Measuring and Improving EVSE Networks and Stranded Assets in VAST™

Scott Robinson
Rebecca Kuss
Kofi Owusu Agyeman

Guidehouse Inc.
1400 Walnut St.
Boulder, CO 80301
303-728-2529
scott.robinson@guidehouse.com

December 2021

Table of Contents

1. Introduction

Electric vehicles (EVs) and the charging ecosystem that serves them are changing rapidly to serve new markets, use cases, and driver needs. This has significant implications for the results presented in any plug-in electric vehicle (PEV) analysis today. Guidehouse is working with clients throughout the transportation electrification ecosystem to address the difficulty of planning through these changes. This white paper uses industry-leading thinking and modeling to predict how changes to the future transportation system will affect the way consumers charge their EVs and what will happen to assets that could be stranded in the transition. We discuss the drivers of high and low charger utilization, examine how OEMs, utilities, charging providers, and consumers can affect the charging ecosystem, and analyze “stranded” electric vehicle supply equipment (EVSE) with perpetual low utilization. We also present a new tool to examine societal tradeoffs in EVSE buildout.[1]

EV charging ports (“chargers”) available for use by the general public make up a very small portion of the total consumer charging ecosystem, but these will likely be crucial to the expansion of EVs into the mainstream. These public chargers can also have large impacts on the electric grid. Most of the time, most EVs will be charged at home where it is inexpensive and convenient. However, public charging will be critical in expanding EV penetration to consumers without access to home charging and allowing EVs to make trips beyond the range of a single charge. The experience of light duty residential vehicles will be an important proving ground for charging business models looking to expand to fleet and heavy duty use cases.

How and how often a charger is used—“utilization”—depends on the supply of competing ports and vehicle demand for charging at that location. What defines high or low utilization depends on the goals of the charging network. The most straightforward goal is to maximize revenue per charger, seeking higher utilization. Some charging network providers such as Tesla and Rivian are using stations to sell vehicles and thus maximizing the perceived usability and value of the vehicle. Other networks might have equity or connectivity (i.e., getting from A to B) goals. L2 networks are most likely to seek higher utilization (e.g., increasing revenue), and Direct Current (DC) fast charging networks more likely to seek other goals such as selling vehicles and increasing connectivity.

The highest utilization public ports may have utilization in excess of 50% while others may be nearly 0%. Charger utilization is affected by many factors related to supply and demand. On the demand side, battery size, vehicle efficiency, and customer driving patterns determine which public chargers will be preferred. On the supply side, charger location, charger technology (L1, L2, or DC), connector type, rated capacity, and pricing structure will all affect utilization. All of these variables are changing over time though the charging network is made up of durable assets.

The changing dynamic between battery size/range and EVSE location can have large implications for vehicle costs and EVSE planning. Consider the first mainstream EV—the 2010 Nissan Leaf battery electric vehicle (BEV). At the time it was released, it was the only widely available BEV, so that made things simple. In the first generation, the Leaf’s 21 kWh battery had a range of about 70 miles. This small battery and limited range were most likely selected due to battery costs. Thus, designing a charging network to suit the Gen 1 Leaf meant spacing

[1] “Comparing EV Costs: Larger Batteries, or Better Charging Networks,” VAST™ Suite Network Cost Comparison, **https://bk-apps.shinyapps.io/siting-opt-and-stranded-assets/.**

chargers less than 70 miles apart. One can weigh the societal choice between a larger, more expensive battery and a smaller EVSE network versus a smaller, less expensive battery and a larger EVSE network. Using the free market as a proxy for this societal choice, we can guess that the incremental charging network built out in those early days probably catered to these smaller batteries. As battery costs come down and vehicle range expands, we might expect new stations to be more widely spaced to cater to new vehicles.

This would be a case study in markets responding to technological change and progress, except for one thing: EVSE is expensive upfront and requires continued maintenance. Everything from the charging equipment to the electric infrastructure required to support high voltage charging can be very costly. These costs can be recaptured over time if the charging site is popular and has high utilization. However, because the ideal location for a charger changes with technology improvements, locations that were once great may become “stranded” as vehicle range continues to improve.

In this white paper, we explore two important dynamics analytically using the Vehicle Analytics & Simulation Tool (VAST™) suite developed by Guidehouse. First, we introduce the new Network Cost Comparison Module to explicitly model[2] the dynamic between battery size, vehicle cost, range, and EVSE network buildout. This model explores whether it is better to invest in larger batteries or a better network. Second, we explore ideal “greenfield” siting configuration output by network optimization versus an example location in the US. The degree to which the two are different suggests a potential method for predicting stranded assets. Finally we look at the implications of stranded assets and what can be done with EVSE that is no longer in demand by customers.

