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Decentralized Energy Storage

To realize an emission free world, the US has begun the mass adoption of clean energy. Maximum penetration of clean energy necessitates a system of storing the volatile wind and solar energy. A promising way to bolster storage capacity is to employ the batteries in electric vehicles. Electric vehicles have the potential to act as a large-scale distributed energy storage solution, but their success hinges upon a restructured electricity market.

The world's largest living organism is the honey fungus. You would never realize its gargantuan size because it's a network that subtly spreads along the earth's surface, spanning thousands of acres. In an oddly parallel manner, the US power grid is one of the biggest continuous machines known to man. Theoretically, a consumer could trace their finger from where a charger is currently plugged into their laptop, to the power box outside their house, along the power lines that run their street, hike along the transmission lines, and end up at one of the many power plants that feed into the system. Being that the power system is one big, delicate, web connecting consumers with producers, the machine must always balance power consumed with power produced. If balance between supply and demand is lost, the power at your socket will start to fluctuate from the all important parameters of 120v and 60hz, meaning the laptop you are reading this on just might get fried.

Renewable energy sources such as wind and solar provide carbon free electricity, however their electricity output is highly unpredictable, making it difficult to balance the load and production. The wind doesn’t always blow and the sun shines half the day at best, thus, these sources can frequently fail to meet demand. On the other hand, wind and solar farms sometimes produce excess electricity at points of high output and low demand. For some variable renewable energy (VRE) sources, the curtailment rate is as high as 19%. Reliability and operability are non negotiable features of energy generation so the solution is to introduce VRE into the system coupled with energy storage. Storage allows VRE to be bought/stored at points of abundant supply and sold/reintroduced at times of large demand. Storage can be looked at as both an electrical engineering and economic solution. For the past century, the American electrical grid has included no storage, this will need to change if we are to achieve mass adoption of green energy.

Currently, the meaningful forms of energy storage are batteries, compressed air, flywheel, and pumped hydro. The different energy storage solutions totaled to 25MWh in 2022, with pumped hydro making up roughly 88% of total storage[7]. To provide some scale in 2022 the US consumed 4.07 billion MWh of energy[8]. Framed another way, storage in the US had a power rating of approximately 31,000 MW while total generation in the US surpassed 1,100,000 MW[8].

I am not suggesting that the amount of storage needed for a functioning decarbonized grid is equal to the amount of consumption, I am only trying to provide some reference of magnitude. According to the National Renewable Electricity Laboratory projections, if the US wants a decarbonized grid by 2050 that uses 94% renewable energy, the grid will need roughly 6 million MWh of energy storage[3]. This amounts to over 85 times the current energy storage capacity. In order to develop a storage capacity that makes a meaningful difference the US must take advantage of the largest group of untapped batteries: electric vehicles. Thanks to FERC order. 2222, this may soon be possible.

FERC passed order. 2222 put in place legislation that would enable Distributed Electrical Resources (DERs) to interact in the wholesale energy markets. DERs include, "[residential] electric battery storage systems, rooftop solar panels, and products like smart thermostats that enable one to reduce power usage"[1]. From a high level, DERs are an aggregation of small electrical tools, who can be coordinated to provide a grid size resource. Examples include a company aggregating a bunch of home solar panels to sell energy on the wholesale market, or networking together the battery systems of homes in a community to bundle them all into one singular storage solution to be used by the grid. Aggregating the individual resources together is fundamentally different from say a singular building's solar panel system interacting with the grid. FERC is not able to safely or efficiently manage the integration of millions of residential solar panels into the grid. However, managing a collection of resources as a singular unit DER companies will be able to offer the grid one singular product. Furthermore, being a player on the wholesale market is a big deal because you have access to the wholesale pricing. Unlike residential consumers who pay a monthly $/kWh to their utility company, the cost of energy in the wholesale market fluctuates over the course of the day. Access to wholesale prices allows DERs to compete with traditional power plants. Aggregation will unlock the enormous potential of batteries in Electric Vehicles on the wholesale market.

