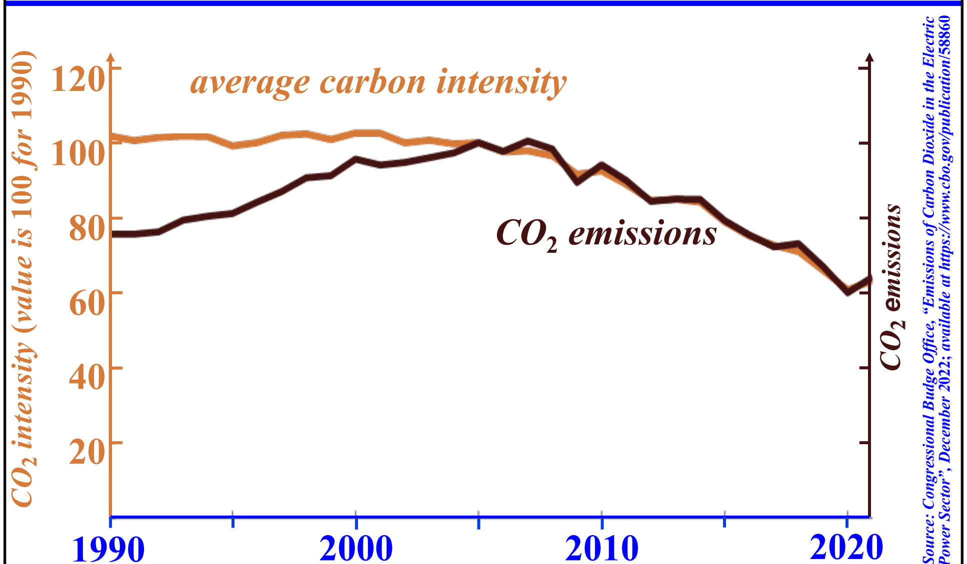
Source: Congressional Budge Office, "Emissions of Carbon Dioxide in the Electric Power Sector", December 2022; available at https://www.cbo.gov/publication/58860

US ELECTRICITY GENERATION CO_2 *vs.* OTHER SECTORS' EMISSIONS: 1990 – 2021



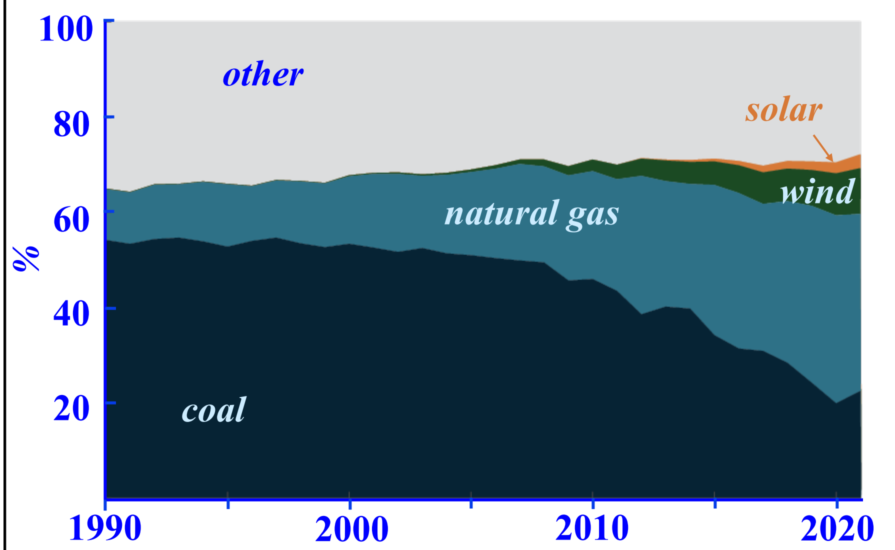
 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ELECTRICITY GENERATION CO_2 EMISSIONS AND CARBON INTENSITY



 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

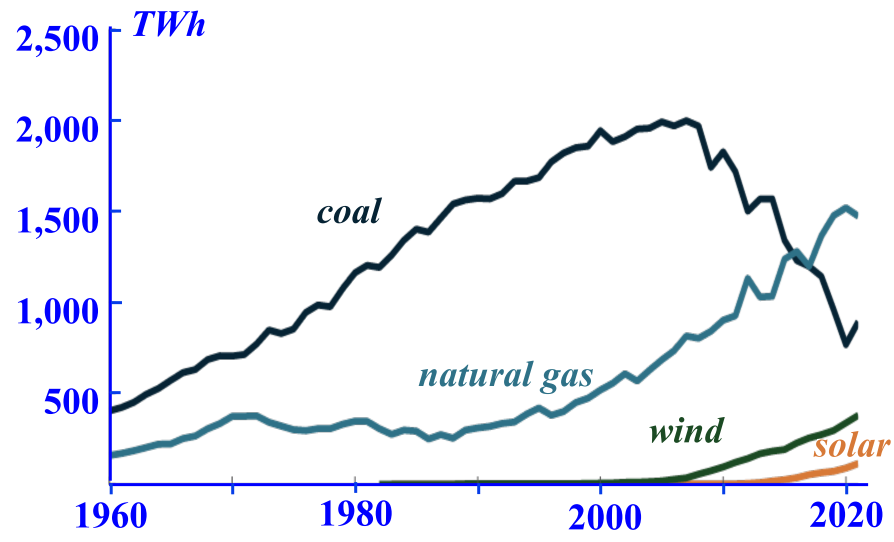
US ELECTRICITY GENERATION SOURCES: 1990 – 2021



Source: Congressional Budget Office, "Emissions of Carbon Dioxide in the Electric Power Sector", December 2022; available at https://www.cbo.gov/publication/58860

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

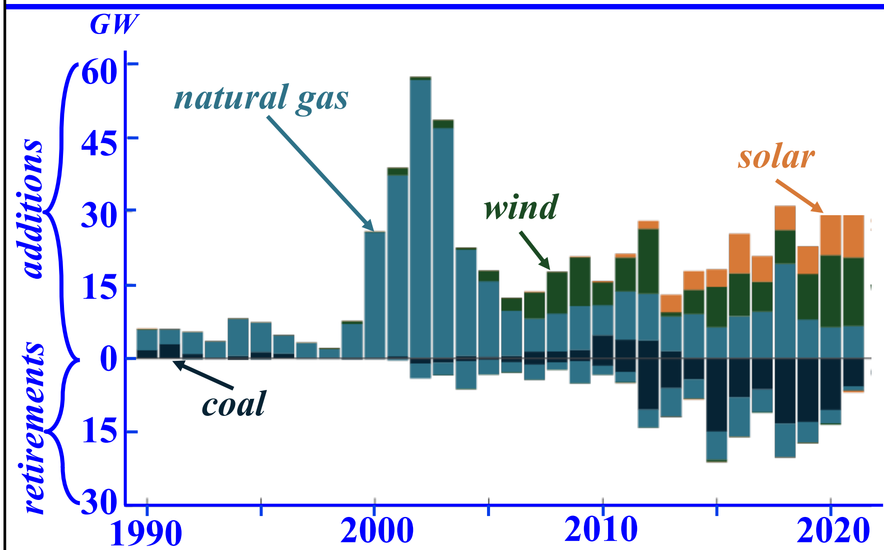
ELECTRICITY GENERATION BY PRIMARY ENERGY SOURCES: 1990 – 2021



Source: Congressional Budget Office, "Emissions of Carbon Dioxide in the Electric Power Sector", December 2022; available at https://www.cbo.gov/publication/58860

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ELECTRICITY GENERATION CAPACITY ADDITIONS & RETIREMENTS: 1990 – 2021

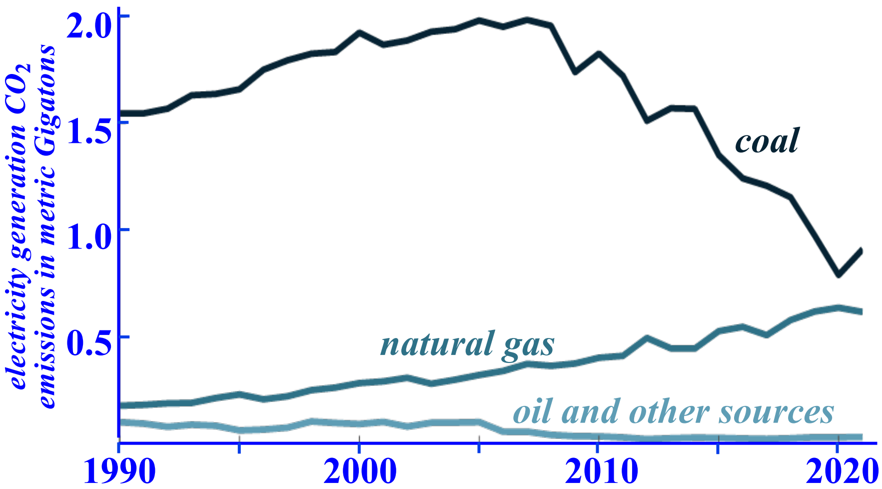


Source: Congressional Budget Office, "Emissions of Carbon Dioxide in the Electric Power Sector", December 2022; available at https://www.cbo.gov/publication/58860

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

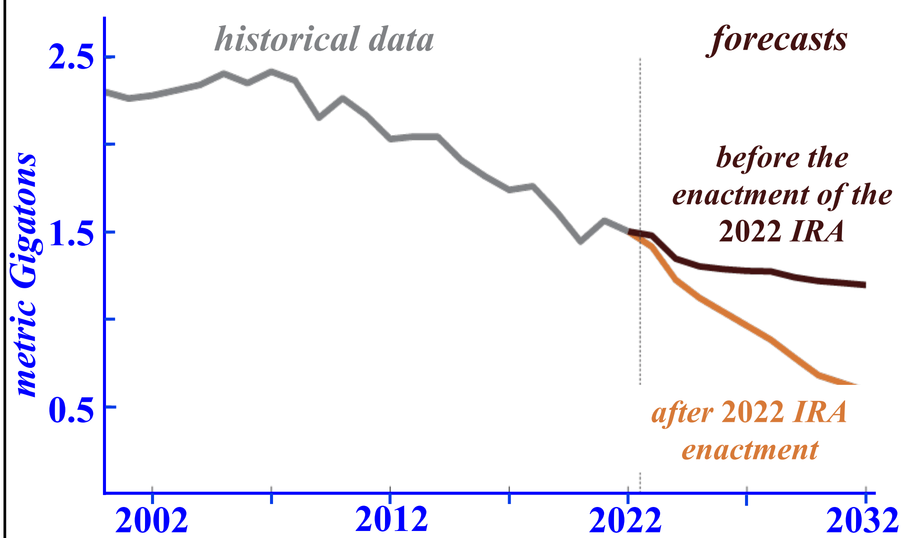
The Washington Post

ELECTRICITY GENERATION BY PRIMARY ENERGY SOURCES: 1990 – 2021



Source: Congressional Budge Office, "Emissions of Carbon Dioxide in the Electric Power Sector", December 2022; available at https://www.cbo.gov/publication/58860

