Student Analysis of Electric Vehicle Charging at Universities

May 2014

Morgan R. Ziegler, James Madison University

Edited and presented by
Kaitlin Pomerleau and Alleyn Harned, Virginia Clean Cities

TABLE OF CONTENTS

Electric Mini Cooper charge door

Disclaimer: This is an initial analysis done as a student project owned by Morgan Ziegler

ABSTRACT

This student project discusses the feasibility of electric vehicle charging at James Madison University. The feasibility criteria studied includes technical requirements, infrastructure needs, user preferences, cost considerations, and institutional policies and constraints to perceive the use and effectiveness of an electric vehicle charger on campus. The methodology used was qualitative analysis of personal interviews with facilities and sustainability staff members at four universities in Virginia: George Mason University, Virginia Tech, University of Virginia and Bridgewater College. Interview data includes logistics, economic, infrastructure, and policy considerations for universities operating these stations. An analysis of the data is present as well as recommendations regarding installation of a pilot electric vehicle charger at James Madison University.

Nissan LEAF electric vehicle parked at a workplace charger

INTRODUCTION

Electric vehicles (EVs) are becoming more prevalent in today's society, with more makes and models available on the market each year. They are a great alternative to a car equipped with an internal combustion engine, as a car running off batteries has no tailpipe emissions[11]. Today, a single charge of an EV's battery can go, on average, about 80 miles, which is longer than the total commuting mileage of most Americans[1]. The Washington Post states that the average person's commute is about 25 minutes or 40 miles, which an electric battery-equipped vehicle would be able to easily accomplish with fewer emissions[10]. This data provides convincing evidence that an EV is a viable option when buying a vehicle intended for short-distance travel.

While an electric vehicle may never be able to completely replace an internal combustion engine for traveling long distances, they are a superior alternative when only making short round trips, due to the low cost per mile and zero tailpipe emissions[11]. Additionally, and perhaps most importantly, this technology helps lower our dependence on fossil fuels for transportation. The transportation sector accounts for 28% of all the energy consumed in a year within the United States, and petroleum provided 93% of this energy[12]. Reduction of this petroleum use could also reduce the amount of harmful emissions coming from the transportation sector as a result of burning fuel. Widespread use of electric vehicles could effectively reduce the amount of petroleum used for transportation, but an electric vehicle infrastructure must be set up to make these vehicles effective.

An infrastructure built for electric vehicles must be established in order to drive demand and ensure effectiveness of this new electric vehicle technology. This includes having a network of charging stations available for use by EV owners. Without a well set up infrastructure, those with electric vehicles will not be able to charge them away from their homes, greatly reducing the benefit and effectiveness of their EV, and limiting their vehicle use. Inversely, areas with a well set up electric vehicle infrastructure can potentially see increased charger use, and perhaps more people will shift to using EVs for their short-distance travel needs. This project attempts to capture all of the infrastructure metrics that must be considered prior to installing a public electric vehicle charger, and compare these metrics between different universities located in Virginia. This comparison will help highlight the specific considerations that are most important or difficult to regulate, providing insight into how to best install and regulate an electric vehicle charger at James Madison University.

BACKGROUND

The potential success of electric vehicle integration into our current system is entirely dependent on the charging station infrastructure available for these EVs. As previously stated, EVs are becoming more prevalent each year, with the number of models tripling in the last 3 years. Now in 2014 almost all auto manufacturers are coming out with their own plug-in hybrid or all-electric vehicle[6]. The different electric vehicle battery types, along with the different charging station outputs available today, and companies available to aid in the installation of charging stations will be discussed. Additionally, one of the available networks for charging station implementation and installation will be explored.

Electric Vehicles Overview

To better understand electric vehicles and charging specifics, the different types of chargers and electric charging output levels must be examined. The purpose of this section is to provide the definition of electric vehicles, their uses and recharging needs. There are three types of EVs available today, and they are categorized by the propulsion source for the car and the method of charging.

