AFTER THE GAS STATION:
Redevelopment Opportunities from Rethinking America's Vehicle Refueling Infrastructure

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cover photo: vacant gas station in Austin, TX

photo credit: Andrew Turco
AFTER THE GAS STATION: Redevelopment Opportunities from Rethinking America's Vehicle Refueling Infrastructure by Andrew Turco

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ABSTRACT
Gas stations are found throughout the US, but their ubiquity causes them to go largely unnoticed. Because their purpose—refueling vehicles—is so uniform and so integral to the existing automotive transportation system, stations share extensive siting and design similarities across many contexts. Recent corporate, market, and regulatory pressures have led to the closure of tens of thousands of these stations in the past few decades. Increasingly stringent Corporate Average Fuel Economy (CAFE) standards will likely continue the trend of station closures. CAFE standards are expected to reduce future US gasoline consumption and spur the production of alternative powertrain vehicles.

Of these new powertrain technologies, electric vehicles (EVs) demand particular attention because their introduction has been quite strong and because their adoption has the potential to significantly change the location and physical environment in which vehicles are "refueled." EVs differ from other propulsion systems in that they rely on electricity for power. Unlike liquid fuels, which are most efficiently distributed from centralized facilities, electric power can be obtained from a number of dispersed outlets. This thesis seeks to rethink the physical infrastructure that is and has been necessary to fuel the US's vehicles by exploring the most effective deployment of EV charging systems and by proposing potential reuses for unneeded gas station sites.

After studying vehicle travel patterns and EV charging requirements, at-home suburban charging systems emerge as the most effective way to support electric vehicles. In addition to the environmental benefits to the transportation system, solar and smart-meter components of this charging system enable the greening of the power grid as well. As such, this thesis posits that the most effective deployment of EVs and their associated chargers would be in suburban areas that currently have dirty energy profiles and high solar capacity. Another promising place for EV charger deployment would be at centralized stations along major transportation routes that could be co-located with uses that actively take advantage of the extended time it takes to recharge an EV battery.

Especially in EV target regions, reduced demand for gasoline can be expected to further unlock opportunities for gas station property redevelopment. Challenges to reuse include environmental remediation costs and liabilities, but this thesis explores strategies for overcoming these obstacles, as well as redevelopment functions that take advantage of gas stations' small and distributed characteristics.

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ACKNOWLEDGEMENTS

The inspiration for this thesis first came from noticing a number of abandoned gas stations in the landscape around me. I soon began to wonder whether there was an exciting opportunity embodied in these parcels. As with many things, once one starts to notice something, it is all of a sudden everywhere. For that, I would like to thank all those – my family, friends, colleagues, DUSP and CRE professors, and teachers growing up – who have played an important role in inspiring me to notice my surroundings and to think critically about them.

Particular thanks goes to Professor Alan Berger for his advising and for his willingness to question commonly held assumptions. Additional thanks goes to my supportive MCP 2013 classmates, many of whom sent me photos of and articles about redeveloped gas stations wherever they went. Thanks also to the CRE class of 2014 and to all from the MCP class of 2014 who adopted me as one of their own while I completed my dual degree. Thank you to Steph for her patience and distractions during this process. Finally, to my family, “it takes a village,” and I couldn’t have accomplished any of this without your unconditional support.

While I acknowledge and appreciate all of the influences of others in shaping my work, any errors in this document are my own.
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Across the country, gas stations occupy prime corner locations, are tucked among other uses, and share similar design typologies. Many still serve their original functions of refueling America's vehicles. Over time, others have become vacant or have been repurposed for other uses.

clockwise from upper left: Brooklyn, NY; Los Angeles, CA; New York, NY; Berkeley, CA; Cambridge, MA; Newport, RI; Somerville, MA; Las Vegas, NV; Cambridge, MA (center)

photo credits: Andrew Turco
INTRODUCTION

They blend into the background of twenty-first century America’s landscapes. They are unnoticed and undistinguished pieces of development that line the nation’s roads, encircle its intersections, and act as unintended gateways to its commercial districts. Though often overlooked, the ubiquity of gas stations throughout the United States makes their impact on the built environment far-reaching. Because private vehicles provide mobility for the majority of US residents and especially for those who live outside of urban cores, the infrastructure and equipment that support automobiles are important components of the built environment. Individually small in size, with many older stations sitting on only three-quarter-acre lots,1 the roughly 116,000 gas stations in operation in the US2 are, collectively, a significant component of nearly every community. Considering an additional 50,000 stations have closed since 1991 alone,3 the footprint of gas station properties on the US’s physical fabric is even more far reaching.

In addition to being ubiquitous, gas stations’ singular purpose gives them nearly homogeneous and repetitive forms, functions, and designs. Across varying contexts and in different regions, gasoline retailers often rely on very similar station design typologies. Facilities are often sited to be highly visible and accessible to drivers. They frequently sit along major roadways and at the corners of prominent intersections. Station components usually include asphalt aprons, pumps covered by a large overhead canopy, and a single-story convenience retail or auto repair structure. This unity in design is partly a reflection of unity in purpose. All gas stations serve to refuel vehicles powered by gasoline combustion engines.

There are trends affecting America’s vehicle fleet, however, which will have repercussions for gas consumption. Gasoline combustion vehicles are becoming more efficient, and automakers are introducing commercially viable alternative-fuel vehicles. Tightening Corporate Average Fuel Economy (CAFE) standards mean that vehicles will need to achieve a fleet average fuel economy of 54.5 mpg by 2025 and will, thus, require less fuel than they do today. Reflecting that change, gasoline consumption in the US is expected to decrease between now and 20404 and will, therefore, cut demand at gas stations. Paralleling a move toward greater efficiency from traditional combustion engines is greater diversification of the US vehicle powertrain systems. In order to reduce the total emissions produced by the US transportation system and to further decrease the country’s dependence on foreign oil, the federal government is pushing for and supporting production of a number of alternative drivetrains. In a radical departure from the historically homogeneous vehicle fleet powered entirely by gasoline combustion engines, future vehicles will be powered by a mix of electric, plug-in hybrid electric,

1. Kaysen, 2012
2. US Census Bureau, 2008
Introduction
Gas stations are prevalent throughout metropolitan regions and throughout the country, often clustering around intersections and along major roads. These images show gas station density and location in the US's ten most populous metropolitan areas. From upper left down the columns: New York-Newark-Jersey City (1); Los Angeles-Long Beach-Anaheim (2); Chicago-Naperville-Elgin (3); Dallas-Fort Worth-Arlington (4); Houston-The Woodlands-Sugar Land (5); Philadelphia-Camden-Wilmington (6); Washington-Arlington-Alexandria (7); Miami-Fort Lauderdale-West Palm Beach (8); Atlanta-Sandy Springs-Roswell (9); and Boston-Cambridge-Newton (10).
fuel cell, natural gas, and liquid biofuel powertrains. The increasingly diverse set of powertrains means that an increasingly diverse set of vehicle-supporting infrastructure will be needed. The gas station will need to evolve or change form.

Of these alternative powertrains, electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) have seen the most dramatic increase in sales and number of offerings since the Nissan Leaf was introduced in 2010 as the first widely available electric vehicle to be sold in the US. Excepting ethanol biofuel automobiles, electric vehicles are the closest to mainstream adoption of all the possible alternative powertrains. Electric vehicles differ from gasoline-powered cars and also from other alternative powertrain vehicles in that they don’t rely on some kind of liquid fuel for propulsion. Instead, they run on electricity stored in on-board batteries. As a result, the requirements for their supporting infrastructure differ from those of other powertrains. This difference has dramatic implications for the potential distribution and physical location of EV-supporting infrastructure.

The delivery of liquid fuel is confined by the locations of large storage tanks and by environmental and zoning regulations that dictate where these tanks can be located and how they can be operated. By contrast, the location of electricity supply is not as restricted. EV charging infrastructure is more flexible and nimble. It can be distributed throughout the built environment in a way that gasoline and other fuel-based powertrain infrastructure cannot. EVs simply need to be able to connect to an electrical source. Increased adoption of electric vehicles, therefore, has the potential to bring change to the physical context of how and where vehicles are “refueled.” Centralized stations would no longer necessarily be the most efficient way to repower vehicles. Instead, equipment can be distributed to homes, workplaces, and commercial centers, as well as to centralized stations. In places with high electric car use, the flexibility of charging infrastructure has the potential to reshape how “refueling” infrastructure is packaged into urban form, while eliminating the need for traditional gas stations that can ultimately be redeveloped.

To prepare for opportunities from these evolving conditions, assessing how EV charging equipment can be most effectively deployed and best incorporated into different building typologies and urban fabric is critical. Doing so informs developers and designers about how to proactively accommodate EV infrastructure within new building projects and how to plan for development opportunities around this equipment. It also hints at whether centralized refueling stations currently used for refilling gas tanks can be unlocked and redeveloped for other uses.