FORECASTED EMISSIONS OF CO_2 FROM *US* ELECTRICITY GENERATION



Source: Congressional Budge Office, "Emissions of Carbon Dioxide in the Electric Power Sector", December 2022; available at https://www.cbo.gov/publication/58860

CONCERNS EMERGING FROM THE 2022 *US GHG* ESTIMATES

- A key source of concern for the 2022 *US* economy was inflation, which further exacerbated the rising prices of goods & services initiated by *COVID* 19 and was impacted by the energy market turmoil that resulted from *Russia*'s war in *Ukraine*
- The war led to a spike in oil prices and a rise in natural gas prices
- *Rhodium Group* estimates, based on preliminary 2022 data, that *US* economy-wide *GHG* emissions increased 1.3 % relative to 2021 – a slight rise due to wider natural gas and renewable deployment

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

CONCERNS EMERGING FROM THE 2022 *US GHG* ESTIMATES

- The estimate of *GDP* growth in 2022 is 1.9 %; thus, the economic growth outpaced the *slight* emission rise – an indication that the *US* economy's *GHG intensity* declined
- The lower *GHG intensity* is a welcome turnaround from the more carbon–intensive rebound in 2021, when *GHG* emissions rose by 6.5 % while the *GDP* growth was 5.9 %
- The severe 2022 winter raised the building *GHG* emissions with slight rises in the other sectors

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

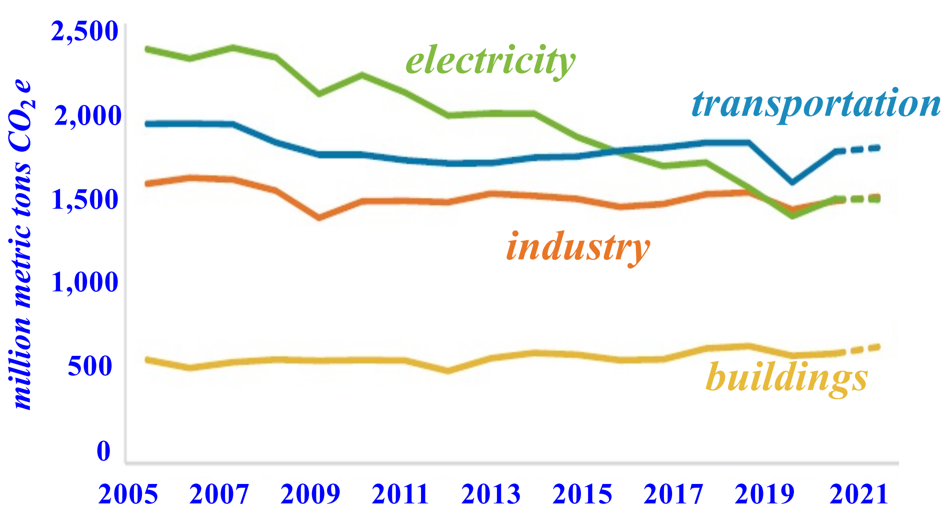
CONCERNS EMERGING FROM THE 2022 *US GHG* ESTIMATES

- The severe 2022 winter raised the *GHG* emissions by buildings; other sectors also had slight rises in their *GHG* emissions
- Bottom line: the reversal in the *GHG intensity* was a positive development, but the slight rise in total *GHG* emissions still fell short of the reductions required to bring about the attainment of the *US* 2025 and 2030 targets

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

US GHG EMISSIONS BY SECTOR: 2005 - 2022

source: Rhodium Group, available at https://rhg.com/research/us-greenhouse-gas-emissions-2022/



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

THE CO_2e UNITS

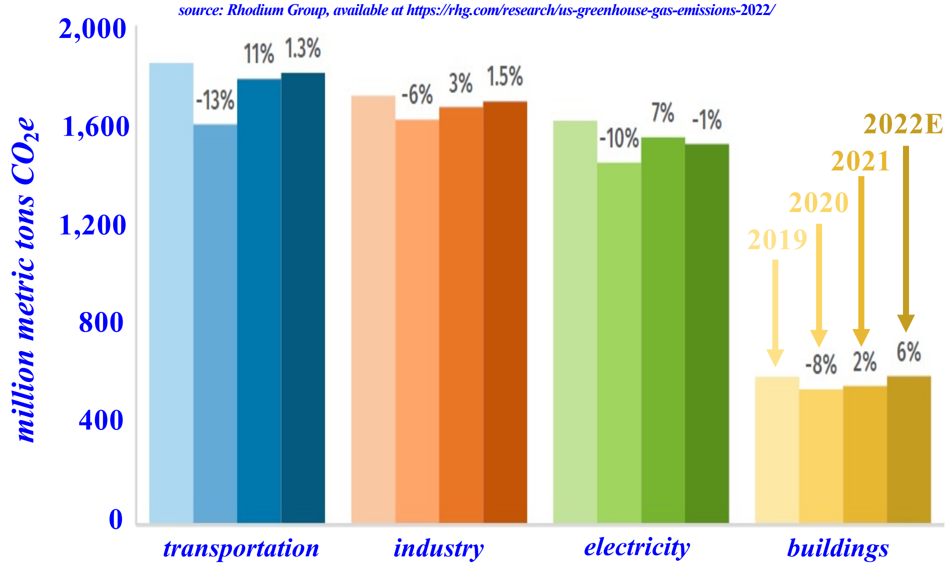
- The GHG emissions which include CO_2 and other GHG, *e.g.*, methane (CH_4), nitrous oxide and ozone, are stated in CO_2 *equivalent* or CO_2e units
- The unit CO_2e represents the amount of a GHG, whose atmospheric impact is standardized to that of 1 unit mass of CO_2, based on the GHG's global warming potential (GWP) for a specified horizon
- By definition, CO_2 has a GWP of 1; methane has a GWP of about 25 using a 100–*year* time horizon
- The meaning is that every ton of CH_4 emission is equivalent of 25 tons of CO_2 emissions

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 33

33

US GHG EMISSIONS AND ANNUAL CHANGES: 2019 – 2022

source: Rhodium Group, available at https://rhg.com/research/us-greenhouse-gas-emissions-2022/

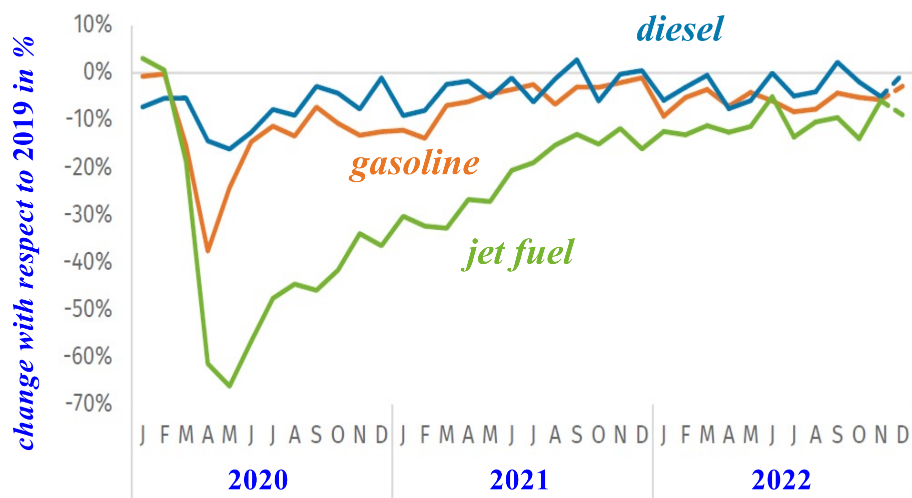


ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 34

34

CHANGES IN *US* TRANSPORTATION ENERGY CONSUMPTION: 2020 – 2022

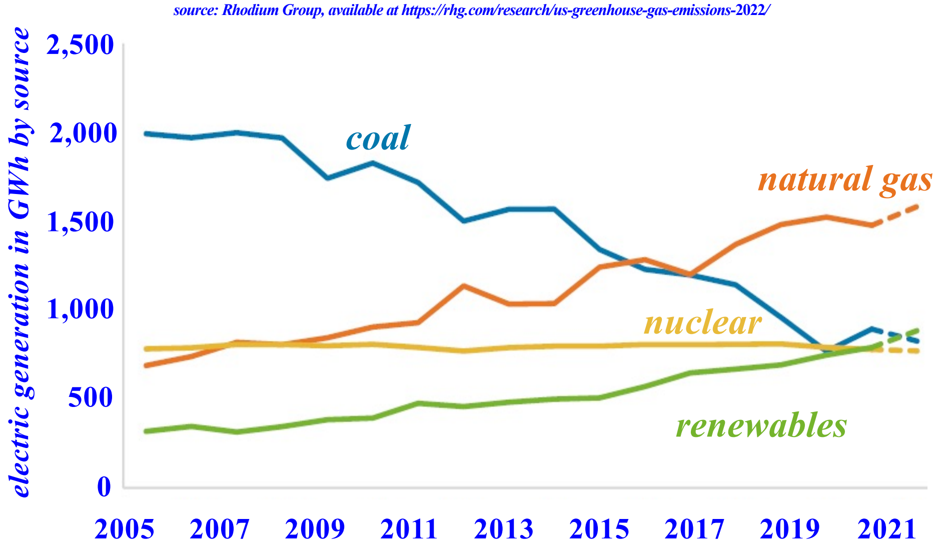
source: Rhodium Group, available at https://rhg.com/research/us-greenhouse-gas-emissions-2022/



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 35

US ELECTRICITY GENERATION BY SOURCE: 2005 - 2022

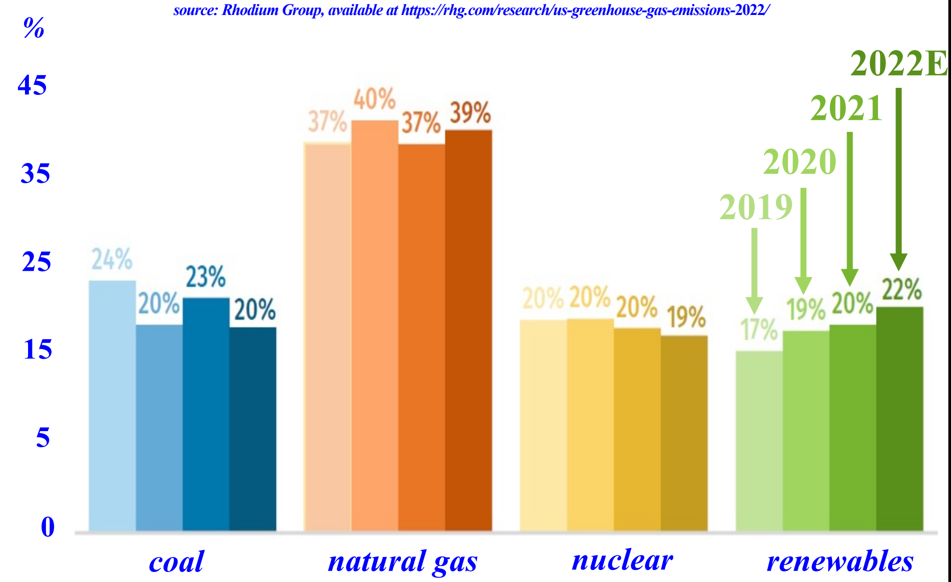
source: Rhodium Group, available at https://rhg.com/research/us-greenhouse-gas-emissions-2022/