The Federal Energy Regulatory Commision passed order 2222 on September 17, 2020[1], and opened the floodgates of decentralized electrical resources (DERs). However, four years later, the US has yet to see meaningful DER deployment. As we have seen, there is an increasingly large and presing demand for electrical energy storage in the US. Electric vehicles have the capacity to meet this demand.

Car batteries can be used to help operate the power grid in two ways, one being passively, and the other actively. Passively, Electric vehicles can be used as sinks for excess energy production. As noted earlier, wind and solar fluctuate unpredictably, leading to cases of surplus in the market. Instead of wasting the opportunity to produce energy, the electricity can be used to charge electric vehicles that can go on to use it at a later point in time. This would mean that electric vehicles only look to get charged at certain times in the day when electricity demand is low, preventing energy curtailment and avoiding applying additional pressure at times of high demand. Electric vehicles could also be used in a much more powerful manner by deploying the batteries actively.

In an active manner, the distributed electrical storage will work as follows. In the future, when an electric vehicle is plugged in, it will be connected to the grid by a bidirectional charger. This bidirectional charger contains Vehicle to Grid (V2G) power electronics that either feeds power from the grid to the car battery, or pumps the power from the battery back into the grid. Utilizing V2G technology, a DER company will provide an aggregate of EVs by coordinating the timing of when electric vehicles are plugged in. With a large enough aggregate of cars the DER allows the grid to store energy in the fleet of EVs and then return energy to the grid when it is requested. How effectively the DERs orchestrate storage using EVs will determine the percentage of total EV battery storage (MWh) that is captured and packaged as a product.

In the US there are already over 2.7 million electric vehicles on the road, the total number of electric vehicles is only going to grow. All car sales are turning electric and in the US right now there are 250 million registered vehicles on the road. By 2030, estimates project there will be over 25 million electric vehicles on the road[6]. The average electric vehicle has a battery that holds 69.5 kilowatt hours (kWh), but this number is brought down by tiny European electric models and lacks data on heavy duty electric vehicles such as buses and semi trucks[5]. This conservative total of lightweight electric vehicle storages comes to approximately

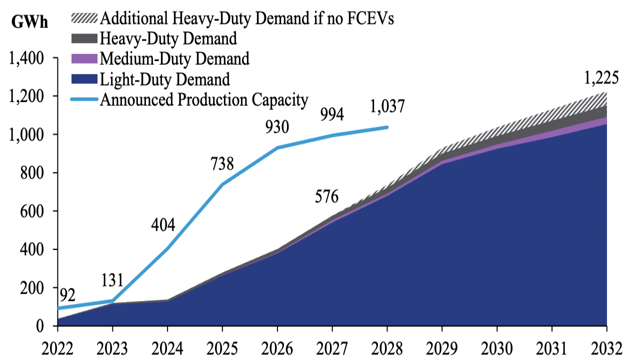

Figure 1: Projected U.S. EV Battery Demand and Announced Battery Production Capacity (2022-2032)

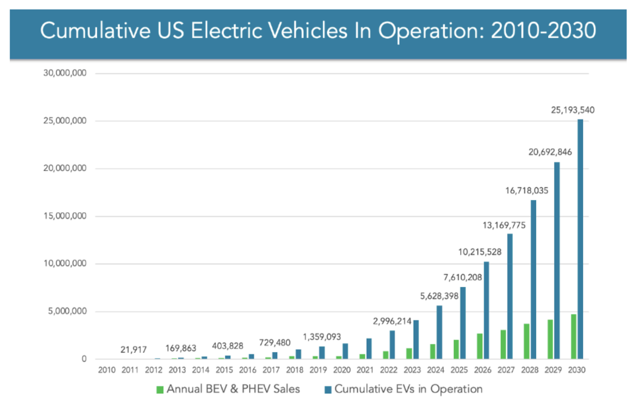

Fig. Battery demand GWh[6]

Fig. Total EVs US [6]

(2.7 million * 69.5 kWh) = 187.65 million kWh = 187,650 Mwh of battery storage. While this is a slight addition to the storage capacity, this number will only grow. The total GWh battery capacity will balloon to over 1,000 GWh or 1,000,000 Mwh. Clearly not all of the million MWh will be captured by DERs but an effective DER storage market could feasibly produce a meaningful amount of storage for the grid.