EVs will be most effectively deployed in areas where their adoption will be attractive to users, either socially or economically, and in regions where their impacts on carbon emissions will be most dramatic. Because EV’s
have more limited range than gasoline-powered cars, determining which development densities and forms best reflect ideal EV driving patterns is one criteria for predicting where EVs will be best suited. Considering the extended period of time required to charge EV batteries, finding specific land-uses or building types that can integrate the recharging process with existing functions will also help predict where EVs will be adopted. Finally, assessing the energy profiles and capacity for alternative power generation of different regions in the US will inform where deployment will better fulfill the goal of lower carbon emissions from the vehicle fleet. Looking at place- and purpose-based travel patterns, the capacity of building typologies to incorporate charging infrastructure, and regional power profiles reveals contexts in which EV adoption is most likely to occur and where it would be most effective to retrofit the physical landscape. Identifying these forms and regions will suggest to developers and designers how they can incorporate EV equipment into projects and may expose potential development opportunities as a result of EV adoption.

Today’s gasoline retailing landscape is already rapidly evolving, independently of widespread EV adoption. Consolidation among major oil companies, increasingly tight environmental standards, and a preference for larger, more centralized stations are leading to the closure of many stations throughout the country. Even for those remaining in operation, low profit margins on gasoline sales, which have some of the thinnest margins in retail, are leading to increased reliance on attached convenience store sales for revenue. The growing importance of other retail sales at these properties hints at an already evolving focus by gas station operators away from the sale of gasoline and towards the sale of convenience items and essentials.

Three driving factors will contribute to the continued reduction and consolidation of gas stations. One, in areas where electric vehicle use becomes widespread, the need for gasoline will be reduced, and EVs can be powered at other locations. Two, the increasing efficiency of traditional combustion engines nationwide will reduce demand for gas and, as a result, the main service that gas stations provide. Three, stricter environmental regulations around gas station operation, strategic consolidation by major oil companies, and low profit margins will lead to fewer gas stations, independently of the expected drop in demand for gasoline resulting from the other two factors. In locations where gas stations close, there will likely be opportunities to site other uses on these properties. The redevelopment of post-industrial urban areas has altered cities’ waterfronts. Big box stores are being repurposed for non-retail civic functions, while failed malls are being retrofitted for office use. In a similar way, the reuse and redesign of America’s gas station sites could transform the physical environment of many communities by introducing new

5. Hughes, 2013

uses at sites no longer needed for their current purpose of refueling.

Assessing the feasibility of and the opportunity for different uses at these sites before their current function becomes obsolete can help developers and designers seek reuse options that maximize the continuity of productive use on these commonplace sites. One of the biggest challenges to redeveloping gas station sites is that they are often environmentally contaminated from underground storage tank (UST) leaks and require environmental remediation before reuse becomes an option. Strategies for reducing risk and obtaining supplemental cleanup funding exist, and the US Environmental Protection Agency (EPA) has instituted a number of programs and released recommendations to help in this process. Once these challenges of contamination are overcome, sites can be reused for a range of functions. Those opportunities that take advantage of gas station sites' good vehicle accessibility and distributed nature, however, and those that build on the growing non-gasoline retail sales at service stations are the most attractive options.

When all of these trends are taken into consideration, effective EV charger deployment will be better integrated into other land uses than current gasoline-based vehicle infrastructure is. A shift to EVs in certain areas and the continuing trend of reduced gas stations will open up opportunities for the redevelopment of current gas station properties.
AUTOMOBILE OWNERSHIP AND USE IN AMERICA

Understanding the prevalence of automobiles in the US and the extensiveness of their use conveys the importance of addressing the infrastructure that supports them. The number of vehicles per household can determine how much drivers are able to tailor specific driving needs with specific vehicle powertrains, thereby furthering the possibility of alternative powertrain adoption. Predictions about changes in vehicle use could impact how drivers refuel, where they refuel, or how frequently they refuel. Identifying these types of characteristics of the US auto fleet and of Americans' travel patterns, as well as variations by different regions and densities, can inform how supporting infrastructure might be best situated and, as a result, how real estate developers and designers can plan for and take advantage of changes.

A snapshot view of automobiles in the US shows that the number of cars on the road is high and is growing. The total number of household vehicles has climbed from 72.5 million in 1969 to 210.8 million in 2009.\(^7\) The rate of that increase has been about 50% higher than the rate of increase in the number of American drivers over the same time period.\(^8\) Ninety-one percent of all households owned at least one vehicle in 2009, while a plurality owned two.\(^9\) Primarily, these statistics demonstrate the importance of considering parts of the built environment that serve automobile needs. Secondly, the higher number of cars per household increases the feasibility of an individual owning vehicles that rely on different powertrain systems. Owning more than one vehicle provides the flexibility for each car to serve a different purpose. This arrangement allows for powertrains to be adopted that wouldn't necessarily be able

| Household Vehicle Ownership in the US |
|-----------------|-----------|
| Three or More Vehicles | 22.7% |
| Two Vehicles | 36.3% |
| One Vehicle | 32.3% |
| No Vehicle | 8.7% |

\(^7\) US Department of Transportation, 2009, p. 7
\(^8\) US Department of Transportation, 2009, p. 8
\(^9\) US Department of Transportation, 2009, p. 34
to make sense, from an operational and financial perspective.

Car ownership and use does vary slightly by region. Differences in levels of ownership are most likely the result of varying development patterns and public transportation options, which change the cost equation and ease of owning cars. The Northeast, which has older built forms constructed with more traditional levels of connectivity and many transit options, has slightly fewer vehicles per driver than any other region. The West and Midwest have the highest number of vehicles per driver.  

11. US Department of Transportation, 2009, p. 36
12. US Department of Transportation, 2009, p. 9
13. US Department of Transportation, 2009, p. 9

Trends in Auto Use in the US

Along with population, the number of household vehicles, household vehicle trips, household VMT, person trips, and person miles of travel have, for the most part, all risen of the past four decades. Total household VMT and person miles of travel have declined for the first time, between 2001 and 2009. This is even in light of continued population growth. However, the economic recession might be a cause of much of this decline.

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<td>US Population (000)</td>
<td>197,213</td>
<td>213,141</td>
<td>229,453</td>
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<td>1,002,139</td>
<td>1,695,290</td>
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<td>Person Trips (000,000)</td>
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<td>211,778</td>
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<td>Person Miles of Travel (000,000)</td>
<td>1,404,137</td>
<td>1,879,215</td>
<td>1,946,662</td>
<td>2,829,936</td>
<td>3,411,122</td>
<td>3,783,979</td>
<td>3,732,791</td>
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Table credit: Andrew Turco | Data credit: US Department of Transportation, 2009, p. 13
Overall, though, the widespread use of automobiles is demonstrated by the dominant role they play in transporting Americans to their jobs. Only about 5% of the working population uses public transit to get to work, and that figure has remained constant since 1995, even during this past decade of resurgent urban downtowns. The proportion of people who walk or travel by other means, like by bicycle, has in fact risen between 1995 and 2001 and between 2001 and 2009. Even so, roughly 90% of Americans continue to commute to and from work by private vehicle. This high number illustrates the important role that private vehicles play in getting people to their jobs and suggests the importance of refueling systems being conveniently located near one's home, near one's workplace, or somewhere in between. Although technology has made remote working more feasible, only 8.7% of Americans work exclusively from home, and only 10.9% of workers say they have the option of working from home. These relatively low numbers show that commuting trips still make up a regular part of daily travel patterns.

Because private vehicles are so common, greening the automobile fleet by increasing its efficiency or powering it with cleaner sources of energy has the potential to reduce carbon emissions. If segments of this large fleet reduce their fuel needs or begin to rely on alternative powertrains, the infrastructure that has been developed

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14. US Department of Transportation, 2009, p. 46
15. US Department of Transportation, 2009, p. 46
16. US Department of Transportation, 2009, p. 46
17. US Department of Transportation, 2009, p. 59

**Household Vehicle Ownership in the US by Density**

[Diagram showing vehicle ownership by population density]

*Image credit: Andrew Turco | data credit: US Department of Transportation, 2009, p. 36*
Trends in Auto Use and Gas Consumption

over the past hundred years to support the growing fleet of cars will need to be rethought.

PREDICTED FUTURE AUTO USE

Total auto travel has dropped in recent years; however, it is predicted to rebound and continue its historically consistent rise in the coming decades. Total household vehicle miles travelled (VMT) rose every time it was measured from when the US Department of Transportation’s (DOT) National Travel Survey first started recording this data in 1969, when total household VMT in the US was about 776 billion miles, to the peak of 2001, when total household VMT was about 2.275 trillion miles. In 2009, that number declined for the first time, to a total of 2.245 trillion miles. This reduced VMT figure indicates that, after decades of growth, the total distance that Americans were logging in cars every year was finally going down, at least over the short term following the large economic downturn of 2008.

Many believe the economic recession is likely the cause of at least some of this change from the historic trend. The average commute trip length to work remained the same between 2001 and 2009, but the number of commuting trips among the population simply declined. This relationship implies that some of the decline in VMT was likely a result of the economic recession causing fewer people to need to commute to work rather than of a large-scale change in the way people were commuting.