[2] “Comparing EV Costs: Larger Batteries, or Better Charging Networks,” VAST™ Suite Network Cost Comparison, **https://bk-apps.shinyapps.io/siting-opt-and-stranded-assets/.**

2. VAST Charger Siting Methodology

Guidehouse's VAST™ suite provides an analytical environment to address the question of stranded assets and EVSE utilization in a robust and consistent way. Before moving on, it is useful to review the siting methods used in VAST™.

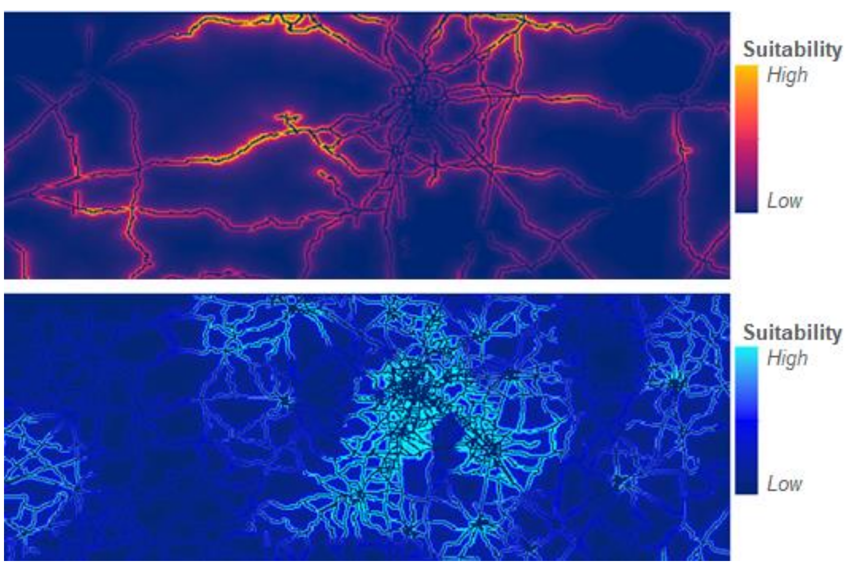
2.1 Calculating Infrastructure Requirements

Fueling infrastructure and vehicle populations evolve together in VAST™. More vehicles on the road with specific fuel requirements for each powertrain stimulate infrastructure development for the relevant fuel. This is accomplished through determining dynamic regional vehicle-per-charger ratios to estimate total port volumes and network optimization to estimate EVSE siting down to an individual intersection. The ratios are local—reflecting traffic and driving patterns—and dynamic—reflecting changing technology, range, and use case preferences among drivers.

2.2 Charging Location Optimization

The VAST™ Siting Module uses a GIS network model built in Python using the ArcPy library to optimally site EV chargers based on local vehicle populations and vehicle miles traveled for a specified street network. As Figure 1 depicts, the model is designed to reflect site connector stations, which are needed to connect major cities and provide for intra-city commerce and tourism, and market stations, which are needed to meet local market demand generated by inter-city PEV traffic and PEV commuter trips.

Figure 1. Illustrative Connector (Top) and Market (Bottom) Station Suitability



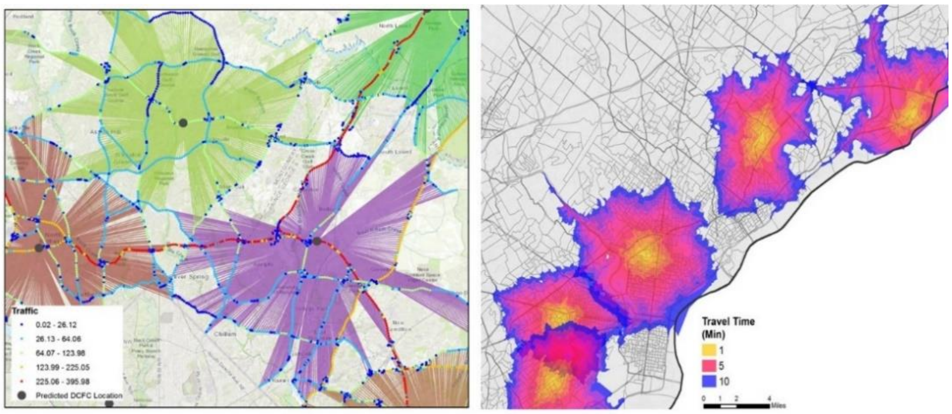
Source: Guidehouse

Figure 2 depicts additional key features:

- Roads are modeled as a network with explicit size, speed limits, navigation rules, travel times, and traffic volume.
- Stations are sited on nodes in the network.

