1. Introduction and Overview

George Gross
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<table>
<thead>
<tr>
<th>sector</th>
<th>goal for the year</th>
</tr>
</thead>
<tbody>
<tr>
<td>US economy</td>
<td>GHG emission reduction by 50%</td>
</tr>
<tr>
<td>transportation</td>
<td>set up of 500,000 EV chargers</td>
</tr>
<tr>
<td>buildings</td>
<td></td>
</tr>
<tr>
<td>power &amp; energy</td>
<td>80 % zero C</td>
</tr>
</tbody>
</table>

BIDEN ADMINISTRATION’S CLIMATE GOALS
THE ORIGINAL BIDEN PLAN:
2.6 TRILLION $


THE ELIMINATED AND THE SHRUNK PARTS OF THE BIDEN PLAN

THE PARTS THAT REMAINED UNCHANGED OR INCREASED

- Pollution
- Transportation
- Utilities

THE SENATE BIPARTISAN PLAN:

550 BILLION $
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

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, EVs 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, EVs, nuclear energy, clean hydrogen and direct consumer rebates for families to buy heat pumps or other energy efficient home appliances, aimed to decrease US CO₂ emissions by 40% by 2030

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 $
Electricity will continue to substitute for less efficient and less productive energy forms.

**US ENERGY CONSUMPTION AND ELECTRICITY USE**

- Energy / GNP ratio (index is 100 for the year 1900)
- Electricity as a percentage of total energy consumed

**US ENERGY – RELATED CO₂ EMISSIONS BY SECTORS: 1990 – 2020**

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

Source: U.S. EIA, available on-line at https://www.eia.gov/outlooks/aeo/pdf/08%20eio%202021%20emissions.pdf; p. 4

US GHG NET EMISSIONS AND INTERNATIONAL COMMITMENTS

GLOBAL ENERGY-RELATED CO$_2$ EMISSIONS: 1990 – 2020


GLOBAL CO$_2$ EMISSIONS FROM FOSSIL FUELS

THE WORLD ECONOMIES RELY ON ABUNDANT AND AFFORDABLE ELECTRICITY

SOURCES OF 2021 US ELECTRICITY GENERATION

- total generation = 4,115.54 TWh

- natural gas 38.28%
- coal 21.84%
- nuclear 18.91%
- other renewable sources 13.76%
- hydro 6.20%
- petroleum/other gases 0.73%
- other energy sources 0.29%

Source: EIA available at https://www.eia.gov/electricity/data.php
NET 2021 US GENERATION BY RENEWABLE ENERGY RESOURCES

- Wind: 46.0%
- Hydroelectric: 31.5%
- Solar: 13.9%
- Wood/biomass: 6.7%
- Geothermal: 1.9%

Total renewable generation = 826 billion kWh


2021 US CO₂ EMISSIONS BY SECTOR

- Transportation: 38%, 1.7 metric Gigatons
- Electricity generation: 33%, 1.5 metric Gigatons
- Industrial: 29%, 0.8 metric Gigatons
- Residential: 0.3 metric Gigatons
- Commercial: 0.2 metric Gigatons

US ELECTRICITY GENERATION $CO_2$ vs. OTHER SECTORS’ EMISSIONS: 1990 – 2021

Electricity generation

Total of other economic sectors

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

ELECTRICITY GENERATION $CO_2$ EMISSIONS AND CARBON INTENSITY

Average carbon intensity

CO$_2$ emissions

CO$_2$ intensity (value is 100 for 1990)

1990 2000 2010 2020

CO$_2$ emissions

120 100 80 60 40 20 0

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US ELECTRICITY GENERATION SOURCES: 1990 – 2021

ELECTRICITY GENERATION BY PRIMARY ENERGY SOURCES: 1990 – 2021
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

(washington post, april 6, 2017)

kentucky coal mining museum in harlan county switches to solar power

(washington post, april 6, 2017)
ELECTRICITY GENERATION BY PRIMARY ENERGY SOURCES: 1990 – 2021


FORECASTED EMISSIONS OF CO₂ FROM US ELECTRICITY GENERATION

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.

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.
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.
THE CO$_2$e 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$_2$e units.
- The unit CO$_2$e 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.