Barring this recent dip, VMT in the US is expected to grow in the next decades. Taking into account age cohorts, the decrease in licensing and travel among young people, and employment and income factors, the US Energy Information Administration’s (EIA) Energy Outlook 2014 still predicts a 30% increase in VMT between 2012 and 2040 for light-duty vehicles (LDVs). If other factors remain the same, increased travel will require increased vehicle refueling, but recent initiatives and regulations that push for greater fuel efficiency and the adoption of alternative powertrains might counteract this expectation. A look at predicted gas consumption trends will show how much of an impact this higher VMT may have on gas consumption and on demand for the stations that provide refueling.

GAS CONSUMPTION IN THE US

Predicted increases in VMT would intuit a parallel increase in the consumption of gasoline to fuel those extra miles of travel. The US, however, currently has opposing trends relating to gasoline consumption. On one hand, gas prices are expected to remain low over the next few decades, which would suggest higher levels of gasoline consumption, especially when higher total

18. US Department of Transportation, 2009, p. 7
21. US Energy Information Administration, 2014, p. 4
22. Libby, 2014
VMT is already predicted. Consumers can more easily afford “cheap” gasoline if gas prices are low. On the other hand, federal fuel economy standards are tightening to a degree that, if travel distances and fuel prices remained the same, the increase in engine efficiency would cause significant declines in gas consumption since drivers can get dramatically higher mileage from each gallon of gasoline. Ultimately, the government is pushing to significantly reduce the negative environmental impact of driving by promoting super efficient vehicles. This approach has the potential to decrease the transportation system’s carbon emissions, just as promoting density and public transportation does. Converting the vehicle fleet to cleaner cars may, in fact, be easier to implement in the near term than these other strategies. When taken together, the higher fuel economy of LDVs is predicted to outweigh any increases in VMT resulting from lower gasoline prices or further suburbanization. This prediction is important in that it indicates that consumers will need to refuel less frequently and, therefore, may need fewer gas stations.

Because of governmental policies, automakers are essentially being forced to sell more fuel-efficient vehicles than the market would otherwise demand. Historic data shows positive correlation between lower gas prices and the purchase of less fuel-efficient vehicles, as well as correlation between higher gas prices and the purchase of more fuel-efficient vehicles, such as hybrid and electric vehicles. Yet specific policies already in place are going to increase fleet fuel economy to an extent that fuel consumption will drop irrelevant of consumer preferences. Automakers are required to achieve fleet fuel economy averages of 35.5 mpg by 2016 and 54.5 mpg by 2025. Car companies are pursuing a variety of technologies to meet these standards, including ones that improve the efficiency of combustion engines as well as some that replace the gasoline-powered engine with alternative drivetrains. Additionally, federal and state incentives like vehicle purchase rebates and access to high occupancy vehicle (HOV) lanes make highly fuel-efficient vehicles more attractive to consumers than they might otherwise be if fuel cost savings alone were the only advantages of super-efficient vehicle. Therefore, there is likely to be a shift to alternative vehicles, irrelevant of gas prices. This shift to alternative powertrains, in combination with more efficient internal combustion engines, will mean that demand for the traditional refueling service of gas station will decline.

The US Energy Information Administration (EIA) expects LDV energy consumption to decline to 12.1 quadrillion Btu in 2040 from 16.0 quadrillion Btu in 2012. More fuel-efficient vehicles replacing older, more inefficient vehicles will raise the overall fuel economy of all vehicles on the road by 2.0% per year between 2012 and 2040, far outweighing the predicted yearly 0.9% in-

24. Libby, 2014
25. Libby, 2014
crease in VMT. This likely transformation to greater efficiency and decreased gasoline demand signals a potential to reevaluate gas station sites for other uses and also hints at the need to assess how other refueling infrastructure that supports alternative powertrains can be integrated into the built environment.

27. US Energy Information Administration, 2014, p. 8
Preparing for a Mixed-Powertrain Future

DIVERSIFYING THE VEHICLE FLEET
Because of the established reliance on automobiles in the US, as well as a lack of other public transportation alternatives in certain parts of the country, private automobiles will continue to play an important role in this country’s transportation system. Due to new government demands for efficiency and funding available for alternative powertrain development, however, the continued use of the automobile doesn’t mean that the same types of vehicles on the road today will exist in the future. More efficient combustion engines—but also alternative powertrains—will be introduced to help automakers meet tightened CAFE standards. These different powertrains will require new systems for refueling that don’t exactly mirror the centralized gasoline refueling stations designed to support today’s vehicles. The new, more efficient vehicles will bring about changes to parts of the built environment currently dedicated to gasoline refueling.

This new vehicle fleet will include more efficient gasoline and diesel engines, fully electric or plug-in hybrid electric vehicles, fuel cell vehicles, natural gas-powered cars, and liquid biofuel automobiles. Overall, the portion of vehicles powered by alternative powertrains will remain relatively small. The US EIA’s 2014 Annual Energy Outlook report predicts that gasoline-powered cars will remain the dominant vehicle type. By 2040, 78% of LDVs will still run on gasoline, down by only a 4% share from today and leaving only 22% of LDVs to run on a combination of all other powertrains.28 Nonetheless, even higher levels of efficiency from gasoline engines and the reduced fuel consumption that comes with it will have some impact on the need for physical refueling stations.

With the emergence of these other powertrains, even in small numbers, consumers will no longer have to depend on one-size-fits-all vehicle solutions. John

28. US Energy Information Administration, 2014, p. 8
Preparing for a Mixed-Powertrain Future

Voelcker, editor of GreenCarsReports.com, advocates for a mix of different powertrains that serve different purposes. In much the same way that people today purchase cars with different body styles for different purposes - minivans for hauling families versus compact cars for city driving - tomorrow's buyers should be able to do the same with powertrains. This change to a purpose-based powertrain system is important because it requires an assessment of what types of trips and what kinds of environments are most appropriate for each type of powertrain. Because each powertrain uses a different propulsion system, this diversity also requires a range of new infrastructure to refuel the vehicles.

IMPACT ON PHYSICAL INFRASTRUCTURE

Understanding the physical refueling requirements and typical ranges of new powertrains allows planners, developers, and designers to better plan for where gas stations will likely remain, where stations may need to be retrofitted, and where properties can be completely transformed to serve other unrelated needs. Although all of these powertrains depend on outside energy sources, only electric drivetrains don't require filling an on-board tank with liquid fuel. EVs simply need access to a source of electricity to charge on-board batteries. In this way, EVs are radically different from the other powertrains in the flexibility they can provide for "refueling." Nonetheless, all will have some effect on the future of gas station sites because their needs differ from those of vehicles today.

Efficient Gasoline and Diesel Powertrains

Today's gas stations already support gasoline and diesel combustion engines effectively. Without overstating the obvious, gasoline-powered cars rely on a system of centralized refueling stations from which they can easily refill their fuel tanks. Because it would be inefficient and environmentally dangerous to deliver gasoline to the homes of every car owner and because drivers may need to refuel throughout any part of their trip, the US has developed an extensive network of gas stations. They are located along major transportation corridors, at the gateways to commercial areas, and at prominent intersections throughout the landscape. For the most part, this system adequately reflects location and quantity demands for gasoline. The major change that will occur in the future is that increased efficiency of gasoline and diesel engines will result in a decrease in fuel demand. This will likely cause the extensive network of gas stations to shrink further, leaving newly vacant parcels available for redevelopment throughout the country.

Fuel Cell Vehicles

Though fuel cell technology is still years away from commercial availability, one of the characteristics of this powertrain is that vehicles can be fueled in much the same way that cars are today. Fuel cell vehicles can travel about the same distance on a single fill-up as petro-
leum-powered automobiles, implying that the existing density of refueling stations could remain the same. Because hydrogen fuel itself is so different than gasoline, though, fuel cell vehicle adoption would require its own system of hydrogen fueling stations. The parallel ranges and refueling needs of hydrogen-powered vehicles and gasoline-powered cars mean existing gasoline fueling infrastructure could likely be harnessed and readapted to serve fuel-cell vehicles. In other words, although the specific tanks and pumps would differ, a conversion of some portion of the vehicle fleet to fuel cells would likely place hydrogen refueling stations on the same sites as current gas stations. The physical impact of this powertrain, therefore, would be a retrofitting of existing stations but not a change in their general form, location, or density.

Natural Gas Vehicles
Although natural gas-powered vehicles, like fuel cell vehicles, can be refueled at centralized stations, as today's vehicles are, this powertrain has more limited range per tank than the current gasoline-based vehicle fleet does. As a result, natural gas refueling could likely be incorporated into existing gas station facilities but might need a greater density of stations to serve this powertrain's more limited range.