- Station locations are determined discretely by network optimization to meet maximum demand for charging, subject to vehicle range and network constraints.
- Each station has a service territory, defined by a drive-time isochrone.
- Stations are assigned plugs based on the total forecast demand at a given location.

Figure 2. Illustrative Traffic and Travel Time Outputs



Source: Guidehouse

3. Batteries versus Chargers: Meeting Demand

The development of a charging network depends on the need for charging. In turn, the need for charging depends on many factors, but the most obvious is the vehicle range. If a vehicle has a larger battery and longer range, it has a lower reliance on charging infrastructure to complete its trips. In this section, we examine a hypothetical model network and how it might meet driver needs with either longer range vehicles or denser charging infrastructure. For this hypothetical we are directly comparing the total societal cost required to travel a set distance via electricity. The range tradeoff at the heart of the problem is thus whether society should spend an extra dollar making batteries in the vehicles a little bigger to avoid charging in between origin and destination, or making the network between origin and destination a little better, allowing smaller batteries to be feasible. In this way, we are equating a stored kWh in the battery with a potential kWh delivered from a charger. This is clearly a simplification, but we believe it to be a useful one.

To compare the cost tradeoffs between batteries and charging infrastructure, we considered a number of parameters that define a network. These parameters are fully customizable in the linked public model.[3] Table 1 describes each of the parameters and how each affects the hypothetical network.

Table 1. Parameter Details

	Parameter	Units	Values Tested	Description
Network Parameters	Network Distance	Miles	100-900	The distance from the center of the network to its outer edge. This can be thought of as a radius around a metro area, for example.
	Vehicle Range	Miles	50-450	Vehicle range in miles. This range dictates the required density of charging infrastructure across the network.
	Vehicles per Charger	Ratio	200-600	Ratio of vehicles to chargers within the network. This relationship determines the relative number of vehicles and chargers so that relative costs can be calculated in the correct proportions.
	Chargers per Site	Ratio	4-20	Ratio of chargers to number of charging sites. The number of charging sites is determined by the charging density, and this value linearly scales the associated number of chargers.
Market Parameters	Battery Unit Cost	$/mile	30-70	Unit cost of a battery in a single vehicle.
	Charger Unit Cost	$/charger	20,000-180,000	Unit cost of installing and operating a single charger.

[3] "Comparing EV Costs: Larger Batteries, or Better Charging Networks," VAST™ Suite Network Cost Comparison, https://bk-apps.shinyapps.io/siting-opt-and-stranded-assets/.

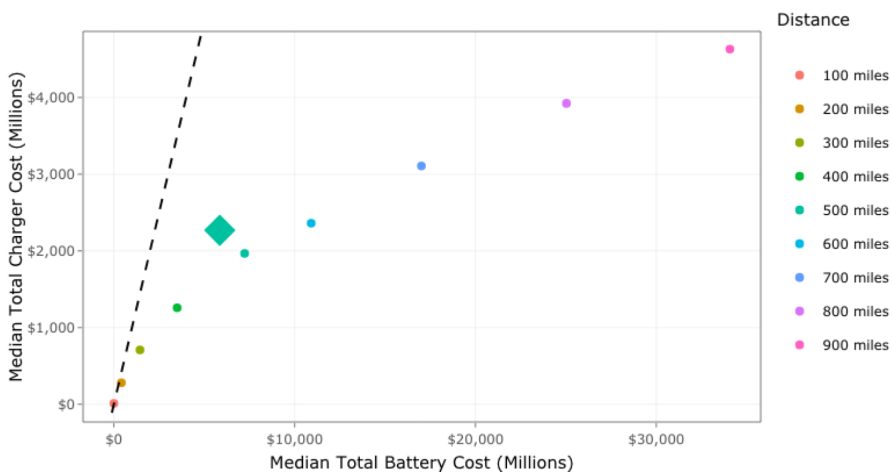
Source: Guidehouse Network Cost Comparison Module: ***https://bk-apps.shinyapps.io/siting-opt-and-stranded-assets/***

By characterizing the above parameters, we can simulate an idealized hypothetical charging network, which we call "Scenario 1: Chargers + Batteries." Chargers are evenly spaced throughout the network to facilitate a trip between any two points. The distance between chargers is determined by the average vehicle range: chargers have to be close enough together to allow an average vehicle to make the trip. Once charging sites are located, we can calculate the total cost of that network of chargers based on the number of chargers per site and the charger unit cost. We can also calculate the number of vehicles present within the hypothetical network using the ratio of vehicles per charger. The total battery cost of the network is the number of vehicles multiplied by vehicle range and battery unit cost. The costs of chargers and batteries constitute the total cost of this hypothetical network.

