SIADS 592 Final Report
Exploring Electric Vehicle Infrastructure and Adoption

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Github Repository w/ Links to Interactive Plots, Choropleth, & Dashboard: https://github.com/Cody-Lange/Exploring-Electric-Vehicle-Infrastructure

Motivation

Electric vehicles have been emerging as a significant response to the current climate crisis, providing a novel way to reduce global greenhouse gas emissions. EVs will make up 10% of global passenger vehicle sales in 2025, 28% in 2030 and 58% in 2040. EVs will make up 31% of all cars on the road in 2040, 67% of municipal buses, 47% of two-wheeled vehicles and 24% of light commercial vehicles.
Electric vehicles are gaining in popularity, but does the United States currently have the infrastructure for electric vehicles to be a practical alternative to traditional gas cars? This report explores the practicality of using electric cars by examining existing EV infrastructure, principally charging stations, the types of charging available, and EV adapters. The availability of EV charging stations, the degree to which adapters are interchangeable, the rates of charging, and the range of existing EVs are key determinants of whether or not existing infrastructure supports EV use in a practical manner.

Additionally, this report examines the growth of e-bike and e-scooter usage in urban transit. These smaller vehicles have also started to play an important role in helping cities transition to sustainable, emissions-free transportation. We will be looking at how these vehicles have grown in usage over the past few years and the overall growth of the micromobility market. We also want to observe real time data to visualize vehicle trips through various cities.

Data Sources

1. **Electric Cars**
    a. **US Department of Energy's Alternative Fuel Station Data**
        i. Alternative Fuel Stations API
        ii. Contains up to date coordinates of all non-personal charging stations registered with the Department of Energy and will be extracted into JSON format using an API with the python requests library.
        iii. 43,504 entries pulled
    b. **2019 US Census Bureau County Boundaries**
        i. https://www.census.gov/geographies/mapping-files/time-series/geo/cartographic-boundary.html
        ii. Provides Cartographic Boundaries for all counties in the United States and Puerto Rico. County lines were chosen of ZIP code tabulation areas because there are some stretches of the country not covered by ZIP codes
        iii. Direct download: 1.66 MB total (cpg,dbf,prj,shp, shx files included in folder)
    c. **United States ZIP Code Data**
        i. https://www.unitedstateszipcodes.org/zip-code-database/
        ii. Relates ZIP codes in the fuel station data to US counties, which is needed to match charging station data to cartographic boundaries
        iii. Direct download CSV file: 4.16 MB

d. **US Zip Codes to County FIPS Crosswalk**
    i. https://www.kaggle.com/danofer/zipcodes-county-fips-crosswalk?select=ZIP-COUNTY-FIPS_2017-06.csv
    ii. Relates County and state FIPS codes found in the geometric data to the names of counties
    iii. Direct download CSV file: 184 KB
e. **US Department of Energy's Fuel Economy Data**
    i. https://www.fueleconomy.gov/feg/ws/index.shtml#ft7
    ii. Contains information on fuel economy of cars available in the US from 1984-present, including an estimate of annual fuel cost for each vehicle under specific conditions
    iii. The csv file is 18.2 MB

2. **Scooters/Bikes**
    a. **U.S. Department of Transportation Bike & Scooter Systems**
        i. https://data-usdot.opendata.arcgis.com/datasets/bikeshare-scooter-systems/data
        ii. Data on bikeshare and e-scooter systems by city in the U.S.
        iii. Direct download CSV file: 1478 records
    b. **U.S. Department of Transportation Bikeshare Dock Connectivity**
        i. https://data-usdot.opendata.arcgis.com/datasets/bikeshare/data
        ii. Data on dock locations and connectivity to other public transportation
        iii. Direct download CSV file: 6609 records
    c. **Louisville, KY Dockless Vehicles Data**
        i. https://data.louisvilleky.gov/dataset/dockless-vehicles
        ii. Louisville data on e-scooters
        iii. Two datasets, one from 08/2018 - 01/2020, one from 02/2020 to present
        iv. Direct download CSV file: 400k records
    d. **Citibike New York City Bikeshare Data(E-bikes included)**
        i. https://www.citibikenyc.com/system-data
        ii. Citi bike (including e-bike) data from New York City, contains dataset from 2013-present as well as real time data in GBFS format
        iii. Numerous datasets (https://s3.amazonaws.com/tripdata/index.html). Lots of data and size will depend on what we decide to use for our visualizations based on visual exploration of the data.
    e. **Los Angeles Monthly Dockless Deployment and Trips**
        i. https://data.lacity.org/Transportation/Monthly-Dockless-Vehicles-Deployment-By-Census-Blo/j5g7-w4y7
        ii. https://data.lacity.org/Transportation/Monthly-Dockless-Vehicles-Trip-Start-By-Census-Blo/d7jk-ufat
        iii. These are two datasets which cover the deployment of dockless vehicles in Los Angeles as well as trip data for the city of Los Angeles between April 2019 and February 2020.
        iv. Direct download CSV files: 22.4K records for deployment, 17.3K records for trips
    f. **City of Chicago E-scooter Data Streams**
        i. http://dev.cityofchicago.org/open%20data/2020/09/14/scooter-gbfs-public-feeds-2020.html
        ii. Accessible via API
    g. **City of Austin, TX Dockless Vehicle Data**
        i. https://data.austintexas.gov/Transportation-and-Mobility/Shared-Micromobility-Vehicle-Trips/7d8e-dm7r

ii. Describes micromobility vehicle trips from April 2018 - December 2020
iii. Direct download CSV: 10.1 million records