Liquid Biofuel Vehicles
Just like the other fuel-based powertrains, liquid biofuel can also be distributed at centralized refueling stations in a similar manner to the way gasoline is today. In fact, the current distribution of ethanol fuel through gas stations in the Midwest shows that doing so would only require a retrofitting of the tanks and pumps but not a rethinking of how fuel is distributed through the environment.

Electric Vehicles
Of all the alternative powertrains, electric cars provide the greatest potential for rethinking the way the physical components of vehicle refueling can be integrated into the built environment. Fully electric vehicles rely on plugging into an external electric source to charge batteries that then power the vehicle. Unlike gasoline or other fuel-based powertrain systems, EVs don't require centralized refueling stations since electricity can be distributed to the vehicle through the existing power system or can be generated with solar panels, wind turbines, or any other on-site technology. This condition allows for much more flexible charging opportunities than the other alternative powertrains. In fact, it opens up the possibility of installing charging infrastructure at homes, work places, parking areas, and other environments where vehicles already sit parked for extended periods of time.

Another unique characteristic of EVs is that they have viable but limited range per charge, meaning they need to connect to a power source more frequently than today's vehicles need to access a gas pump. Most EVs today have a range of about 100 miles on fully charged.

batteries, except for a few higher end models like Tesla's Model S that can travel significantly further between charges. Recharging also takes longer than refilling a fuel tank. These characteristics mean that, even though EV chargers can be more easily distributed throughout the environment, they might actually have to be more densely distributed so that frequent recharging doesn't become an obstacle to their adoption or use. If EV charging is distributed throughout the landscape to places where electricity access already exists, to where electricity can be generated without the electrical grid (solar), or to where drivers already travel, it will free up many gas station sites to be repurposed for other uses.

Only for long trips that require on-the-road recharging will it make more sense for EV chargers to be sited at centralized stations rather than in distributed locations. Because electric vehicles depend on a distributed charging network, these vehicles can also be phased in over time. Vehicles don't need a full system of fuel-supply facilities to be in place from the start for any single vehicle to be used, as some of other powertrains require. In contrast to the other powertrains, EV adoption opens up a wide range of development options at gas station sites, and it also demands that developers and designers begin to incorporate electrical charging elements into building forms and other site design elements.
EV Infrastructure Needs

Electric vehicles sales are growing rapidly in contrast to other alternative powertrains, most of which are still not widely available. Increasing familiarity with the technology, a growing number of models, federal initiatives supporting their purchase, and dropping prices make it likely that EVs will continue to grow in popularity. Because EVs are actively joining the US vehicle fleet, special attention needs to be paid to how EV charging infrastructure can be implemented in a way that most effectively supports these vehicles. Consumer hesitation about purchasing EVs is often related to the powertrains’ more limited range and a lack of convenient charging options. These are issues that can be solved through smart implementation of recharging infrastructure that is dispersed throughout the physical environment and incorporated into regularly visited destination. Doing so would both support the growing number of current owners and further increase the appeal of EV ownership.

PRESSURE FOR EV INFRASTRUCTURE

Although EVs make up less than 1% of vehicles on the road today, their rate of growth is high. Before 2010, there were virtually no electric vehicles on the road. By 2012, Americans had purchased more than 50,000 plug-in electric vehicles. Double the number of EVs were purchased in the first half of 2013 as were during the same part of 2012, illustrating that growth is continuing. As more EVs are seen on the road, an increasing number of Americans will likely become comfortable with the idea of purchasing a vehicle with this new technology. The growing number of EV models available will also likely increase this powertrain’s attractiveness, as consumers can more easily find vehicles that suit their particular tastes and needs. Government tax-credits of up to $7,500 for the purchase of plug-in vehicles expand EVs’ appeal by reducing the price

31. Voorhees, 2009
32. US Energy Information Administration, 2014, p. 8
34. US Department of Energy, “Electric Vehicles”
35 Voorhees, 2009
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premium. Plus, the technology is still benefiting from efficiencies of scale as the number of vehicles produced grows, which will likely bring costs down further. Battery costs have already fallen more than 50% over the last four years. All of these factors speak to the growing appeal and likely adoption of EVs. A McKinsey and Company study showed that there are up to 38 million US households that could realistically purchase an EV today, based on the criteria of how many households owned at least two cars, had low mileage on one of those two cars, and had high enough income deemed necessary to afford an EV.

For all their potential, deploying the right supporting infrastructure will be critical for widespread adoption. Many consumers are hesitant about range issues, and these concerns could be ameliorated with well-placed charging equipment. Though range is common concern, a GM study of Volt owners’ driving patterns reveals that the average Volt driver uses battery power from a single overnight charge 82% of the time, even though the battery range is limited to only 38 miles. This suggests that electric vehicles are more widely feasible than they are perceived to be and argues for robust infrastructure that can allay concerns about EV usefulness. For example, the results of the GM study greatly support the installation of at-home chargers to enable average drivers to complete a full day’s worth of driving by simply plugging the EV in at home each night.

BATTERY CAPACITY

Issues around battery range, battery recharging, and battery costs are a few of the most significant obstacles

37. Hodson and Newman, 2009, p. 3
facing EV uptake, but these issues can be at least partially addressed by appropriately designing charging equipment to match EV needs and by deploying EVs in the appropriate physical contexts. Moving away from centralized charging centers and towards distributed infrastructure that's incorporated into regular destinations reduces battery-range and charging-time issues. Tailoring EV deployment to specific areas with appropriately short driving missions also minimizes these battery range drawbacks. Both solutions emphasize the importance of attending to the physical components of EV equipment.

Today, electric cars have shorter range than that of their gasoline counterparts, and when the range needs to be exceeded, recharging an EV's batteries takes longer than refilling a fuel tank. Gas- and diesel-powered vehicles can go about 625 miles on a single tank of gas, while most battery-powered vehicles can go only 90-125 miles before depleting their charges, excepting the Tesla Model S's 260-miles range. When EV batteries do run out of energy, the recharging process is slow. A typical 240-volt charger takes 4-8 hours to fully recharge an EV battery pack. Even Tesla's Superchargers take 30 minutes for an additional 150 miles of range. Because there are fewer charging ports than traditional gas stations and because recharging takes longer than filling up with gas, potential customers fear that they'll be left on the side of the road for a number of hours with a powerless vehicle. This range anxiety dampens enthusiasm for electric vehicles. At the same time, however, it shows how tailoring EV deployment to communities with many short commutes rather than a few longer ones, in addition to conveniently locating


Comparison of Vehicle Range and "Refueling" Time

<table>
<thead>
<tr>
<th>Gasoline</th>
<th>625 miles</th>
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<tbody>
<tr>
<td>Electric</td>
<td>125 miles</td>
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charging infrastructure at locations where vehicles already sit between trips, could greatly expand the usability of electric cars.

Matching EVs with specific driving patterns will greatly improve their adoption. A McKinsey and Company study found that the way to expand the market for electric vehicles is to tailor driving missions of vehicles to specific consumers. Different people use their cars in different ways. For example, long but infrequent commutes to an office are different than multiple short trips between shops throughout the day. Range issues would not be relevant for those who make only short trips and who have multiple opportunities to recharge between those many trips.

In addition to range anxiety, another disadvantage that electric cars face is their higher cost relative to traditional combustion engine automobiles. The Economist estimates that batteries add about $15,000 to the cost of an equivalent combustion-powered vehicle. Although the cost of operation is minimal since the electricity needed to power these vehicles is significantly cheaper than gasoline, the extra upfront capital cost far outweighs any operational savings. Again, tailoring EV use to the right environment would allow automakers to right-size the battery capacity so that customers wouldn’t be paying for extra battery capacity that they really won’t use. McKinsey found that energy storage requirements of EVs varied greatly based on mission. By providing frequent charging opportunities and having EVs used primarily in areas with short distances between destinations, battery size – and therefore cost – could be reduced.

**EV CHARGING EQUIPMENT**

Because EVs rely on an entirely different system of propulsion and charging than gasoline-powered vehicles do, a strong charging infrastructure needs to be created for them to succeed. Today, there are three commonly used types of chargers. Each supports different types of EV auto use. Level 1, Level 2, and Level 3 (Supercharger) Electric Vehicle Supply Equipment (EVSEs) vary in terms of the ease and cost of installation and in terms of the speed with which they can charge EV batteries. These differences determine where they would be best sited since different locations often correspond with different vehicle uses and needs. Just as importantly, each requires an adjacent physical space for a car to occupy while it is charging. Though seemingly straightforward, this need for directly adjacent parking also influences within which environments EVSEs can be most effective deployed.

The Level 1 and Level 2 EVSEs are the simplest systems to install and are feasible for widespread installation. Level 1 systems charge batteries through a typical 120-
volt AC circuit found in any American home and use a standard 3-prong cord to attach the vehicle and the outlet. Level 2 systems rely on a 240-volt circuit that is also common in most building electrical systems. The fact that both of these charging systems can be connected with most home and workplace electrical systems opens up locations for recharging that wouldn’t be available to gasoline-based automobiles. Installation prices of around $1,000 also make these EVSEs feasible for widespread, at-home application. The ease and cost of connecting these systems makes them more easily incorporated throughout the environment than the large storage tanks needed for traditional fuels. Additionally, since they rely on electricity that is already being fed through all types of buildings, there is no need for extra safety precautions, environmental standards, or other restrictions that affect gasoline distribution and limit its use to specific sites.