Recharging a plug-in Toyota Prius

The first type of EV to be discussed is known as a hybrid electric vehicle (HEV). These are regular cars equipped with an internal combustion engine (ICE) and also have a smaller electric engine and battery[11]. The onboard electric motor is used to help power the car during acceleration, and power functions such as air conditioning and headlights to not tax the ICE more. There are two different types of HEVs, mild or full hybrids. Mild hybrids have a smaller battery and electric motor, and the vehicle is unable to be powered entirely off of electricity. A full hybrid has a larger and stronger electric motor that can power the vehicle entirely from electricity at slower speeds. The full hybrids gains the highest benefit of both electric and ICE vehicles, as they have much better fuel economy at lower speeds and are still able to have the high driving range. The battery in these hybrid vehicles is charged differently than the other types of EVs, through a process called regenerative breaking. These vehicles take the energy that would have been lost to heat and friction while breaking and convert it to electricity that is stored in the onboard battery[11]. After a decade of market growth, this type of EV is the most used; mostly due to the convenience of the onboard ICE which allows continued refueling from gasoline from public service stations and doesn't cause people to drastically change their driving habits. The second type of electric vehicle now available is a plug-in hybrid electric vehicle, or PHEVs. These vehicles are powered mostly using electricity, but still have an ICE located onboard for when the car is low on electricity[11]. These cars differ from HEVs as they are able to plug in to a source of electricity to charge the batteries, and are not entirely dependent on gasoline or regenerative breaking. When operating at initial electric range, a PHEV's power comes primarily from the electricity stored in the batteries. These vehicles are especially versatile due to the ICE, which will only power the vehicle when the batteries are almost depleted. There are two variations of PHEVs, which are parallel and series. The parallel hybrid can be powered directly by the electric motor or the ICE. In contrast, a series hybrid can only be powered by the electric motor, and the ICE located onboard is only used to generate additional electricity. These vehicles are becoming more and more prevalent as car manufacturers see rising sales, with the addition of cars such as the Chevrolet Volt with 40 miles of electric range and the Toyota Plug-In Prius[1] with 12 miles of electric range.

The last type of EV available to the public is an all-electric vehicle. As the name suggests, an all-electric vehicle only has an electric motor and battery equipped and no ICE[11]. These vehicles are best suited for short commutes and round trips so that the car can be recharged. The U.S. Department of Energy states that the typical range for an all-electric vehicle is about 80 miles on a fully charged battery[1]. Driving habits and conditions vary the overall mileage, but this number proves that an all-electric vehicle could easily handle the needs of a college student only looking for a car to commute to class with. A disadvantage to these all-electric vehicles is how much the outside weather conditions affect these cars. Extreme temperatures tend to reduce effectiveness of the battery, which can reduce the overall mileage available on a full battery charge. Examples of these all-electric vehicles include the Nissan Leaf, and the new Tesla models[1].

Charging Types

Both the type of engine equipped and the method of charging differentiate electric vehicles from one another. There are currently three different "levels" of charging equipment, each with different output voltages and charging times[9]. Many of the electric vehicle types listed above can be charged using different levels of equipment, with only difference being the necessary time required for a full charge. The cars are limited by their specific make, model, and the charger outputs they are compatible with[7].

Level 1 charging refers to charging through a typical household wall socket, rated at 120V in the U.S.[11] All PEV's come with a cord to connect to the car to charge the battery, with a three-prong plug on one side with a car-specific connector on the other. This will probably be the most widespread type of charging, as people will use this method to charge their EVs overnight before leaving for work the following day. While this method is effective for at-home use, the slow rate of charging prevents Level 1 charging from being viable as a public charger. It can take around 8 hours for a Level 1 charger to fully charge an EV.

Level 2 charging comes out of a residential 240V plug, like those equipped on a clothes drier. So far, this type of charging equipment has been used at most of the public facilities available to EV drivers[11]. With twice the voltage output of Level 1 equipment, Level 2 equipment can charge a vehicle in half the time, which takes about 4 hours for a full charge.

The last method of charging to be explored is DC fast charging. These chargers have an extremely high output of 480V and are used at rapid charging stations in heavily trafficked areas[3]. The DC power used in these chargers does not need to be converted in the battery, allowing electricity to be charged right into the battery, greatly reducing charging time. This method of charging can recharge the battery to a distance of 60 miles in about 20 minutes[11]. Due to the high output of these chargers, there are other considerations that must be made upon installation, such as the overall safety of the charger. Additionally, these chargers usually require specific changes to the infrastructure to allow for these high outputs, as they must have a high voltage source, and dedicated underground line to supply the increased voltage to the charging station. Due to this infrastructure demand, these types of chargers are not yet widely used today.