While the capacity will meet demand, it's been two years since FERC order 2222 and no successful DERs have materialized. Storage, electricity, power reduction, and other DER markets will thrive, but they demand that the US wholesale electricity markets are restructured to reflect the dynamic nature of the services they are offering. Right now, the US operates two different markets for electricity, the day ahead and the real time market. In the day ahead market energy is bought and sold for the next day based on the 24 hour forecast of supply and demand. The majority of transactions happen under the day ahead market, the difference in electricity between projection and reality is then traded at a premium in the real time market[2]. This current structure discourages DERs from entering the market.

To incentivize DERs to enter the market, the wholesale market must be restructured to include intermediate trading blocks. Understandably, the wholesale markets, as they stand today, were designed to serve centralized, dispatchable power plants[2]. While it's never been possible to predict exactly how much energy will be used the following day, traditional power plants have the advantage of full control over their energy output. This gets at the crux of the issue with integrating renewables and DERs into the current energy market: both renewables and DERs are inherently unpredictable. DERs, “can be unpredictable due to the weather, human behavior, and system visibility”[2]. DERs are disincentivized from entering the market since,“ Day-ahead DER forecast errors create uncontrolled exposure to real-time price variations, as resources committed in the day-ahead market are required to rebalance in real-time. The day-ahead market is ill designed for DERs, leading to crude and inefficient outcomes”[2]. Where traditional

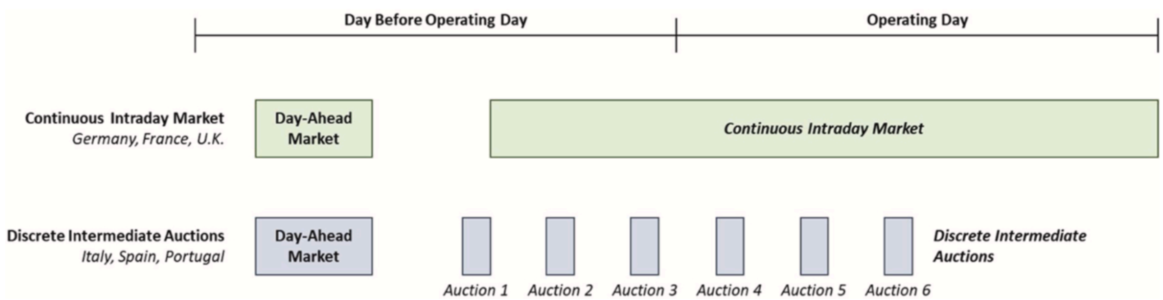

Fig. Breakdown of discrete auction structure[2]

fossil fuel plants can safely forecast output, DERs are trying to predict both demand and supply. This makes even a 24 hour projection very risky.Instead of just a day ahead market, the US should institute a discrete intermediate auctions[2] that mitigate the uncertainty facing potential DER entrants. This way, DERs would only be forced to project out a few hours. In relation to distributed EV storage, it would be a huge difference between confidently estimating the number of EVs plugged in and providing storage two hours ahead vs. a day ahead. Evidence that holding multiple energy auctions throughout the day promotes DERs can be found in Europe where, “Distributed generation has increased… from 19 TW h in 2015 to over 83 TW h in 2019” [2] under a discrete intermediate auction structure. The US needs to take strong measures to promote DER competition in the wholesale market by creating a structure that is inclusive to the emerging companies.

Electric vehicle production is providing enormous electrical storage capacity. FERC order 2222 took the first step towards setting up policy to enable DERs in the US electricity market. The final piece of the puzzle is for our wholesale market to be restructured. If this happens the ground has been sowed for DER companies to come and build DER solutions with EV batteries.

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