The drawback to both of these types of chargers, however, is that they require a number of hours to fully recharge EV batteries. Level 1 chargers add only about 2-5 miles of range per hour of charging time, greatly limiting EV trips to single and very nearby destinations. Level 2 EVSEs add 10-20 miles of range per hour of charging. While still lengthy, Level 2 EVSEs can fully charge most electric vehicles overnight. As a result, this is the most common installation for residential, workplace, fleet, and public facilities, all places where lengthy charging times become less inconvenient since they are places a car would stay for extended lengths of time, regardless of its powertrain type.

Level 3 EVSEs – or superchargers – are different from these other two types of chargers in that they provide rapid recharging and are typically deployed along heavily trafficked corridors and at public stations where they can serve to repower vehicles mid-trip. Because of their expense, they are not commonly deployed at homes or workplaces, where such charging speed is often not needed. Their significant advantage is that they are much faster than either the Level 1 or Level 2 chargers. A 20-minute charge with one of these DC chargers adds 60-80 miles of range to a vehicle's batteries. However, except during truly long-haul trips, EVSE chargers may not really be needed for the full 20 minutes to entirely recharge a battery and may simply be used to add a few extra miles of range to the battery to get the vehicle to its regular charging station, where a long-term charge can take place. Thus, their application may be limited to places where long-distance travel requires recharging partway through trips. Tesla’s nationwide supercharger system that aims to support out-of-town travel uses these rapid chargers.

45. Lavrinc, "At Long Last," 2013
47. National Renewable Energy Laboratory, "Plug-In," 2013, p. 6
49. Johnson and Hettinger, 2011, p. 29
51. Johnson and Hettinger, 2011, p. 29
Even superchargers require more time to recharge batteries than gasoline pumps need to fill gas tanks. Thus, if all EV charging infrastructure were to be more integrated into larger developments, these projects would have captive audiences for at least 20-40 minute periods of time. Drivers could accomplish other activities, such as running errands or shopping, which aren’t possible at stand-alone gas stations. Additionally, since electricity itself is cheap and since EVSE operators wouldn’t be able to charge high prices for the recharging, placing superchargers among retail or restaurant destinations could provide much of the needed sales to offset the cost of providing the EVSE infrastructure. This is analogous to the way that convenience stores at gas stations allow gas to be sold for virtually no profit because they attract consumers to the attached retail stores.

The slower EVSE systems would be best suited for places where vehicles sit for many hours, like at the home. At-home plug-in opportunities are important since, according to various studies, 80-95% of EV charging currently takes place at home. According to Tanvir Arfi, President of Bosch’s automotive service solutions, most EV drivers will continue to charge their vehicles primarily at home in the future as well. Like any EVSE equipment, having a dedicated parking spaces or an adjacent garage or driveway space for a vehicle to park while it’s plugged in for a significant stretch of time is important in making this type of charging installation feasible.

The lack of dedicated parking and the inability to link a charging port with an individual home’s electrical system is a challenge in certain development configurations. This situation is common in multi-occupancy buildings, where residents would have to rely on the building management or neighborhood association to install the necessary charging infrastructure and where linking the charging system with one’s personal energy system would be more difficult. There are solutions to get around this issue. Common parking areas with shared charging infrastructure can be used by surrounding households, as is proposed in MIT P-REX’s “Petro Metro” EV proposal for shared suburban charging facilities. Nonetheless, this requires buy-in from multiple residents and a system for allocating electricity use. The lack of private, adjacent parking is less of an issue in single-family suburban and exurban areas, where a charging system can be directly linked to a particular household’s electrical system and where one can guarantee vehicle access to the charging port. In denser suburban environments, a form of common parking and charging facilities can be used because there is still enough physical room for dedicated parking spaces; even if they are not directly adjacent to drivers’ homes. These at-home charging systems, however, may not be as viable in dense urban areas where fewer cars have

52. McDonald, 2013
53. Lavrinc, “At Long Last,” 2013
54. Berger and Brown, 2013
dedicated parking spaces and where those spaces may be far from the driver’s home.

Even considering the challenges of installing charging equipment in denser environments, vehicle owners with access to a dedicated parking space still comprise a large portion of the country’s population. This would indicate that at-home charging is probably the most effective way of boosting EV batteries. A Carnegie Melon study that used data from the American Housing Survey found that 79% of households have at least one off-street parking space, and 56% of vehicles had dedicated parking spaces. Since a plurality of households have more than one vehicle, many multi-car families have access to at least one space that could be used for EV charging but would not be able to charge multiple vehicles at one time. This situation could encourage a vehicle ownership model in which one of a household’s vehicles is electric and used for local, shorter trips while the other is powered by gasoline or by one of the other alternative fuels and used for longer trips.

The same Carnegie Melon study found that only 22% of vehicles have access to a parking space within reach of an outlet that can support overnight charging and concludes that market penetration of more than 22% won’t be possible without further infrastructure investment. This statistic argues for the need for more purposeful and strategic deployed of EV infrastructure if EVs are to gain wider acceptance. Additionally, other regularly visited locations, such as workplaces and retail or entertainment centers, could provide complimentary charging opportunities beyond at-home charging.

Promoting new buildings that are specifically designed to consider at-home charging system will encourage the incorporation of vehicle parking that is well served by EV electrical equipment and may be the best way of deploying this new EV infrastructure. This might mean focusing EV adoption and infrastructure on areas of new development in the suburbs and exurbs rather than on existing urban areas and may mean passing new development codes to support the provision of charging equipment. Alternatively, California is looking at ways to promote convenient charging even outside of areas where single-family, at-home charging would be convenient. California Bill 1092 requires state agencies to set standards for installing charging outlets in apartment and commercial buildings in order to address obstacles to urban residents who park on the street and otherwise have trouble charging at home. This idea begins to plant the seed of a new typology of charging infrastructure that could be shared but still be used at natural travel destinations or vehicle resting spots. Either approach effects the built environment, one in the way homes are constructed and oriented around the parking and plugging-in of automobiles and the other on

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55. McDonald, 2013
56. McDonald, 2013
57. McDonald, 2013
58. Lavrinc, “California’s Sustainable Transport,” 2013
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the way cities' streetscapes and commercial areas are designed.

Overall, the three different EVSE infrastructures mean that charging equipment can be tailored to location and trip purpose. Slower chargers can be used at places where vehicles typically sit for many hours, while fast chargers can be placed along long-distance corridors to help a vehicle quickly recharge mid-trip. No such range of refueling options exists for gasoline-powered cars, and as a result, this flexibility isn't reflected in the current gasoline-based refueling infrastructure.
Locating EV Infrastructure

Because of EV charging site flexibility, understanding drivers' trip patterns and learning where vehicles are parked for lengthy periods of time is important for optimizing the locations of Level 1 and Level 2 chargers. Similarly, if there are specific types of trips that commonly exceed the distance of EV range, these routes may require the installation of supercharger equipment at points along the way. A better understanding of how people actually use their vehicles will define how an ecosystem of charging infrastructure should be placed. Ultimately, incorporating charging equipment into homes and at commercial centers that draw shoppers, diners, audiences, and other users from far distances is likely the most effective way to support EV use.

VEHICLE TRIP PATTERNS & OVERNIGHT PARKING
Understanding when vehicles are used and for what purposes can help situate EV infrastructure in the most appropriate development products and within the most effective development patterns. Looking at the temporal distribution of trips over the course of the day provides insight into how private vehicles are actually used. Vehicles often sit unused between 10:00 PM and

Distribution of Person Trips by Start Time in 2009

<table>
<thead>
<tr>
<th>Time</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:00 PM</td>
<td>11.0%</td>
</tr>
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<td>22.4%</td>
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<tr>
<td>01:00 AM</td>
<td>22.6%</td>
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<td>1.8%</td>
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<tr>
<td>04:00 AM</td>
<td>2.6%</td>
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<tr>
<td>05:00 AM</td>
<td>24.8%</td>
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*Image credit: Andrew Turco | Data credit: US Department of Transportation, 2009, p. 51*
According to the US DOT's National Travel Survey, only 4.4% of all trips are made during this timeframe, meaning that vehicles spend a good portion of their time physically located wherever they are parked overnight. For electric vehicles, which require extended periods of charging, locating supporting infrastructure where cars sit unused overnight makes sense. Whether these at-rest locations are in personal driveways, in public garages, or along streets, these venues demand further study when siting charging infrastructure because of their capacity to charge for extended periods.