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 36

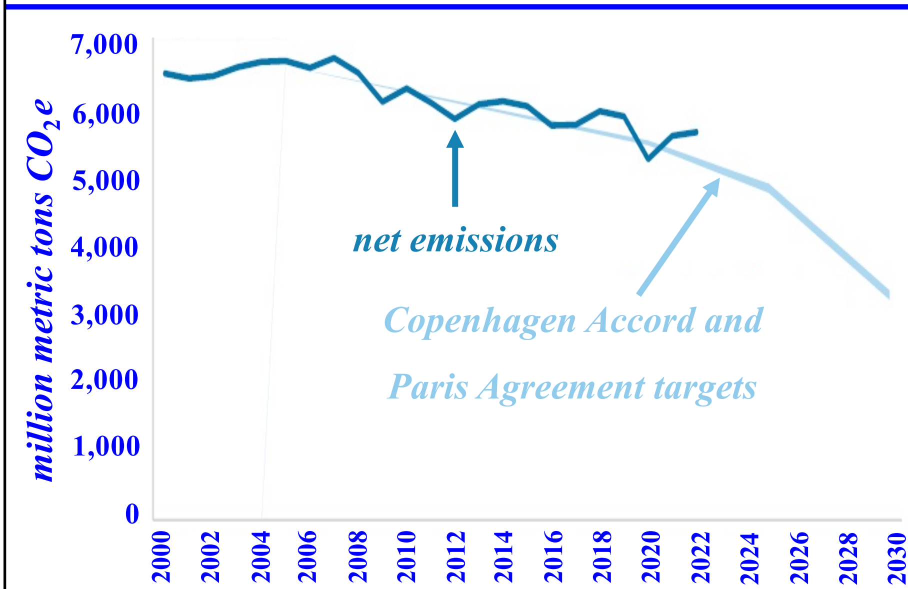
US ELECTRICITY GENERATION SHARE BY SOURCE: 2019 - 2021

source: Rhodium Group, available at https://rhg.com/research/us-greenhouse-gas-emissions-2022/



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

US GHG NET EMISSIONS AND INTERNATIONAL COMMITMENTS



Source: Rhodium Group, available at https://rhg.com/research/us-greenhouse-gas-emissions-2022/

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

EV DEPLOYMENT GOAL: CLEAN THE AIR RAPIDLY

source: ACEA, CAAM, EA-Volumes; available online at https://www.weforum.org/agenda/2021/02/electric-vehicles-europe-percentage-sales/

KEY *EV* BENEFITS

- Replacement of fossil fuel by electricity is a very effective way to reduce fossil fuel consumption – a key objective for decarbonization, given the heavy reliance by transportation on these fuels
- Various studies have shown that it is possible to integrate *EV*s into grids in a way that *economies-of-scale effects* can reduce the electricity prices via the efficient management of supply to meet *EV* loads

KEY *EV* BENEFITS

- *EV*s are viewed as *deferrable loads* on the electric grid – such flexibility is extremely useful since *EV* batteries can both absorb and inject electricity and so can help to meet grid needs
- Wider *EV* deployment can be a driver of deeper renewable resource penetrations and increase the effective harnessing of such resources
- The replacement of fossil fuels by electricity for transportation provides a *sustainable pathway* for *GHG* emission reductions in the economy

THE SINGLE BIGGEST *EV* HURDLE

- The *key barrier* to the realization of the *EV* benefits is the low sales of *EV*s to date
- The two key causes for the low sales stem from
  - range anxiety
  - sheer lack of *EV* charging facilities
- Some factual information is of interest:
  - in 2015, *EV* sales were less than 1 % of the *US* auto sales – of the 17.4 *million* passenger vehicles sold, 116,597 or 0.7 % were *EV*s

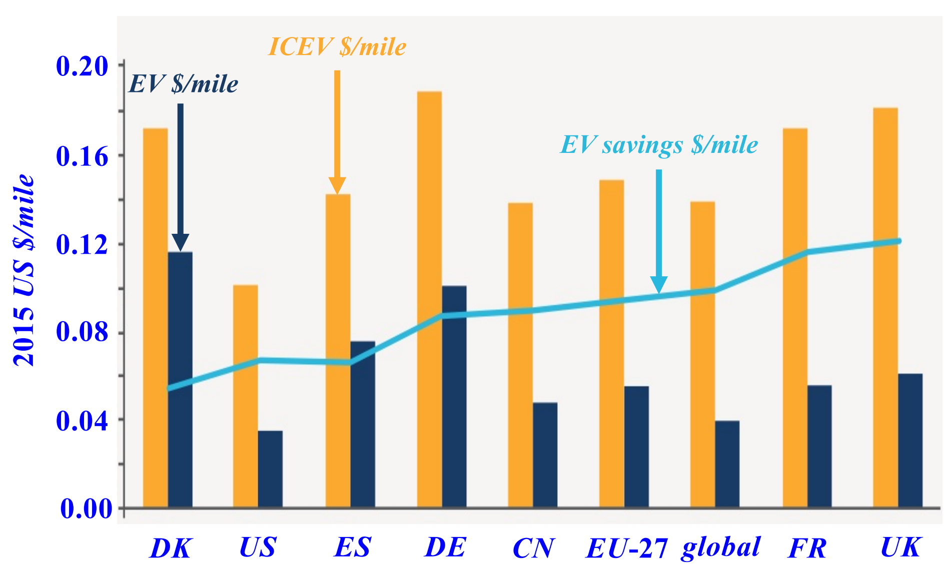
THE SINGLE BIGGEST *EV* HURDLE

- since the start of *EV* sales in 2010, total *US* *EV*s sold by 2015 numbered 407,136 – 0.16 % of the total *US* passenger fleet
- global *EV* sales grew 60 % from 2014 to 2015

- By 2015, it was clear that the cost per mile of an *EV* was well below that of an *ICEV mile* in various jurisdictions around the world

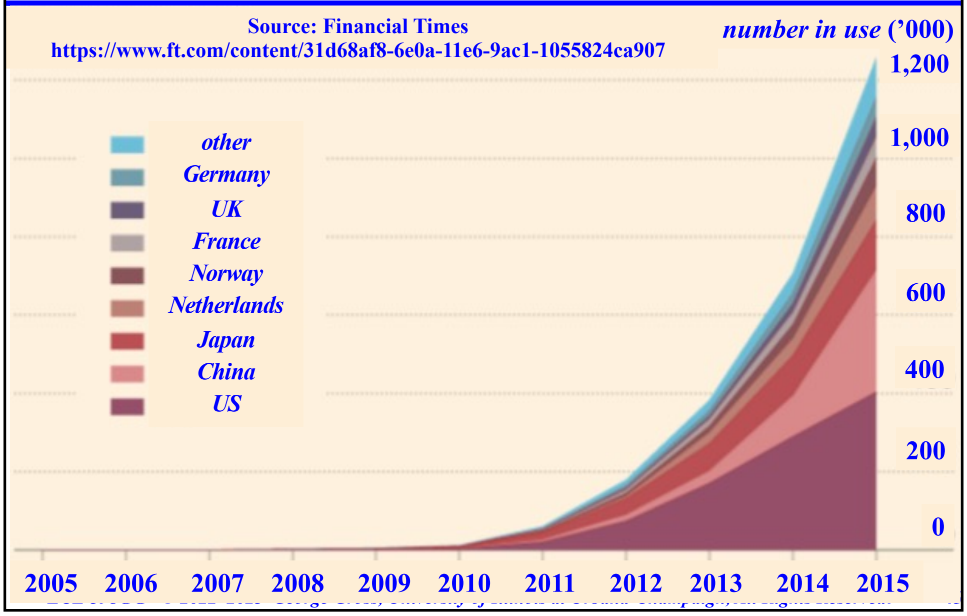
ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