As a point of comparison, we can also calculate the cost to serve the same network without any charging infrastructure—solely by increasing the vehicle range to equal the network radius. In this case, the total battery cost of the network without charging infrastructure is the number of vehicles multiplied by the network radius and battery unit cost. We call this "Scenario 2: Batteries Only."

Figure 3 shows the cost tradeoffs between the "Chargers + Batteries" scenario and the "Batteries Only" scenario described previously. The dotted reference line shows where the total scenario costs are equal. Each dot represents the median cost value across all other parameters tested (see Table 1 for parameter details). The large diamond shows the cost comparisons when all parameters are set to the median value. All comparison points are below the reference line, meaning total charger cost is less than total battery cost. As network distance increases, the gap widens until the battery cost is nearly 10 times the charger cost for a 900-mile network.

Figure 3. Cost Comparison between Charger and Battery Scenarios by Network Distance



Source: Guidehouse Network Cost Comparison Module: ***https://bk-apps.shinyapps.io/siting-opt-and-stranded-assets/***

The total charger cost scenario includes the total upfront cost of the batteries required to travel from charger to charger. Even with this cost included, "**Scenario 1: Chargers + Batteries" is significantly less costly than "Scenario 2: Batteries Only."**

If we know that charging infrastructure is a worthwhile investment because it can offset the need for more expensive batteries, how can we encourage the expansion of today's charging networks? The next section of this paper evaluates an existing network to understand how we can further optimize these assets. Then, we propose a set of ideas to repurpose stranded charging infrastructure so that a few bad apples do not sour network operators' appetite to continue installing infrastructure.

4. Evaluating an Existing Network

To understand the coverage of existing charging networks, we compared the geographic spread and traffic demand served by an actual EVSE network in Sacramento County, California, to a hypothetical optimal network built using the VAST™ Siting Module.

4.1 Example of Sacramento "Ground-Truth"

We modeled the "Ground-Truth" case using road network layers and existing charging sites within Sacramento County, so this case represents the state of the actual charging network in Sacramento as of 2021. This network contains a total of 387 charging sites with various plug configurations. This snapshot was taken using Alternative Fuels Data Center (AFDC) data as of October 2021. The goal of the "Ground-Truth" case is to estimate the geographic coverage and traffic demand met in order to compare it to the "Greenfield" optimal case developed using network optimization in VAST™.

4.2 "Greenfield" Optimal Case

The "Greenfield" case represents a hypothetical network, which can be thought of as a brand new network built to serve traffic in Sacramento County if no chargers existed today. To model this case, we used only the road network layer without charging sites. New charging sites are optimally assigned to nodes in the road network based on traffic flow and travel times between stations, given the objective of maximizing EVSE coverage. Like the "Ground-Truth" case, the optimal network contains a total of 387 charging sites—thus, the total number of sites will be the same in both cases. The only difference is site locations along the road network.

The objective of maximizing coverage is frequently used in location allocation problems to site fire stations, police stations, and emergency response centers because emergency services are often required to arrive at all in-demand locations within a specified response time. This siting represents a societally optimal allocation of resources to ensure service of as much area as possible. Notably, this generates quite different results than a revenue or market share maximization objective, which is often used in the location of fast-food restaurants and other retail locations not designed to provide a public good or serve all customers.

4.3 Comparison

In the following sections, we compare the optimal network to the existing network using both network coverage and network efficiency metrics. In the following charts, we represent the existing network ("Ground-Truth") in red and the optimized network ("Greenfield") in green.

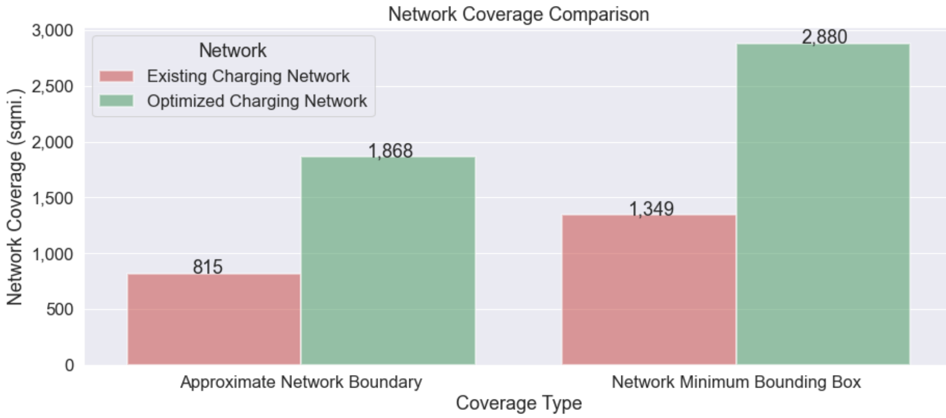
4.3.1 Network Coverage

We use two approaches to calculate a network's area of coverage. Both are designed to approximate the total service area of the network:

