



ENERGY POLICY PRACTICUM

BUSINESS 33701 – 01

Electric Vehicles & the Grid

November 7, 2016

Judy Chen

Hong Zhang Durandal

Doug Sexauer

Yicheng Shen

I pledge my honor that I have not violated the Chicago Booth Honor Code during the preparation of this assignment.

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Overview

As regulatory landscape in the United States has moved to standards and efforts to reduce greenhouse gas emissions, multiple solutions are being pursued, including efficient vehicle technologies, clean fuels, and alternative fuels. Efficient vehicle technologies include electric drive technologies such as hydrogen fuel cell vehicles and battery-powered electric vehicles, will play increasingly important roles in the transportation sector in the coming 10 to 15 years.

In this paper, we will look at the various issues that may arise from the adoption of electric vehicles (EVs) in the next 15 years. Specifically, we will start by looking at the amount of increase in electricity consumption in the U.S. under different scenarios, how we can meet this demand using existing energy capacity on the grid, the expected energy mix in consideration of both practicality of resources and greenhouse gas emissions standards, and lastly, necessary changes to the grid infrastructure and their respective challenges.

Electric Vehicles vs. Hydrogen Vehicles

With an eye towards the future of energy consumption and production, renewable energy has become increasingly popular. Renewable energy investment accounted for two-thirds of all United States electric generation capacity over the past year.¹ The remaining one-third was largely new power plants fueled by natural gas, a nonrenewable energy source, but considerably cleaner than coal. This type of growth will have massive implications for the structure of the nation's grid system.

¹ MICHAEL BIESECKER, "EPA chief: US quickly phasing out coal for clean energy," <http://www.seattletimes.com/business/epa-chief-us-quickly-phasing-out-coal-for-clean-energy/>, (May 6, 2016)

In 2014, the transportation sector accounted for approximately 28% of the United States' overall energy consumption.² The transportation sector includes all modes of transportation—from personal vehicles (cars, light trucks) to public transportation (buses, trains) to airplanes, freight trains, barges, and pipelines.³ Electricity, used by all electric vehicles as well as many hybrids, accounted for less than 1% of the total energy used within the transportation sector. This is widely expected to increase as Electric Vehicles (“EVs”) become more common and cost-effective. However, there is significant debate over the growth of the transportation industry and the technology of the future. While EVs are becoming increasingly popular, other vehicles such as Hydrogen Fuel Cell Vehicles (“HFCVs”) may have the upper hand going forward. Below is an analysis of these very different types of technology.

Analysis of Electric Vehicles

EVs have a number of factors that work in their favor. They have been proven to be produced in a relatively inexpensive manner. Tesla Motors Inc. (“Tesla”) has revealed plans to produce the Model 3, a \$35,000 EV sedan with a range of approximately 215 miles.⁴ Similarly, Chevrolet has released plans to produce the Bolt, an \$37,500 EV sedan with a range of more than 200 miles.⁵ The average price of a new car sold in the United States in 2015 was \$34,428.⁶ At these price points, which do not include government

² “Energy Use for Transportation,” EIA, https://www.eia.gov/Energyexplained/?page=us_energy_transportation, (July 17, 2015)

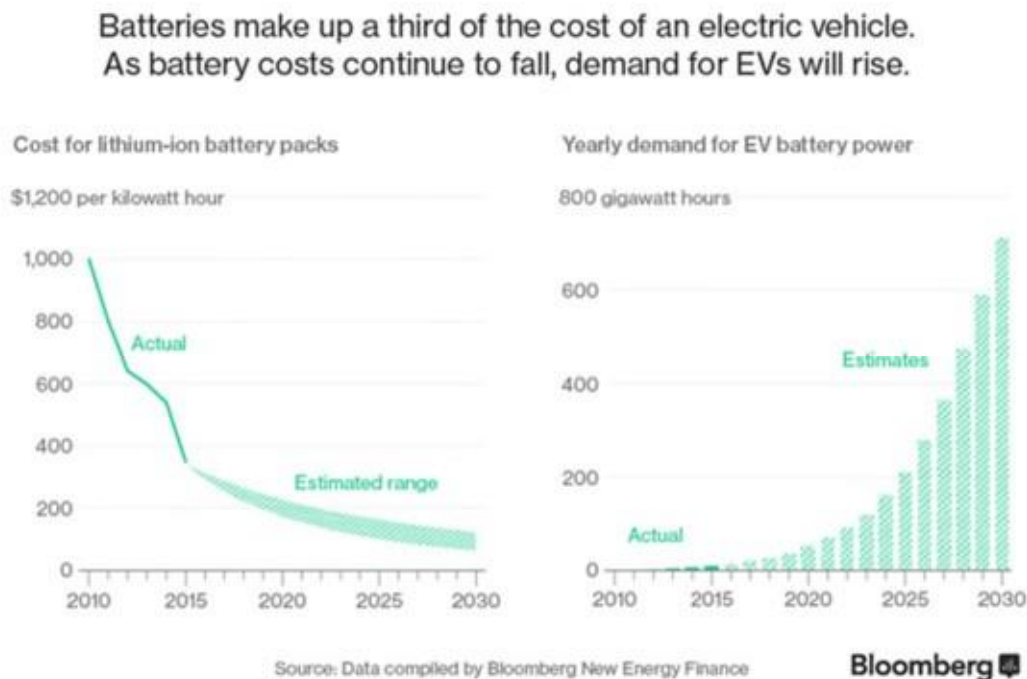
³ “Transportation”, National Academies of Science, <http://needtoknow.nas.edu/energy/energy-use/transportation/>

⁴ Tesla Motors, <https://www.teslamotors.com/model3>

⁵ Chevrolet Bolt, <http://www.chevrolet.com/bolt-ev-electric-vehicle.html>

⁶ “Record New-Car Transaction Prices Reported In December 2015, According To Kelley Blue Book,” Kelley Blue Book, <http://mediaroom.kbb.com/record-new-car-transaction-prices-reported-december-2015>, (Jan 5, 2016)

subsidies of up to \$7,500, EVs are directly comparable to their internal combustion counterparts. Currently, the largest direct cost of EVs are the battery used to store the electricity. However, prices for lithium-ion batteries have decreased significantly since 2010 and are expected to continue to fall. It can be expected that EVs will continue to become price competitive with internal combustion vehicles. See below for cost and demand expectations.⁷



The Zero Emission Vehicle (ZEV) program is another mandate that provides an important contribution to the efforts of polices to increase the number of electric vehicles out in the market. Below is a time line of the program and its milestones:⁸

⁷ Tom Randall, "Here's How Electric Cars Will Cause the Next Oil Crisis,"

<http://www.bloomberg.com/features/2016-ev-oil-crisis/>, (Feb. 25, 2016)

⁸ <http://www.zevfacts.com/zev-mandate.html>

1990: The California ZEV rule was adopted as part of the 1990 Low Emission Vehicle Program regulated by the California Air Resources Board.

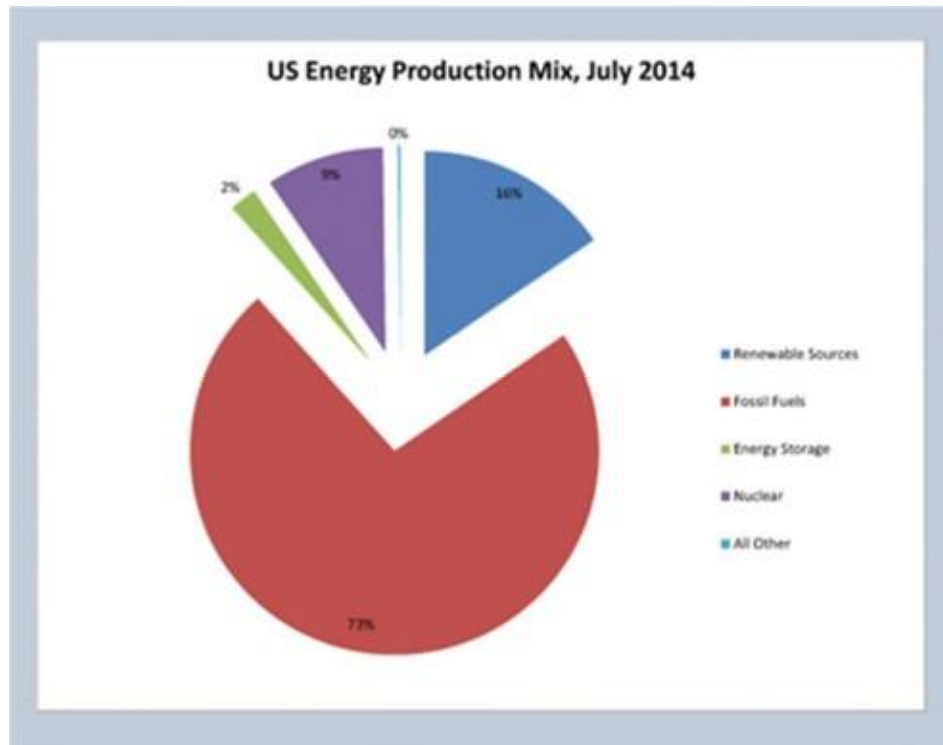
1998-2017: Originally, the ZEV rule required that 2 percent of the vehicles produced by large manufacturers for sale in California would be ZEVs by 1998, increasing to 5 percent in 2001 and 10 percent in 2003. Unforeseen costs, unexpectedly long lead times and technical challenges with batteries resulted in California adopting five rounds of significant modifications to the 1990 ZEV regulation. Through each of these modifications, manufacturers have been required to produce an increasing number of ZEVs, which started at “technology demonstration levels” (100s of ZEVs annually) in 2005-2012 and increased substantially to “early commercial launch levels” (1000s of ZEVs) in the 2012-2017 timeframe.

2018: This year marks the beginning of significant changes to the program. The volumes effectively triple in 2018 and then rapidly ramp up through 2025, when about one out every seven cars sold must be a ZEVs.

2025: The ZEV mandate requires that 3.3 million ZEVs be sold, or about 15 percent of new vehicles sales.

EVs also rely on clean, renewable energy. It is true that the United States’ energy production is produced in large part by non-renewable energy sources, such as coal and natural gas⁹; however, this production is changing rapidly and is increasingly shifting towards renewable sources.

⁹ “American Renewable Energy Production: Current State of Affairs,” Formaspace, <https://formaspace.com/articles/american-renewable-energy-production-current-state-of-affairs-2/>, (October 1, 2014)



Therefore, the CO₂ footprint of EVs will continue to be reduced as the United States evolves in its overall energy production. It is also important to understand that energy production mix varies by City, State and Country.¹⁰ For example, an EV being driven and charged in California will have less of a pollution footprint than an EV being charged in West Virginia. This is due to the fact that California produces more energy with renewable resources, while West Virginia relies more heavily on pollution heavy fossil fuels such as coal.¹¹

Another advantage of EVs is that the charging infrastructure is largely in place. Due to large investments within the production and distribution of electricity, EVs benefit from an infrastructure that requires relatively little investment. For the additional investment

¹⁰ Wilson, Lindsay. "Shades of Green: Electric Cars' Carbon Emissions Around the Globe", Shrink That Footprint, 2013

¹¹ EIA, <http://www.eia.gov/>

that is required, Tesla CEO Elon Musk, said the company is able to build the supercharge stations for “\$150,000 without solar and \$300,000 if they have solar panels.” Home charging stations are estimated to cost between \$1,000 and \$2,000, although federal subsidies are available to help offset these costs.¹² Additional costs may be borne by local utilities as they upgrade residential capacity; however, these are largely built into the required capital investment associated with the modernization of the grid.

There are factors that could limit the impact of electric vehicles. For example, range anxiety continues to impede the growth of EVs. Range anxiety is the concern of consumers that the EV will not have enough power to travel to their destination of choice. A trip from Chicago to St. Louis is approximately 300 miles, well outside the average EV range of 200 miles. Most trips made on a daily basis will be well within the EV’s range, however, many longer trips will require charging stops. These stops will most likely be made at Supercharger stations. Currently, the Tesla Supercharge stations are capable of charging a depleted battery to 80% in 40 minutes. This is compared to refueling an internal combustion engine in approximately 3 minutes. It is important to note that some Supercharge stations allow for full battery swap/replacement, which can occur in approximately 3 minutes. However, this is a pilot program and its long-term feasibility is uncertain.¹³ Additionally, many worry that if they were to run out of power, there is no easy battery replacement/charge. This means that after losing power, a

¹² “Home charging installation,” Tesla Motors, <https://www.teslamotors.com/support/home-charging-installation>

¹³ “Battery Swap Pilot Program,” Tesla Motors, <https://www.teslamotors.com/blog/battery-swap-pilot-program>, (December 19, 2014)

driver may require a tow to the nearest charging station, whereas an internal combustion engine would only require a few gallons of gas.

Also, the weight of the battery pack limits their effectiveness in other uses. Mass transportation vehicles, such as buses, would require extremely large batteries and would therefore be unlikely to rely on EVs. Likewise, transportation of goods by heavyduty trucks will likely be infeasible with the technology as it stands today.

Analysis of HFCVs

Ultimately, Hydrogen Fuel Cell Vehicles also present a number of factors that may work in their favor. Similar to electricity production for EVs, “producing the hydrogen itself can lead to pollution, including greenhouse gas emissions, but even when the fuel comes from one of the dirtiest sources of hydrogen, natural gas, today’s early fuel cell cars and trucks can cut emissions by over 30 percent when compared with their gasolinepowered counterparts.”¹⁴ Eventually, as energy production becomes more reliant on clean resources, it can be expected that the emissions used to produce the hydrogen will continue to decrease. An important distinction between EVs and HFCVs is that EVs store the electricity in their batteries while HFCVs store hydrogen which then relies on a chemical reaction to combine the hydrogen with oxygen. Ultimately this produces electricity to run the motor and water as a by-product.