COMPARISON OF *US $/MILE* COSTS OF *EV*s AND *ICEV*s: 2015

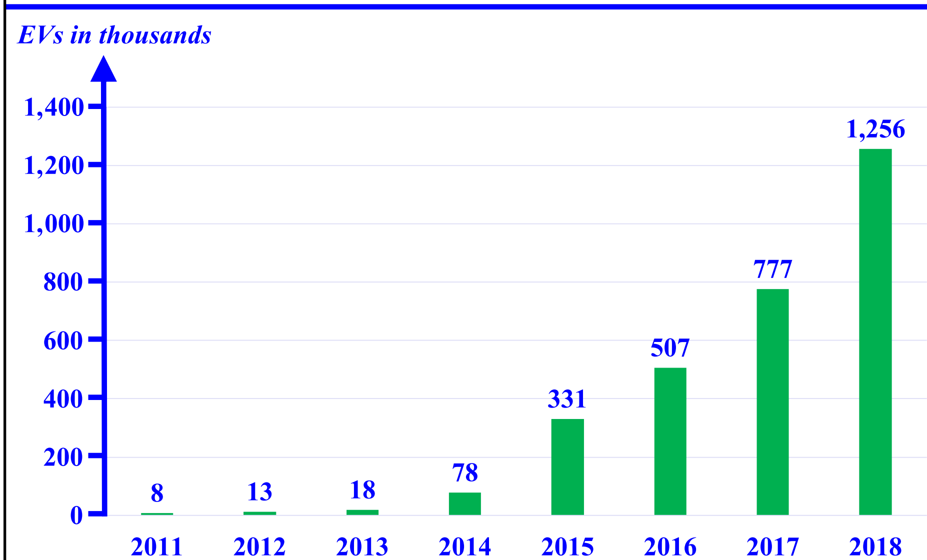


ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

EVs ON THE ROAD

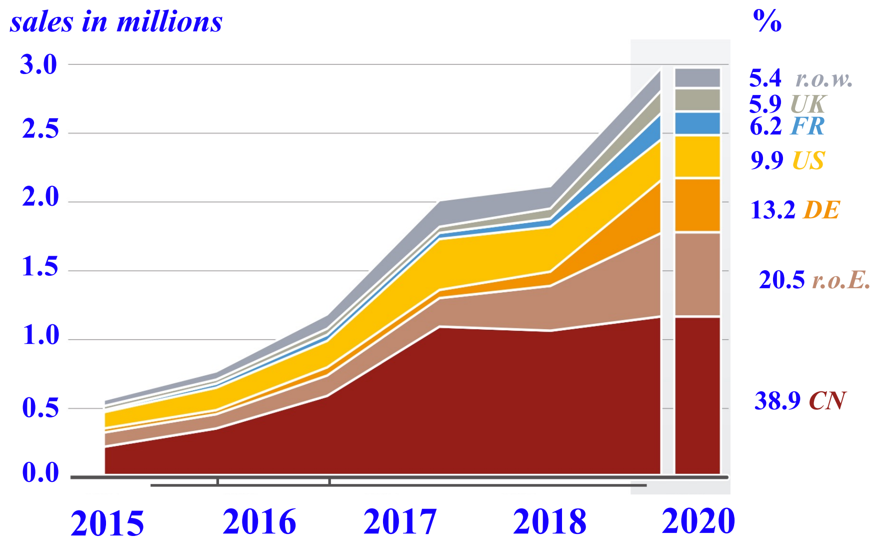


CHINA EV SALES



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

GLOBAL *EV* SALES

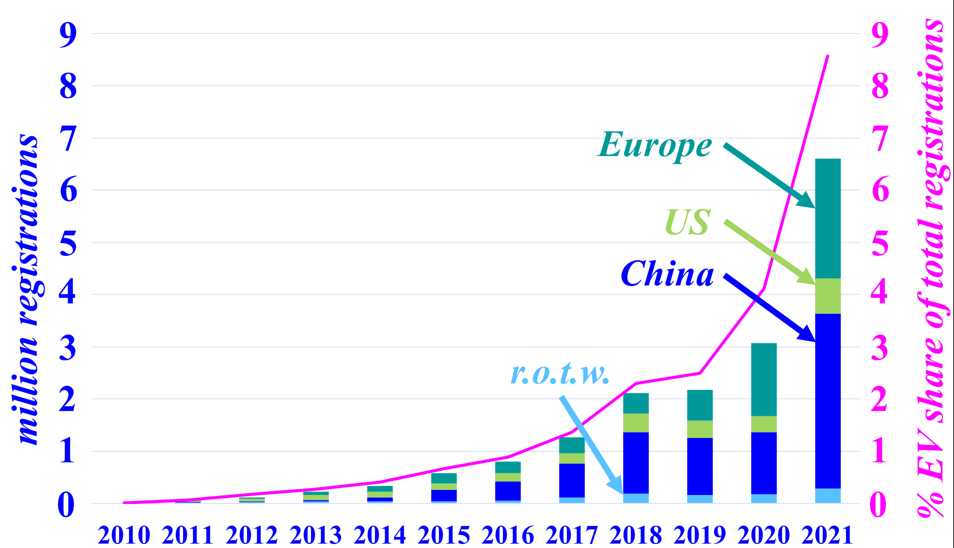


Source: REN 21, p.208 at https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

ECE 398GG © 2022–2023 *George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.*

GLOBAL ANNUAL *EV* SALES: 2010 – 2021

Source: IEA, https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales

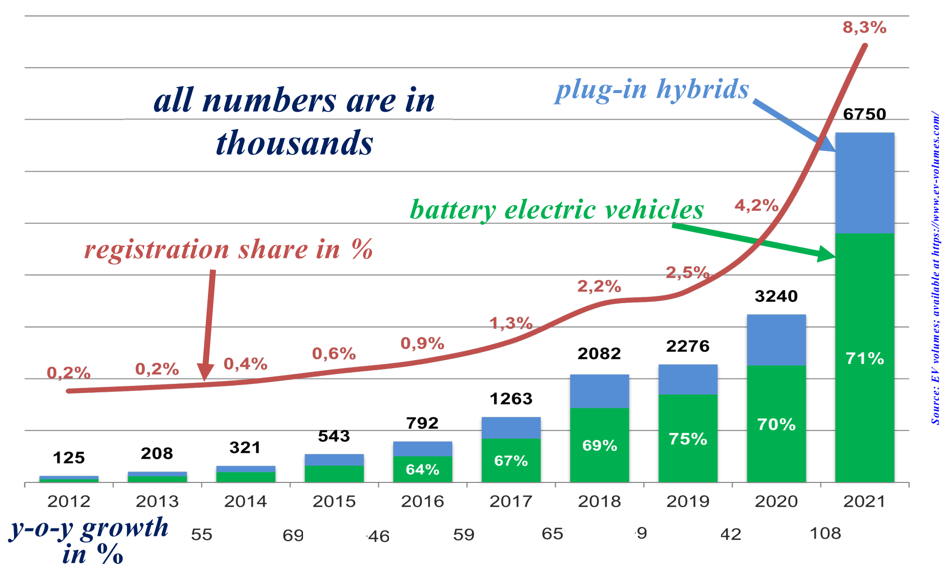


ECE 398GG © 2022–2023 *George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.*

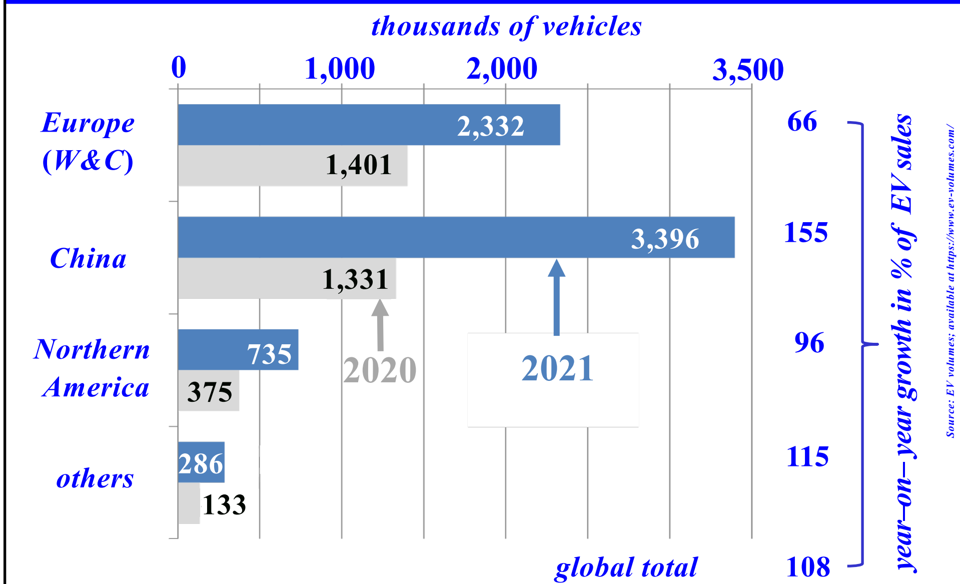
GLOBAL *EV* SALES

- Global *EV* sales in 2021 more than doubled to 6.6 million with respect to the 3 million *EV*s sold in 2020
- Global *EV* sales in 2012 amounted to 130,00 – roughly the weekly sales in 2021
- The *EV* market share in 2021 was 9 % of the global vehicle shares up from 4.1 % in 2020
- *Tesla* — the world's biggest *EV* manufacturer and considered to be the barometer for the health of the global *EV* market — delivered 936,172 vehicles in 2021, up 87.4 % over 2020

GLOBAL *BEV* AND *PHEV* SALES: 2012 – 2021



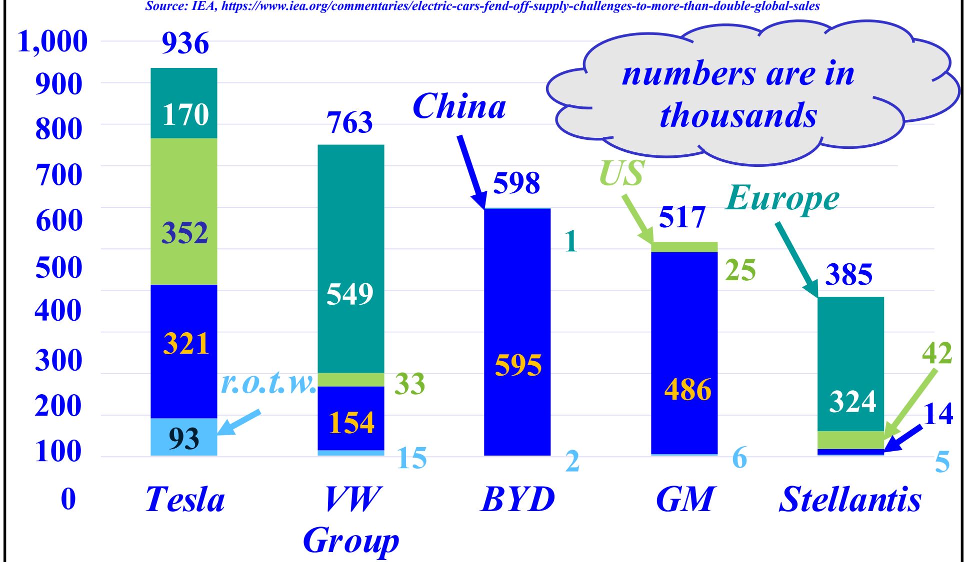
2021 GLOBAL *BEV* & *PHEV* SALES BY REGION



 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

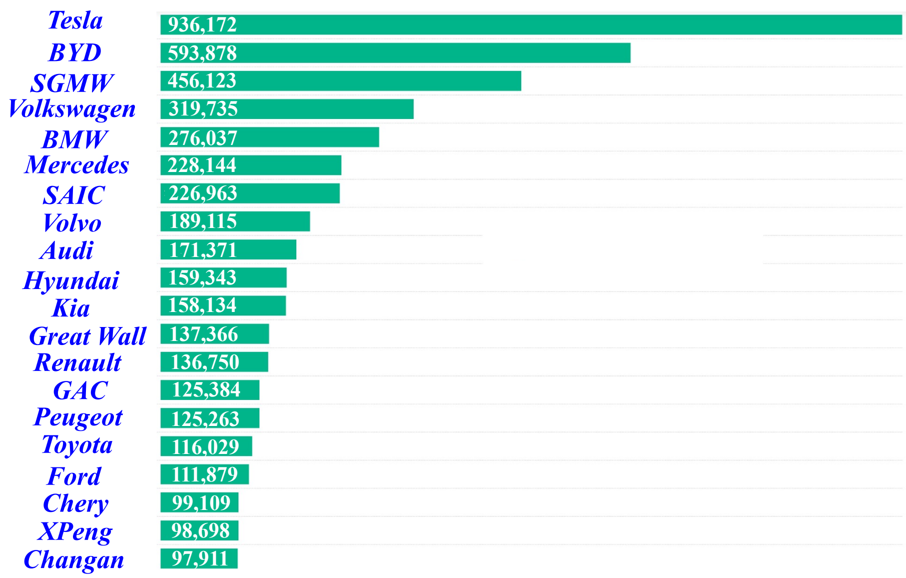
TOP 5 AUTOMAKERS' GLOBAL *EV* SALES BY REGION: 2021