DC Fast Charger

One of the perspective downsides that has been brought up about using more electric vehicle chargers is the increased load of charging stations on the electrical grid[2]. However, even DC fast charging does not have a great negative impact on the grid, as extensive modeling has been done to observe the load necessary for six DC fast chargers in a configuration similar to a gas station one could find now[8].

ChargePoint

With increased demand for electric vehicle chargers, several companies have established themselves to help others fund, install, and regulate electric vehicle charging stations. One of these companies is ChargePoint, who has become a leading member in the electric vehicle charging community. ChargePoint is an online network of charging stations available for public use, and a network platform that helps regulate these stations. This service helps prospective charger owners find the best available charging station for use in their area, and available federal grants that can reduce the cost of the charger[4]. Additionally, ChargePoint allows the EV charging station owner to set up a payment plan, using the ChargePoint Network, ChargePass, or other credit cards. An EV owner can apply for a ChargePass, which is essentially a debit card that has money deposited to it for use only at electric vehicle charging stations within the ChargePoint Network. Using the ChargePoint website, an EV owner can search for charging locations near their location by inputting their ZIP code, or using the mobile phone application and location services within the software.

ChargePoint strives to better improve the communication and functioning between electric vehicle owners, electric vehicle manufacturers, and the charging station owners to better integrate this technology into the current infrastructure[5]. The online ChargePoint Network has more than 16,500 charging locations listed across the United States and other countries. This network also allows for the remote access of the station from the ChargePoint headquarters, which allows for troubleshooting and software updates directly from the source[4]. This ChargePoint Network could be a very valuable resource in the addition and management of an electric vehicle charger at JMU.

METHODOLOGY

James Madison University's Facilities Management and the Office of Sustainability have proposed the building of a public electric vehicle charger on campus for use by the faculty and students. Prior to installing this electric vehicle charger, JMU needs to ensure that specific regulatory and safety information are in place to allow all electric vehicle drivers to take advantage of this technology. Additionally, the location of the charger must be considered to ensure the most effective use of this charging station. These recommendations for location and regulations will be based on the experience of these other Virginia schools: University of Virginia, Virginia Tech, George Mason University, and Bridgewater Community College. These schools were selected based on universities with chargers located on campus, and their proximity to JMU. Additionally, the enrollment data, school size acreage, and percentage of commuter students were all used in the selection process to better relate these findings to James Madison University.

Once the selected schools were selected, a protocol was written for an in-person interview with the facilities management and sustainability coordinators at these schools. This protocol surveys the technical, economic, regulatory, and maintenance trends and issues of the electric vehicle chargers located on these campuses. A sample of the protocol used at these interviews can be found below.

1. Charging Technology Specifics and Economics
    a. Number of chargers installed on campus and location
    b. Type of charger
    c. How to track use
    d. Installation costs
    e. How the charger was installed
    f. Grants
    g. Payment options available

2. Parking Policies and Regulatory Considerations
    a. Parking time limit
    b. Regulatory enforcement
    c. Intended use of chargers
    d. How many users
    e. Details of the unveiling process
    f. Overall maintenance and issues

These metrics were selected to best capture the most important details of the trends of use for electric vehicle charging, and to model what JMU might expect when installing a charger. This data was collected from the schools and reviewed, with emphasis on the common problems and trends found at different universities. With answers to the specific questions above, considerations for the best use, regulation, and location can be recommended for JMU's electric vehicle charger.

ANALYSIS

The above protocol was broken into four different sections in order to best display the charging station data collected at the other universities during the interviews. These sections are as follows: charging technology specifics, charging station economics, parking policies and regulatory considerations, and the unveiling and maintenance of the station. The first section discusses the charging station basics and the specific model information, including the number and type of charger on campus, along with how to track the charger's use. A table of this first section of data can be found below in Table 1.

Table 1. This table shows the location and type of the charger located on campus, along with how each school tracks the use of the electric charger.

Charging Technology Specifics			
School	**Number of Chargers**	**Type of Charger**	**How to Track Use**
UVA	1 – in parking garage	Eaton Pow-R-Station Level 2	"Tell the attendant"
VT	3 – in front of the Skelton Conference Center	Schneider Electric Level 2 Stations	No way to track use
GMU	8 – two in each garage	ChargePoint CT2100	ChargePoint
Bridgewater	1 – Behind Flory Hall	ChargePoint CT2100	ChargePoint

Next, it was necessary to explore the economic considerations of the charging station, and what the overall costs were to the university. This would help provide a model for James Madison University to compare to, providing information about the trends and fairness of the payment options, if any, available. This section explored installation costs, installation data, grants used to offset costs, and the payment options available at each of these locations, and can be found in Table 2.