- The first is an approximation of a network's bounding region created by connecting the network's vertices (facilities on the outskirts of the network).
- The second is the minimum bounding box that can enclose all facilities within a network.

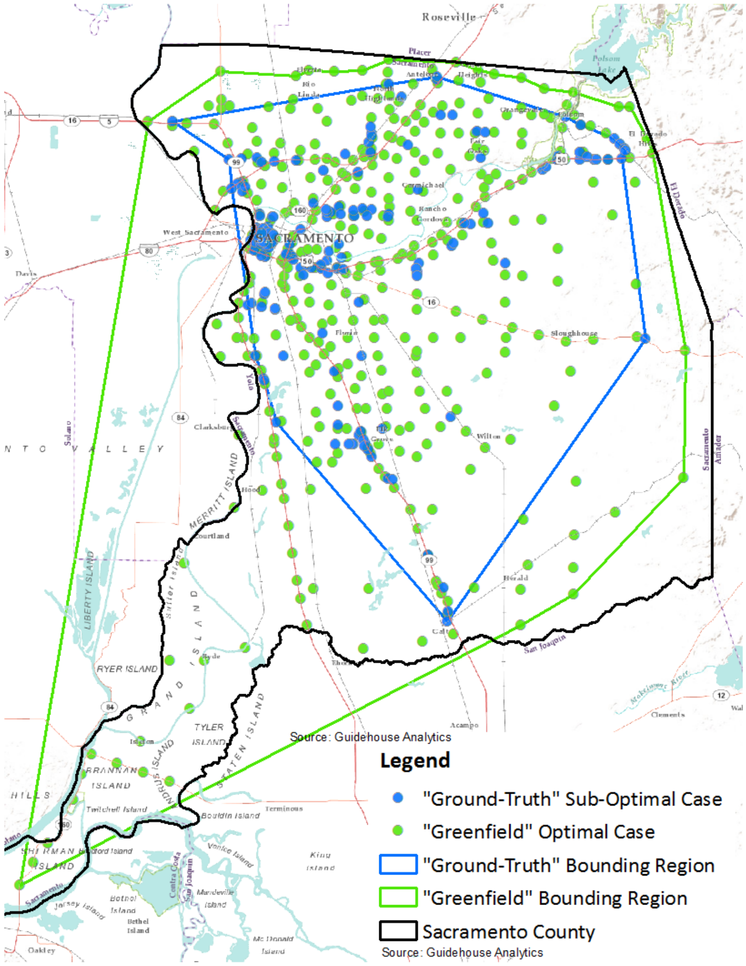
Figure 4 shows that the existing network has lower coverage in both approaches. This means that the optimized network is better from a societal perspective because it enables more trips and connects more customers to the network, though it may have lower utilization overall due to higher coverage in lower traffic areas. A simple optical comparison using Figure 5 suggests that the density of chargers in urban areas is lower in the "Greenfield" case because chargers are more spread out with sites serving rural areas. In the "Ground-Truth" case, most charging sites are closer to urban cities and city centers.

Figure 4. Network Coverage Comparison between Existing and Optimal Charging Networks (Chart)



Source: Guidehouse analysis

Figure 5. Network Coverage Comparison between Existing and Optimal Charging Networks (Map)