Source: IEA, https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales



 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

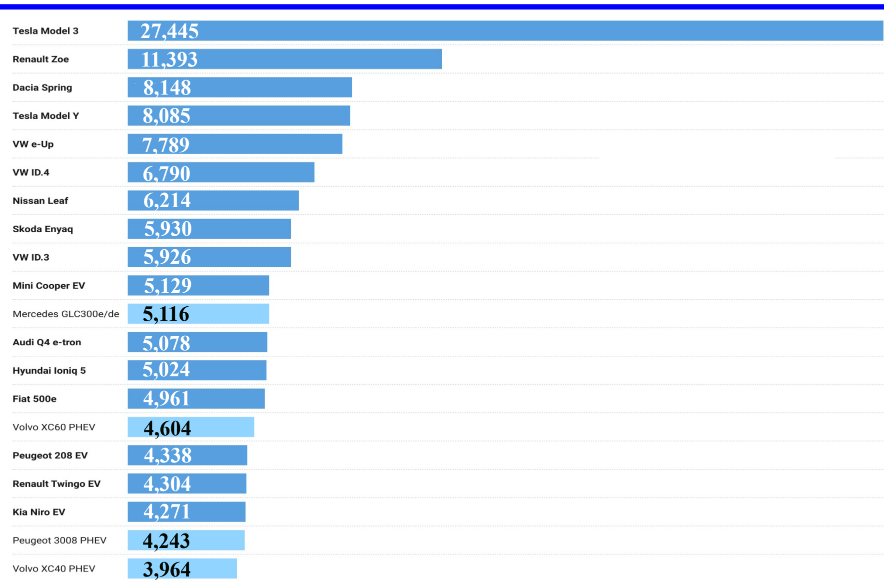
THE LEADING PLUG-IN VEHICLE SALES IN 2021



Source: CleanTechnica; available online at https://cleantechnica.com/2022/01/31/tesla-1-in-world-ev-sales-in-2021/

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

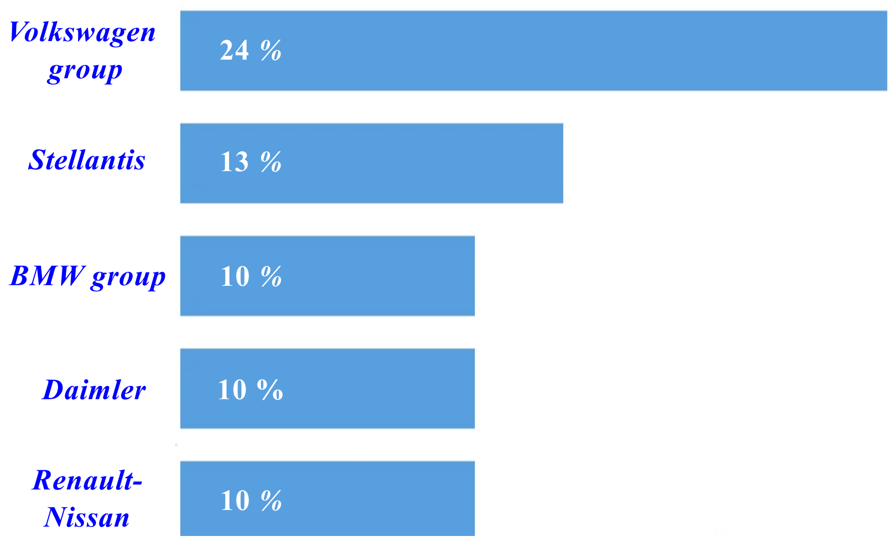
DECEMBER 2021 PLUG-IN VEHICLE SALES IN EUROPE BY MANUFACTURER



Source: CleanTechnica; available online at https://cleantechnica.com/2022/01/30/29-of-cars-sold-in-europe-were-plugin-electric-vehicles-in-december/

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

SHARES OF 2021 PLUG-IN VEHICLE SALES OF THE TOP 5 EUROPEAN CAR MANUFACTURERS

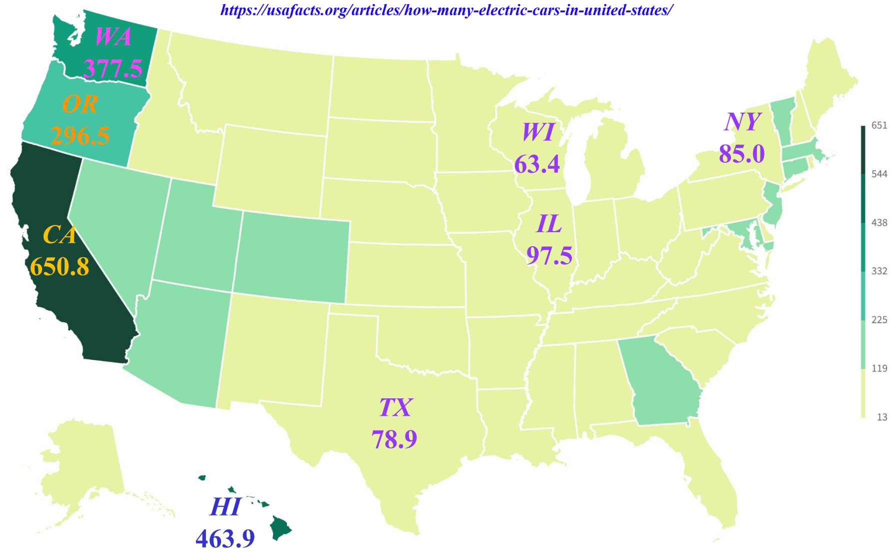


Source: CleanTechnica; available online at https://cleantechnica.com/2022/01/30/29-of-cars-sold-in-europe-were-plugin-electric-vehicles-in-december/

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

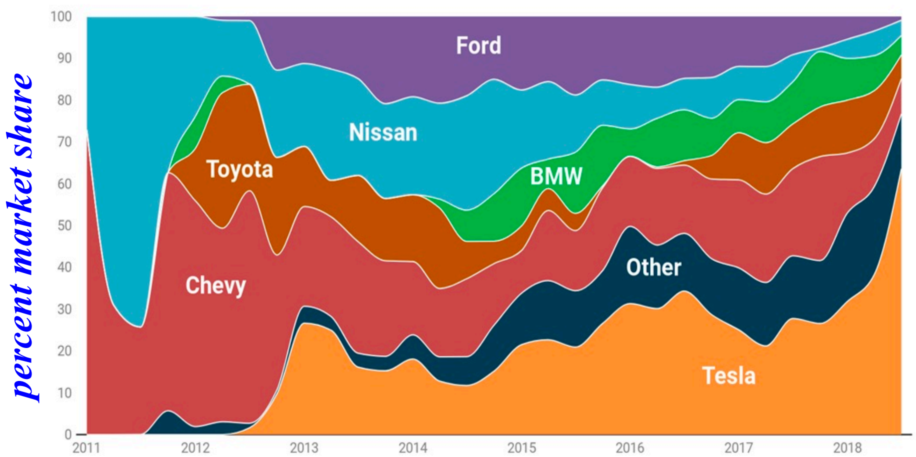
2018 *US EV* REGISTRATIONS PER 100,000 RESIDENTS

Source: USAFacts; available online at https://usafacts.org/articles/how-many-electric-cars-in-united-states/



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

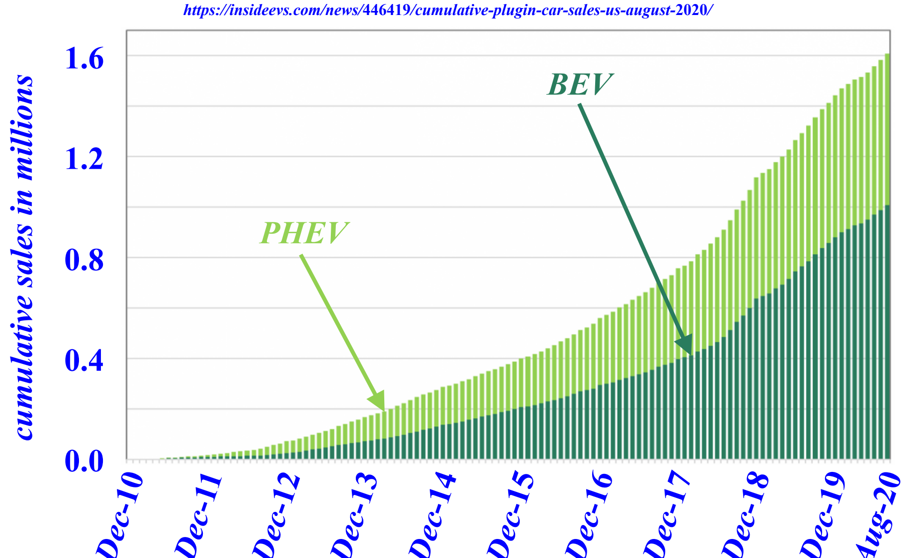
CUMULATIVE *US EV* SALES: 2011–2018



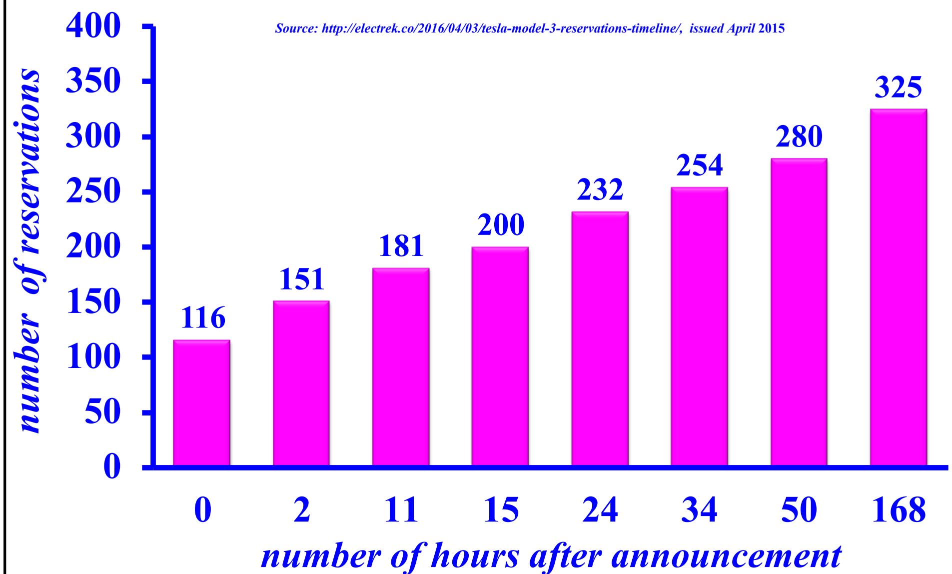
Source: https://energ... us-reaches-1-million-electric

CUMULATIVE *US EV* AND *PHEV* SALES: DECEMBER 2010 – AUGUST 2020

Source: data from Argonne National Laboratory as reported by Inside EVs; available online at https://insideevs.com/news/446419/cumulative-plugin-car-sales-us-august-2020/