Table 2. A table detailing the comparison of the economic considerations of electric vehicle charging stations at the selected universities

Charging Station Economics				
School	**Installation Costs**	**How Charger was Installed**	**Grants**	**Payment Options**
UVA	$5800	No data	Parents committee GIFT RideForward	$2 added to parking toll
VT	Mounting and dedicated line = $2000	ECK Supply	Charger was donated	Free for guests
GMU	No cost for stations $25,000 for concrete blocks and electrical work	Bith Energy installed stations, after infrastructure was ready.	ChargePoint America Transportation Electrification Initiative managed by the Department of Energy	ChargePoint account or Visa/Mastercard
Bridgewater	$900 commissioning + $1100 dedicated line = $2000	NovaCharge installed and programmed the system	ChargePoint America	No fee

The next data set to be presented is the parking policies and regulatory considerations for the charging station. These discussion questions are extremely important when trying to install the most effective charging station, as there must be enforcement of policies and a strict parking limit to avoid someone monopolizing the station. This data set can be found below in Table 3.

Table 3. This table shows the different parking limits and enforcement options available at the other Virginia universities as well as the confirmed number of users for the charging station.

Parking Policies and Regulatory Considerations				
School	**Parking Limit**	**Regulation Enforcement**	**Intended Use of Chargers**	**Number of Users**
UVA	4 Hour Limit on charger Hourly parking rates apply	Parking attendant in booth	Public (not for employees)	6 for certain
VT	None	None	Public, for anyone	No specifics, but often see 2 cars
GMU	4 Hour Limit	Police, like other time zones are enforced	Anyone signed up to the ChargePoint network	6-12 users per day Mon-Thur
Bridgewater	None	Campus police and safety	Faculty/staff/ student	5-10 weekly

The last data set to be presented discusses the unveiling process for the charger that took place at each of these universities, and any maintenance issues that have come up, so that we may catalogue them for our own experiences. A table of this data is found in Table 4.

Table 4. This table shows the unveiling details and maintenance issues found at the charging stations at other universities.

Unveiling and Maintenance		
School	**Unveiling Details**	**Maintenance Issues**
UVA	Ribbon cutting party with Dean of Students, City Council	No problems
VT	Ribbon cutting with Schneider electric, ECK Supply, Sustainability coordinator	Latches on charger can be sticky and hard to remove from casing
GMU	No details	All maintenance conducted by Bith Energy and ChargePoint
Bridgewater	Ribbon Cutting	Controlled by ChargePoint, no problems within a year

These tables all represent the information that is necessary in ensuring the most effective use of the charging station at JMU. Studying these results can help avoid issues with maintenance or setbacks with the installation of the charger, making the installation and regulation fair and effective.

Discussion

Analyzing the tables above provides some insights for the charging station proposed at James Madison University. Each school noted the strengths and weaknesses of the charging station installed on their campuses, and can help highlight the potential problems with the logistics of the electric vehicle charging station and its use.

For the charging station specifics, the type of charger used was dependent on the grant type or the charger donated. Each of the schools interviewed had the specific cost of the charging station augmented by grants or donations from JMU or ChargePoint. The number of chargers is dependent on the amount of funding given in the grants and the specifics of the installation projects. Finally, there were a few methods shown for tracking the use of the charging station. At UVA, there was simply a parking attendant in a booth who charges the standard rate for parking in the garage. If one uses the charging station, they would tell the parking attendant and he would add a small fee to the ticket due to the electricity used. Virginia Tech had no mention of how they track use, and both GMU and Bridgewater college use ChargePoint to track the electrical output. Both of these schools had great reviews regarding the ChargePoint service, mentioning that they helped take care of the software and maintenance issues while also providing an easy to use network for the station.