Additionally, HFCVs offer benefits in terms of range, which are comparable to conventional cars or trucks (200 – 300+ miles). Further, the time required to refill a hydrogen fuel cell is similar to conventional cars and trucks, estimated at approximately

¹⁴ “How Do Hydrogen Fuel Cell Vehicles Work?,” Union of Concerned Scientists,
<http://www.ucsusa.org/cleanvehicles/electric-vehicles/how-do-hydrogen-fuel-cells-work#.VzLCafkrKUk>

4 minutes.¹⁵ This helps to assuage some of the fears faced by EV owners worried their vehicle would be forced to make multiple prolonged stops over an extended trip.

Hydrogen fuel cells are also significantly lighter than comparable battery substitutes. This is important when evaluating the feasibility of this technology in vehicles that are very large, or haul significant payloads.

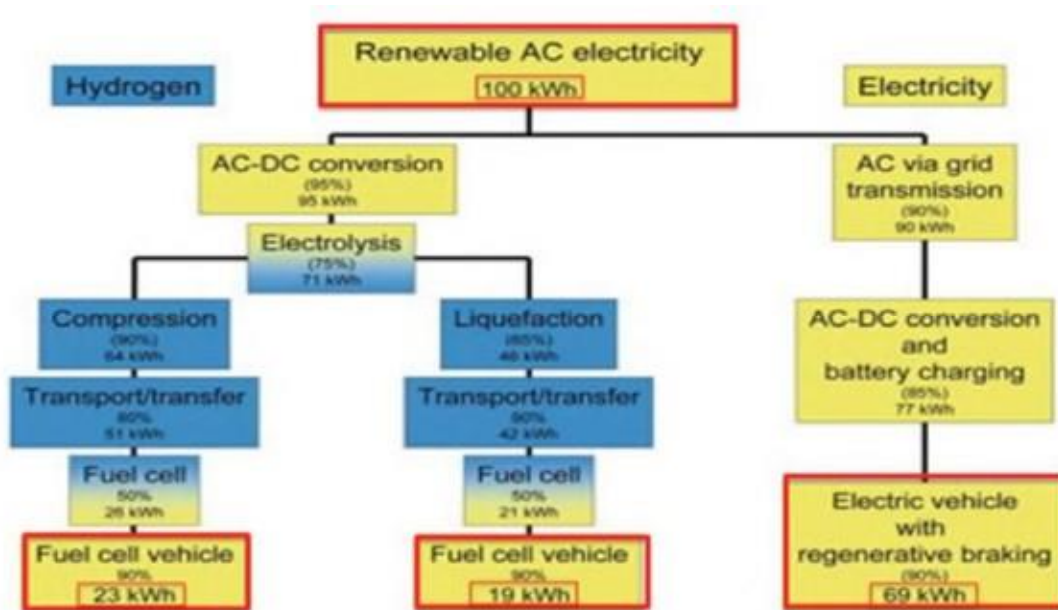
While HFCVs present a number of positives, there are significant detractors. Arguably, the “biggest obstacle to introducing HFCVs to the market is the lack of hydrogen fueling infrastructure. A hydrogen infrastructure rollout is a significant undertaking that requires careful planning, synergistic efforts among governments, academia, and industrial stakeholders.”¹⁶ These costs include building production sources large enough to produce hydrogen at scale, developing a delivery infrastructure (likely some combination of liquefied hydrogen, compressed hydrogen tube trailers, pipelines and potentially onsite hydrogen production¹⁶), and building the physical station. The stations themselves are expected to range from \$500,000 – \$5,000,000 depending on the specifications.¹⁷ The cost of pipelines and other transportation will largely depend on the scale of production and use; however, these costs are expected to be significant. Additionally, there is expected to be leakage or waste of electricity involved with the production, transportation and use of hydrogen. Any additional steps between

¹⁵ STEVE SILER, “Pump It Up: We Refuel a Hydrogen Fuel-Cell Vehicle,” <http://www.caranddriver.com/features/pump-it-up-we-refuel-a-hydrogen-fuel-cell-vehicle-the-half-hour-fill-uppage-2>, (November 2008)

¹⁶ Qin, Nan. *Hydrogen Fueling Stations Infrastructure*. Cocoa, FL: Electric Vehicle Transportation Center, 2014 ¹⁶ Ibid

¹⁷ STEVE SILER, “Pump It Up: We Refuel a Hydrogen Fuel-Cell Vehicle”

production and consumption will contribute to leakage. See below for a comparison of hydrogen vs battery production.¹⁸



“In a recent study, fuel cell expert Ulf Bossel explains that a hydrogen economy is a wasteful economy. The large amount of energy required to isolate hydrogen from natural compounds (water, natural gas, biomass), package the light gas by compression or liquefaction, transfer the energy carrier to the user, plus the energy lost when it is converted to useful electricity with fuel cells, leaves around 25% for practical use — an unacceptable value to run an economy in a sustainable future.” Mr. Bossel continued, “This found that the output-input efficiency cannot be much above 30% (for hydrogen fuel cells), while advanced batteries have a cycle efficiency of above 80%.¹⁹ See below for an analysis of hydrogen efficiency vs battery efficiency.¹⁹

¹⁸ “Why a hydrogen economy doesn't make sense,” Phys.org, <http://phys.org/news/2006-12-hydrogen-economydoesnt.html>, (December 11, 2006) ¹⁹ Phys.org (December 11, 2006)

¹⁹ Tony Seba, “Toyota vs. Tesla – Can Hydrogen Fuel-Cell Vehicles Compete with Electric Vehicles?,” <http://tonyseba.com/toyota-vs-tesla-can-hydrogen-fuel-cell-vehicles-compete-with-electric-vehicles/>, (January 15, 2015)

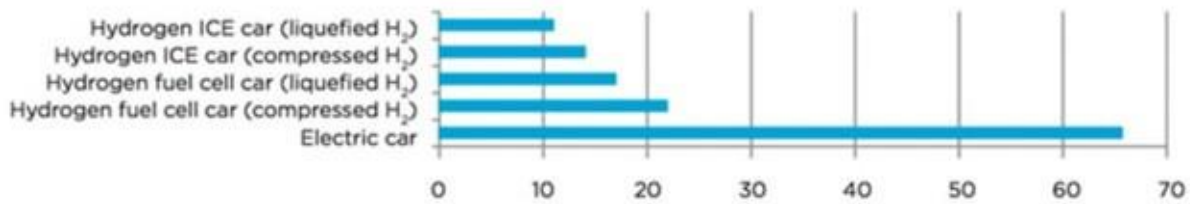


Figure 1: Relative distance travelled by vehicle type per kWh of electricity consumed (km)

Therefore, it can be determined that batteries will likely run approximately 3 – 6 times more efficiently than hydrogen fuel cells.

A final detractor is ultimately the uncertainty of this technology. To begin with, hydrogen has not been commercialized to the extent it would need to be if transportation were to make a meaningful shift to a hydrogen source. Therefore, the current price is relatively high as compared to other vehicles. Toyota's Mirai is an HFCV and Toyota's Environmental Communications Manager Jana Hartline estimated that today's hydrogen is "maybe \$10-\$12 per kg, which would mean \$50-60 for a complete fill for the 312-mile Mirai." This is "compared to a 50 mpg Prius, assuming today's average \$2.577 per gallon for gas, 6.24 gallons to go 312 miles would cost \$16.08." Additionally, "a 93 MPGe Tesla Model S P90D would cost \$13.57 for 312 miles."²⁰ The HFCV are at a considerable price disadvantage as compared to plug-in hybrids and EVs; however, as production increases, it can be expected that prices will fall. Again, the extent of those prices drops cannot be certain.

In the analysis above, we have focused on two advanced technologies; purely battery powered electric vehicles and hydrogen fuel cell vehicles. However, there are other technologies that may play a meaningful role in the evolution of the transportation

²⁰ Jeff Cobb, "Technologies & Fuel Types," <http://www.hybridcars.com/pros-and-cons-of-hydrogen-fuel-cellvehicles/>, (August 25, 2015)

sector. These may include compressed natural gas, ethanol, biodiesel, and propane.²¹ While each are interesting in their own right, they will not be directly investigated in this report.

EVs' Impact on the Grid

Ultimately, we believe that the mass adoption of EVs will be inevitable in the next 10-15 years, since they provide us a compelling combination of smaller carbon footprint, familiar infrastructure, decreasing costs, and increasing range and capability. The increasing number of EVs on the road is one factor among many (environmental concerns, Clean Power Plan, increase in energy use) that is pointing us towards a changing U.S. grid, from capacity, its infrastructure revolutionizing an industry that is still relying on technology largely unchanged over the last century.

The EVs' impact on the grid, including energy use and emissions, occur in the context of the equilibrium between power demand and power generation. Equilibrium exists without the EV load, and it is changed by the addition of that load. The difference between these two states is the grid impact that we seek. The case with EVs is defined first by the extent of EV power demand, which is the product of the vehicle market share held by EVs and the charging requirements and timing for the EV fleet. In order to meet the charging load associated with EVs, suppliers would utilize available units of marginal generation, seek trade among regions, and/or expand their generation

²¹ "Technologies & Fuel Types," Drive Clean,
http://www.driveclean.ca.gov/Search_and_Explore/Technologies_and_Fuel_Types.php

capacity. To begin with, we estimate the magnitude of charging load of EVs in United States for different scenarios (low, medium, high) in 2040.

Energy Demand - Scenario Analysis (low, medium, high) of Charging Load

Different Levels of Market Penetration

Given the uncertainties of battery and vehicle development, vehicle costs, fuel costs, and other determinants of market share, most reviewed studies use speculation or assumption as the basis of assumed EV market penetration. Some of the studies make projections by assuming constant growth rate of EV's market share. It is unreasonable to use constant growth rate for analyzing the development of new technology like electric vehicles. In our analysis, we first review credible projections of EV's market share (e.g., logit model) from other researches. As a result, we set our scenarios of EV market penetration in 2040 as below.

Scenarios	Low	Medium	High
Percentage of Light Vehicles Stock by 2040	15	30	45

Projection of Energy Demand from EVs

In order to estimate the power demand from EVs, we first calculate the number of electric vehicles in United States by 2040. Given that the projection of US Light Duty Vehicles ("LDV") stock from EIA reference case is 277.12 million by 2040²², we could generate the projections of EV stock for three scenarios as below:

Scenarios	Low	Medium	High
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²² Annual Energy Outlook 2015, EIA, 2015

EV Stock (millions)	41.568	83.136	124.704
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For the rest of calculation, we assume the ratio of pure battery EV and PHEV stock to be 35/78 by 2040 based on the projection of US LDV stock from EIA reference case.²³ Next we estimate the annual charging load per EV based on a few assumptions that remain unchanged from present values. According to Transportation Energy Data Book #34, the average annual vehicle mileage is 11,824 miles for 2013.²⁴ Moreover, we assume the percentage of PHEV annual miles driven on electricity to be 55% based on the current industry standard, SAE J2841²⁶ assuming a 33 miles weighted average of PHEV allelectric range. In addition, based on sales weighted average of 2016 model year vehicles with sales in 2015 and MPGs from 2016 Fuel Economy Guide, we consider the parameter kWh/mile to be 0.32 and 0.367 for battery EV and PHEV respectively.²⁵ The list of the assumptions we used is as below:

Parameter	Value	Source
LDV stock	277.12 million	<i>Annual Energy Outlook 2015</i>
BEV / PHEV ratio	0.45	<i>Annual Energy Outlook 2015</i>
Average Annual Vehicle Mileage (miles)	11824	http://cta.ornl.gov/data/download34.shtml
Percentage of PHEV annual miles driven on electricity	55%	http://avl.inel.gov/pdf/EVProj/EVProjectUtilityFactorVolt.pdf
PHEV all electric range (miles)	33	http://www.afdc.energy.gov/data/vehicles.html
kWh/mile	BEV: 0.32 ; PHEV: 0.367	http://www.afdc.energy.gov/data/vehicles.html

²³ Annual Energy Outlook 2015, EIA, 2015

²⁴ “Transportation Energy Data Book,” Oak Ridge National Laboratory, <http://cta.ornl.gov/data/download34.shtml>

²⁶ Smart, John. “Actual Versus Estimated Utility Factor of a Large Set of Privately Owned Chevrolet Volts,” Idaho National Lab, 2014

²⁵ “Hybrid and Plug-In Electric Vehicle Emissions Data Sources and Assumptions,” DOE, http://www.afdc.energy.gov/vehicles/electric_emissions_sources.html, (March 11, 2016)

The results of our estimated energy demand from EVs are as below:

Scenarios	Low	Medium	High
Battery EV Charging Load (Gwh)	48,733	97,466	146,199
PHEV Charging Load (Gwh)	68,506	137,012	205,518
Overall EV Charging Load (Gwh)	117,239	234,478	351,717

Time-Variation of EV's Power Demand

The other dimension of EV's power demand is that it is time-variant. In order to depict an hourly demand curve of EVs, we need to consider factors like driven mileage, vehicle types, charging start time, charging level, etc.. Generally, the demand would be higher during the night and lower during the daytime since most charging of EVs occur in the evening. Moreover, there would be a small peak around noon if charging at workplace are considered available. There is high uncertainty for the prediction of hourly power demand associated with EV due to relatively small research sample of EV fleet and evolving characteristics of both vehicles and the grid itself.