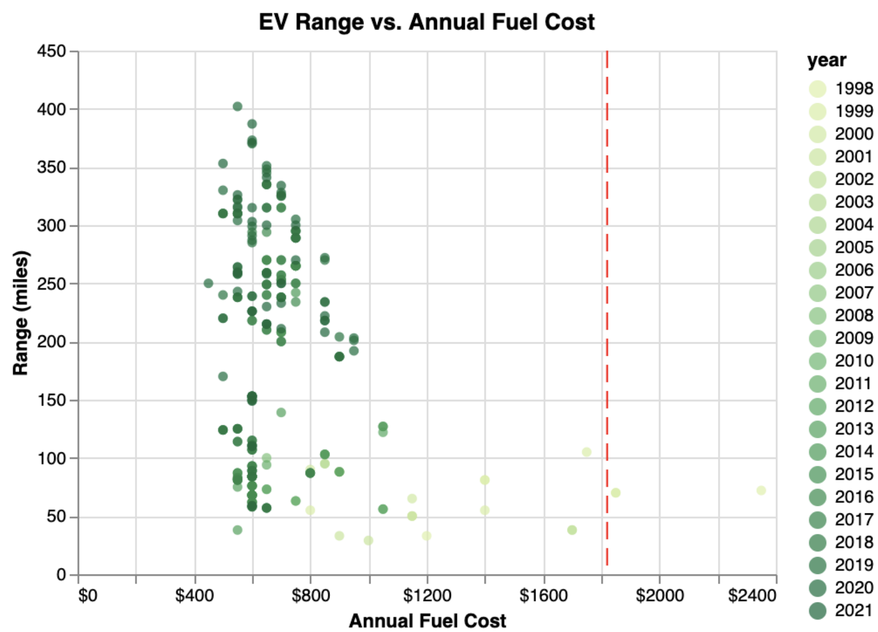
Data Cleaning and Manipulation

The fuel station dataset from the Department of Energy did not need much cleaning, other than eliminating useless columns and replacing null values for EV counts with zero so that they're included in the choropleth that is created as having zero EV stations. From a manipulation standpoint, the data is grouped by state, US counties, and Texas cities, to get an overview of the number of charging stations and supported charging types at each level. There were also some entries in the fuel station data that did not have county boundaries (Guam, Samoa, etc.), so they were dropped from the data. The geometric data had to have its FIPS codes mapped to county names with the FIPS crosswalk data, and the fuel station data had to have ZIP codes mapped to county names with the US Zip Code data. Afterwards, the geometric and fuel station data were merged and had the information available for the interactive choropleth. The fuel economy dataset required minimal cleaning as well. Unnecessary columns were dropped and the data frames were filtered to only use pertinent information (EV range, make, etc.)

The e-scooter and bikeshare datasets all share very similar columns and the datasets will be used both independently and in tandem. For cities that share data over the same time frames, we will be able to compare national growth for those time frames. Some columns in these datasets will need to be dropped for certain tasks and some will need to be merged, but we can easily perform an SQL Join on common columns to aggregate data. Data stream data from the Chicago API will be used independently and will be compared to other data stream data in the same format.

Analysis and Visualization

Figure 1 depicts the range of electric vehicles in miles versus their annual cost of fuel as determined by the US Department of Energy. The annual fuel cost is calculated assuming 15,000 miles at 55% city driving. Each point represents a specific model, with the color of said point representing the model year of that vehicle. The red dashed line presents the mean value of annual fuel costs for traditional gas cars of model year 2018 or newer. As is clearly seen in **Figure 1**, there is a large gap between the annual cost of modern EVs and traditional gas cars. One could easily cut their fuel budget in half by switching to an EV, this advantage of EVs is clear.



A traditional gas car that gets 25 mpg with a 12 gallon tank would have a range of 300 miles, and many fuel-efficient cars get far more than 25 mpg. EVs are beginning to reach a similar range, as seen above. However, the advantage of traditional gas cars is the ability to fill the gas tank in just minutes. Say a salesman must visit a client who is 250 miles away. He can travel the 250 miles to visit this client in a traditional vehicle, refill his tank, and make the return journey all in one day. EVs do not provide that luxury, as seen in **Figure 2** below.