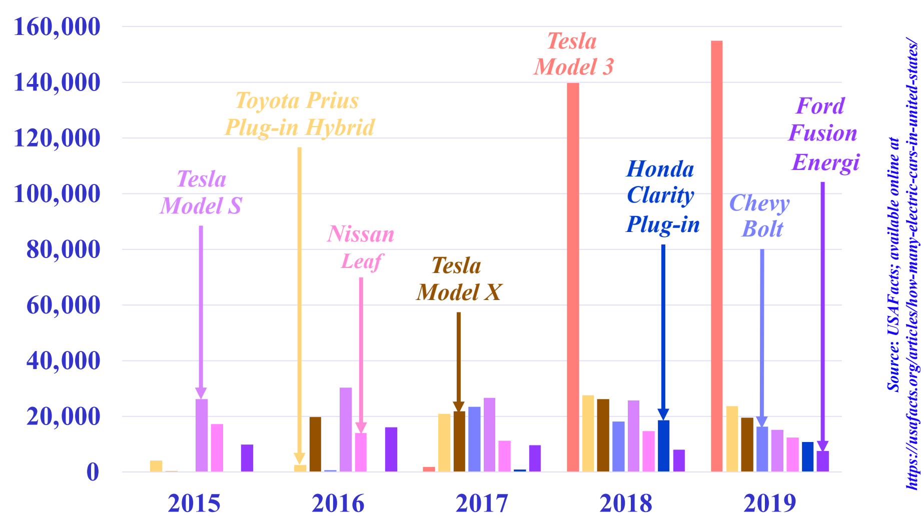


TESLA MODEL 3 RESERVATIONS



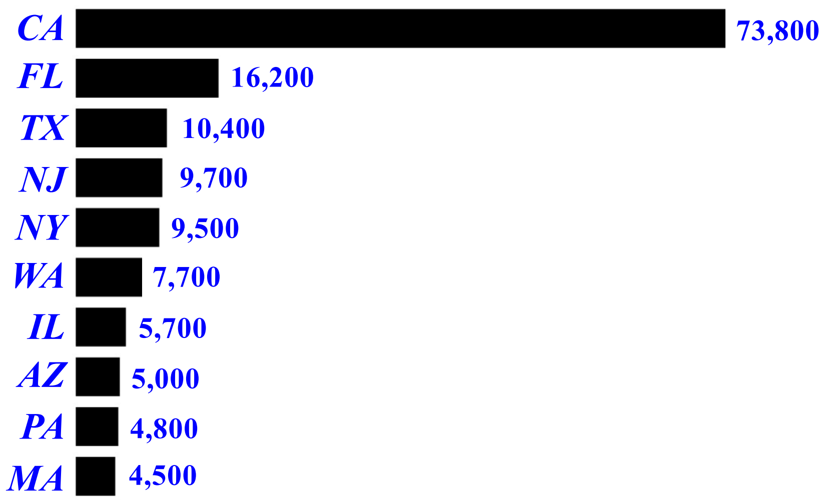
ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA 3 MODEL ESTABLISHES *US EV* MARKET DOMINANCE



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

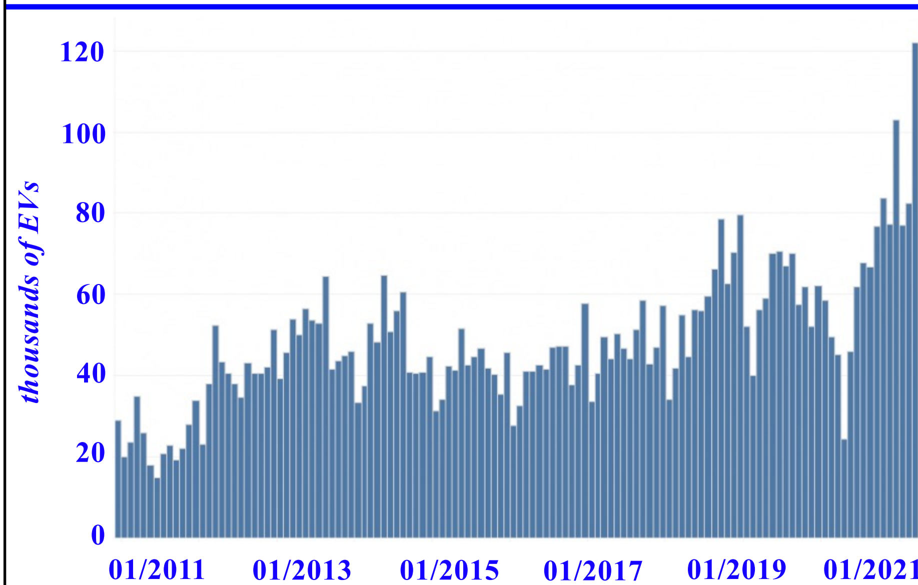
THE TOP 10 STATES FOR *TESLA* REGISTRATION IN 2020



Source: HIS Markit

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 61

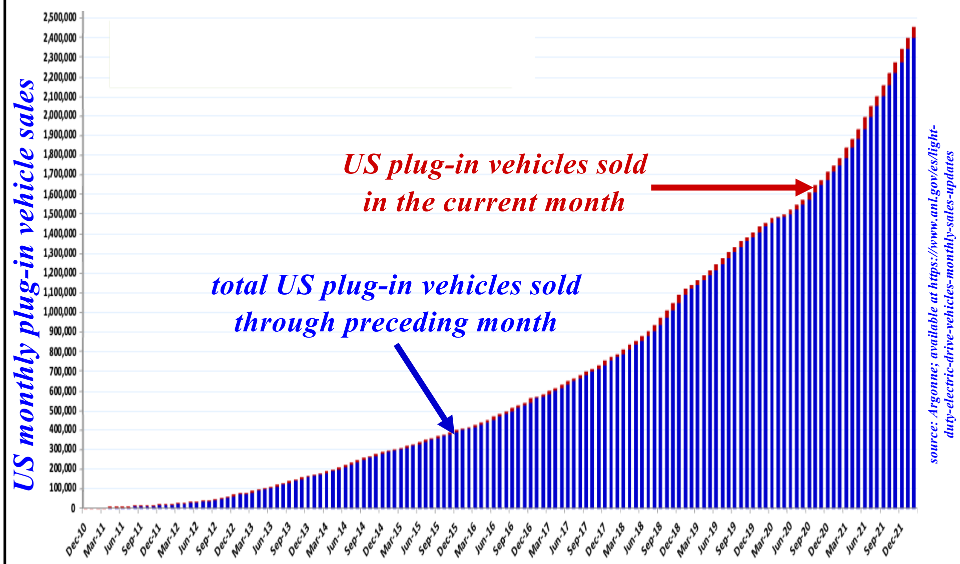
MONTHLY *US EV* SALES: *DECEMBER* 2010 – *MARCH* 2021



Source: Bureau of Transportation Statistics; available at https://www.bts.gov/data-spotlight/electric-vehicle-use-grows

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 62

TOTAL *US PLUG-IN* VEHICLES SOLD: DECEMBER 2010 – DECEMBER 2021



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 63

NOTABLE TRENDS IN *US EV* SALES IN 2021

- *EV* sales reached 55,007 in October 2021, which means a 25.1% increase from August 2021; *ANL EV* data indicate annual sales increased by 45.9% compared to October 2020
- Cumulative October 2021 *EV* sales totaled 448,434
- *Tesla* models have accounted for over half (59.5%) of *EV* sales in October 2021

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 64

TESLA : 2021 PERFORMANCE

- Unlike the established automakers, *e.g.* , *GM* and *Ford*, which closed one factory after another in 2020 – 21, *Tesla* had record sales each quarter with sales nearly double those in 2020
- The computer chip shortage problem seems to not have impacted *Tesla* to the extent the rest of the automobile manufactures were affected

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA : 2021 PERFORMANCE

- The *Tesla* car design and manufacturing relies very little on external sources – a distinct contrast to that of the the current auto industry, which heavily relies on external suppliers for much of the software and computing expertise in both hardware and software; *Tesla* from its start did not outsource its coding and hardware

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA : 2021 PERFORMANCE

- Given the chip shortage situation, *Tesla* engineers recoded their software to replace chips in short supply by those available – an option unavailable to the other manufacturers
- In 2021, *Tesla*'s global sales of 936,000 *EV*s were nearly twice its 2020 sales of 499,550 cars; the big auto giants sold fewer cars in 2021 than in 2020

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA : 2021 PERFORMANCE

- Such solid 2021 performance is a stark turnaround from 2018, when the *Tesla* production and supply problems were rather severe
- A key cause of the manufacturing snafus came from *Tesla*'s insistence on self-production of many on the *EV* components
- Other auto manufacturers have realized that they must follow *Tesla*'s approach to have control of their onboard computer systems, *e.g.*, *Mercedes* will

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA : 2021 PERFORMANCE

customize "standardized chips" in their cars and use its own software

- The *Tesla* decision to rely on its own in–house production emulates the early days of automobile manufacturing when companies such as *Ford* owned its own steel plants and rubber plantations; the shift away from in–house production to reliance on outside production left the companies exposed to *supply-chain vulnerabilities*

TESLA: 2021 PERFORMANCE

- A distinguishing feature of *Tesla EV*s is the small number of models and fewer options than those of established auto manufactures; the *Tesla EV*s' fewer components use fewer chips and so *Tesla*'s vulnerability to supply-chain turmoil is considerably reduced

TESLA: 2022 PERFORMANCE

- *Tesla*'s 2022 sales grew 40 % *y-o-y* to 1.31 *million*, but fell short of the 50 % growth figure the company had once projected for the year
- While *Tesla* broke quarterly delivery records in *Q*4 2022 with 405,278 vehicles, sales fell short of *Wall Street*'s expectations and its forecasts
- *Tesla* 's sales of *China*-made vehicles fell to a five-month low in December 2022 with a total 55,796

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA: 2022 PERFORMANCE

vehicles delivered representing a 44 % decrease from November 2022 and a 21 % decrease from November 2021

- *Tesla* suspended production at its *Shanghai* factory from December 24 to January 2 as part of an effort to reduce production
- *Tesla* closed its worst year in its stock's history, shedding about *$* 675 *billion* in market valuation in 2022

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA'S RESPONSE TO ITS *DEMAND PROBLEM*

- Towards the end of 2022, it became evident that *Tesla* was struggling to drum up orders in *China* and subsequently in both *US* and *Europe*
- In *China, Tesla* launched two rounds of reductions during a 10-week period once it became apparent that the company produced over 34,000 more cars than it delivered in *Q*4
- In the final weeks of 2022, *Tesla* offered *$* 7,500 discounts in the *US* to entice buyers and still came up short of its annual growth target

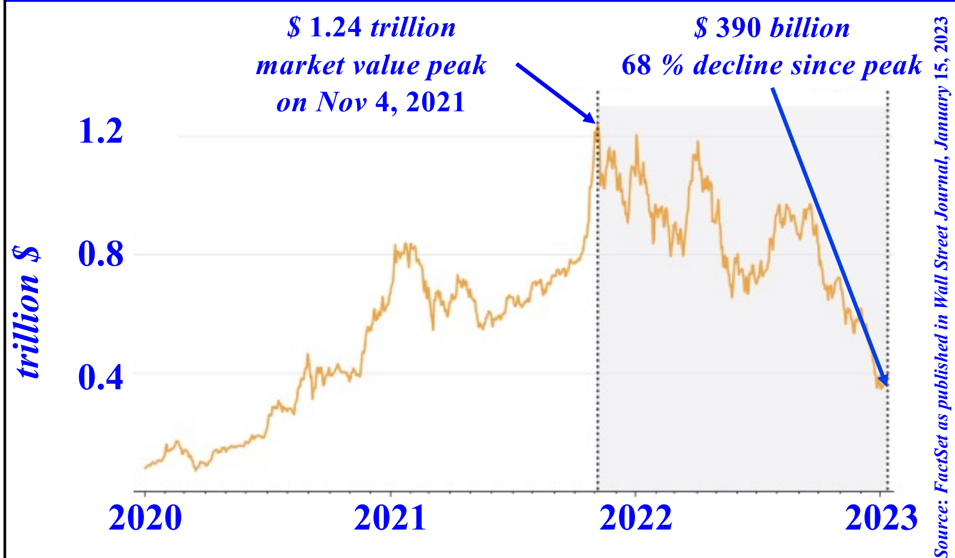
ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