How to meet Demand

One of the biggest issues facing the United States is attempting to meet the upcoming capacity needs. We're confronted with a number of issues: demand is increasing, older plants are being decommissioned, rising levels of CO₂, limitations of renewable energy sources, and the ever increasing sway of lobbyists. In this section we will attempt to breakdown these issues and present a plan moving forward that best suits the United States' evolving energy needs.

To start, it is important to understand the levelized cost of electricity ("LCOE"). This "is a convenient summary measure of the overall competitiveness of different generating technologies. It represents the per-kilowatt hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type."²⁶

There are certainly limitations to this type of analysis, for example, these estimations can vary widely by region, utilization, scale, existing energy resource mix and many other factors. Additionally, it is important to view different types of energy sources within "dispatchable" and "non-dispatchable" categories. These should be viewed separately because non-dispatchable "technologies only supply electricity generation when the resource (e.g. wind or sun) is available, but they do not supply capacity that can be relied on to provide electricity."²⁷ Essentially, this means that dispatchable energy

²⁶ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *U.S. Energy Information Administration (EIA)*. N.p., 3 June 2015. Web. 10 Apr. 2016.

²⁷ Levelized Cost of New Electricity Generating Technologies - IER." *IER*. N.p., 12 May 2009. Web. 10 Apr. 2016.

sources are more reliable than non-dispatchable sources, at least within the current configuration of the grid.

Therefore, non-dispatchable or “intermittent power sources, such as wind and solar, may incur extra costs associated with needing to have storage or backup generation available.”²⁸ At the same time, intermittent sources can be competitive if they are available to produce when demand and prices are highest, such as solar during mid-day peaks seen in summertime load profiles.²⁹ Despite these time limitations, leveling costs is often a necessary prerequisite for making comparisons on an equal footing before demand profiles are considered, and the levelized-cost metric is widely used for comparing technologies at the margin, where grid implications of new generation can be neglected.”³⁰

Another important factor is the passage of the Clean Power Plan (“CPP”). “On August 3, 2015, President Obama and EPA announced the Clean Power Plan – a historic and important step in reducing carbon pollution from power plants that takes real action on climate change. The CPP will reduce carbon pollution from power plants, the nation’s largest source, while maintaining energy reliability and affordability. Also on August 3, EPA issued final Carbon Pollution Standards for new, modified, and reconstructed

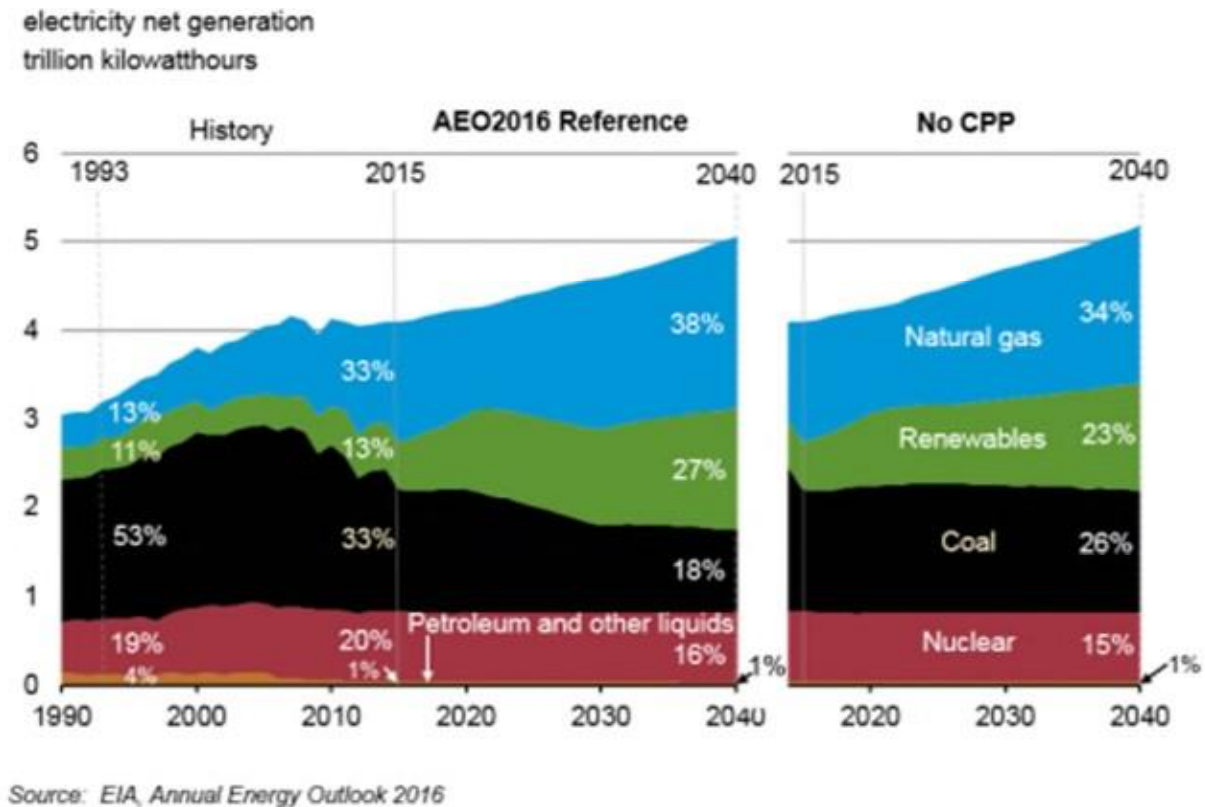
²⁸ Joskow, Paul L. "Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies." N.p., 27 Sept. 2010.

²⁹ Queen's University - Utility Bar." *QSpace at Queen's University: A Review of Solar Photovoltaic Levelized Cost of Electricity*. N.p., n.d. Web. 10 Apr. 2016.

³⁰ Mermaid Power | Empowering Lives in Harmony with Natur." *Mermaid Power | Empowering Lives in Harmony with Natur*. N.p., n.d. Web. 10 Apr. 2016

power plants, and proposed a Federal Plan and model rule to assist states in implementing the CPP.”³¹

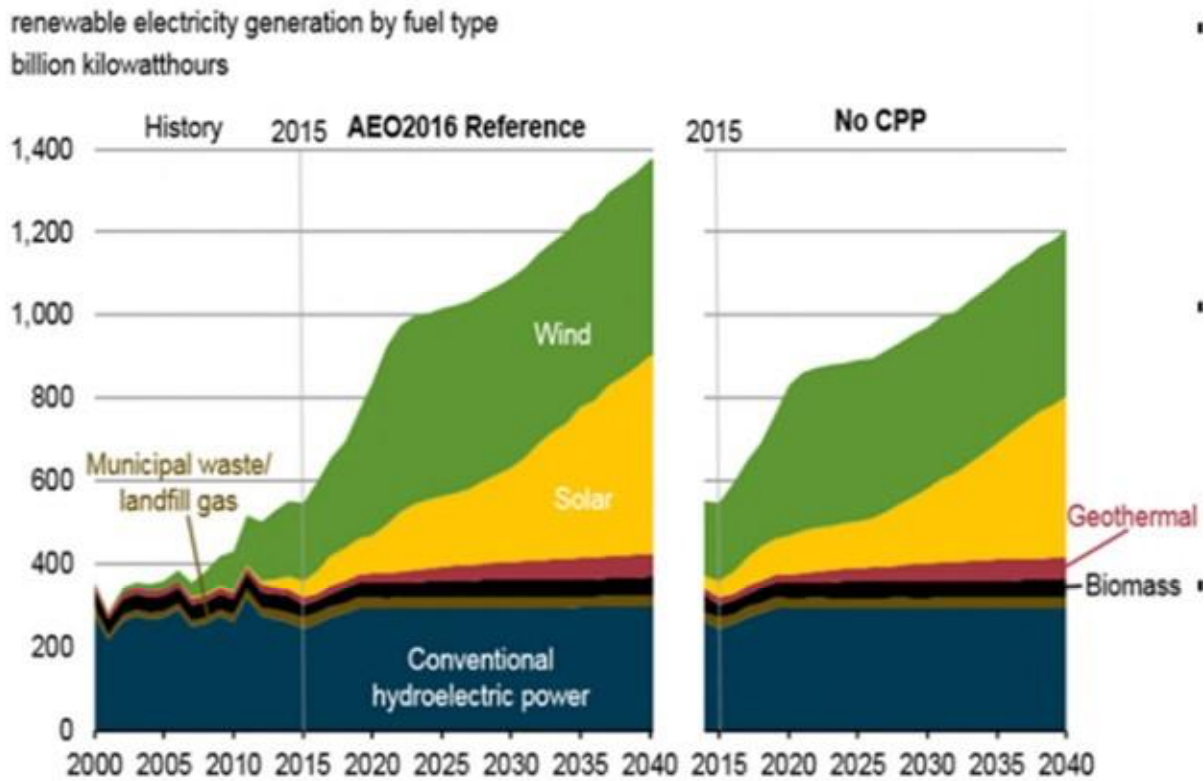
Taking the CPP and future expectations into account, we will now compare our capacity today vs. the Energy Information Administration’s (“EIA”) prediction for 2040. See below:



This graph shows three important trends. First, renewable energy is expected to more than double over the 25 years to 2040. Second, natural gas is expected to increase from 33% to 38%. And finally, Coal will take the brunt of these increases as its percentage of electricity generation falls from 33% to 18%. This fall will mostly take the form of retiring coal generation as a way to comply with the CPP.

³¹ FACT SHEET: Overview of the Clean Power Plan." EPA. Environmental Protection Agency, n.d. Web. 10 Apr. 2016.

Looking deeper into renewable sources, the graph below breaks down the expected growth of Wind, Solar, Hydro and other renewable resources.



Source: EIA, Annual Energy Outlook 2016

Wind generation experiences very large increases from 2015-2022, at which point the growth slows due to the expiration of the production tax credit. What is more striking is the 12-fold increase in solar generation from 2015-2040, due to decreasing solar costs and extended tax credits. All other sources of renewable energy are expected to remain relatively stable over the projection period.

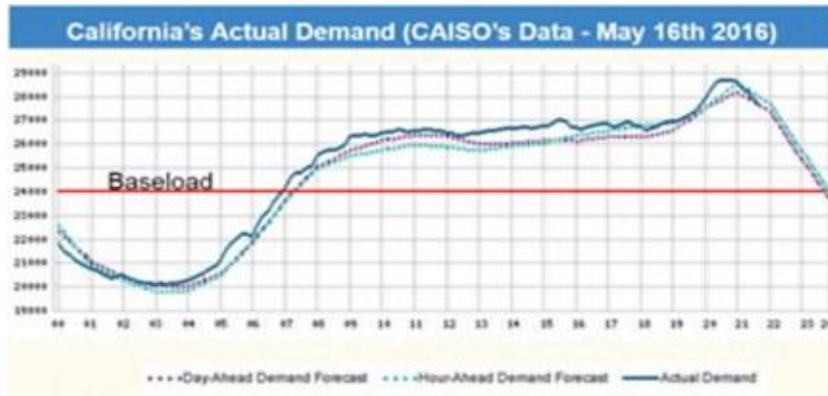
We feel that the renewable expectations from the EIA are relatively low. Solar and wind generation have been decreasing in relative price incredibly quickly.

Utilize Marginal Existing Generation Capacity

Three scenarios were estimated for California to account for the growing adoption of EVs both for pure electric vehicles and plug-in hybrid vehicles. These three scenarios assume different percentages of EVs of all the light weight vehicle fleet in 2040: 15% (low), 39% (medium), and 45% (high). Based on historical vehicle registration data, California accounts for 12% of US light-duty vehicle (LDV) sales approximately (from Auto News and the CA New Car Dealers Association).³²As a result, California would need: 14,069 GWh (low), 28,137 GWh (medium), and 42,206 GWh (high).

California can use its existing marginal generation capacity as the lowest hanging fruit option to accommodate the rise of electric vehicles across the state. To understand the existing generating capacity in California real time data from CAISO was gathered to plot the actual demand over a 24 hour period (*CAISO Energy Today*). The aggregate electricity demand in California changes significantly over the course of a day and throughout the year. July is the month with the most demand typically increasing by two thirds from early morning to afternoon. The figure below shows the actual demand of electricity in California and a base load for a typical Monday in late spring. The base load was estimated by taking the middle point between the peak and the trough.