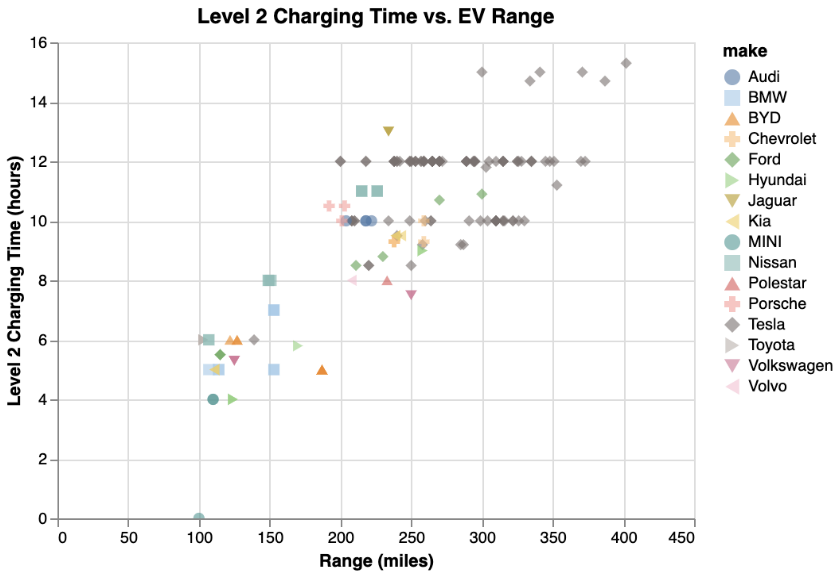


Figure 2: Charging Time vs. Range

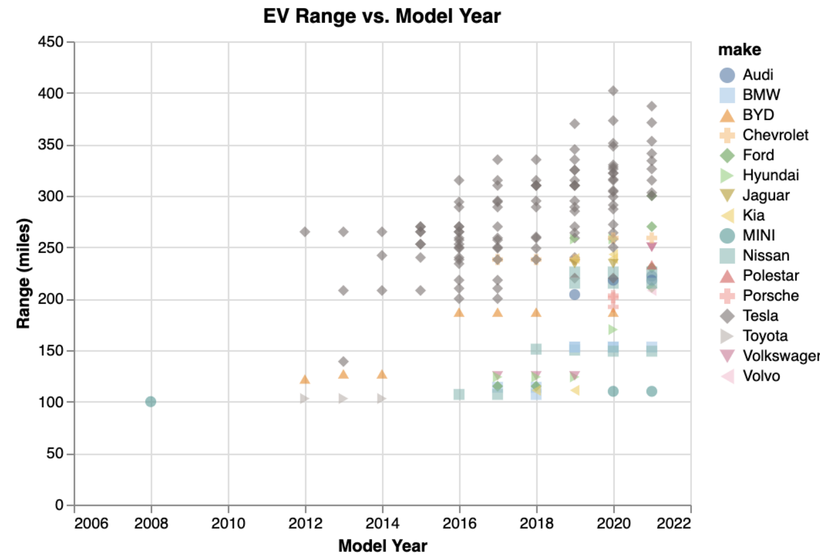


Figure 3: Range vs. Model Year

There is a relatively linear relationship between an EV's range and its charging time. The larger the battery life, the longer it takes to recharge. The effectiveness of EVs given these ranges depends on the use case. Any of these EVs would be effective for someone with a standard commute that purchases a home charger. This does, however, require the ability to charge your vehicle at your residence. This is easy enough for homeowners, but is no guarantee for someone who lives in an apartment. Though, this problem could be remedied if there is a charger available at one's workplace.

For the aforementioned salesman travelling 250 miles, however, any EV that has the range to make that trip will take at least 7.5 hours to recharge (assuming a level 2 charging station, this will be discussed in more detail later), likely making it necessary to stay overnight. This is a waste of both time and money for the salesman. There are two obvious solutions to this situation: the range of the cars could increase or the charging time could decrease. **Figure 3** below addresses the former option, showing the relationship between EV range and model year, including only those models newer than 2007 and that have a range of greater than 100 miles.

More EVs with ranges around and above 200 miles have appeared, especially since 2019. Though there are also a number of newer EV options with lower ranges, there is reason to believe that these ranges will begin to increase. Since Tesla's first few years in the market, fairly steady growth in range can be seen in their vehicles. Tesla of course specializes in only EVs, while many of these other traditionally gas vehicle manufacturers are only recently pivoting in this direction. Tesla, which had an impressive range from the start, has used the past 8 or 9 years to improve their range even further. It seems reasonable to assume that other companies too will improve the range of their EVs over time.

Unless there is more than just this slow and steady growth, the range will likely not be sufficient to turn our salesman's visit to his client into a day trip. Until EVs can have a range far greater than that of a traditional gas car, the traditional car will still have the advantage of taking no more than a couple minutes to fill their tank. For this reason, the other previously mentioned option, faster EV charging, is desirable. The different kinds of EV chargers are detailed in the **Table 1** below.

Table 1 Features the three most widely used charging types, which are categorized by levels that indicate the rate of battery charging. Level 3 charging is significantly faster than both level 1 and level 2 charging. It is only available commercially due to special installation and electrical requirements, but it delivers charge at a much faster rate than what is provided by the standard 240V available to a standard residence. However, for people that do not need to travel large stretches at a time, level 1 and 2 charging at home would suffice.. The quick charge is more important in the case of someone doing a large amount of driving at one time, such as our salesman visiting his client. Level 3 charging stations are the best gas station equivalents for EVs and are the most convenient; however, it does require special charging adapters. All EVs on the market today, except for Teslas, have a J1772 charge port. Teslas have their own charging port and come with a J1772 adapter. Due to the adoption rate and compatibility issues with level 3 charging, level 2 charging is the most abundant charger type.

Breakdown of Different Charging Types Available

Level	Primary Applications	Charge Rate	Connector Type	Number of Stations
Level 1 Charging	Residential	2-5 Miles / hr Charging	J1772 charge port	627
Level 2 Charging	Residential, Commercial	10-20 Miles / hr Charging	J1772 charge port	30,089
Level 3 Charging (DC Fast Charging)	Commercial	180-240 Miles / hr Charging	CCS charge port CHAdeMO charge port Tesla charge port	4,529

https://afdc.energy.gov/fuels/electricity_infrastructure.html

Table 1. Attributes of the three main charging types

Figure 4 shows the adoption of the different charging levels by giving the percent of public-access, 24/7 charging stations that supports each charging level. Public access and 24/7 were qualities that were filtered for in the fuel station dataset because charging stations have to be readily accessible to the general public at any time of the day for them to help build the case of electric vehicles being practical alternatives to traditional gas cars. As discussed, level 2 is the most widely adopted, coming in at 89% of the current 33,935 stations available. The newer Level 3 charging is only supported by 13% of existing stations, and level 1 is only supported by 2 % of the country's public, 24/7 charging stations.

The numbers make sense in that level 1 only charges at a rate of 2-5 miles/hr and is only convenient for EV users that only have access to a wall outlet, while level 3 is newer and requires special, more costlier installation.