TESLA'S RESPONSE TO ITS *DEMAND PROBLEM*

- In 2023, *Tesla* implemented deep price cuts in both the *US* and *Europe* by slashing 20 % off the cost of the *Model Y* and making performance versions of the *Model S* and *X* roughly *$* 20,000 cheaper
- While *Tesla*'s profit margins are higher than every other *OEM* outside *China*, its dominance has slipped considerably since 2021
- The lowered sales prices of will make more of those models eligible for new *US* tax credits introduced by the *IRA*

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

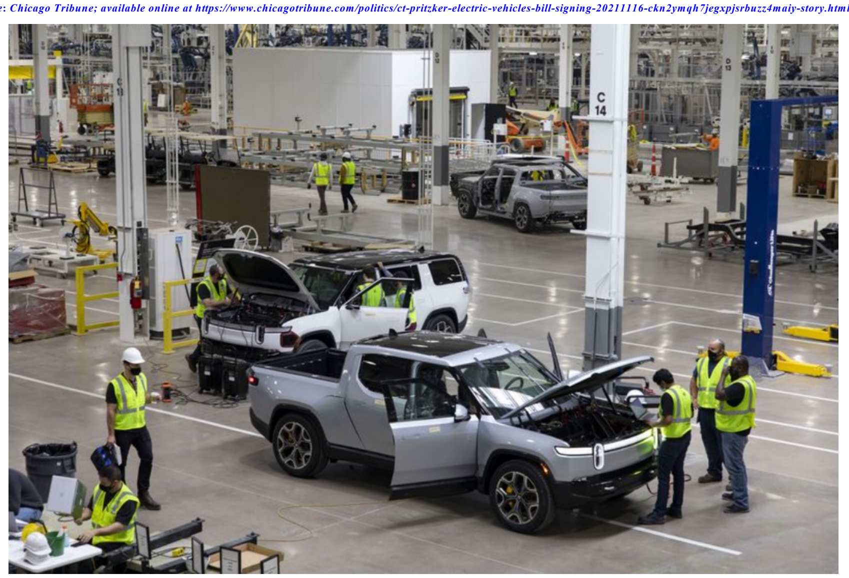
TESLA STOCK PRICE



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 75

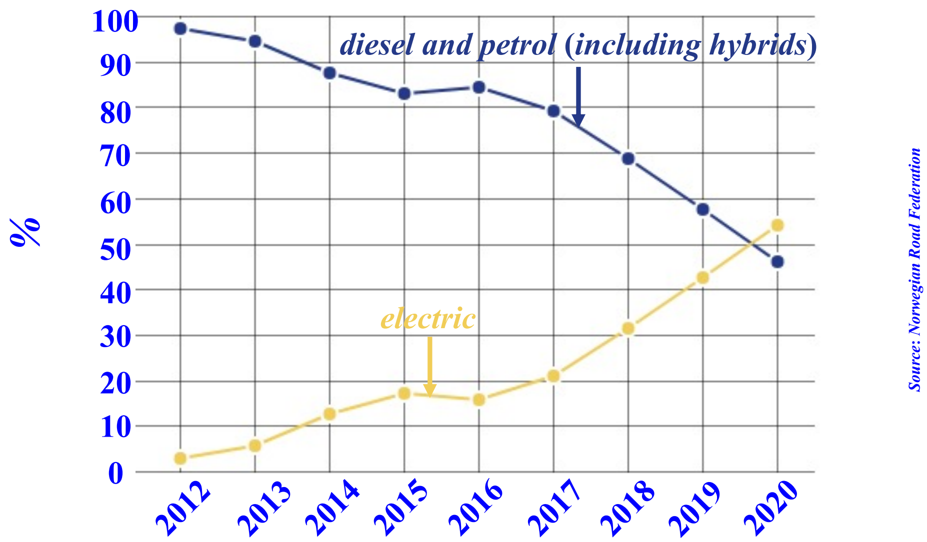
RIVIAN TRUCK ASSEMBLY

Source: Chicago Tribune; available online at https://www.chicagotribune.com/politics/ct-pritzker-electric-vehicles-bill-signing-20211116-ckn2ymqh7jegxpjsrbuzz4maiy-story.html



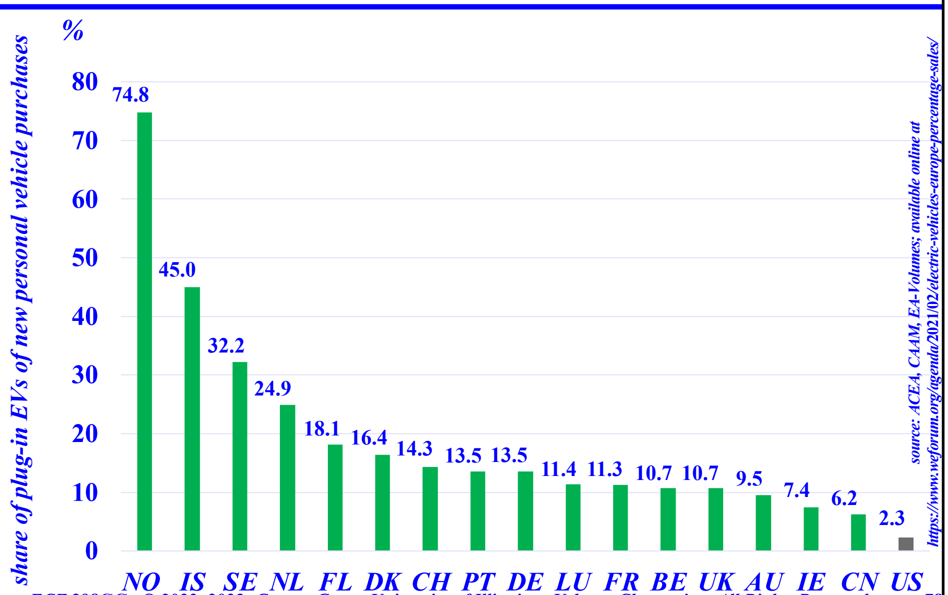
ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 76

NORWAY CAR SALES: 2012 – 2020



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 77

THE LEADING NATIONS IN *e-MOBILITY* IN 2020



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 78

EV CHARGING INFRASTRUCTURE

79

79

EV CHARGING STATIONS


Source: http://4.bp.blogspot.com


Source: http://cdn2.ubergizmo.com

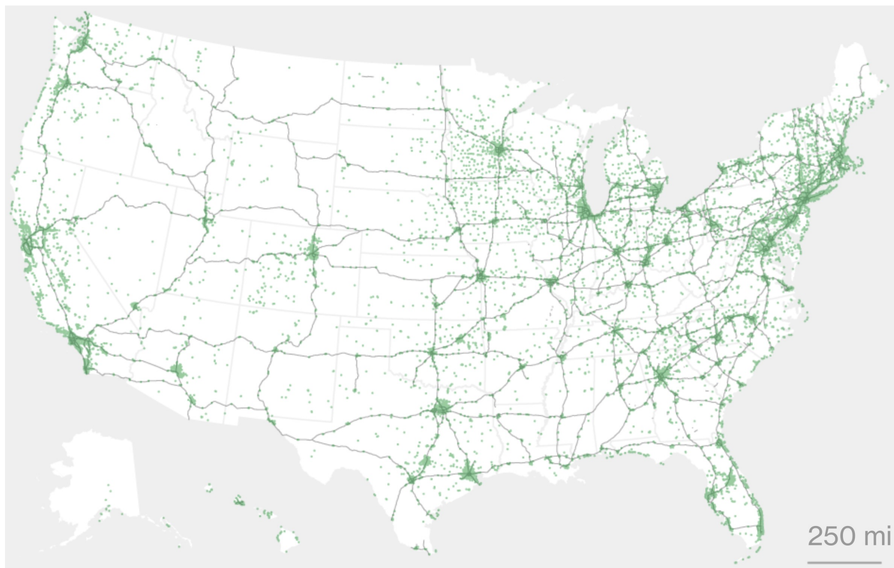

Source: http://earth2tech.files.wordpress.com


Source: http://www.autoconcept-reviews.com/cars_reviews/ford/ford-focus-electric-vehicle-2011

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved. 80

80

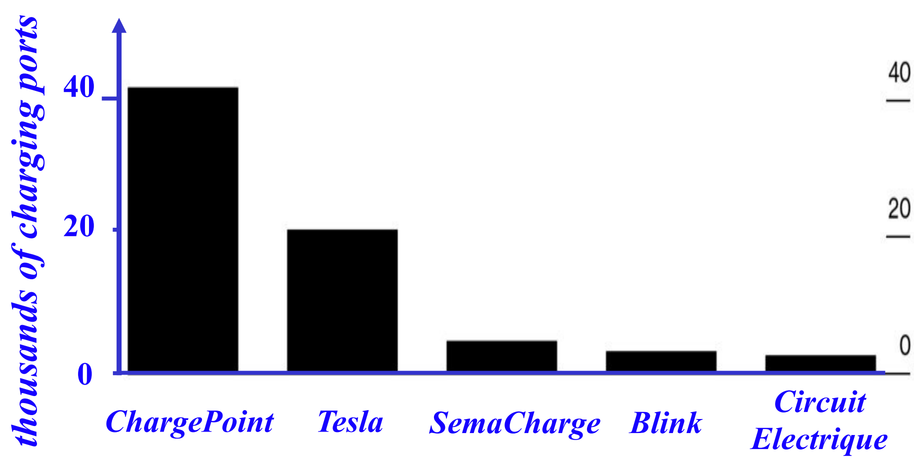
THE CONCENTRATION OF PUBLIC CHARGING STATIONS ON COASTS AND IN CITIES



Source: BloombergNEF; available online at https://www.bloomberg.com/news/articles/2021-04-30/ev-charging-industry-is-doing-everything-except-showing-a-profit