³² Taylor, Dean. *SCE's PEV Forecast Methodology Overview*, Southern California Edison, 2013



According to our analysis, the most optimal time period to recharge EVs in California is between 12 pm to 6 am. This time period is when there are available resources that are below our estimated base load which are relatively cheaper than those above the base load line. To quantify the available resources, we approximate the area below the base load line between 12 am to 6 am.³³ If we assume that this same load curve is constant throughout an entire year, the total existing available energy load is:

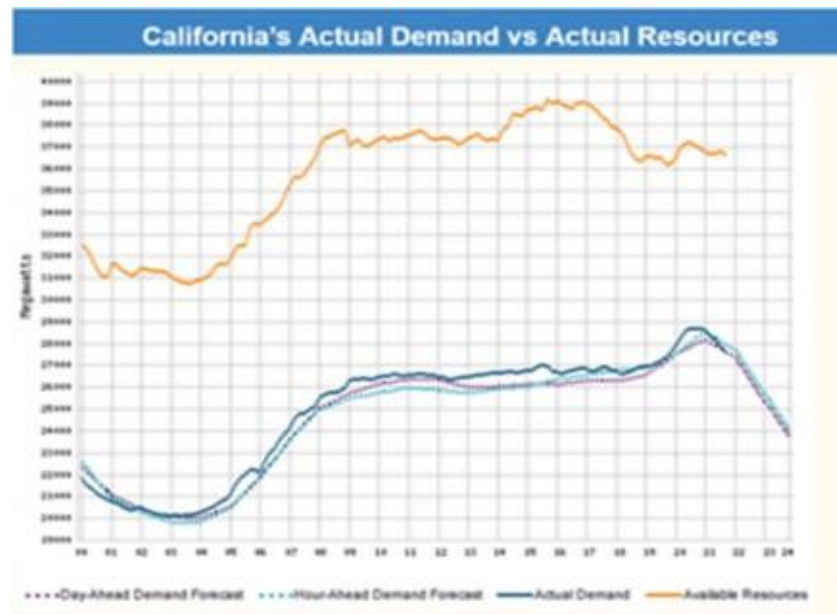
$$3,000 \text{ MW} * 6 \text{ hours} * 365 \text{ days} = \mathbf{6,570 \text{ GWh}}$$

This energy load is enough to cover 45% of the low scenario demand. In addition, this option would require utilities to enforce that vehicles are recharged between 12 pm and 6 am to successfully use the existing generation capacity at night time.

California could use its full generation capacity to recharge EVs. The chart below shows California's actual available resources versus the actual demand. There is still room to generate more electricity in California but these resources are mostly composed of natural gas and oil plants (peaker plants) that are able to be called on within 10

³³ "Today's Outlook," California ISO, <http://www.caiso.com/outlook/SystemStatus.html>

minutes.³⁴ This means that the energy load produced by these plants is very expensive and puts out more CO₂ per energy unit produced than base load plants.



We estimated the potential energy load by taking the difference between the actual resources curve and demand curve.³⁵ The result is as following:

$$8,000 \text{ MW} * 24 \text{ hours} * 365 \text{ days} = \mathbf{70,080 \text{ GWh}}$$

This energy load is enough to cover 160% of the high scenario demand. However, this option is very unfeasible and is too expensive to execute it.

California needs 42,206 GWh in our high scenario. To put this in perspective, we can quantify it in terms of number of wind farms or natural gas plants. With wind farms of 100 MW capacity and 25% net capacity factor, we would need 193 wind farms to reach

³⁴ "Today's Outlook Supply and Demand Graph Tutorial," California ISO, <http://www.caiso.com/Documents/TodaysOutlookTutorial.pdf>

³⁵ "About Today's Outlook," California ISO, <http://www.caiso.com/Pages/AboutTodaysOutlook.aspx>

the high scenario requirements. Now if we assume we have a natural gas plant of 500 MW capacity and a 60% net capacity factor, we would need 16 natural gas plants. Before going over the different type of energy sources California could potentially generate, we must understand California's current energy mix. The chart below shows California's energy mix in 2014.³⁶

California Energy Mix in 2014

Fuel Type	California In-State Generation (GWh)	Percent of California In-State Generation	Northwest Imports (GWh)	Southwest Imports (GWh)	California Power Mix (GWh)	Percent California Power Mix
Coal	1,011	0.5%	-	17,877	18,888	6.4%
Large Hydro	14,052	7.1%	160	2,138	16,350	5.5%
Natural Gas	121,934	61.3%	1	10,151	132,087	44.5%
Nuclear	17,027	8.6%	-	8,193	25,220	8.5%
Oil	46	0.0%	-	-	46	0.0%
Other	16	0.0%	-	-	16	0.0%
Renewables	44,887	22.5%	11,423	3,493	59,803	20.1%
Biomass	6,721	3.4%	762	24	7,507	2.5%
Geothermal	12,186	6.1%	150	694	13,030	4.4%
Small Hydro	2,426	1.2%	361	-	2,787	0.9%
Solar	10,557	5.3%	-	2,009	12,566	4.2%
Wind	12,997	6.5%	10,151	766	23,913	8.1%
Unspecified Sources of Power	N/A	N/A	25,676	18,757	44,433	15.0%
Total	198,973	100.0%	37,261	60,609	296,843	100.0%

61% of California's in-state energy generation comes from natural gas and 22.5% from renewable energy (not including hydro). Although California has significantly reduced its in-state coal and fossil fuels generation of electricity California imports a significant amount of cheap fossil fuel generated electricity from other states as show in the chart

³⁶ "Total Electricity System Power," California Energy Commission

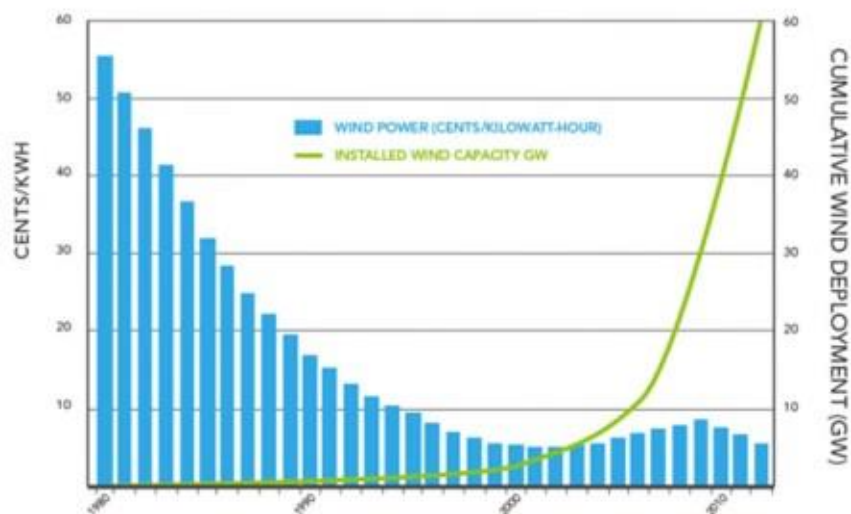
http://energy.almanac.ca.gov/electricity/total_system_power.html, (September 10, 2015)

above (Energy Almanac California). In total, combining in-state generation and imports solar and wind energy make up 12.3% of the entire California energy mix (CA Total System 2014).

Potential Sources of Energy

Wind Generation

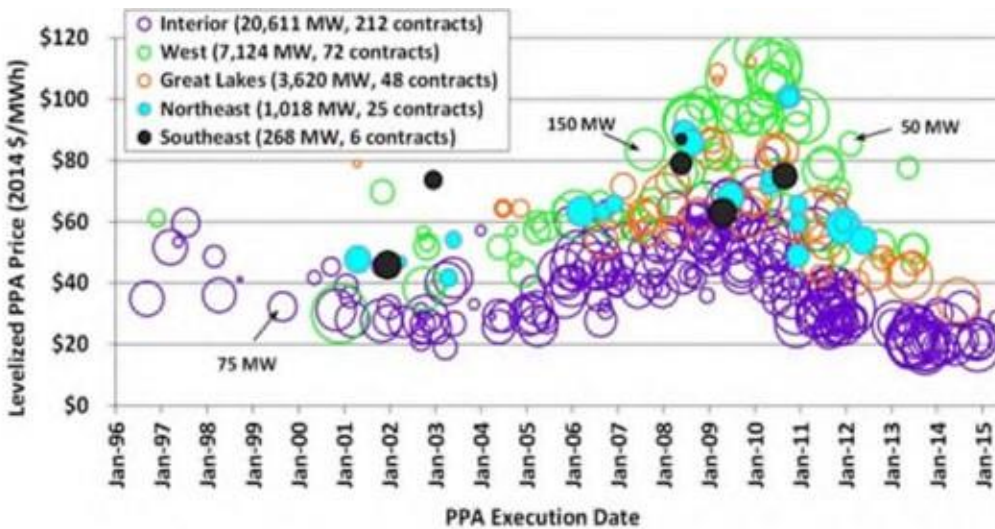
The graph below depicts the cost reduction in wind energy alongside U.S. wind energy deployment, showing a decrease in cost of more than 90% since the early 1980's.³⁷ The graph emphasizes two key points. First, average costs have been falling over time, and second, wind generation has been increasing exponentially.



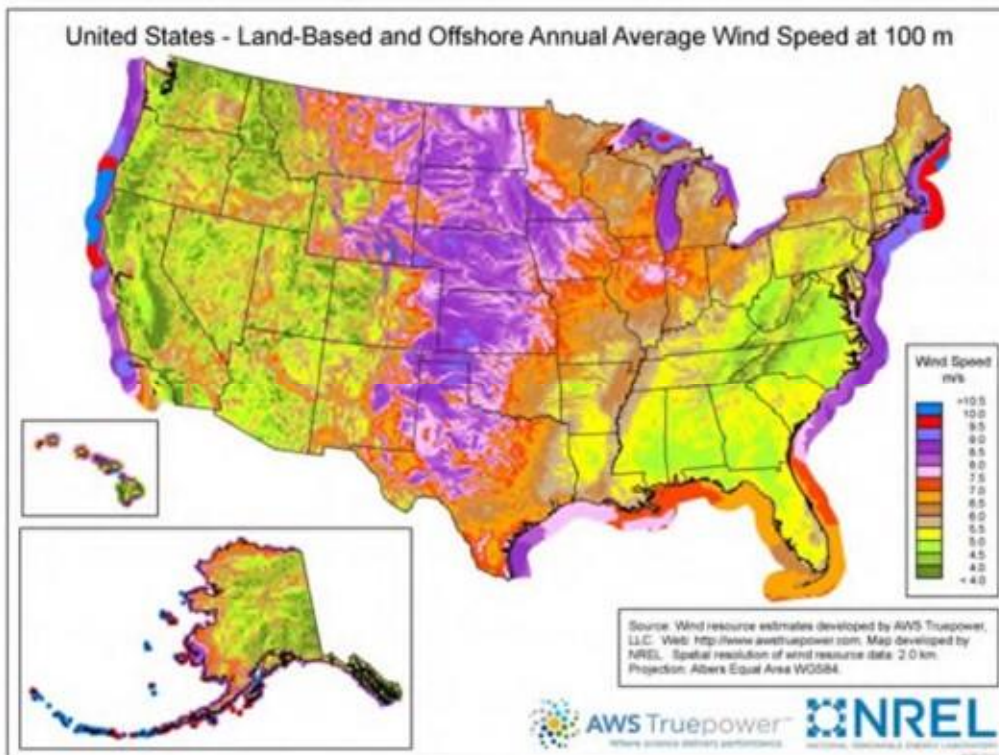
The graph below shows the average cost of wind by region and in particular, how some areas are much better at producing wind generated electricity than other areas. The interior of the country has greater capacity to produce wind energy.³⁸

³⁷ "The Cost of Wind Energy in the U.S.," AWEA,
<http://www.awea.org/Resources/Content.aspx?ItemNumber=5547>

³⁸ Solar & Wind Power Prices Often Lower Than Fossil Fuel Power Prices." *CleanTechnica*. N.p., 13 Apr. 2015. Web. 10 Apr. 2016.



See below for wind speeds across the United States.



As we can observe, wind speeds are highest in the middle of the country, specifically, North and South Dakota, Nebraska, Kansas, Oklahoma and Texas. However, the main challenge here is that while those areas are suitable to produce wind generated

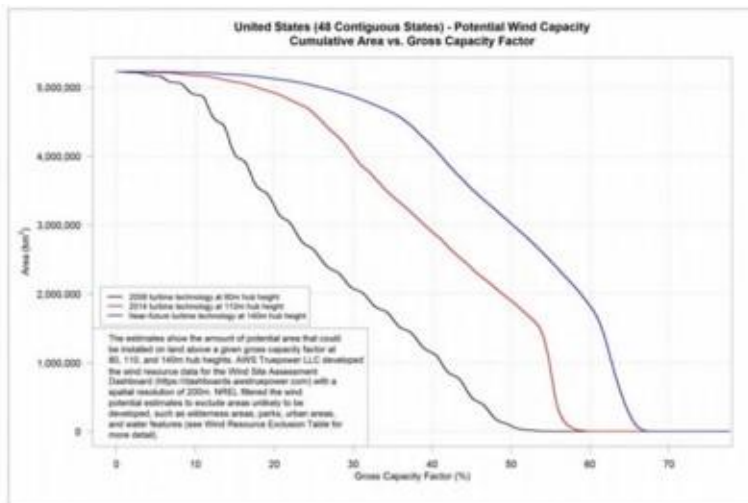
electricity, there isn't sufficient demand in those states due to low population. The graph below shows where electricity is being used within the United States.



This shows that while the interior states can produce high energy levels, they would need to transport that electricity over long distances to meet demand. Currently, the grid infrastructure is not suitable to transfer this energy.

As we look forward, it is important to try and estimate the cost for each type of energy. One of the most important factors for the falling cost of wind generation is the size of the wind turbine. This is because the taller the turbine, the higher the efficiency/capacity per turbine. Due to a phenomenon called “wind shear,” wind speeds are lower close to the Earth’s surface and more wind power is available at higher altitudes. The average hub height of most modern wind turbines is 80 meters off the ground while average capacity is approximately 32%.³⁹ As is shown in the graph below, the taller the turbine, the higher the capacity per turbine.