Charging a Plug-in Toyota Prius

The next metric to be discussed is the economic factors of the charging station installation. The installation costs found in Table 2 all refer to the out-of-pocket cost to the schools. The main costs to the school for a charging station is the mounting of the station, usually made out of concrete, and a dedicated line of electricity to the charging station. These lines are usually placed underground, further increasing the cost of charging station installation. However, this issue could be combatted with improved planning of station sites, so that a number of stations may be able to run off of the same line, or lines that are combined into the same underground trench. Each of the surveyed schools had different installation methods, but each had the installation conducted by other contractors in the area. The grants show what methods the schools used to lessen the cost of installing the electric vehicle, as there are a number of government programs designed to make this technology more appealing for growth using discounts. Finally, the last metric of the economics is the payment options for the charging station. This is one of the most important considerations for the charging station, as the electricity used by the charging station is not free and will still cost the school money. UVA has a flat rate for using their charging station, and GMU requires a ChargePoint account to pay. Both Tech and Bridgewater have no fee for using the charging station, but this could be because of extremes of size. On one hand, Bridgewater is happy to encourage anyone to use their charging station, and so it is free for guests. On the other hand, Virginia Tech is so large that a payment for electricity use is not worth the infrastructure or time spent on infrastructure or enforcement.

The next data set explored was the parking policies and regulatory considerations for the charging station on each of these campuses. The parking limit has become the most highlighted metric, as this is the key to an effective charging station that can be used by everyone. If someone is taking advantage of the charging station parking spot, the use of the station is blocked, nullifying its positive effects. Both UVA and GMU have 4-hour limits for their charging stations, and are enforced by the parking attendant and campus police, respectively. The chargers are all intended for public use, although the charging stations at GMU requires one to be signed up to the ChargePoint network. The number of users of the station at each school was catalogued, with some interesting results. Bridgewater College notes that they see almost the same amount of traffic at the charging station as GMU does in a week, despite the fact that GMU has a much greater student body and seven additional charging stations. This interesting find helps show that the demand for electric vehicle charging is dependent on the availability of charging stations in that area. This could mean that there is already a demand for electric vehicle charging at James Madison University, but the infrastructure is not available for these new technologies.

Many of the schools listed unveiling ceremonies as part of the opening of the charging station, for both improved public relations and emphasizing the energy savings of these new technologies. The schools did not mention many issues with maintenance since the installation of the charging stations, other than some use errors. Additionally, the schools that use ChargePoint mention how they are able to remotely access the charging station from their headquarters and troubleshoot some of the issues that may be affecting the charging station. This remote access also allows ChargePoint to upgrade the software and distribute it to the charging stations, keeping the chargers technologically up to date.

The last question on the protocol asks what each school would have done if they were given another chance, and yields some interesting results. UVA mentions it would have rather found a better method for paying for the electricity, as users simply do not tell the parking attendant that they used the charger. GMU mentions that they would have tried to coordinate the installation better, as faulty communication between the facilities management and installer caused delays for the opening. Both Virginia Tech and Bridgewater College mention that they wish they had installed more chargers, and Tech mentions that these considerations could have saved them a large sum of money by avoiding underground boring for the dedicated line.

For the installation of a charging station at JMU, we must take into account the location of the charger, the regulations and enforcement of the charger, and also the accommodation for more chargers to be installed in the future if demand increases.

CONCLUSION

After reviewing the data collected in the surveys, there are a number of conclusions that can be drawn from other school's experiences. Most importantly, the location of the charger should be somewhere that allows people to follow a proposed 4-hour parking time limit, as we want to maximize the number of people who are able to use the charging station. To combat this, the charger should be installed in a high-turnover public lot. This means that this lot is commonly used for parking during classes, and many people do not plan to park here in the morning and stay until late at night. The more accessible the charger is, the greater chance of its effectiveness and the chance that more people will be able to use this technology.

In order to help combat this skewing of the new technology, I propose creating a community of users that have electric vehicles to help regulate the parking limit. By creating a community, people must be accountable for their own actions, and try to not inhibit the actions of others. For this example, people must try not to take advantage of this new resource and should do their best to share. Another method of enforcement for this charging station would be to ticket the charging station just like a metered spot. The charging stations are able to say when they are done charging, and cars that are beyond the limit will be ticketed. These tickets will hopefully be enough to discourage people from taking advantage of the charging station, and leave it open for more users. The main consideration to focus on is how to increase turnover of the charging station, as this single-handedly tells whether or not the charging station is effective. Using these other schools as a model, we can help avoid the same problems that other universities faced when opening an electric charging station for use on James Madison University's campus.