It would be ideal for level 3 charging to be more prevalent in commercial settings, but another determinant of whether or not electric vehicle usage is practical is the proximity to charging stations of a given region. Charging station data provided by the US Department of Energy alternative fuel station dataset gives the location of each charging station within the United States and can be used to get a sense of what regions are more developed in terms of EV infrastructure.

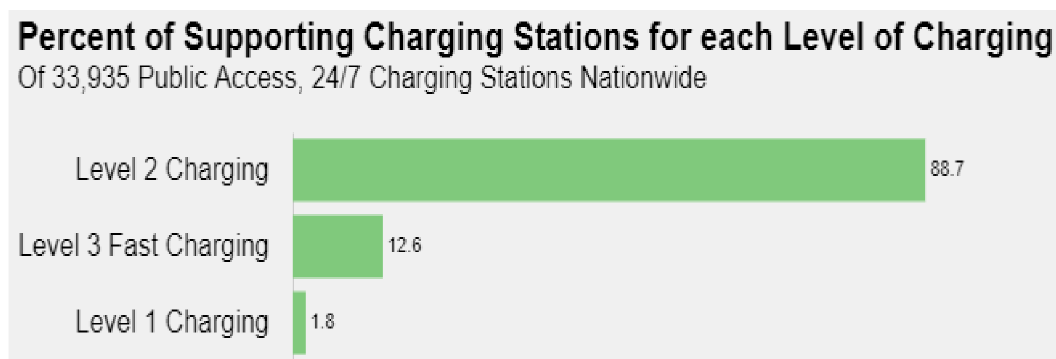


Figure 4. Percent of Stations that Support each Charging Level

Figure 5 provides the number of public-access, 24/7 charging stations in each of the states, D.C., and Puerto Rico. California far outnumbers the other states in terms of public access, 24/7 charging stations, but the next seven states still have over 1000 charging stations . Most of the states that are on the lower end in terms of number of charging stations are either generally more rural and less-populous, or small in terms of area. It can be generalized that Electric vehicle usage is more practical in the states with several-hundreds to thousands of stations, but there's much diversity within those states, so the question of whether or not EV usage is practical should be reduced to a county-by-county basis.

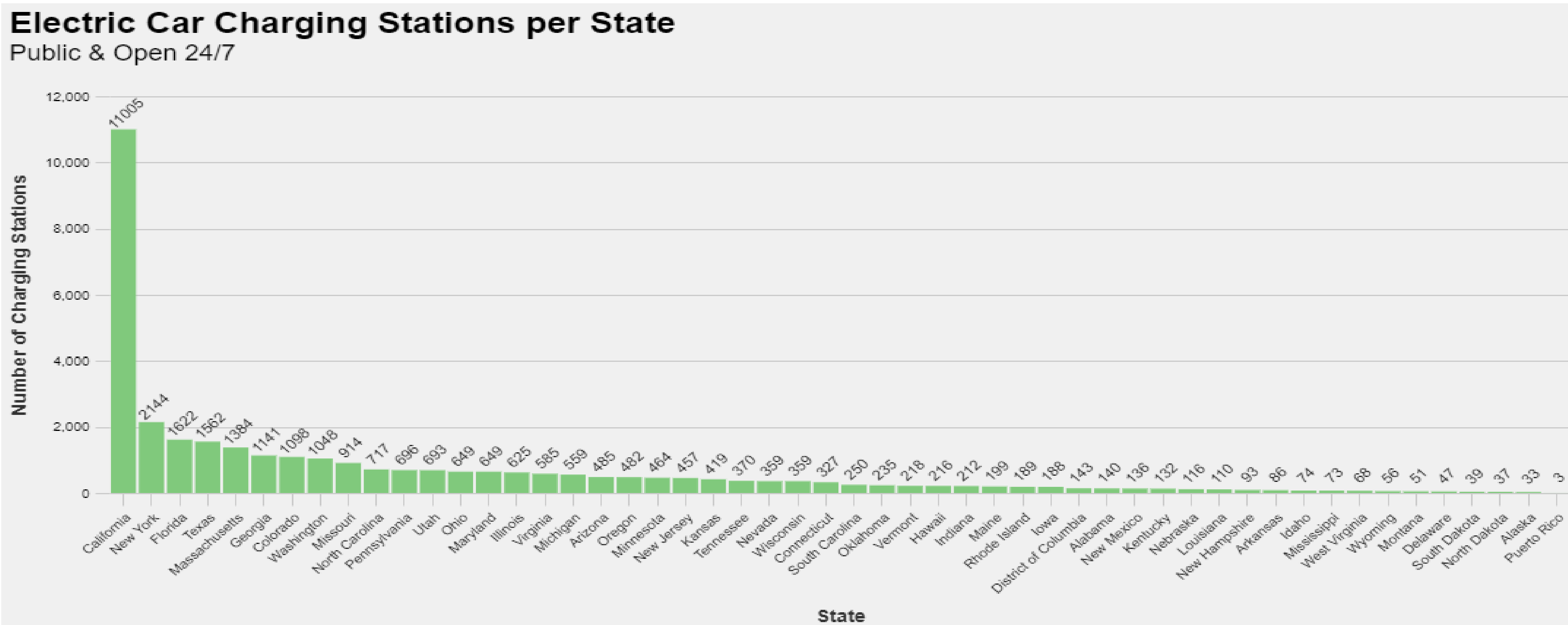


Figure 5. Number of Public, 24/7 Charging Stations by State

Figure 6 below groups the public, 24/7 charging station data down to the county level and shows the 30 counties with the most EV charging stations. Matching up with the state data, California counties make up for 11 out of the top 30 counties. It should be noted that other counties making an appearance are also large urban centers. King County is home to Seattle, Fulton County is home to Atlanta, Travis County is home to Austin, etc. It's a safer assumption that these particular counties has the infrastructure to make EV usage practical.