³⁹ “Wind Energy,” University of Michigan, http://css.snre.umich.edu/css_doc/CSS07-09.pdf



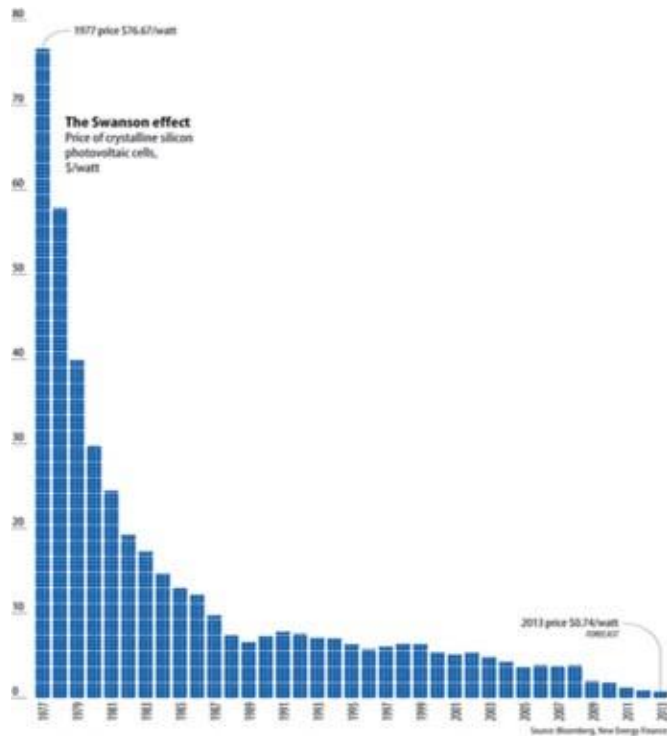
The graph below assumes that natural gas production costs will remain stable through 2040, while wind energy costs are likely to fall due to scale of production, increased turbine size and technological advances.⁴⁰



⁴⁰ How Steady Can Wind Power Blow?" Ramez Naam. N.p., 30 Aug. 2015. Web. 10 Apr. 2016.

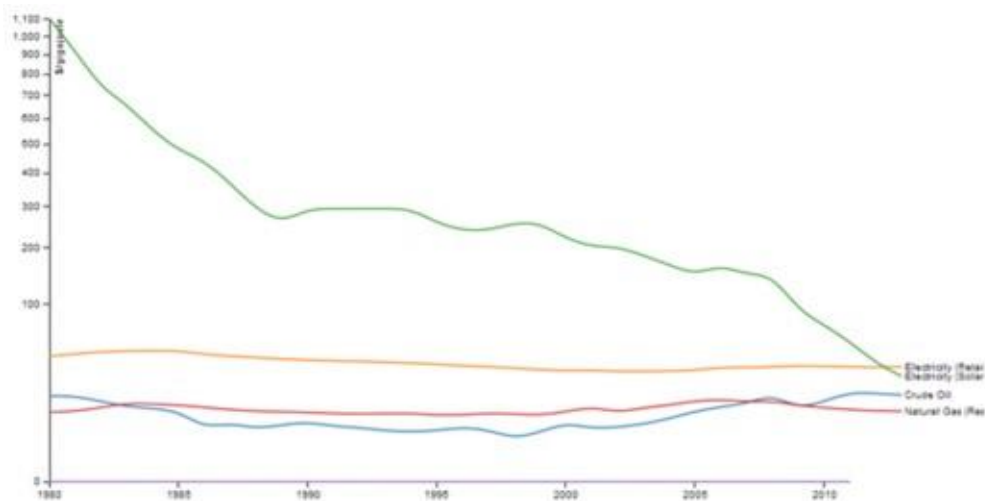
Solar Generation

Similar to the trends that we have been seen within wind generation, costs for solar generation have been falling quickly. Below is the cost to build a solar panel from 1977 through 2013.⁴¹



This trend clearly shows that the cost of building solar panels has fallen significantly. The graph below depicts the average cost of electricity from solar panels versus other sources of generation.⁴⁴

⁴¹ Zachary Shahan, "13 Charts On Solar Panel Cost & Growth Trends," <http://cleantechnica.com/2014/09/04/solarpanel-cost-trends-10-charts/>, (September 4th, 2014) ⁴⁴ Ibid

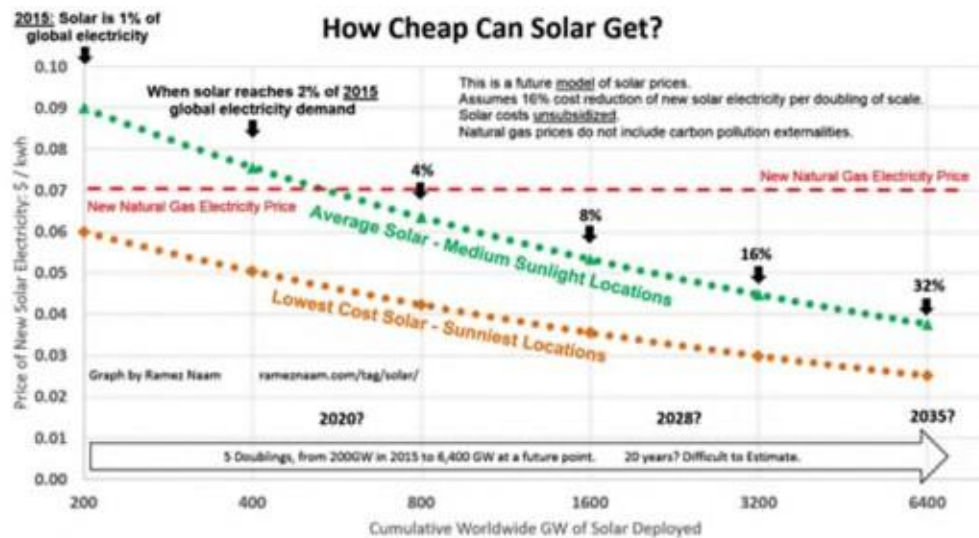


Clearly, solar energy generation is becoming increasingly price competitive against other sources of energy generation. However, it is important to note that solar has been the beneficiary of significant government subsidies and will continue to receive subsidies through 2023 for homeowners and indefinitely for businesses.⁴²

The graph below shows the projection of future solar prices given the trends seen within solar prices and does not include subsidies currently in place.⁴³

⁴² “Solar Investment Tax Credit (ITC),” Solar Energy Industries Association, <http://www.seia.org/policy/financetax/solar-investment-tax-credit>

⁴³ Ramez Naam, “How Cheap Can Solar Get? Very Cheap Indeed,” <http://rameznaam.com/2015/08/10/how-cheapcan-solar-get-very-cheap-indeed/>, (August 10, 2015)



“The graph above shows unsubsidized prices, ranging from solar in extremely sunny areas (the gold line) to solar in more typical locations in the US, China, India, and Southern Europe (the green line).

What the graph above shows is that, if solar electricity continues its current learning rate, by the time solar capacity triples to 600GW (by 2020 or 2021, as a rough estimate), we should see unsubsidized solar prices of roughly 4.5 cents/kwh for very sunny places (the US southwest, the Middle East, Australia, parts of India, parts of Latin America), ranging up to 6.5 c / kwh for more moderately sunny areas (almost all of India, large swaths of the US and China, southern and central Europe, almost all of Latin America). And beyond that, by the time solar scale has doubled 4 more times, to the equivalent of 16% of today’s electricity demand (and somewhat less of future demand), we should see solar at 3 cents per kwh in the sunniest areas, and 4.5 cents per kwh in moderately sunny areas.”⁴⁴

⁴⁴ Ibid

If this assumption holds, solar will cost *less than half* what new coal or natural gas electricity cost, even without factoring in the cost of air pollution and carbon pollution emitted by fossil fuel power plants.

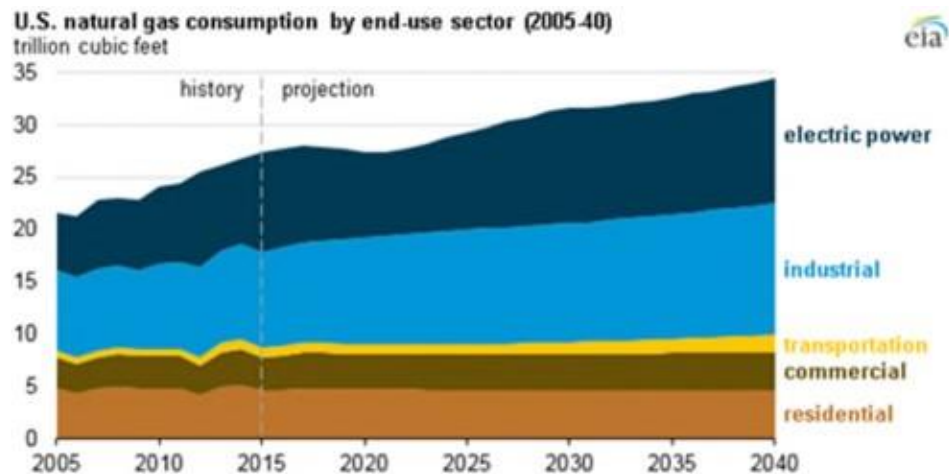
One of the most important factors to consider when evaluating solar is the full potential of the resource. Currently, the world uses approximately 18 terawatts of electricity within a year, while the sun supplied approximately 170,000 terawatts in the same year. Obviously, we would not be able to harness 100% of that energy. However, if the world were to produce solar panels with capacity of “20%, we'd only need to cover a land area about the size of Spain to power the entire Earth renewably in 2030.”⁴⁵ There are a number of limiting factors; however, the sheer vastness of solar potential is why it is expected to become a major component of energy production.

Natural Gas Generation

Natural gas has seen an incredible expansion in a very short period of time. Due to new fracking technology, we are able to access a much larger quantity of natural gas for relatively inexpensive prices. As shown below, we can see how the United States’ consumption of natural gas has progressed and is expected to grow into the future.⁴⁶

⁴⁵ Harrington, Rebecca “Here's how much of the world would need to be covered in solar panels to power Earth” September 24, 2015.

⁴⁶ “ANNUAL ENERGY OUTLOOK 2015,” EIA, https://www.eia.gov/forecasts/aeo/electricity_generation.cfm, (June 3, 2015)

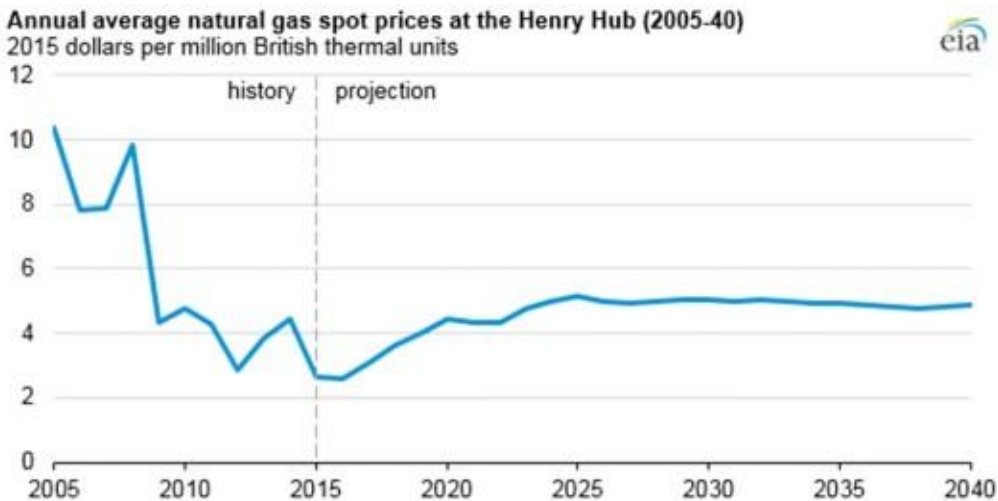


There are three critically important reasons for the growth of natural gas. First, burning natural gas releases approximately 50% less CO₂ than does burning coal.⁴⁷ Second, natural gas plants can be run much more efficiently and quickly than coal plants. This means that if renewable sources are not supplying enough energy to meet demand, the natural gas plants can turn on and/or adjust their output to generate power much more quickly than coal plants can.⁴⁸ This ultimately reduces the excess capacity that would be needed due to the variability of renewable resources. A final reason for natural gas is that we have a large quantity of the resource and we can produce it at a very low price. See below for the expected price of natural gas, and note the dramatic decrease in prices due to technological advances.⁴⁹

⁴⁷ U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. "How Much Carbon Dioxide Is Produced per Kilowatthour When Generating Electricity with Fossil Fuels?" N.p., n.d. Web. 10 Apr. 2016

⁴⁸ Spence, David, and Ross Baldick. "Why America's Power Grid Needs Natural Gas Now More than Ever." *Fortune Why Americas Power Grid Needs Natural Gas Now More than Ever Comments*. N.p., 26 Sept. 2015. Web. 10 Apr. 2016.

⁴⁹ U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. "Industrial and Electric Power Sectors Drive Projected Growth in U.S. Natural Gas Use." N.p., n.d. Web. 10 Apr. 2016.



Natural gas will most likely play a leading role in the energy mix of the United States going forward. There are unintended and potentially unknown impact on the environment due to the extraction of natural gas. Natural gas is extracted through hydraulic fracking, simply, this is a practice that involves “tapping shale and other tight rock formations by drilling a mile or more below the surface before gradually turning horizontal and continuing several thousand feet more... Once the well is drilled, cased and cemented, small perforations are made in the horizontal portion of the well pipe, through which a typical mixture of water (90 percent), sand (9.5 percent) and additives (0.5 percent) is pumped at high pressure to create micro-fractures in the rock that are held open by the grains of sand.”⁵⁰ The main concerns involve the chemicals used in the extraction process and the methane that may be released by the natural gas.