Special Thanks

I would like to take an opportunity to thank all of the facilities management and sustainability coordinators at the other universities who were interviewed for their contribution to this analysis. These individuals are: Becca White, the Director of the Department of Parking and Transportation at UVA, Chris Compton, the Chief Engineer of the Skelton Conference Center at Virginia Tech, Josh Cantor, the Director of Parking and Transportation at George Mason University, and Teshome Molalenge, the Sustainability Director at Bridgewater College. Also, I would like to thank Alleyn Harned, the Executive Director with Virginia Clean Cities at James Madison University, for this help in networking with these charging station specialists. Lastly, I would like to thank my senior capstone advisors, Dr. CJ Hartman and Dr. Maria Papadakis, for their assistance and expertise during the formulation and execution of this project.

Special thanks to Kaitlin Pomerleau of Virginia Clean Cities for editing and formatting this for publication and thanks to NREL for the images.

For more information about electric vehicle charging please contact Virginia Clean Cities at info@vacleancities.org, 540-568-8896 or visit us online at www.vacleancities.org.

References

[1] All-Electric Vehicles: Compare Side-by-Side. (n.d.). *All-Electric Vehicles: Compare Side-by-Side*. Retrieved April 2, 2014, from http://www.fueleconomy.gov/feg/evsbs.shtml

[2] Basu, M., Gaughan, K., & Coyle, E. (2004, September). Harmonic distortion caused by EV battery chargers in the distribution systems network and its remedy. In *Universities Power Engineering Conference, 2004. UPEC 2004. 39th International* (Vol. 2, pp. 869-873). IEEE.

[3] Botsford, C., & Szczepanek, A. (2009, May 13). Fast Charging vs. Slow Charging: Pros and cons for the New Age of Electric Vehicles . . Retrieved May 1, 2014, from http://www.cars21.com/assets/link/EVS-24-3960315%2520Botsford.pdf

[4] ChargePoint Brochure. (2014, January 1). . Retrieved April 24, 2014, from http://www.chargepoint.com/files/ChargePoint_Brochure.pdf

[5] ChargePoint Facts: April 2014. (2014, January 1). . Retrieved April 18, 2014, from http://www.chargepoint.com/files/ChargePointFacts.pdf

[6] Kelly-Detwiler, P. (2014, March 13). Building Out The Electric Vehicle Charging Infrastructure: Greenlots Advocates For Open Standards. *Forbes*. Retrieved April 4, 2014, from http://www.forbes.com/sites/peterdetwiler/2014/03/13/building-out-the-electric-vehicle-charging-infrastructure-greenlots-advocates-for-open-standards/

[7] Kisacikoglu, M.C. [ORNL], Bedir, A. [ORNL], Ozpineci, B. [ORNL], & Tolbert, L.M. [ORNL]. (2012). *PHEV-EV Charger Technology Assessment with an Emphasis on V2G Operation*. Retrieved from http://www.osti.gov/scitech/servlets/purl/1050257

[8] Monteiro, Vítor, Henrique Gonçalves, and João L. Afonso. "Impact of Electric Vehicles on power quality in a Smart Grid context." *Electrical Power Quality and Utilisation (EPQU), 2011 11th International Conference on*. IEEE, 2011.

[9] "Plug-In Electric Vehicle Handbook for Public Charging Station Hosts." *Alternative Fuels Data Center*. U.S. Department of Energy, n.d. Web. 8 Apr 2014. http://www.afdc.energy.gov/pdfs/51227.pdf

[10] Plumer, B. (2013, March 05). Commuting in the u.s. is hellish — but at least it's not getting worse. *The Washington Post*. Retrieved from http://www.washingtonpost.com/blogs/wonkblog/wp/2013/03/05/commuting-in-the-u-s-is-long-and-hellish-but-at-least-it-hasnt-gotten-worse/

[11] U.S. Department of Energy. (2013, April 24). *Alternative fuels data center*. Retrieved from http://www.afdc.energy.gov/vehicles/electric.html

[12] U.S. Energy Information Administration. (2011, January 1). Annual Energy Review. *Total Energy*. Retrieved April 8, 2014, from http://www.eia.gov/totalenergy/data/annual/pecss_diagram.cfm

[13] Images provided by the National Renewable Energy Laboratory's Image Gallery. Retrieved May 22, 2014, from http://images.nrel.gov/