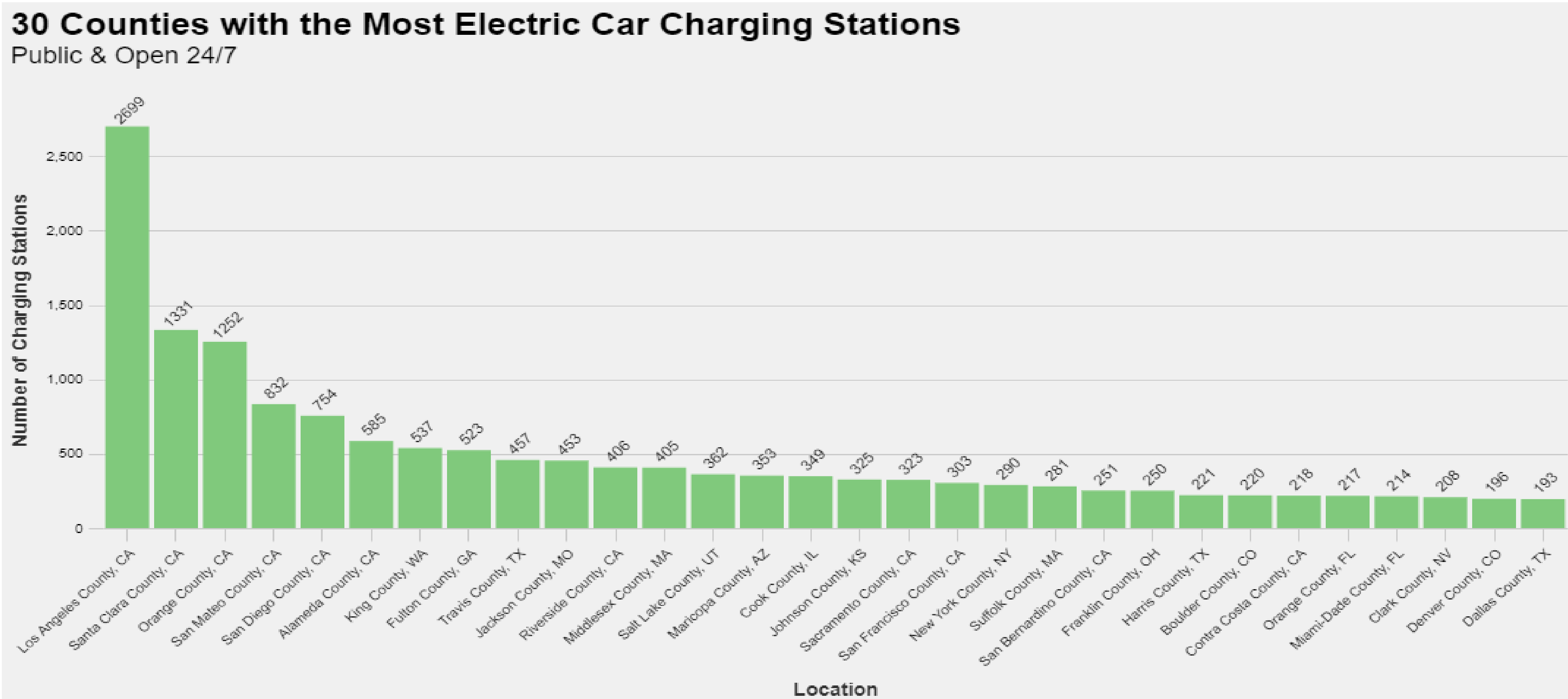


Figure 6. Number of Public, 24/7 Charging Stations by County

However, the United States is vast, and it is impossible to gage the practicality of each US county or region with simple charts. Hence, the folium and geopandas libraries were used to create an interactive choropleth in **Figure 7** that shows the number of charging stations in each US county, with a tooltip that provides more specific information like the number of stations that support the different levels of charging.

Practicality of Electric Vehicles ultimately comes down to which county an EV user resides in and what their driving habits are like, so a choropleth makes for a useful tool in addressing the practicality of EV usage in a given region. The choropleth provides a top-down overview of which regions have the most (or least) charging stations, and any area can be zoomed on to gain more specific information on the number and types of charging stations. The regions that are shaded a darker green and have relatively more charging stations are the entirety of the West Coast, Florida, New England, Michigan, and other urban centers, so the case for practicality is much stronger in those regions than areas such as Montana, the Dakotas, etc.