There have been a number of incidents regarding the safety of hydraulic fracking. These frequently involve the “chemical additives used in the drilling mud, slurries and fluids required for the fracking process. Each well produces millions of gallons of toxic fluid

⁵⁰ "Introduction - What Is Hydraulic Fracturing? | What Is Fracking." *What Is Fracking*. N.p., n.d. Web. 10 Apr. 2016.

containing not only the added chemicals, but other naturally occurring radioactive material, liquid hydrocarbons, brine water and heavy metals. Fissures created by the fracking process can also create underground pathways for gases, chemicals and radioactive material.

The Environmental Protection Agency and United States Geological Survey have recently confirmed what residents of Pavilion, Wyoming had been claiming—that hydro fracking had contaminated their groundwater.”⁵¹

Additionally, methane, the primary component of natural gas, is a powerful, short-lived greenhouse gas. It is more than 100 times more potent at trapping energy than carbon dioxide (CO₂), the principal contributor to man-made climate change.”⁵² Methane leakage occurs “during the production, delivery and use of natural gas has the potential to undo much of the greenhouse gas benefits we think we’re getting when natural gas is substituted for other fuels.”⁵³ Therefore, if we are unable to limit the leakage of methane, or if we do not detect the leakage, we could potentially undo any progress or accelerate our progression towards increased temperatures.

Obviously, these are very serious concerns and the positives and negatives of natural gas must be fully understood as natural gas continues to play an important factor in the United States’ long term energy policy.

⁵¹ Joe Hoffman, “Potential Health and Environmental Effects of Hydrofracking in the Williston Basin, Montana,” http://serc.carleton.edu/NAGTWorkshops/health/case_studies/hydrofracking_w.html, 2012

⁵² “The climate impacts of methane emissions,” Environmental Defense Fund
<https://www.edf.org/energy/methaneleakage>

⁵³ Ibid

Coal Generation

As evidenced by the CPP, it has been determined that the United States will be weaning itself off of coal powered electricity; therefore, we will not fully examine its potential. It is important to note that while coal will remain an important source for the foreseeable future, all existing coal plants will need to be replaced over time with a mix of renewable and non-renewable sources.

Nuclear Generation

Nuclear power is very interesting due to its limited impact on the environment, its long term consistency and reliability as well as its relatively low cost. For these reasons, the United States currently relies on nuclear for approximately 20% of its energy generation.⁵⁴ However, the United States has stalled on their production of new nuclear plants. This is due to four main reasons. First, there is high public sentiment against nuclear power. Second, nuclear generation produces nuclear waste, which is difficult to store or maintain. Third, nuclear plants are very expensive to build and other sources of energy are comparable to its cost. And finally, there is always a safety concern with nuclear due to its potential for destruction. There have been numerous examples of this, from Fukushima to Chernobyl.

The United States has not built any new nuclear plants for at least the past two decades. In the United States most electricity generation development is done through private investment. Investors look for relative risk free return on investment for such large capital commitments and long term contracts. In 1978, The U.S. Congress passed

⁵⁴ World Energy Outlook 2004 (Summary in Japanese)." *World Energy Outlook 2004 World Energy Outlook* (2004): n. pag. Web.

the Public Utility Regulatory Policies Act (PURPA) which provided the foundations for competition and deregulation by opening wholesale power markets to no-utility electricity producers.⁵⁵ This helped electricity markets become more competitive in many states and reduce the price of electricity but at the same time it made investments in nuclear energy less attractive. Investments in nuclear energy are no longer guaranteed to have a guaranteed return on investment without a national electricity rate regulated system.

As the United States has slowed down its investment in nuclear energy and has distanced itself from providing nuclear assistance in the Middle East and other countries, it has left a significant void. This void has been filled mainly by Russia through its national nuclear corporation Rosatom. Russia is the new leader in nuclear energy. In September 2015, Rosatom reported to have 30 nuclear plants orders in 12 different countries worth more than \$300 billion.⁵⁶

The role of government in other countries in providing electricity as a public good have played a major role for the success of Russia and other countries that actively promote their nuclear technology. The close tie between government and nuclear developers go through several bilateral processes that ultimately result in the sale of nuclear technology. Russia also provides readily available financing to fund nuclear projects and has developed a build-own-operate model. Rosatom pays the cost of construction and owns the plant, and receives revenue for the electricity supplied. This sales tactic has been very successful in the Middle East. For example, Jordan chose

⁵⁵ Tocco, A. and Lyon. 2006. "Lock's Opportunity: Deregulation and Restructuring in the Restructuring in the Electric Power Industry," Society for Case Research, Annual Advances in Business Cases.

⁵⁶ President of Russia. 2015. "Meeting with CEO of Rosatom State Atomic Energy Corporation Sergei Kiriyenko." Transcript, September. <http://en.kremlin.ru/events/president/news/50373>

Rosatom over other vendors because of the financial support that Russia guarantees which will cover 49.9 percent of the nuclear plant costs.⁵⁷ Furthermore, in February 2015, Russia and Egypt announced plans to build Egypt's first nuclear plant.

Nuclear will remain an integral part of the United States' energy mix, it will most likely stay at 20% without considerable increases or decreases for the foreseeable future.

Interstate Energy Trading & Competition

Another alternative to increase energy capacity and efficiency is increasing the amount of competitive electricity traded between states. Businesses and homeowners could procure clean energy and relatively cheaper electricity from neighboring or nearby states.

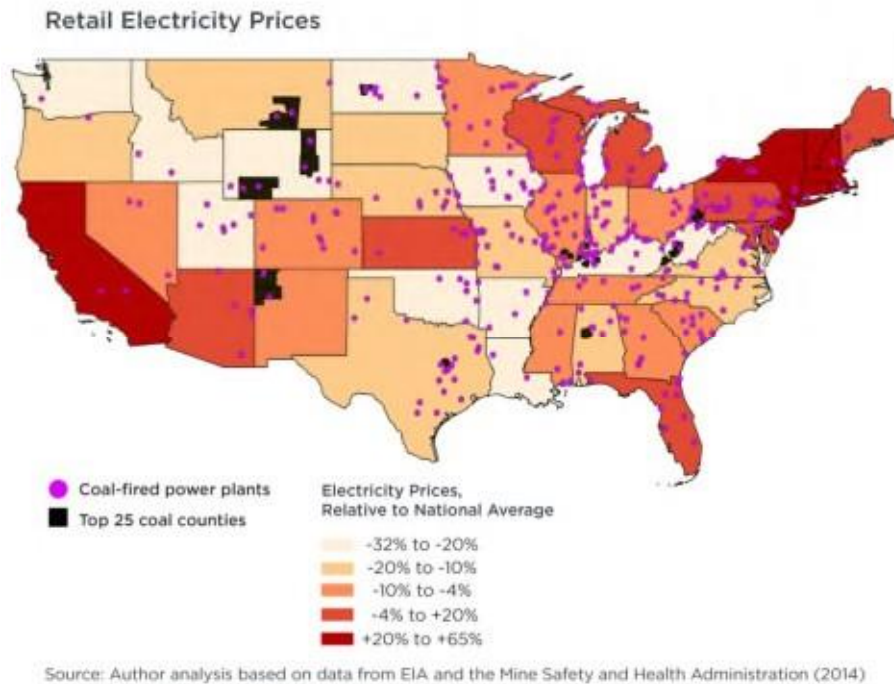
The regulatory framework has always treated power generation as a local issue. In the early days of electricity, it was difficult to transmit electricity over long distances.

Therefore, power plants were built evenly throughout the country so that electricity can be produced near the device or service requiring that energy. However, as transmitting electricity has gotten cheaper, the regulatory framework did not catch up.

For example, coal was and still is the main fuel source for electricity generation. While it seems that there are coal-fired power plants built in every state, retail electricity prices still varied significantly from state-to-state. This is because two-thirds of America's coal is produced in 25 counties in just a handful of states, and these coal is then shipped to

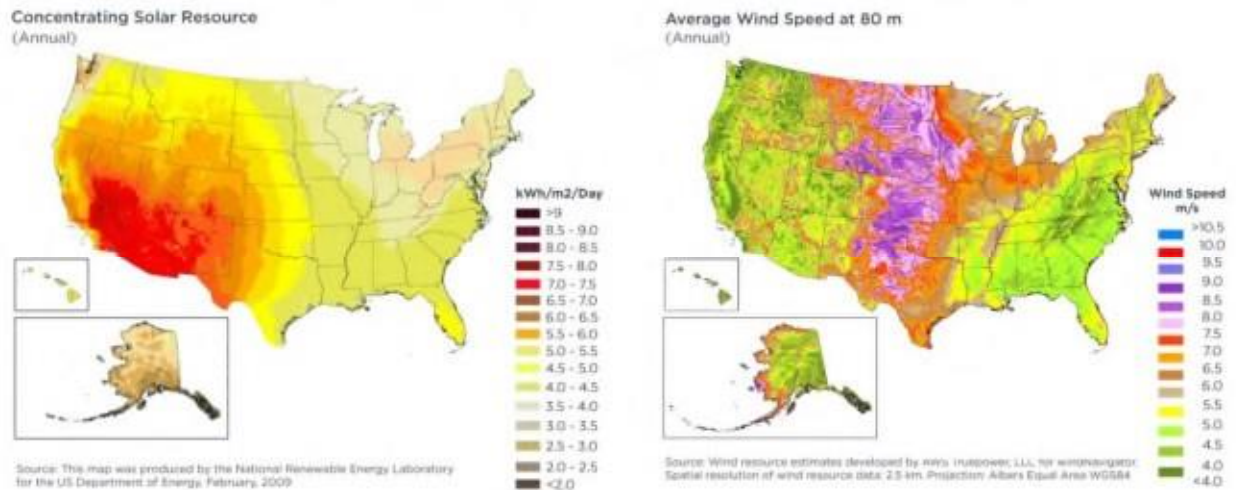
⁵⁷ Bora, K. 2015. "Russia, Jordan Sign \$10B Deal on Nuclear Power Plant." International Business Times, March 25. <http://www.ibtimes.com/Russia-jordan-sign-10b-deal-nuclear-power-plant-1858290>

power plants all over the country. “The farther away a plant is from a mine, the greater the coal—and with it, electricity—costs. Customers in the coal-producing state of West Virginia also get their electricity 25% cheaper than most Americans.”⁵⁸



On the other hand, it is much more difficult to “transport” wind and solar energy, since not every state has the same level of resources (see graphs below of the concentration of solar and wind resources in different geographical locations). Therefore, a robust transmission network has become evermore important to transport renewable electricity from one region to another and encourage America’s transition to renewables.

⁵⁸ Steve Cicala, “How Going Local Is Hamstringing The Clean Energy Transition,” <http://www.forbes.com/sites/ucenergy/2016/05/12/how-going-local-is-hamstringing-the-clean-energytransition/#6c4f4b93a27d>, (May 12, 2016)



Unfortunately, certain states, like Massachusetts, are doing the exact opposite by adopting “in-state generation-based renewable portfolio standards”. While these policies may encourage investments in renewable energy development within their own states, the plan is extremely costly to the state and its ratepayers, less reliable and diversified from a lack of economies of scale, and most of all, could have generated more renewable energy when investments are made in states like Nebraska.

What prompted states to do so is a mix of local utility interests and local economic impact, which has hindered efficient energy production in the past. For example, in 1993, a group of Western U.S. coal companies and railroads called “The Alliance for Clean Coal” filed a lawsuit against the Illinois Commerce Commission to challenge the controversial two-year-old Illinois law - Illinois Coal Act - designed force some electric plants to burn only Illinois coal.⁵⁹ This was mainly used to protect the jobs of 2,500

⁵⁹ Rob Karwath, “Law Forcing Use Of Illinois Coal Challenged” http://articles.chicagotribune.com/1993-0728/business/9307280070_1_illinois-coal-clean-coal-illinois-commerce-commission, (July 28, 1993)

Illinois miners even though there is plenty of low-cost, low-sulfur coal from Wyoming that can be used and recent federal clean-air laws will soon force these local high-sulfur plants to reduce emissions.

Overall, benefits far outweighs the costs, making interstate energy trading an important step to incorporate more renewables into the U.S. energy mix. Utility companies will be able to draw power from different regions and sources to ensure a constant stream of reliable power at cheaper bulk prices and to satisfy peak load demand. For example, one region may be producing cheap solar power during the day, but at night, another area may be producing cheaper power through wind. Interconnection will also promote open competition amongst providers, which then would encourage distributed generation (DG), where smaller private generators are treated as another source for power.

Interconnection will also enable the many benefits of a "smart grid", which include better prediction of utility demand, even an implementation of time-of-use based charge.

Benefits of Competition - Illinois' Case (1997 - 2014)

In 1978, The U.S. Congress passed the Public Utility Regulatory Policies Act (PURPA) which provided the foundations for competition and deregulation by opening wholesale power markets to no-utility electricity producers.⁶⁰ An important development of this movement was the Public Utility Holding Company Act (PUHCA) which imposed the breakdown of massive interstate companies and required them to divest their holding until each of them became a single entity serving a defined geographic region.