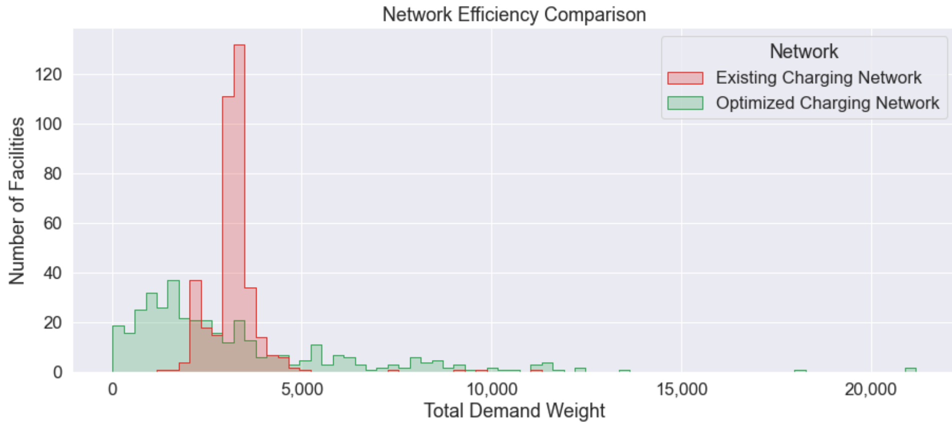
Source: Guidehouse analysis

4.3.2 Network Efficiency

The efficiency metric represents the total modeled demand allocated to each charging facility within a charging network. This will be higher for sites that serve more traffic and are not in competition with other sites. As service areas overlap or traffic served decreases, efficiency decreases.

In Figure 6, the optimal network (green) has a longer right-hand tail, meaning that it has more charging sites that serve high demand relative to the existing network (red). This can be explained by the geographic location of chargers and station density (see next sections). While the green distribution has a longer right-hand tail, it also has more mass on the left side. This represents stations sited to connect underserved locations into the network that will tend to have lower utilization. The existing market is dominated by charging providers attempting to maximize their revenue; thus, chargers tend to be sited close together (this is known as Hotelling's Law in economics and explains societally suboptimal clustering of services). This fact explains the more concentrated distribution of blue dots in Figure 5 and red in Figure 6.

Figure 6. Network Efficiency Comparison between Existing and Optimal Charging Networks



Source: Guidehouse analysis

5. Repurposing Suboptimal Sites

What happens to charger locations that are not well sited? Often retail charging providers (ChargePoint, Blink, EVgo, etc.) will not own stations directly. Rather, the station is owned by the building owner, and the retail charging provider handles payment processing. Similarly, the building owner is typically responsible for any electrical upgrades that need to happen to support the EVSE, such as upgraded electrical service, upgraded panels, and independent 240 V circuits to the EVSE. Direct current fast charging (DCFC) represents higher costs and additional upgrades (208/480 V three-phase circuit).[4] If the charger turns out to have low utilization, these costs represent either large sunk costs or a potential pathway to new opportunities. In some cases, a low utilization charger may serve a very beneficial purpose for drivers by connecting underserved areas. In other cases, a low utilization site may serve as a backstop for the owner or the utility.

EVSE Cost Components

- EVSE hardware
- Electric panel work
- Trenching
- Transformer or other electric service upgrades
- Americans with Disabilities Act (ADA) compliance
- Signage and lighting
- Permitting and inspection
- Engineering review

5.1 Characteristics of a Typical Charging Site:

Before we explore additional use cases for low utilization sites, it is helpful to identify several characteristics that completed EVSE sites share:

1. The premise has completed “Make-Ready,” and the electric system is upgraded.
2. The real estate owner is engaged and at least partially educated in energy and electrification topics or technologies.
3. The site is “on the map” and logged into EV station finder applications such as PlugShare,[5] AFDC,[6] and ChargeHub.[7]
4. An EVSE provider and the property owner have a shared interest in the site.
5. The site has at least some parking facilities.
6. The soft costs (utility/provider communication, permitting, financing, installation) have been addressed.[8]

5.2 Solutions and Options

Many options exist for repurposing sites that are not well sited, with some solutions discussed here:

[4] New West Technologies, *Costs Associated With Non-Residential Electric Vehicle Supply Equipment,* U.S. Department of Energy, November 2015, **https://afdc.energy.gov/files/u/publication/evse_cost_report_2015.pdf.**
[5] PlugShare, **https://www.plugshare.com/.**
[6] “Electric Vehicle Charging Station Locations,” Alternative Fuels Data Center, U.S. Department of Energy, **https://afdc.energy.gov/fuels/electricity_locations.html.**
[7] ChargeHub, **https://chargehub.com/en/.**
[8] Chris Nelder and Emily Rogers, “Reducing EV Charging Infrastructure Costs,” Rocky Mountain Institute, 2019, **https://rmi.org/insight/reducing-ev-charging-infrastructure-costs.**