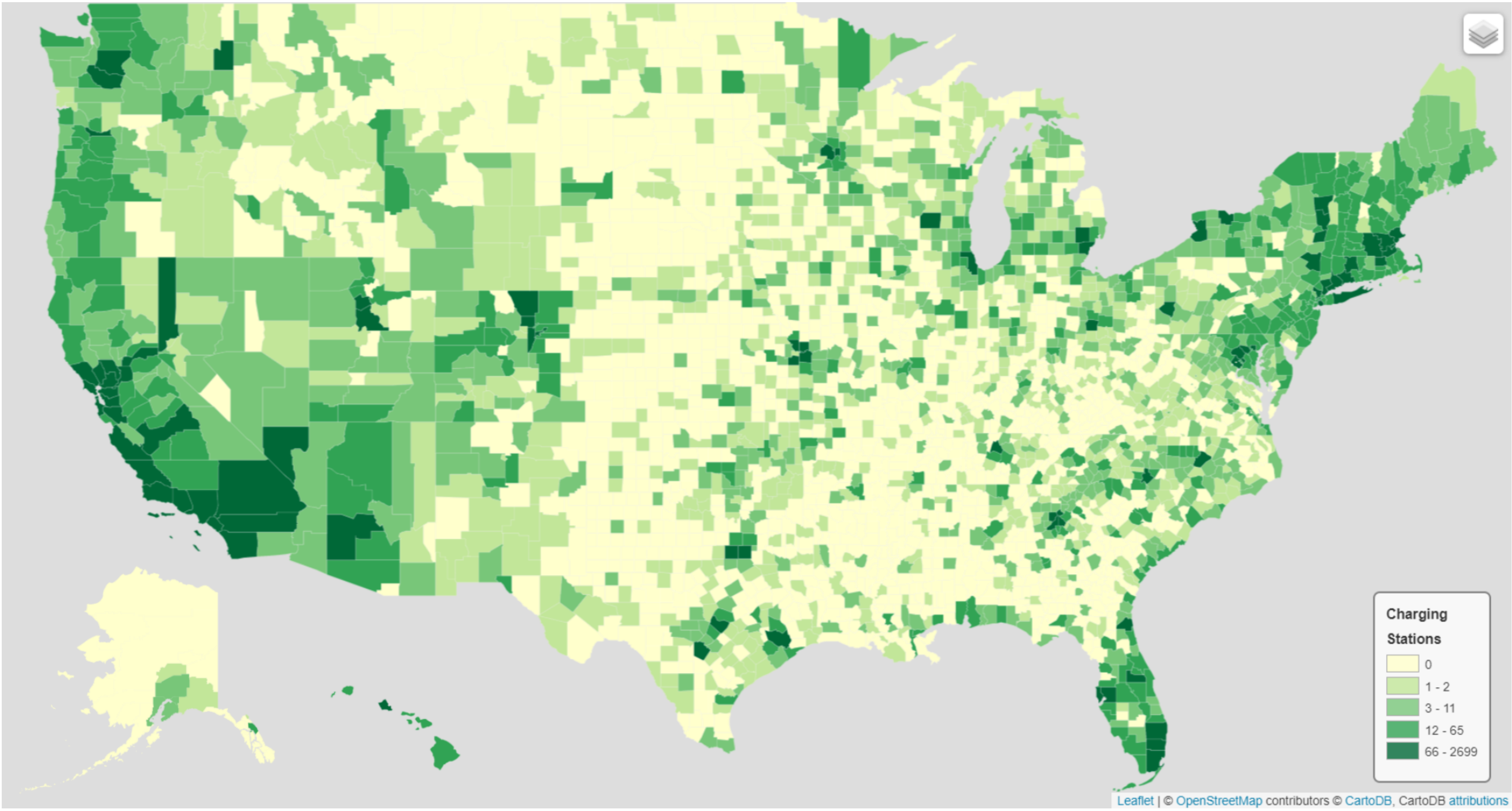


Figure 7. Choropleth of Public, 24/7 Charging Stations by US County.Interactive version can be found here: https://nbviewer.jupyter.org/github/Cody-Lange/Exploring-Electric-Vehicle-Infrastructure/blob/main/us_chargingstations_county.html

An interesting case study for the adoption of electric vehicle charging stations is Texas. With 1,562 charging stations, the state ranks 4th in the country for number of 24/7, public charging stations. However, the chasm between the cities with the most and least chargers is quite large. As shown in **Figure 8,** the top 5 cities hold 952 out of Texas' 1,562 public, 24/7 charging stations. Also of note is that 150 out of Texas' 254 counties don't have a single public, 24/7 charging station. The more densely populated areas have the infrastructure to make the lives of EV owners easier, but the more rural areas have catching up to do in terms of practicality.