Looking at time-of-day trips by purpose also provides important information about how vehicles are really used so that the possible needs for charging access during the course of the day can be determined. This data also provides information about where recharging equipment that is potentially needed during the day could be placed to maximize its effectiveness. When viewing the total number of trips of all types by time of day, vehicle use appears to rise dramatically with the start of the morning commute and remain roughly constant throughout the day until the end of the evening commute. Looking at the distribution of trips by purpose, however, shows that there are actually a few different patterns of travel that don't appear constant when broken out by task. Commuting trips peak in the early morning and then again in the early evening, but there is a dramatic decline in the middle of the day when these types of trips don't contribute significantly to total overall trip numbers. In contrast, trips relating to family and personal errand form a bell curve that peaks from late morning to mid-afternoon. Lastly, social and recreational trips peak after commuting and errand-related trips have already begun declining.

Considering the need for employees to remain at work during the workday, it is likely that many work com-
mute trips and the midday errands are being made by different drivers and different vehicles. Vehicles used to get to and from work are likely sitting in parking lots or parking garages during most of the workday. Drivers making errands throughout the middle of the day are likely using a different fleet of vehicles. Because trips for social and recreational purposes begin later in the day when commutes and errands have already begun to decline, these trips likely involve drivers and vehicles that had been involved in either commuting or errands earlier in the day.

These trip patterns provide relevant insight for electric car infrastructure provisioning. It suggests that workplace charging for electric cars could be a possible and productive way to extend EV driving range since vehicles sit at workplaces for an extended period of time, just as they do at homes overnight. Ninety-five percent of the time, personal vehicles sit immobile.60 Placing chargers at homes and at workplaces could, therefore, take advantage of the fact that automobiles are actually driven for only very short periods of time each day. When private vehicles are actually used, they are driven less than 40 miles per day on average.61 This suggests that, though feasible, providing recharging opportunities at workplaces is not critical for serving most daily travel patterns since EV range extends well beyond those 40 miles and could be handled by at-home charging. The same immobility that makes at-work charging possible also suggests that the average private vehicle is not used extensively enough on a regular bases to require charges between the two legs of a commute to and from work. Because many consumers have EV range anxiety, providing at-work chargers could provide piece of mind to EV drivers who know they can use at-work boosters. This level of assurance itself might make at-

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60. Ben-Joseph, 2012, p. xi
61. Newcomb, 2012

On average, vehicles are stationary for 95% of the day, meaning there is ample opportunity to charge them and suggesting that average driving patterns don't exceed EV range.
work EVSE provisioning beneficial, but it wouldn't be necessary in most contexts to enable average driving patterns. Where mid-day recharging may be more appropriate is in serving trips relating to errands, social activities, and recreational purposes. These trips happen more frequently and involve greater total distances than commuting trips. At the same time, these non-work trips wouldn't necessarily be served by at-work recharging facilities.

The average American now makes 3.79 car trips per day, with most being for family and personal errands (1.61 trips per day) and for social and recreational purposes (1.04 trips per day). These types of trips are also where Americans drive the most total number of miles per day. Americans drive an average total of 10.68 miles per day for family and personal errands and 10.93 miles per day for social and recreational reasons.62 They drive an average of only 6.85 miles per day to get to and from work.63 This travel pattern data shows that trips to and from work do not make up the majority of trips for Americans drivers, either in terms of number of trips or total distance of trips. It suggests that non-residential recharging infrastructure would be more appropriately placed in a way that serves trips for errands, social purposes, and recreational pursuits than at workplaces.

One of the two main determinants of EV energy needs is how the vehicle is used.64 Factors such as driving distances, speed, and frequency of starts and stops must be considered.65 In contrast to gasoline-powered engines, EVs actually obtain better mileage and further range with short-distance, low-speed trips.66 Though the total distance of non-commuting trips is greater than that of commuting trips, this total distance is the result of multiple shorter trips. As a result, these non-commuting trips may actually be able to be accomplished with the same amount of charge as commuting trips. The in-

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62. US Department of Transportation, 2009, p. 23
63. US Department of Transportation, 2009, p. 23
64. Hodson and Newman, 2009, p. 2
65. Hodson and Newman, 2009, p. 2
creased overall total distance doesn’t necessarily translate into an equal increase in demand for power because of the nature of the short, frequent trips.

Mid-trip charging for these retail, social, and recreational uses are probably only needed at those destinations that draw people from distant locations. The focus for deploying EV equipment should remain first on homes, where vehicles sit unused for hours at a time, and then at destinations where vehicles are driven further than their usual daily distances and may, as a result, need out-of-home recharging.

Most trips are relatively short distance. Sixty-five percent of driven trips are less than a mile in length. For regular day-to-day auto use, at-home infrastructure would adequately support an EV fleet, and range anxiety is unwarranted in these conditions. Average driving patterns show that electric vehicles are well suited to most environments that do not have excessive distances between origins and destinations. For those rare times when irregular trips are made that might exceed typical driving distances or extend beyond the accessibility of slow-charging EVSEs, mid-trip recharging opportunities should be provided. To satisfy this need, supercharger stations could be placed along long-distance routes or at destinations that specifically draw people from great distances.

**POLYNODALISM & VEHICLE USE**

The increasingly polynodal nature of suburban form creates trip patterns that are appropriate for EV use. Fewer residents living at the edges of metropolitan areas commute all the way to a city center than they did in the past, when employment density was concentrated in city centers. Jobs have followed their employees to the suburbs. As Alan Berger et al. lays out in “Where Americans Live: A Geographic and Environmental Tally,” suburban travel patterns are increasingly suburb-to-suburb in nature. Between 1990-2000, 64% of the growth in commuting within metro areas was due to suburb-to-suburb trips. As a result, the distances travelled between home and work are more likely to be within an electric vehicles’ range. Moreover, public transportation use is often low to non-existent in suburban and rural areas. The introduction of EVs in this context would, therefore, be possible and beneficial.

Higher levels of car ownership in the suburbs also make these areas attractive for EV adoption because a single household can own vehicles with different powertrains and use them for different driving missions. Suburbanites own more vehicles than their urban counterparts. At average densities of less than 10,000 people per

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67. National Complete Streets Coalition, 2014

70. Pisarski 2006, as cited in Berger, Brown, Kousky, Laberteaux, and Zeckhauser, 2014, p. 43
square mile, a majority of households own at least two automobiles. Currently, there are no anticipated battery technology break-throughs that would greatly extend the range of electric cars. As a result, Larry Nitz, a senior engineer at GM, says the best use for battery-powered vehicles may be as second vehicles for short and predictable commutes, for school runs, or for light delivery van runs. This is only possible in the context of owning multiple vehicles and, thus, shows why suburban rates of vehicle ownership might make EV adoption more economically feasible in this context.

71. US Department of Transportation, 2009, p. 37
Retrofitting the Suburban Home

Formulating an approach for incorporating EVSE equipment into suburban residential uses is important since at-home charging best supports EV needs and because suburban trip patterns are adequately served by EV characteristics. Focusing on retrofitting the suburban home in particular is beneficial because it will affect a large portion of the population. If EVs become widely available in suburban areas, for example, then the effect on gasoline demand and, in the process, on gas station properties would be large.

At the physical property level, suburban homes are well-suited for charger installation. They are often single-family houses, which provide opportunities for on-site EVSE installation, easy vehicle access, and simple ownership structure that make retrofitting for EV equipment easier than in more urban, multi-family contexts. Moreover, suburban-style properties typically have the space needed to install on-site sustainable power sources, such as solar panels or small-scale wind turbines, that can then provide clean energy to the electric vehicle. In fact, the coupling of EV charging equipment with smart-grid capable, distributed power generation at residential homes is one of the ways that installing EVSEs can significantly change the way homes draw and use electricity. Not only can a distributed network of at-home chargers support an electric-powered fleet of vehicles, but it can also greatly improve the overall balancing of the electricity grid through its installation.

SUBURBAN CONTEXT
The growth rate of US suburbs is lower today than it has been in past decades. Nonetheless, the suburbs are still growing. By 2000, 67% of the US population lived in the suburbs of major metropolitan areas. Not

unsurprising then, three-fourths of America's housing units are single-family or mobile homes, according to the 2010 US Census. This means that an effort to retrofit single-family suburban homes for better EV capability will have a widespread impact.

Suburban residents are also especially dependent on their private vehicles for mobility, and thus, a change in the powertrain that supports these communities would have widespread impacts. Nationwide, public transit is used by only 3% of suburban residents, compared with 10% of city center residents and 23% of city centers residents of large metropolitan areas. In reality, dependence on automobile travel in suburban areas is probably even higher than these statistics suggest since, in city centers, some of the non-transit trips can also be accomplished by foot or on bike.

SMART GRID AND SOLAR CHARGING INFRASTRUCTURE

The most beneficial way to introduce EV infrastructure at residential properties is to install a smart-grid capable EVSE system. This system usually includes on-site solar panels, an EVSE Level 2 charger, and the capability for electricity demand and use to be monitored and shifted between various sources and end uses. In a typical installation, the EVSE charger is wired into a home's grid-supplied electricity system but also connected to on-site solar panels. The electric vehicle draws power from either the solar panels when that source is available or from the home's standard electrical source when needed. What makes this system innovative and smart, however, is that the flows can also be reversed so that an EV battery that's been fully charged but not needed can power the house's electricity needs as well. This system also uses electric vehicles as a means for introducing alternative power sources into suburban homes.