US GHG EMISSIONS AND ANNUAL CHANGES: 2019 – 2022


Change with respect to 2019 in %

Diesel
Gasoline
Jet fuel


Electric generation in GWh by source

Coal
Natural gas
Nuclear
Renewables

US ELECTRICITY GENERATION SHARE BY SOURCE: 2019 - 2021


US GHG NET EMISSIONS AND INTERNATIONAL COMMITMENTS

**EV DEPLOYMENT GOAL: CLEAN THE AIR RAPIDLY**

*Source: ACEA, CAAM, EA - Volumes available online at https://www.weforum.org/agenda/2021/02/electric-vehicle-usage-impact-study/

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**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 EVs 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

- EVs 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 EVs 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 EVs
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

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

![Graph comparing US $$/mile costs of EVs and ICEVs in 2015, including savings per mile.]
**EVs ON THE ROAD**

Source: Financial Times
https://www.ft.com/content/31d68a8f-6e0a-11e6-9ac1-1055824ca907

**CHINA EV SALES**

*EVs in thousands*

Source: Financial Times
https://www.ft.com/content/31d68a8f-6e0a-11e6-9ac1-1055824ca907
GLOBAL EV SALES


GLOBAL ANNUAL EV SALES: 2010 – 2021

GLOBAL EV SALES

- Global EV sales in 2021 more than doubled to 6.6 million with respect to the 3 million EVs 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

*Source: EV volumes; available at https://www.ev-volumes.com/*

- All numbers are in thousands
- Registration share in %
- Y-o-y growth in %

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### 2021 GLOBAL BEV & PHEV SALES BY REGION

#### Thousands of Vehicles

<table>
<thead>
<tr>
<th>Region</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe (W&amp;C)</td>
<td>1,401</td>
<td>2,332</td>
</tr>
<tr>
<td>China</td>
<td>1,331</td>
<td>3,396</td>
</tr>
<tr>
<td>Northern America</td>
<td>735</td>
<td>2020</td>
</tr>
<tr>
<td>others</td>
<td>375</td>
<td>286</td>
</tr>
<tr>
<td><strong>Global Total</strong></td>
<td><strong>108</strong></td>
<td><strong>108</strong></td>
</tr>
</tbody>
</table>

*Source: EV volumes; available at https://www.ev-volumes.com/
Year-on-year growth in % of EV sales
Global total 108

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### TOP 5 AUTOMAKERS’ GLOBAL EV SALES BY REGION: 2021

#### Numbers are in thousands

<table>
<thead>
<tr>
<th>Automaker</th>
<th>China</th>
<th>US</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla</td>
<td>936</td>
<td>170</td>
<td>352</td>
</tr>
<tr>
<td>BYD</td>
<td>763</td>
<td>549</td>
<td>517</td>
</tr>
<tr>
<td>Stellantis</td>
<td>598</td>
<td>1</td>
<td>385</td>
</tr>
<tr>
<td>GM</td>
<td>598</td>
<td>486</td>
<td>324</td>
</tr>
<tr>
<td>VW Group</td>
<td>598</td>
<td>2</td>
<td>42</td>
</tr>
</tbody>
</table>

R.O.W. numbers are in thousands

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THE LEADING PLUG-IN VEHICLE SALES IN 2021

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Sales 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla</td>
<td>936,172</td>
</tr>
<tr>
<td>BYD</td>
<td>593,378</td>
</tr>
<tr>
<td>SGMW</td>
<td>456,123</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>319,735</td>
</tr>
<tr>
<td>BMW</td>
<td>276,037</td>
</tr>
<tr>
<td>Mercedes</td>
<td>228,144</td>
</tr>
<tr>
<td>SAIC</td>
<td>226,963</td>
</tr>
<tr>
<td>Volvo</td>
<td>189,115</td>
</tr>
<tr>
<td>Audi</td>
<td>171,371</td>
</tr>
<tr>
<td>Hyundai</td>
<td>159,343</td>
</tr>
<tr>
<td>Kia</td>
<td>158,134</td>
</tr>
<tr>
<td>Great Wall</td>
<td>137,366</td>
</tr>
<tr>
<td>BYD</td>
<td>136,750</td>
</tr>
<tr>
<td>GAC</td>
<td>125,384</td>
</tr>
<tr>
<td>Peugeot</td>
<td>125,263</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>116,029</td>
</tr>
<tr>
<td>Ford</td>
<td>111,879</td>
</tr>
<tr>
<td>Chery</td>
<td>99,109</td>
</tr>
<tr>
<td>XPeng</td>
<td>98,698</td>
</tr>
<tr>
<td>Changan</td>
<td>97,911</td>
</tr>
</tbody>
</table>