1. **Wait it out.** Utilization will probably increase with higher penetration. Initial capital costs are sunk. If operations and maintenance costs can be managed, keep the charger around for the future. Keep in mind that if the station develops a reputation as "abandoned," it will be difficult to resurrect it even if demand increases.
2. **Cater to fleets or ride-hailing.** If the charger is close to an optimal destination, then it might be perfect for commercial operators to charge up before their next ride or delivery. These same locations might have low non-fleet charging utilization due to long-term or unavailable parking. A long-term contract with fleet operators could bring utilization up and increase the value of the charger in the network.
3. **Explore alternate business models.** Pay-as-you go is a very common charging business model and has several convenience benefits. However, it also provides few externalities. Consider a pivot to subscription programs and memberships or incentivize charging through a loyalty or rewards program. This can influence customers to charge at a site rather than at home.
4. **Employ vehicle-to-grid (V2G) solutions.** If a station is underutilized but in a high traffic area such as a shopping center, it could be a good fit for V2G. EVs that are not in need of charging could be incentivized to plug in to support grid services or building load management.
5. **Use beneficial electrification and utility customer programs.** Electrification programs go beyond electrification of transportation. If EVSE is on the premises, the building owner is likely already engaged with the utility and has electric service to support expansion of beneficial electrification to other end uses such as pumping, motors, and drives. They might also be interested in switching to electric fuel for end uses such as water heating, clothes dryers, and ovens/ranges.
6. **Add RV charging.** RVs typically plug in to NEMA TT-30R or NEMA 14-50 outlets, which are compatible with EV charging. This allows the station to serve EV drivers as well as RV owners, increasing usage, visibility, and popularity.
7. **Examine the charging station's purpose.** Charging networks have different purposes and customer bases. For example, the network may have been originally designed with commuters in mind, but the high volume of home charging and longer range EVs has made the station unpopular. A network catering to longer trips could have more success. Some networks such as those designed by Tesla and Rivian might be designed to generate externalities like selling cars, which makes utilization less important than the visibility of the station. The same is true for sites in lower and middle income areas, multifamily housing neighborhoods, or areas with low EV penetration.
8. **Switch charging standards.** One complicating factor for EVSE is the type of plug that the EVSE deploys. Because not all vehicles use all plug types and the distribution of vehicle make and model combinations varies greatly by region, a popular plug in one area might be nearly abandoned in another simply because the vehicles are incompatible. This is most problematic for DCFC.

North American Charging Standards

Level 1-2

- J-1772
- NEMA 5-15 (wall)
- NEMA 14-50
- NEMA TT-30R
- Tesla

DCFC

- CCS
- Tesla Supercharger
- CHAdeMO

9. **Increase comfort.** Waiting for a vehicle to charge sufficiently to continue a journey can mean waiting for hours at one location. Therefore, drivers may prefer locations with amenities. Station operators can advertise existing amenities, add new ones, or partner with other businesses on joint offerings. Here are a few common options:
    a. Covered charging/parking
    b. Different payment options
    c. Wi-Fi
    d. Vending or shopping
    e. Access to parks/open space
    f. Last-mile solutions such as e-bikes, scooters, public transit, and ride-hailing
10. **Convert fuel.** An outside-the-box solution to low utilization might be to keep the site but switch fuel. Stations could become compressed natural gas,[9] hydrogen,[10] ethanol, or biodiesel refueling stations. However, it is unlikely that much of the existing EVSE infrastructure will be salvaged for these fueling enterprises, and some of these fuels have very low vehicle adoption and uncertain economics.
11. **Rethink utilization metrics.** Finally, station operators may want to reconsider what they consider low utilization by identifying goals. These might be number of customers served, financial breakeven, energy discharge, number of sessions, number of daytime sessions. Since nighttime utilization will be low for most use cases, it is possible to have the station serve a split use case during the night. Across the country, electric utilities are exploring using batteries to level out load. EVSE could charge a stationary battery overnight and discharge it to meet load in daylight hours. Other use cases are certainly waiting to enter the spotlight.

[9] George Mitchell, *Building a Business Case for Compressed Natural Gas in Fleet Applications,* National Renewable Energy Laboratory, March 2015, **https://www.afdc.energy.gov/uploads/publication/business_case_cng_fleets.pdf.**

[10] "Hydrogen Fueling Infrastructure Development," Alternative Fuels Data Center, U.S. Department of Energy, **https://afdc.energy.gov/fuels/hydrogen_infrastructure.html.**

6. Conclusion

This white paper sought to examine EVSE charging networks from the perspective of network buildout costs, optimal siting locations, and stranded assets. Through this paper, Guidehouse released a new public module to the VAST™ Suite: the Network Cost Comparison Module.[11] We then used network optimization to compare a theoretical "Greenfield" optimized network to a network built in Sacramento, California. Finally, we examined options for how to best take advantage of stranded assets.