This arrangement comes with major advantages in balancing electricity demand and shifting power generation to greener sources. In the first place, EV charging during the day can draw its energy from the solar panels and avoid putting added demand on the grid's existing power sources. When a vehicle is charged at night and solar energy is not available, the vehicle can draw from the same grid-based power source that the home normally does, but this demand comes during off-peak times. At these times, grid-supplying power plants already have extra capacity not being efficiently utilized, so this doesn't put significantly more stress on the system. The fact that the time of day when there is good solar supply is the opposite time of day when there is off-peak grid energy supply makes this an efficient and environmentally friendly way to charge EVs.

Another innovative aspect of this smart grid energy system is that, because energy demand and energy use

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in the house and vehicle is being monitored by a smart meter, the system can take advantage of this knowledge to move electricity among the different components. Although the house may rely on grid-supplied energy for most needs, it can draw electricity from the EV's batteries during peak demand, when grid-supplied demand is expensive and carbon-intensive. This essentially means that the electric vehicle serves as a temporary storage system for energy generated from the solar panels or for energy taken from the grid at off-peak times. This stored power can then supply other household needs during periods of high electricity demand.

In theory and if the energy utility allows for this, this stored energy could even supply other uses connected with the grid but outside the immediate property. This system essentially transforms an electric car into a distributed piece of energy storage equipment for any home that it's plugged into. It not only changes the auto infrastructure of suburban America but also transforms the energy infrastructure of these areas.

ENVIRONMENTAL BENEFITS AND COST SAVINGS
The advantage of deploying this system on a large scale is that it has the potential to introduce significant solar-based energy into suburban environments. It also has the potential to flatten electricity demand over the course of the day and reduce peak demand. In doing so, this system can help eliminate increased carbon emissions and higher electricity costs resulting from dirty plants being brought online to meet extra high electricity demand. According to a Georgia Institute of Technology analysis cited by Ford's EVSE division, a single home that implements this smart-metered EVSE and solar panel system would reduce energy costs by 60% and CO2 emissions by 55%. According to Ford, if every home in the US implemented this system, it would be the equivalent of taking all of the 32 million homes in California, New York, and Texas off the power grid. Much of these benefits come from the ability to schedule when electricity is drawn rather than from the adoption of electric vehicles themselves, yet this capacity to store energy and then release it at different times to power household appliances, for example, would not be possible without the electric vehicles' battery storage capacity.

Deploying EV infrastructure as part of this holistic, at-home energy system is important in order to avoid putting significant strain on the existing power grid because of EV adoption. Maximum load-potential electricity use from a Level 1 EVSE is 4,000 kWh per year, and for a Level 2 charger, it can range from 6,500-13,000 kWh per year. For comparison, the average American home uses 11,000 kWh of electricity per year. If EVs

82. Ford Motor Company, 2013
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Different Ways Energy Can be Generated, Distributed, and Used with At-Home Suburban Charging Installations

Solar Generation to EV Storage:

Grid Generation to EV Storage:

Image credit: Andrew Turco
were to draw electricity at full potential and from infrastructure that didn't incorporate alternative power sources or smart metering, the introduction of electric vehicles could greatly increase residential demand for energy. At small-scale use, individual chargers would have little impact on an area's overall energy demand, but with widespread implementation, this additional energy demand could place significant stress on the existing power system. This concern is one of the reasons siting EV infrastructure where complete charging systems can be incorporated is important.

**PHYSICAL DEPLOYMENT**

Several of the same factors that make single-family homes attractive for EV adoption, such as their dedicated spaces for automobiles, also enable them to receive this infrastructure more easily. Low-rise suburban homes often have adequate roof area or open lawn where photovoltaic (PV) panels can be sited. The energy generated by these panels needs a relatively quick path to a storage battery. Because of the prevalence of attached garages and driveways, electric vehicles are more easily parked in close proximity to the panels, which minimizes the complication of getting the energy from the panels to the EV batteries.

From the perspective of keeping track of energy consumption and supply, the system is significantly more straightforward if the same person or household has control over the EV, the solar panels, and the smart-wired house. This is also more common in single-family homes than in other building types. Under a single owner, there is less need to track which devices or appliances supply or consume energy and at what time in order to determine payments for that energy. Additionally, people would likely be less hesitant about supplying excess energy to other functions if the same people are also benefiting from those other uses. For these rea-
sons, this at-home solar- and smart meter-based system is most appropriate and most likely to be adopted in suburban environments, where single-family houses dominate.

A similar system can work in an urban environment or in a setting with multi-family housing, but the added complications are twofold. One is physical and one is logistical. The physical separation of PVs, the EV, and the individual home would make it very difficult for these systems to be easily connected, especially in situations where parking was primarily done through on-street spaces. An attached parking garage would reduce the physical complexity to a certain extent, because EVs could pull into assigned spaces and connect with specific EVSEs, but connecting these different components would still be difficult. Additionally, the PV area on tall buildings might not allow for enough solar energy to be generated compared to the number of residents and drivers housed within the building. Beyond the physical complication, however, shared solar panels and a central building-wide connection to the grid would require extensive sub-metering that might outweigh the benefits of the system.
Constructing Centralized Supercharger Stations

The most widespread and commonplace recharging will happen through the system of distributed, at-home infrastructure due to the ease of recharging, duration of vehicle availability, and optimization of the electricity network. However, to make less frequent long-distance travel by electric cars possible, there will be a need for supercharger stations along major travel corridors and in areas of intense mid-day activity to boost EV power mid-travel. These destinations should take advantage of existing gas station sites along interstates and should also harness retail and entertainment centers to provide uses that complement one another.

SUPERCHARGER MODEL
The model for this network of stations is similar to the one currently being constructed by Tesla that provides an extensive network of superchargers along major highways and outside of major cities for its car buyers to extend the range of their vehicles during longer trips. Just as Tesla has located its chargers at rest stops along highways, these stations would not be intended for residential neighborhoods, where at-home systems are more appropriate. They are simply to boost battery charges when trips take EVs beyond their single-charge range.

Unlike the EVSE Level 2 chargers deployed in suburban homes, these proposed charging stations would take advantage of Level 3 EVSEs ability to provide nearly complete recharges in 20-40 minutes. This supercharger equipment is too expensive and requires too much extra infrastructure to justify installing it in individual houses for at-home charging, but at strategic public places, these chargers can serve to supplement at-home charging in a productive and targeted way. Like the at-home charging systems, however, these stations would be installed together with solar panels so that the energy needs of the EV equipment would place as small
Constructing Centralized Supercharger Stations

Tesla's Existing and Proposed Supercharger Locations

Tesla's proposed system of supercharger stations aims to make it possible to travel anywhere in the US by electric vehicle. The superchargers are strategically placed along highways and between destinations in order to provide mid-trip recharging that extends the overall range of an EV beyond a single charge. The maps show (1) current Tesla supercharger locations, (2) proposed supercharger locations by the end of 2014, and (3) proposed supercharger locations by the end of 2015.

RETAIL & ENTERTAINMENT CENTERS

These supercharger locations should be thought of as development opportunities for satellite retail and entertainment centers. Although the EVSEs provide quick recharging when compared with at-home systems, the required 20-40 minute wait is still a significant inconvenience for the EV driver but also an opportunity to program complimentary uses at the same site. Mobile applications that monitor charging progress mean that drivers are free to leave their vehicles charging while eating, shopping, or doing other activities.

Although the Tesla superchargers are currently limited to only its Model S vehicles, a system that is usable by all EVs would increase the scale of these supercharger systems. In much the same way that areas around airports are beginning to be thought of as "aerotropolises" that support an ecosystem of hotels, offices, and retail centers because travelers have to pass through them on their way to other places, supercharger recharging centers could be thought of as small retail and entertainment centers. For example, sports stadiums that provide entertainment and that may also draw people beyond their typical driving distance or regional malls that provide similar levels of activity and may also draw people beyond their daily travel patterns are the types...
of uses that should be incorporated at logically placed supercharger stations. In these contexts, a combination of supercharger infrastructure and retail-entertainment uses could reinforce and strengthen one another. The system of superchargers that allows for extended range could end up creating a series of dense and program-filled nodes between larger metropolitan areas. This would serve to concentrate development in specific micro-areas in the spaces between dense urban forms while allowing electric vehicle travel range to expand beyond the immediate suburban context.

Tesla currently describes their superchargers being located near amenities so that "road trippers can stop for a quick meal and have their Model S charged when they're done." Nonetheless, Tesla's supercharger stations have so far under-delivered on this concept. The first supercharger stations in the Northeast, for example, were located at traditional rest stop plazas along I-95 in Milford, CT. Although fine for a quick gasoline fill-up, these locations are not the agglomeration of EVSEs, retail, restaurant, and other activities that would make these recharging experiences enjoyable, and they don’t take advantage of the 20-40 minutes that drivers will spend recharging.