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

DECEMBER 2021 PLUG-IN VEHICLE SALES IN EUROPE BY MANUFACTURER

<table>
<thead>
<tr>
<th>Model</th>
<th>Sales 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Model 3</td>
<td>27,445</td>
</tr>
<tr>
<td>Renault Zoe</td>
<td>11,393</td>
</tr>
<tr>
<td>Opel Adam</td>
<td>8,148</td>
</tr>
<tr>
<td>Tesla Model Y</td>
<td>8,085</td>
</tr>
<tr>
<td>VW e-Up</td>
<td>7,789</td>
</tr>
<tr>
<td>VW ID.4</td>
<td>6,790</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>6,214</td>
</tr>
<tr>
<td>Honda e</td>
<td>5,930</td>
</tr>
<tr>
<td>VW ID.3</td>
<td>5,926</td>
</tr>
<tr>
<td>Mini Cooper EV</td>
<td>5,129</td>
</tr>
<tr>
<td>Mercedes GLC300e/Be</td>
<td>5,116</td>
</tr>
<tr>
<td>Audi Q2 e-tron</td>
<td>5,078</td>
</tr>
<tr>
<td>Hyundai Ioniq5</td>
<td>5,024</td>
</tr>
<tr>
<td>Fiat 500e</td>
<td>4,961</td>
</tr>
<tr>
<td>Volvo XC60 PHEV</td>
<td>4,604</td>
</tr>
<tr>
<td>Peugeot 308 EV</td>
<td>4,338</td>
</tr>
<tr>
<td>Renault Twingo EV</td>
<td>4,304</td>
</tr>
<tr>
<td>Kia Niro EV</td>
<td>4,271</td>
</tr>
<tr>
<td>Peugeot 308 PHEV</td>
<td>4,243</td>
</tr>
<tr>
<td>Volvo XC90 PHEV</td>
<td>3,964</td>
</tr>
</tbody>
</table>

Source: CleanTechnica; available online at https://cleantechnica.com/2022/01/29/of-cars-sold-in-europe-were-plugin-electric-vehicles-in-december/
SHARES OF 2021 PLUG-IN VEHICLE SALES OF THE TOP 5 EUROPEAN CAR MANUFACTURERS

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>SHARE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volkswagen group</td>
<td>24 %</td>
</tr>
<tr>
<td>Stellantis</td>
<td>13 %</td>
</tr>
<tr>
<td>BMW group</td>
<td>10 %</td>
</tr>
<tr>
<td>Daimler</td>
<td>10 %</td>
</tr>
<tr>
<td>Renault-Nissan</td>
<td>10 %</td>
</tr>
</tbody>
</table>

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

2018 US EV REGISTRATIONS PER 100,000 RESIDENTS

Source: USAFacts; available online at https://usafacts.org/articles/how-many-electric-cars-in-united-states/
**TESLA MODEL 3 RESERVATIONS**

Source: [http://electrek.co/2016/04/03/tesla-model-3-reservations-timeline/](http://electrek.co/2016/04/03/tesla-model-3-reservations-timeline/), issued April 2015

**TESLA 3 MODEL ESTABLISHES US EV MARKET DOMINANCE**

Source: USAFacts; available online at [https://usafacts.org/articles/how-many-electric-cars-in-united-states/](https://usafacts.org/articles/how-many-electric-cars-in-united-states/)
THE TOP 10 STATES FOR TESLA REGISTRATION IN 2020

<table>
<thead>
<tr>
<th>State</th>
<th>Registration Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>73,800</td>
</tr>
<tr>
<td>FL</td>
<td>16,200</td>
</tr>
<tr>
<td>TX</td>
<td>10,400</td>
</tr>
<tr>
<td>NJ</td>
<td>9,700</td>
</tr>
<tr>
<td>NY</td>
<td>9,500</td>
</tr>
<tr>
<td>WA</td>
<td>7,700</td>
</tr>
<tr>
<td>IL</td>
<td>5,700</td>
</tr>
<tr>
<td>AZ</td>
<td>5,000</td>
</tr>
<tr>
<td>PA</td>
<td>4,800</td>
</tr>
<tr>
<td>MA</td>
<td>4,500</td>
</tr>
</tbody>
</table>

Source: HIS Markit

MONTHLY US EV SALES: DECEMBER 2010 – MARCH 2021
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.
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 manufacturers were affected.