6.1 Batteries versus Chargers

The simulation comparison between battery costs and EVSE network costs using the VAST™ Network Cost Comparison Module illustrates that for the vast majority of scenarios, chargers are a very good investment from a societal perspective. The cost of installing chargers may be expensive initially, but it is negligible when compared to increasing the range of every vehicle in the network. Chargers can serve the demand of many vehicles at a much lower cost than increasing the range of those vehicles. One reason for this is because chargers are a shared asset; a single public DC fast charger serves many vehicles. On the other hand, increasing the range of vehicles for the sole purpose of meeting charging demand for only a handful of road trips per year is costly.

US Market Share (Percentage of Total Charger Count)

- Retail Providers: 76%
- OEMs or Dealers: 15.6%
- Government: 2.7%
- Utilities: 0.4%
- Unknown: 5.4%

How do we square this with low utilization and the difficultly of generating revenue for DCFC networks? Our hypothetical simulation shows that the installation of a DCFC network means avoided investment in larger batteries, which makes economic sense despite low utilization. OEMs are also incentivized to make charging infrastructure proprietary to shield their investment from free riders. Resolving this dilemma could lead to an interesting role for public utilities, NGOs, or state and local governments. Though these entities are well-positioned to deliver EV charging as a public good, together they currently operate just over 3% of all chargers in the US (see callout box).[12]

6.2 Evaluating Existing Networks

The large percentage of the EVSE market controlled by retail providers (76% in 2021) explains why the "Greenfield" optimized network displayed much higher coverage than the existing "Ground-Truth" network. While our example analysis was limited to Sacramento County, we expect this to hold true across the US for the simple reason that retail network providers are chasing revenue and market share. Network operators with broader scope—OEMs, governments, NGOs and public utilities—will be incentivized to build out networks that are closer to optimal.

This trend will mean that some stations are very highly utilized and some may appear stranded but serve an important network connectivity function (as Figure 6 illustrates). The higher

[11] "Comparing EV Costs: Larger Batteries, or Better Charging Networks," VAST™ Suite Network Cost Comparison, **https://bk-apps.shinyapps.io/siting-opt-and-stranded-assets/.**

[12] Alternative Fuels Data Center, U.S. Department of Energy, **https://afdc.energy.gov/** (accessed December 2021).

utilization sites (right tail) show concentration, which avoids the cannibalization of charging demand from one nearby charging site to another and increases positive feedback from increased visitation and visibility. The lower utilization sites (left tail) fill in gaps in the network, bringing more customers and increasing equity while allowing more diverse and longer range trips. Even though they will not generate large revenue from charging, these stations are not "stranded" but rather are enabling EVs to move from town/commuter vehicles to primary vehicles. While these stations will show low utilization, they will have slow and steady visitation rates. Truly stranded assets are more likely to be in high density areas where charging coverage is simply not needed because it is already being met by home, workplace, or competing market chargers.

6.3 EVSE Stranded Assets

The societal economics of charging networks are very strong, stranded stations can be at least partially predicted using network optimization, and assets that can be stranded can be partially recovered through the strategies explored in Section 5. So, should there be more of an effort to build out charging infrastructure? The answer is a resounding yes if we are only thinking about economics. Even though it is expensive, installing chargers is still much cheaper than putting very large batteries in vehicles. However, drivers do care about range, and our simulation does not put a quantitative value on that preference. Also, our simulation calculates a total cost for the entire system without considering who pays each of the costs. Drivers ultimately pay for the batteries, and if they are willing to pay for larger batteries, manufacturers will make batteries larger. At the system level, the economics tell us that installing chargers is a bargain even if one ends up with a few stranded assets along the way.

When evaluating a network or an individual charger, perspective is critical. There are many options for what to do with low utilization sites. The most important place to start is to the purpose of the site. Whether the low utilization station is a critical connector, ahead of the adoption curve, or behind it will determine whether the station should be repurposed or left alone. With EV adoption increasing exponentially around the world, the dominant narrative is about the inadequacy of existing charging networks with a focus on quantity. We have shown that although expensive, the cost of EVSE networks can be easily justified by the counterfactual cost of increasing battery range,[13] but existing networks are suboptimal. Actors such as public utilities, governments, and OEMs have an integral role to play in the development and maintenance of charging infrastructure because they are able to build networks with an eye toward externalities, long range planning, network coverage, and equity rather than a focus on revenue.

[13] "Comparing EV Costs: Larger Batteries, or Better Charging Networks," VAST™ Suite Network Cost Comparison, **https://bk-apps.shinyapps.io/siting-opt-and-stranded-assets/.**