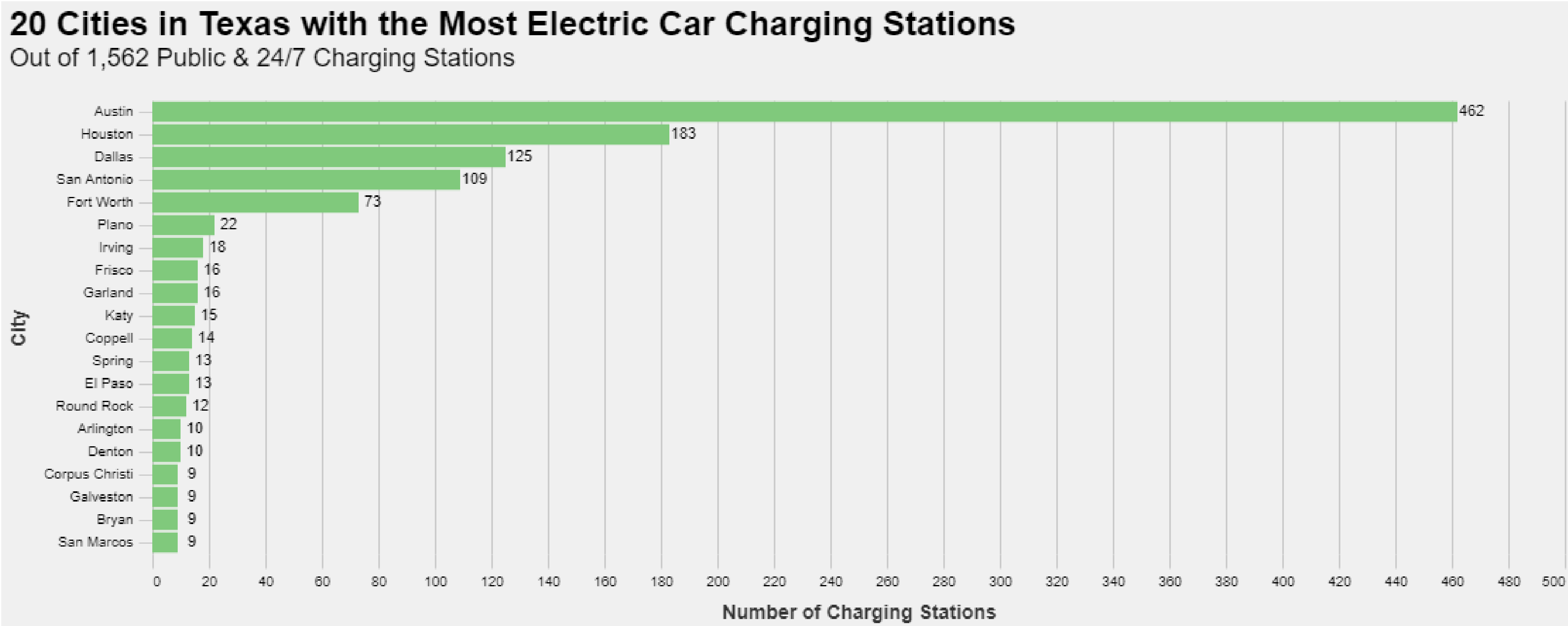
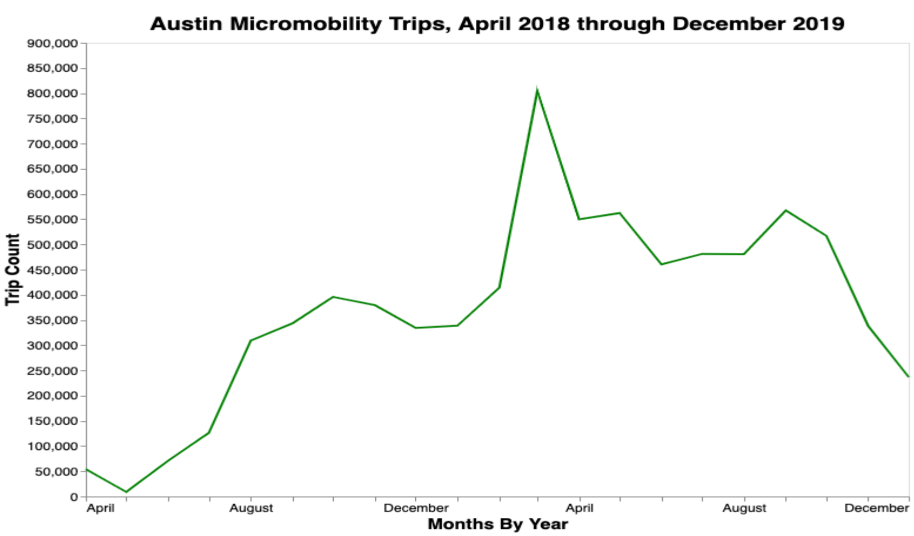


Figure 8. 20 Cities in Texas with the Most Public, 24/7 Charging Stations



Since Austin, Texas has a large collection of charging stations, it makes for a great case study into the potential for micromobility in an already electric-friendly city. In contrast, a county like Jefferson County which is home to Louisville, KY, has much fewer charging stations and thus serves as a worthwhile case study site for micromobility in an area not served by electric car charging stations.

The figure below shows Austin micromobility data from 2018 and 2019. From the beginning of the program, the city of 950,000 has seen at its peak close to 850,000 scooter trips in a single month (when the festival South by Southwest occurred). Nevertheless, this represents an increase by a factor of 10 or more since the beginning of the program. We also see that volume dips in the Winter months and rises in the summer.

Figure 9. Number of Austin Micromobility Trips ordered by Month from April 2018 to December 2019