The Tesla car design and manufacturing relies very little on external sources – a distinct contrast to that of 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.

65
**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 EVs were nearly twice its 2020 sales of 499,550 cars; the big auto giants sold fewer cars in 2021 than in 2020.

**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*
customized “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.

A distinguishing feature of Tesla EVs is the small number of models and fewer options than those of established auto manufactures; the Tesla EVs’ 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 Q4 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 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.
**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 *Q4*
- 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

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**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*
**TESLA STOCK PRICE**

$1.24$ trillion market value peak on Nov 4, 2021

$390$ billion $68\%$ decline since peak

Source: FactSet as published in Wall Street Journal, January 15, 2023

**RIVIAN TRUCK ASSEMBLY**

Source: Chicago Tribune; available online at https://www.chicagotribune.com/politics/political-electric-vehicles-bill-signing-20211116-ydbo29mgh75cgpg5jzgjlo34s.html
NORWAY CAR SALES: 2012 – 2020

THE LEADING NATIONS IN e-MOBILITY IN 2020
EV CHARGING INFRASTRUCTURE

Source: http://earth2tech.files.wordpress.com
Source: http://4.bp.blogspot.com
Source: http://www.autoconcept-reviews.com/cars_reviews/ford/ford-focus-electric-vehicle-2011
Source: http://cdn2.ubergizmo.com

EV CHARGING STATIONS

Source: http://4.bp.blogspot.com
Source: http://www.autoconcept-reviews.com/cars_reviews/ford/ford-focus-electric-vehicle-2011
Source: http://cdn2.ubergizmo.com
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

CHICAGO DOWNTOWN PARKING LOT WITH EV CHARGING

EV CHARGING AT THE ILLINOIS STATE CAPITOL COMPLEX, SPRINGFIELD


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

Source: Bloomberg photo
THE USE OF THE TERM \textit{EV}

- We use the term \textit{EV} to refer to \textit{plug-in vehicles}, which fully or partially depend on electricity.

- We include:
  - plug-in hybrid \textit{EVs} – \textit{PHEVs}
  - extended range \textit{EVs} – \textit{EREVs}
  - battery \textit{EVs} – \textit{BEVs}
  - all electric \textit{EVs} – \textit{AEVs}

- We exclude all hybrid vehicles that \textit{cannot be plugged in}.
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 (ICEVs) by EVs.

- The very nature of the topic involves multiple disciplines that range from basic physics, circuit 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 EVs operate; their integration into the grid – as
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 ELECTRIC VEHICLES (EVs) TOPICAL OUTLINE

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

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 (EVs) 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

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## ECE 398GG ELECTRIC VEHICLES (EVs) 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 (EVs)

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

- Electric drives for traction application in EVs
  - 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 ELECTRIC VEHICLES (EVs)
TOPOICAL OUTLINE

- EV integration into today’s grids
  - the impacts of EV loads on distribution grids
  - EVs as a deferrable load
  - EVs as distributed storage resources and the vehicle-to-everything (V2X) concept
  - role of EV aggregations

- EV energy efficiency analysis and evaluation
  - the wells-to-wheels reference metric used for internal combustion engine vehicles (ICEVs)
  - cumulative impacts of the constituent efficiencies – electricity generation

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ECE 398GG ELECTRIC VEHICLES (EVs) 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

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ECE 398GG ELECTRIC VEHICLES (EVs) TOPICAL OUTLINE

- Power electronics topics: the analysis of \( DC \) – \( DC \) converter operations in the continuous 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 (EVs) 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

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### ECE 398GG ELECTRIC VEHICLES (EVs) 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 EVs**
  - further transportation electrification in airplanes, buses and freight mobility
  - battery technology enhancements
  - wireless charging
A JOBY AVIATION EVTOL AIRCRAFT OUTSIDE THE NYSE