⁶⁰ Tocco A. and Lyon, Lock's Opportunity: Deregulation and Restructuring in the Restructuring in the Electric Power Industry," Society for Case Research, Annual Advances in Business Cases, 2006.

For nearly 20 years, two retail electricity models (competitive choice and monopoly) in the United States have been functioning in parallel, thus allowing comparison of key indicators. Currently there are 14 states or jurisdictions that operate the customer choice model and the rest of the US operates under the monopolies model with exceptions of some states that allow limited competitive electricity choice. Customer choice states account for 1.2 Billion MWh in total annual consumption or 33% of the contiguous U.S. electrical load. Figure 1 illustrates this contrast between the two existing models in the U.S. Customer choice jurisdictions are mostly in the northeast quadrant with the exception of Texas.

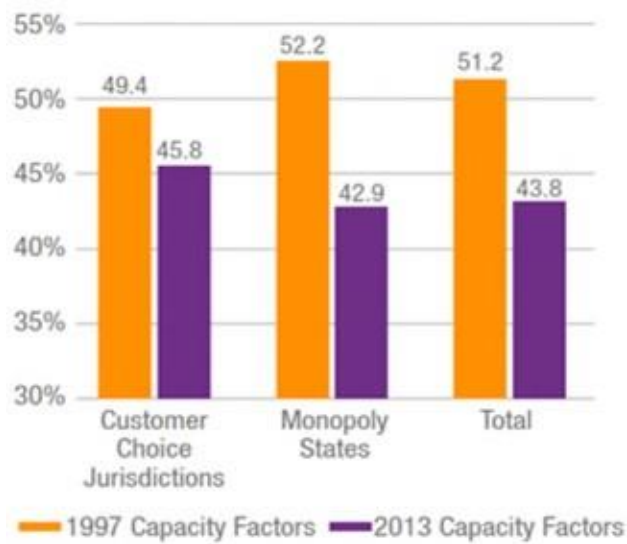
Legend:

- Customer Choice Jurisdiction
- Monopoly States

⁶¹ Borenstein, S. and Bushnell . The U.S. Electricity Industry After 20 years of Restructuring, 2015.

O'Connor in his recent paper on competitive choice and monopolies argues that competitive states have been able to attract more investment for new generating capacity than monopoly states. But most importantly competitive states have been able to become more efficient in the generation of electricity. Figure 2 shows that competitive states have surpassed monopoly states in capacity factor, a measure of generation efficiency (i.e. the ratio of output to total potential production of electricity of a power plant).⁶²

1997 to 2013 % change in Capacity Factor: Competitive Choice vs. Monopoly



63

We can observe that in Customer Choice Jurisdictions capacity factor is higher than Monopoly states and the U.S. national average. The introduction of competition over the past 20 years has helped pushed generators to become more efficient in their output efficiency of electricity. In some cases states within the Customer Choice Jurisdiction have become net exporters of electricity. The figure below to the right shows the ratio of

⁶² O'Connor P. R. and O'Connell-Diaz, Evolution of the Revolution: Sustained Success of Retail Electricity Competition, 2015.

“Electric power sales, revenue, and energy efficiency Form EIA-861 detailed data files,” EIA, <https://www.eia.gov/electricity/data/eia861/>, (October 21, 2015)

electricity prices of 2014 compared to prices in 1997. Competitive states have lower prices for electricity compared to those monopoly states.⁶² Illinois saved \$41.3 Billion from 1997 to 2014 shown below.



Eminent Domain

On January, 2015, 80 people gathered in the basement of the local bank in Tipton, Iowa in opposition to Rock Island Clean Line (RICL, a Texas company with \$2B in plan to build towers) taking their farmland to deliver wind power from northwest Iowa to Chicago, even though RICL is offering to pay landowners. This came as the result of RICL asking Iowa Utility Board to classify it as a utility franchise, a status that would enable the company to seek eminent domain rulings, a legal process for the government to gain ownership of private properties.

⁶² 3. U.S. Energy Information Agency, Electric power sales, revenue, and energy efficiency Form EIA-861, <https://www.eia.gov/electricity/data/eia861/>, Accessed May 25 2016.

The federal government's power of eminent domain has long been used in the United States to acquire property for public use, and landowners have been challenging this power ever since the 1870s. Land has been acquired to preserve historic sites and natural habitats, to facilitate transportation infrastructure, to set up national defense grounds, to build and improve the grid structure, and to enable any other authorized public use.

In light of the drive to replace fossil fuels and President Obama's Clean Power Plan that calls for reduction in carbon dioxide emissions from electricity generation by 32% from 2005 levels by 2030, solar panels and wind turbines are changing the landscape across America. While this provides jobs, accessible electricity, local tax revenues and an economic boon for their communities, some rural residents oppose having these disturbances in their homeland. Even though these landowners are paid fair market value for allowing wind turbines to be set up on their property, some still oppose to the idea of giving up their homes or farmland for simply reducing a fraction of the global warming effect.

The image below is an example that describes their frustration⁶³:

Before

After

⁶³ Andrew Morriss, "EMINENT DOMAIN & ENERGY INFRASTRUCTURE," <http://www.perc.org/articles/eminent-domain-energy-infrastructure#sthash.MMV9xpEB.dpuf>, (May 14, 2014)



The arguments against such government interference is that residents have to involuntarily agree to utility companies building these structures on their properties, which may create difficulty for maneuvering farming machinery, turning farmlands into substations, and increasing the price of electricity. Also, in the past where eminent domain is exercised, the majority of takings were for things that did not force landowners into a long-term relationship with the entity taking his/her land. “Today’s infrastructure projects are both more intrusive—larger, higher voltage, etc.—and more contested in their benefits by those who doubt the benefits of massive investments in alternative energy.”⁶⁴

As renewable energy technologies develop and prove to be a worthwhile investment, state and lawmakers should enable wind developers to use eminent domain just as any other industry - people need the electricity to enjoy all the conveniences of a modern life, and hosting power lines is for the betterment of a public good by creating jobs, cutting carbon emissions and enhancing the reliability of our grid. In addition, the Quadrennial Energy Review (QER) conducted by the Obama administration

⁶⁴ Andrew Morriss, “EMINENT DOMAIN & ENERGY INFRASTRUCTURE,” (May 14, 2014)

acknowledged the importance of establishing transmission lines to facilitate remote generation development of renewable energy. Therefore, in order to take advantage of the advancements in renewable technology and to modernize the grid, the U.S. needs to build new transmission lines in order to move America's renewable energy resources to market. In fact, the wider the area that solar and wind farms are integrated over, the higher percentage of carbon-free sources are implemented, the more reliable they become and the cheaper clean energy becomes for the consumers. Also, when renewable powers are regionalized, it is more susceptible to weather interference, such that when a bad storm knocks down solar power over most of Texas, the entire Texas grid may be affected. However, if the transmission grid system is over a larger geographical area, weather patterns in different locations may actually be complimenting each other. For example, wind might not be blowing in one part of the country, it will be blowing in another; also when the east coast is experiencing the peak of electricity use from late afternoon to early evening, the sun has not yet set a thousand miles to the west. This is something that requires the most assistance from policy.

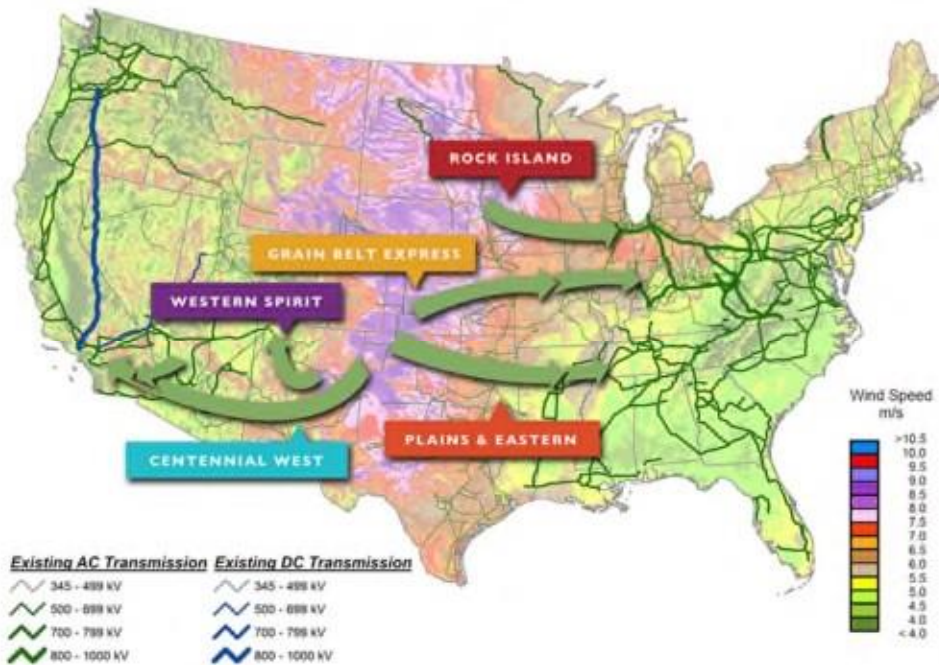
An example of a recent breakthrough in Oklahoma proves support from the federal government. For the very first time, in efforts to modernize the grid and accelerate the deployment of renewable energy, the Department of Energy (DOE) said "DOE will participate in the development of the Plains & Eastern Clean Line Project (Clean Line), a major clean energy infrastructure project. The Clean Line project will tap abundant, low-cost wind generation resources in the Oklahoma and Texas panhandle regions to deliver up to 4,000 megawatts of wind power via a 705-mile direct current transmission line — enough energy to power more than 1.5 million homes in the mid-South and

Southeast United States.”⁶⁵ In order for the project to succeed, eminent domain will have to be exercised by the federal government, but only as a last resort. The project will ensure that it has met significant milestones to prove its viability, and that the process remain transparent and fair to every landowner.

Clean Line Energy is an independent developer of long-distance transmission line projects that will deliver thousands of megawatts of renewable power from the windiest areas of the United States to communities and cities that have a strong demand for clean, reliable energy but lack access to clean energy resources. Here is the project overview and a map of potential wind power with current transmission lines to make the point visually poignant⁶⁶:

⁶⁵ “Energy Department Announces Participation in Clean Line’s Large-Scale Energy Transmission Project,” DOE, <http://energy.gov/articles/energy-department-announces-participation-clean-line-s-large-scale-energy-transmission1>, (March 25, 2016)

⁶⁶ Clean Line Project, <http://www.cleanlineenergy.com/sites/cleanline/media/projects-map-20150204.gif>

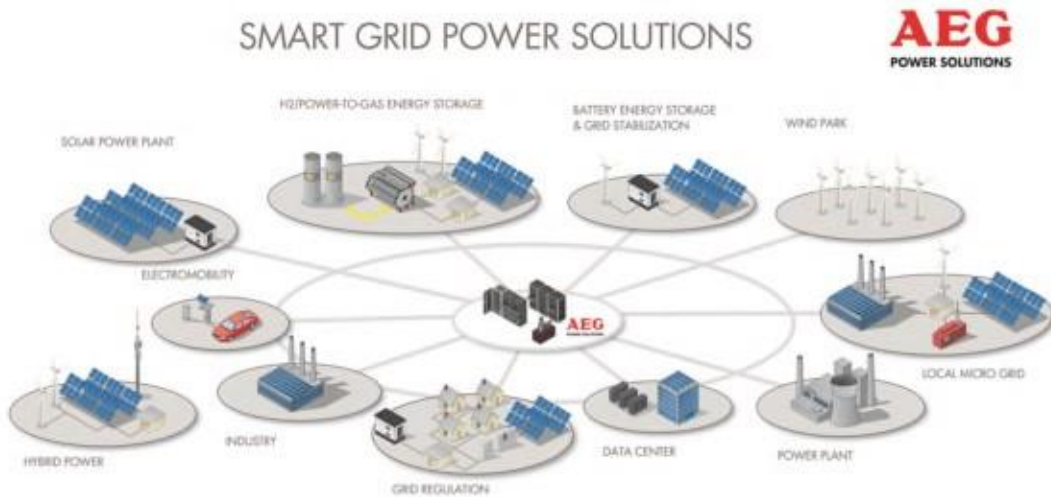


Infrastructure - Modernize the Grid

Smart Grid

The smart grid is a modernized grid, where traditional physical infrastructure is replaced with a digital one that allows a two-way flow of electricity and real-time information. It is a network of various electricity efficiency technologies and resources, which may include (but not limited to) renewable energy resources, smart meters and other data monitoring systems, remote control technologies, and smart appliances. It is being implemented globally to improve the communication between energy producers, utility companies, and end commercial and residential consumers. Since the dominant sources of energy is becoming cleaner, the technologies behind the smart grid will enable all users to better understand the needs and resources in order to make the system more reliable, flexible and efficient. Data monitoring systems especially plays an

important part gathering and analyzing data from consumer charging behavior, which will help predict and even alter behaviors in the future. See below for an example illustration of a smart grid:



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Energy Storage

Developing an EV infrastructure also presents opportunities in technological development. Energy storage technology is the fundamental element needed for the grid evolution. There are many different kinds of batteries (lead acid, Li-ion, flow, aqueous hybrid iron, sodium sulfur, etc.), with different classifications based on composition of cathode, anode and electrolyte. Lithium-ion battery technology is the most popular and

⁶⁹ Brendan Tripp, “Building a smart grid,” <http://www.chicagonow.com/green-tech-chicago/2013/10/building-smart-grid/>, (October 28, 2013)

widely adopted. This is due to its long life cycle, energy density, and scalability. Below is a chart illustrating the difference in energy storage technologies.⁶⁷