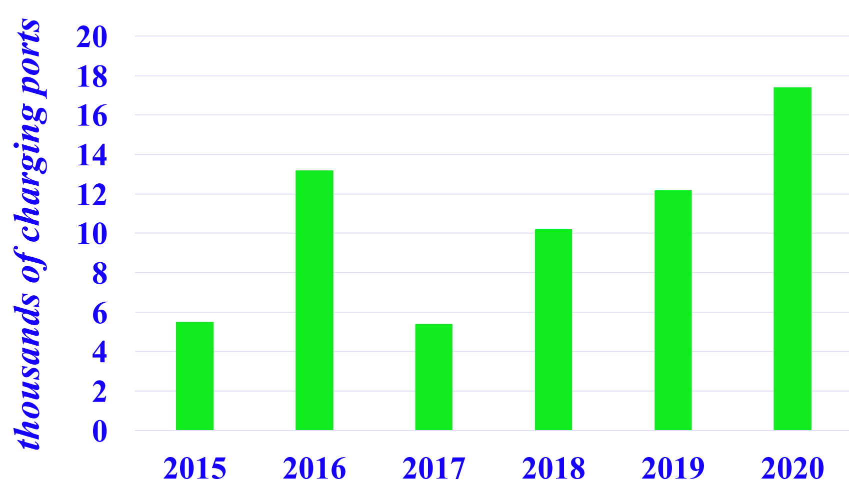
PUBLIC CHARGING STATIONS: THE MAJOR *NORTH AMERICAN* PLAYERS

Source: BloombergNEF; available online at https://www.bloomberg.com/news/articles/2021-04-30/ev-charging-industry-is-doing-everything-except-showing-a-profit



PUBLIC CHARGING STATIONS: THE SLOW GROWTH

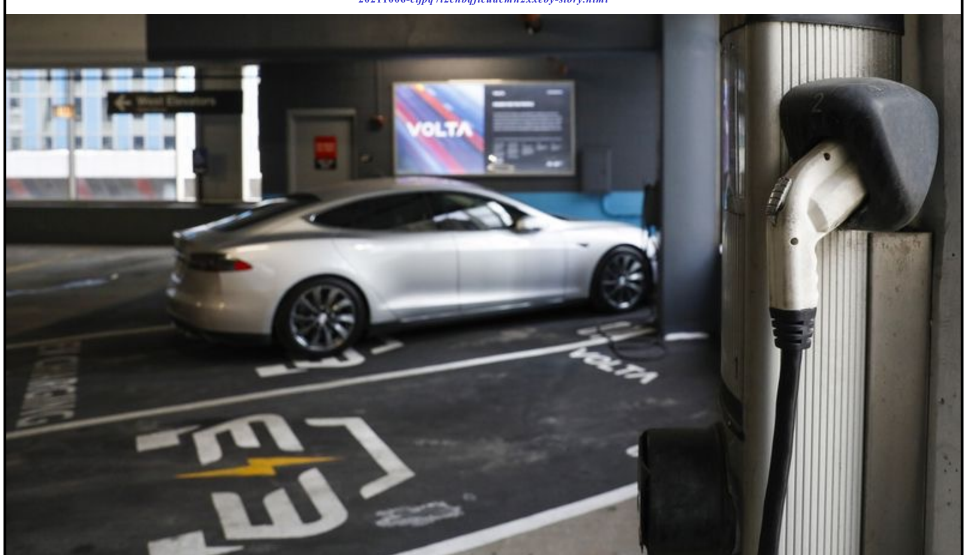
source: BloombergNEF; available online at https://www.bloomberg.com/news/articles/2021-04-30/ev-charging-industry-is-doing-everything-except-showing-a-profit



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

CHICAGO DOWNTOWN PARKING LOT WITH *EV* CHARGING

source: Chicago Tribune; available at https://www.chicagotribune.com/news/breaking/ct-illinois-clean-energy-law-consumer-opportunities-0930-20211006-cijpq7i2cnbqficudcmh2xxeoy-story.html



ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

EV CHARGING AT THE *ILLINOIS* STATE CAPITOL COMPLEX, SPRINGFIELD

source: Capital News Illinois; available online at https://capitolnewsillinois.com/NEWS/new-report-shows-illinois-job-economic-growth-in-electric-transportation-sector

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

A VEHICLE CHARGER AT THE *TESLA MOTORS INC. GIGAFACTORY IN McCARRAN, NV*

Source: Bloomberg photo

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ROCKLIN, *CA*: *TESLA EV*s CHARGING

Source: Bloomberg photo

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

THE USE OF THE TERM *EV*

- We use the term *EV* to refer to plug-in vehicles, which fully or partially depend on electricity
- We include:
  - plug-in hybrid *EV*s – *PHEV*s
  - extended range *EV*s – *EREV*s
  - battery *EV*s – *BEV*s
  - all electric *EV*s – *AEV*s
- We exclude *all hybrid vehicles that cannot be plugged in*

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

OVERVIEW OF THE COURSE

- ECE 398GG is essentially an energy course, which examines the various facets of the electrification of transportation and its significant impacts via the replacement of internal combustion engine (*ICE*) vehicles (*ICEV*s) by *EV*s
- The very nature of the topic involves multiple disciplines that range from basic physics, circuit

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

OVERVIEW OF THE COURSE

theory and economics to public policy, environmental analysis and regulation, and from drives and machines, *power electronics* and *control* to *sociology*, *market research* and *automotive design* to vehicle safety and the set-up of the *EV* charging infrastructure (*EVCI*)

- This course explores: the basics of how *EV*s operate; their integration into the grid – as

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

OVERVIEW OF THE COURSE

charging and/or discharging *distributed energy resources*; the effective utilization of *power electronics* in *EV* operations and charging; the role of electric *generators, machines* and *drives*; the environmental benefits; some notions of *automotive design*; battery hazards and safety; vehicular safety; and the key challenges and developments in the establishment of the *EVCI*

COURSE OBJECTIVES

- Expose students to the high, *strategic* importance to the power industry of the emerging market of electrified transportation
- Provide adequate background to understand the multi-disciplinary nature of *EV* and *EVCI* topics
- Cover in adequate depth the diverse aspects of energy systems, electro-mechanical energy conversion, motors, drives, generators, power

COURSE OBJECTIVES

electronics, electricity grids together with the relevant public and regulatory policy, economics and environmental issues

- Serve as an "unofficial" gateway course to students who wish to pursue the specialized senior level courses offered by the *Power and Energy Systems* faculty

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- Introduction and general overview
  - salient features of transportation industry
  - key drivers of transportation electrification
  - history of *EV*s in transportation sectors
  - energy and environmental issues
  - global *EV* deployment and *e-mobility*
  - course objectives and scope

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- Vehicle dynamics and energy/power requirements
  - basic physics of rolling vehicles
  - gravity, aerodynamic drag, hill climbing and descent, rolling resistance & braking forces
  - tractive force determination
  - the role of inertia, acceleration/deceleration
  - energy/power requirements for vehicle rolling motion; energy storage/transfer impacts; illustrative examples

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- Key *EV* design and operations considerations
  - *EV* size and weight
  - range implications
  - vehicle parameters and performance metrics – their nature and typical values
  - definition and role of drive cycles in performance assessment
  - performance evaluation

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- *EV* Architectures and configurations
  - the major *EV* subsystems – motors, drives, inverters, batteries and energy storage, chargers, sensors and control
  - architectural structures and configurations
  - generator sets and hybrid subsystems
- Energy Conservation Principle
  - the energy invariance principle that underlies all of nature's processes
  - illustrative examples
  - "*wells to wheels*" energy tracking

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- The *EV* batteries and their management
  - key portable energy requirements beyond rechargeability
  - key battery components: roles and nature
  - electrochemical cell as the building block of battery packs; modules and packs
  - battery operations phases – charging, discharging and idle
  - battery features
  - major figures of merit – capacity, storage capability, efficiency, health, life, energy density, specific power, state of charge (*s.o.c.*), depth of discharge, voltage/current characterization, temperature and geometry
  - dominance by *Li-ion* batteries and their limitations

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- Basic principles of, and design considerations in, *EV* electric motors and generators
  - concepts of *electromechanical energy conversion* – energy, co-energy, force and torque
  - review of low-frequency electromagnetics (*EM*) and *EM* force calculations of shear stress, machine power density and efficiency
  - comparative assessment and equivalent circuits of motor types – induction, surface and internal permanent magnet, switched and synchronous reluctance

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- Electric drives for traction application in *EV*s
  - basic nature and role of electric drives in electro-mechanical energy conversion
  - fundamentals of electric drives and their operation from an *EV* perspective; the *DC* – *AC* conversion process and approaches to generate controllable *AC* waveforms
  - traction inverters and their control
  - inverter applications to *EV* acceleration, deceleration/constant-speed maintenance

ECE 398GG © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- *EV* integration into today's grids
  - the impacts of *EV* loads on distribution grids
  - *EV*s as a deferrable load
  - *EV*s as *distributed storage resources* and the *vehicle-to-everything* (*V*2*X*) concept
  - role of *EV* aggregations
- *EV* energy efficiency analysis and evaluation
  - the *wells-to-wheels* reference metric used for internal combustion engine vehicles (*ICEV*s)
  - cumulative impacts of the constituent efficiencies – electricity generation

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

efficiency, grid efficiencies, charging efficiency and battery-to-wheels efficiency
  - definition and evaluation of efficiency metrics – miles per gallon equivalent and *kWh per* 100 miles
  - key assumptions; data sources
- *EV* Environmental Attributes
  - quantification of *EV GHG* emissions & comparison with the *ICEV* "tailpipe" emissions
  - evaluation of *EV* lifecycle emissions
  - *EV* battery life extension and disposal

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- *EV* Battery Charging Fundamentals
  - voltage levels and charging types
  - charging connectors
  - charging process; protection issues
- *EV* battery charging power electronics
  - *AC* grid analysis – power system in the sinusoidal steady state, complex power, single and three-phase power, average power and circuit analysis

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- power electronics topics: the analysis of *DC* – *DC* converter operations in the conti-nuous conduction regime and *PWM* rectifier circuit analysis; applications in *EVSE* – *EV* supply equipment – and the implementation of *EV* charging stations; specification of basic and buffer requirements; power converter types for the *EV* charging levels; and, *DC* fast buffer charge
- technology implementations and challenges

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- The *EV* charging infrastructure (*EVCI*)
  - the critical role *EVCI* plays to enable massive *EV* adoption; interdependence and interactions of *EVCI* with existing infrastructures
  - the establishment of *EVCI*: principal objectives
  - roles renewable and storage energy resources play; their effective integration into *EVCI*
  - location/implementation of *EVCI* stations
  - current *EV* charging providers and their business models; identified gaps and major challenges
  - policy and regulatory aspects

ECE 398GG ELECTRIC VEHICLES (*EV*s) TOPICAL OUTLINE

- Policy and Regulatory Issues
  - the nature/scope of policies to drive stronger *EV* sales and *EVCI* station implementation
  - policy formulation and implementation at various levels of government
  - *EV* adoption policies and incentives
  - replacement of the gasoline tax funding source in an electrified environment
- Beyond *EV*s
  - further transportation electrification in airplanes, buses and freight mobility
  - battery technology enhancements
  - wireless charging

A *JOBY AVIATION EVTOL* AIRCRAFT OUTSIDE THE *NYSE*

source: Bloomberg Hyperdrive, October 29, 2021; available at https://www.bloomberg.com/news/newsletters/2021-10-19/canada-poised-to-become-battery-leader-in-north-america

 © 2022–2023 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.