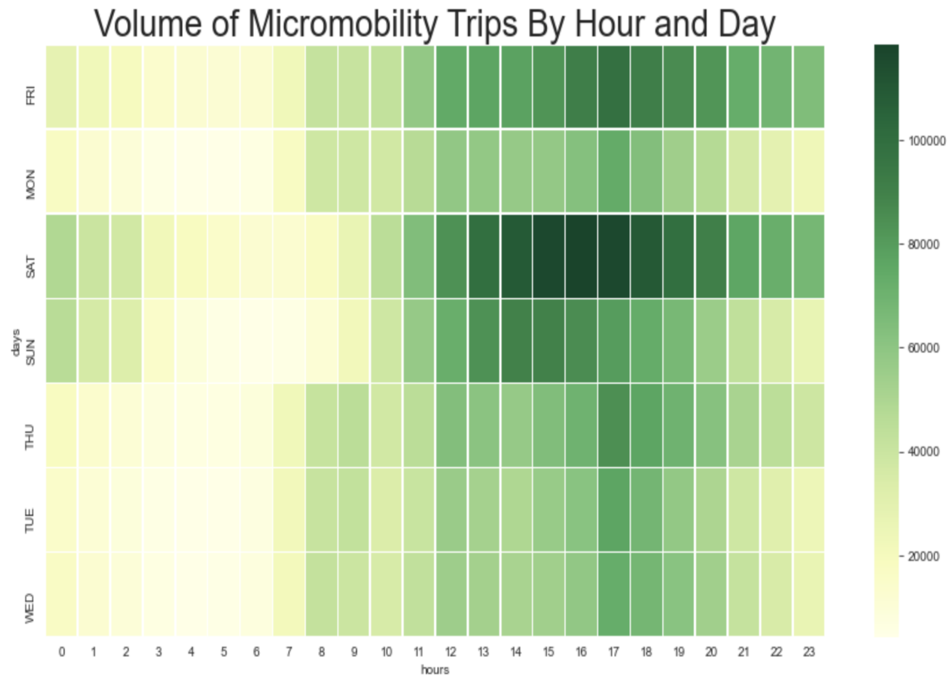


Figure 10a. Micromobility Volume Heatmap By Hour and Day

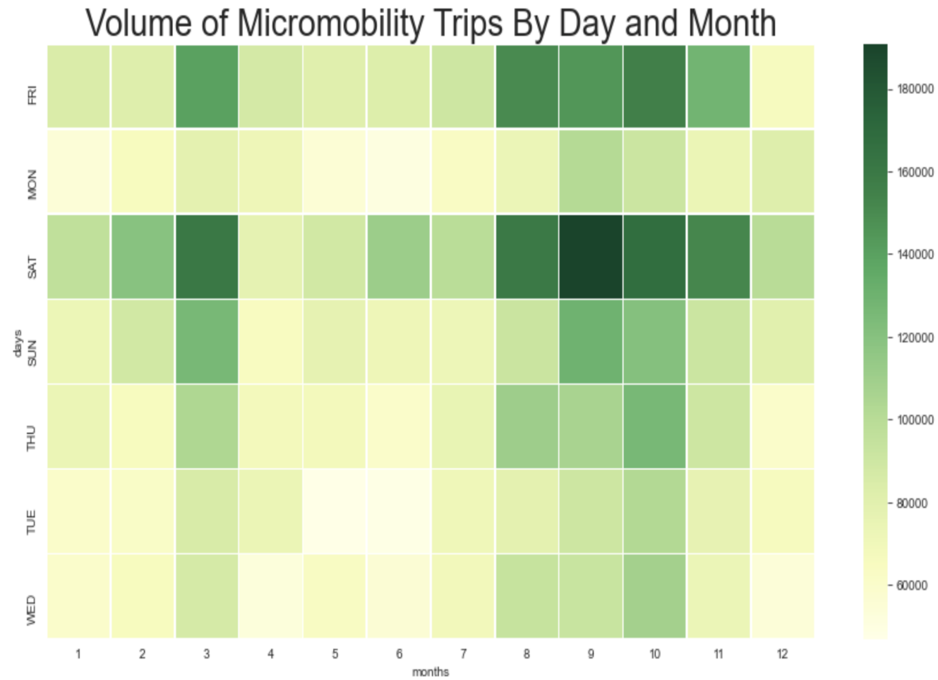


Figure 10b. Micromobility Volume Heatmap By Day and Month

The data visualized by the above graphics give us some insight into the timing of micromobility trips, specifically by hour and day, which could point to or mirror patterns in transportation needs. Judging by the volume of scooter trips in Austin across different hours of the day, we can see that weekends are by far the most popular for e-scooter trips, although rush hour at the end of weekdays is also a very popular time for e-scooter usage. When we zoom out to observe the day and month data, we can see that indeed Saturday is the busiest day, followed by other weekend days. The sheer volume of trips that are counted by day and month on the right hand visualization gives us an idea into the demand and availability of e-scooters in Austin, showing that the demand for and usage of micromobility in Austin are both high. This indicates that e-scooters are available and practical in that they are affordable for an average person and have the range and battery life to sustain commutes.

In contrast to Austin, Louisville has not been served by a large number of electric car charging stations, but as we will see from the proceeding visualization, electric infrastructure in the form of e-scooters is still a viable and practical alternative to personal vehicle transportation. In this case, looking at data from Louisville represents an important contrast to the Austin data.

In the visualization on the left we see individual e-scooter rides in Louisville over the month of February 2019. We're able to do this because the e-scooter experiment in Louisville occurred much after its counterpart in Austin, but we are still visualizing close to 13,000 trips on the map.

Although the volume of trips is much lower than that in Austin, here we get a geographical standpoint on how e-scooters can function in a city to relieve congestion and other transportation needs. Scooters are used in conjunction with other public transportation facilities and occur in highest intensity along certain paths. Since these vehicles are much smaller and cheaper to operate than personal automobiles, there exists a viable transportation option to commuters and civilians in general, especially those without ownership of a vehicle.

Figure 11. Map of individual scooter trips in Louisville, KY during February 2019.

Next Steps

On a region-by-region basis, the interactive choropleth can be used to determine regions that have an abundance of EV infrastructure— or a lack thereof. However, for electric vehicles infrastructure to support the ever-increasing amount of electric vehicles being introduced to the road, the technology needs to get better and more charging stations need to be made available. A potential next step would be to identify regions which are growing markets for EVs but currently lack the infrastructure to support adoption. The charging station data is regularly updated, so growth of charging availability can also be monitored, and compared against the areas in which EVs are becoming more abundant. Additionally, to support those with longer drives, areas that need stations with more advanced charging technology can be identified.

Statement of Work

Ryan used the Department of Energy API to access charging station data, as well as analyzed data on the fuel economy of electric vehicles. Viraj collected and merged datasets on micromobility solutions to analyze their use in urban areas. Cody pulled together the information on the different types of charging available and analyzed the fuel station data to better understand the distribution of accessible charging stations and supported charging levels nationwide. The team was equally involved with writing the report.

References

"Developing Infrastructure to Charge Plug-In Electric Vehicles." *Alternative Fuels Data Center: Developing Infrastructure to Charge Plug-In Electric Vehicles*, afdc.energy.gov/fuels/electricity_infrastructure.html."