Energy Storage Technology/Chemistry Comparison

⁶⁷ http://batteryuniversity.com/learn/archive/whats_the_best_battery

Score Card*

● Strong ● Medium ● Weak

		Molten Salt				Flow Batteries				
	Li-ion	Redox Lead Acid	Aqueous Ion	Nickel Iron	Zinc Air	Sulfuric Sulfur	Sulfuric Phosphate Chloride	Flow Bromide	Iron Chromate	Vanadium
Deployed Base/Market	Strong	Medium	Weak	Medium	Weak	Strong	Weak	Medium	Medium	Medium
Control System Costs	Strong	Medium	Strong	Strong	Medium	Strong	Strong	Medium	Medium	Weak
Cycle Life @ 80% DOD	Strong	Weak	Medium	Strong	Medium	Strong	Strong	Medium	Medium	Medium
Max Depth of Discharge	Medium	Medium	Strong	Strong	Medium	Strong	Strong	Strong	Medium	Medium
DPF Maintenance	Strong	Strong	Strong	Strong	Medium	Medium	Medium	Medium	Medium	Medium
A/T Efficiency	Strong	Strong	Medium	Strong	Weak	Medium	Medium	Weak	Weak	Weak
Temperature Tolerance	Medium	Weak	Strong	Strong	Strong	Medium	Medium	Medium	Medium	Medium
Safety	Medium	Medium	Strong	Strong	Strong	Weak	Medium	Strong	Strong	Strong
Environmental Safety	Medium	Medium	Strong	Strong	Strong	Medium	Medium	Medium	Strong	Strong
Scalability	Strong	Strong	Strong	Strong	Medium	Weak	Medium	Medium	Weak	Weak
Energy Density	Strong	Medium	Medium	Strong	Weak	Strong	Strong	Medium	Weak	Weak
Discharge Rate (e.g. Power Application)	Strong	Strong	Medium	Medium	Medium	Medium	Medium	Medium	Weak	Weak
Example OEM's	AES, Tesla, Toshiba, etc.	East Penn, Aeon, Panasonic	Aqueon	Excell	Eos, Iron, Svalit	NGK, Posco	GE, FIAMM	Promax, ZBB	Shervault	Energy

Cost of the batteries may be alarming for regular consumers, identifying ways to best utilize energy storage is important. For example, batteries may be a suitable flexible resource because of their fast response and broad window of applications throughout the electronic value chain. The chart below summarizes different applications battery storage systems are capable of.⁶⁸

Electric Grid Applications for Energy Storage

⁶⁸ “What’s the Best Battery?,” Battery University, <http://energystorage.org/energy-storage/applications-energystorage-technology>

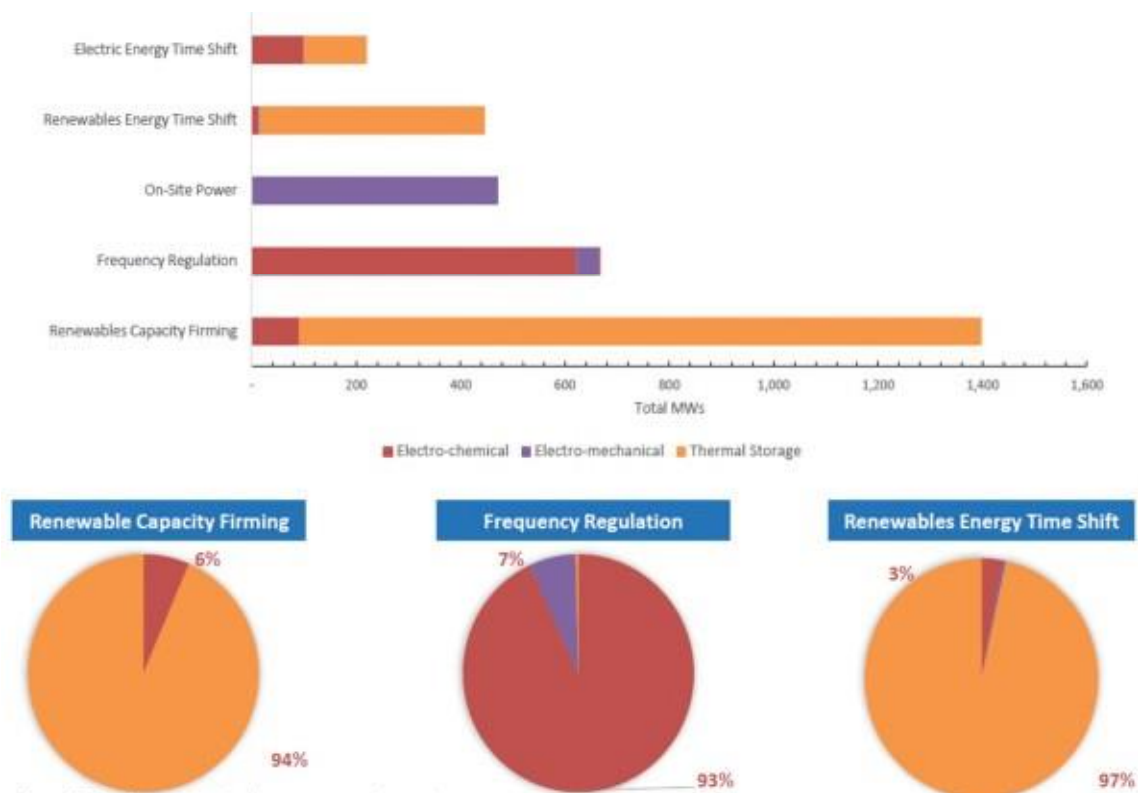


Energy storage is an enabler of electrified transportation and international competition for energy-storage market share will emerge. The best use of limited supply of batteries must be investigated. Dedicating a large battery for a vehicle used less than one hour per day for personal travel may limit potential benefits. Large batteries could provide additional value, e.g., by providing grid services in or out of a vehicle. There is opportunity in analyzing the battery capabilities, potential value, and ownership scenarios.

Distributed storage systems that dynamically aggregate and filter a collection of loads—such that the collected load is smooth, consistent, and repeatable—aid in the efficient and cost-effective delivery of electricity. Electrochemical energy storage technologies, such as PEV batteries, have not yet been cost effective for grid applications. Market expansion could benefit vehicle and grid operations if common energy-storage attributes are identified so that production volumes could be increased. The work of American Electric Power (AEP) on community energy storage and Southern California

Edison (SCE) on the “garage of the future” are consistent with developing complementary markets for energy storage in mobile and stationary applications. Energy storage technology is the fundamental element needed for PEV market evolution. While high battery costs limit market penetration, identifying multi-value stream pathways for PEV energy storage is important. The chart below shows the top 5 uses of energy storage in the world.⁶⁹

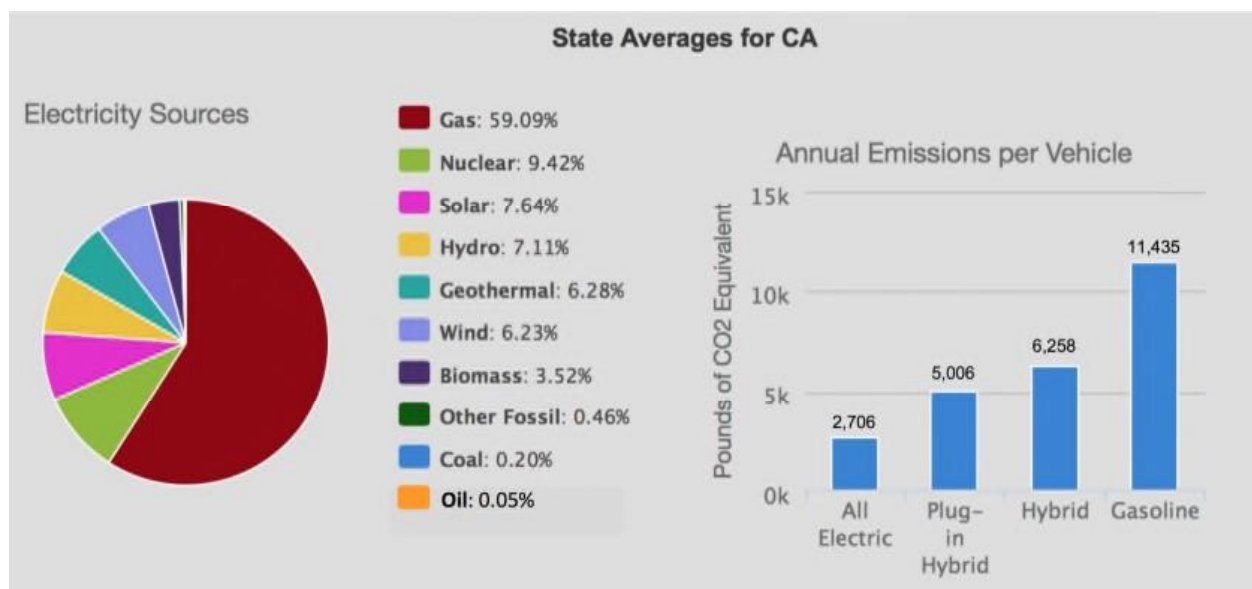
Top 5 Uses of Energy Storage in the World



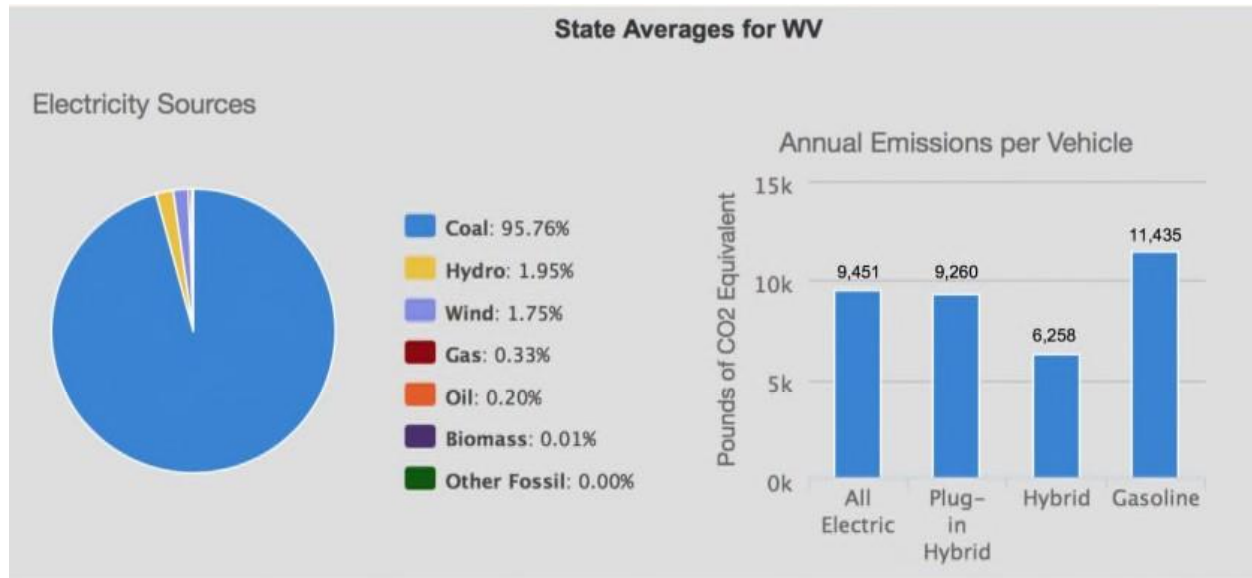
⁶⁹ DOE Global Energy Storage Database, <http://www.energystorageexchange.org/>

Impact of EV in terms of GHG emissions

Intuitively, EVs are considered to have advantages over conventional vehicles in terms of greenhouse gas emission. However, this conclusion depends heavily on the cleanliness of power generation mix. In regions that use relatively low-carbon energy sources for electricity generation, EVs typically have a well-to-wheel emissions advantage over conventional vehicles running on gasoline or diesel. In regions that rely heavily on conventional fossil fuels for electricity generation, PEVs may not display a well-to-wheel emissions benefit. For instance, a comparison between the State of California and the State of West Virginia is listed below according to DoE's analysis.⁷⁰



⁷⁰ "Emissions from Hybrid and Plug-In Electric Vehicles," DOE, http://www.afdc.energy.gov/vehicles/electric_emissions.php



Conclusion and Next Steps

Electric vehicles have the potential to help the environment by reducing CO₂ emissions, however, as we have seen through this paper, the way electricity is generated and the type of fuel that is used influences how clean EVs are. EVs and the increase in demand of electricity year after year will have a tremendous impact in the US grid system. The increase in the development of renewable energy resources and energy storage will require a grid that is well integrated and connected through the smart grid system. Trade among regions and upgraded transmission lines are crucial to be able to transport electricity from major renewable energy hubs like the midwest for wind and the southwest for solar energy.

From our research, we conclude that it is important for the US to develop a national energy policy as opposed to state level policies. This will enable the US to take advantage of regions that have competitive advantages in generating one type of renewable energy

resource. Another important recommendation is that the US should invest in high efficiency/voltage transmission lines. This will help other states without abundant renewable resources to obtain cheap and reliable electricity from those states that can produce it.

With a robust and upgraded electric grid system, there is more opportunity to invest in renewable energy resources and as well energy storage across the country. The US will need to investment in renewable energy and battery storage to be able to adequately meet future electricity demand.