LEARNING FROM GAS STATIONS
Gas stations are already undergoing a transformation, and the lessons learned from that evolution should be applied to EV infrastructure as well. One of the reasons that smaller gas stations are having difficulty attracting customers today is that big-box retailers have introduced gas pumps at their stores. Drivers like one-stop trips, and successful supercharger property owners and developers will learn from Walmart and Costco by colo-locating charging infrastructure with other uses that allow people to make a single stop for multiple purposes.

84. Kaysen, 2012
Gas stations have learned to rely on convenience stores for revenue, which allows them to survive even though profit margins on gasoline are very low. Although gasoline accounts for 73% of the sales at gas stations, it only accounts for 36% of the profits. Level 3 EVSE charging equipment will be no different and, thus, other business opportunities must be created that take advantage of the time required to recharge a vehicle. EVSE electricity sales at these centralized stations will not be profitable on their own. IHS Automotive suggests that public charging installers turn to alternative sources of revenue at their stations, like advertising, in order to actually profit from the EVSE installations. The fact that Tesla offers supercharger access to all Model S drivers free of charge and only to Model S drivers shows that the company is not looking to profit from the delivery of electricity but from the way in which free and easy recharging incentivizes consumers to buy Tesla vehicles. As more companies introduce EVs and as supercharger connections become more standardized, it will become inefficient for each auto company to supply its own superchargers as incentives for just their car buyers. Just as gas stations make much of their money from convenience stores rather than from the sale of gasoline itself, supercharger stations along major transportation chargers should also see the chargers as part of larger developments that generate income for the charger provider.

Although IHS Automotive suggested advertising opportunities would provide revenue to charger installers and operators, this strategy doesn't play to EV use or to charging needs, which any supplemental use should. The 20-40 minute charge at supercharger EVSEs means that drivers are captive for that period of time while their vehicles are plugged in, but unlike when a driver has to stand by his car while refilling a tank with gasoline, an EV driver simply needs to plug the cord into the socket and is then free to leave the vehicle. This mobility creates an opportunity for drivers to accomplish other errands, pursue entertainment, or eat and drink while the car is recharging. Essentially, these characteristics suggest the opportunity for rest stop-style recharging centers that are significantly more built-out and programmed than today's typical highway gas stations.

86. IHS Automotive pressroom, 2014
Regional characteristics also influence where EV infrastructure can be most effectively rolled out. Because EVs will only comprise one component of a mixed-powertrain system, their adoption should be targeted at areas that have the most capacity for their use and that would provide the most benefits from their adoption. One of the motivating factors behind electric vehicle adoption is its capability to green the private vehicle fleet. Additionally, implementing smart-metered, solar-based EVSE systems can reduce demand on existing power sources. Because of these environmental goals, the power profile and solar capacity of different parts of the US must be assessed to determine where EVs and their charging systems will have the biggest environmental impact.

**REGIONAL ENERGY PROFILES**
The amount of carbon emission from electricity used to power EVs will affect how green electric vehicle use is. The variance in environmental impact of different energy sources supplying energy to EV batteries can be significant. To illustrate this point, an electric car in heavily nuclear-powered France produces only 8g of carbon-dioxide emissions per mile of travel. In contrast, that same vehicle travelling a mile in China or India would emit 120g of carbon dioxide because these countries rely heavily on coal for their electricity generation. Although tailpipe emission from EVs in either country is zero, the net carbon impact takes into account how the electricity powering the battery is generated.

The inclusion of solar energy generation and smart-meter capability in the at-home charging network outlined for application at suburban single-family homes, however, turns this equation on its head. Deploying EVs and this kind of supporting infrastructure would actu-

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ally be more impactful in areas that currently have very carbon-intense energy generation. Because the EV acts as a mobile energy storage unit that can reduce peak demand by storing energy in the off-peak and supplying it during peak times, the adoption of electric vehicles can flatten a region's electricity demand. The dirtiest plants in operation can likely be retired if energy demand is more evenly distributed throughout the 24-hour day because plants that operate solely to meet a few hours of extra demand would no longer be needed. Additionally, the solar component of the at-home single-family infrastructure and of the supercharger station system means that the adoption of EVs and the installation of EV equipment are also a way of introducing alternative energy sources into the energy supply system of otherwise carbon-intense energy systems.
Certain parts of the country have dirtier energy generation than others. The greenhouse gas intensity of an area is dependent on the mix and type of power facilities. Looking at data from the US EPA's Emissions and Generation Resource Integrated Database (eGRID), which captures the environmental characteristics of electricity generated in the US, shows that the eastern Rockies, the Midwest, the Plains, and the South release the most carbon dioxide per megawatt hour (mWh) of electricity produced. The Southwest and Appalachia are about average, and the Northeast, California, and the Pacific Northwest are the cleanest.

Looking at the types of power plants that supply these areas' electricity reflects what one would expect: the dirtiest areas are overwhelmingly powered by coal power plants, while gas, nuclear plants, and hydro facilities power a good portion of the cleaner Northeast and West's energy supply.

This data suggests that a transportation system based on electric vehicles would be more environmentally productive if targeted in the Mountain West, Midwest, Plains, and South because adoption of EVs and the accompanying retrofitting and construction of suburban homes with solar panels, smart metering, and distributed energy storage capacity would reduce demand on these dirty coal power plants.

This recommendation for EV deployment by region does not necessarily wholly reflect where demand for that electricity is originating from or suggest that EV deployment will be a cure-all for high levels of carbon emissions. Demand for products manufactured in the middle of the country, with its higher dependence on coal, might come from the "clean" Northeast or West Coast, for example. Additionally, there are other carbon-intense activities, such as trucking, that are not reflected in the eGRID carbon assessment, which focuses on electricity generation in particular. These qualifications:

89. US Environmental Protection Agency, 2014
90. US Environmental Protection Agency, 2014
Optimal EV Regions

Deployments should be considered. Deployment of EVs in regions with high electricity emissions will at least result in some decrease in carbon emissions. Additionally, the private automobile-based pollution in these areas will be reduced, but this sector is only one component of a much larger system of carbon-generating uses. Electric vehicles and EV infrastructure can also be adopted in other regions of the US that already have cleaner energy profiles. The introduction of the at-home system will further green the energy supply in these areas too, though the impact may be less substantial than they will be in the identified regions.

Solar Energy Potential in the US

SOLAR CAPACITY

The introduction of at-home, smart-metered EVSE systems would better balance energy demand and reduce carbon emitted from peak energy generation, but the environmental impact of this proposed charging network is further amplified by the inclusion of solar panels and their ability to feed energy to EVs and even back into the grid.

Parts of the US have significantly different solar profiles, and they vary to the point of making solar a truly reliable source of power. Tesla, for example, is only installing PV canopies over its supercharger EVSEs in “sunnier environments” because the small amounts of energy that can be drawn from these panels in other environments does not justify the cost of its purchase and installation.91 A look at solar capacity across the country is helpful in determining the best regions for EV deployment that can take advantage of the PV component of the proposed charging infrastructure systems. Calculations by the National Renewable Energy Laboratory show that the Southwest has significantly more solar capacity than elsewhere in the country but that most of the West, the western Plains, and the Deep South also have reasonable potential.

SYNTHESIZED REGIONAL ASSESSMENT

Taking these regional power supply and solar potential criteria together determines where in the US the adoption of EVs, the implementation of suburban home retrofits, and the siting of supercharger stations would

91. Tesla Motors, 2013
make the biggest energy impact. The Mountain West, the South, and parts of the western Plains are the three areas where both dirty energy and solar potential are aligned to maximize the benefits of the smart meter and solar panel EV infrastructure systems. Deployment of these systems in the Midwest or in the Southwest would also allow EVs to significantly reduce carbon emissions because of the Midwest’s dirty energy profile and the Southwest’s high solar capacity. In places where neither of the energy or solar criteria is met, adopting EVs and installing the supporting EV infrastructure can still bring positive benefits, but a focused effort should be made to deploy these systems in the areas that will accrue the most benefit.

Other trends relating to the dispersion of jobs and the continued rate of suburban development support EV deployment in some of the same areas highlighted by the energy and solar analysis. The West, Southwest, South, and Midwest have experienced the most decentralization in recent years, and as a result, residents are most likely dependent on private vehicles for transportation. They also have the polynodal characteristics that were shown to support EV use. The highest rates of suburban growth are outside of major cities in the South and the West. Employment is also more spread out in these areas of the country than it is in the Northeast, meaning there are fewer opportunities to group rides. The ongoing new construction in the West, Southwest, and South also make the provisioning of proposed EV infrastructure more feasible than in older areas with less suburban growth, such as in the Northeast. Building EV charging capability into new construction is four times cheaper than retrofitting existing structures. Additionally, buildings can be better designed to incorporate solar panels and to accommodate charging equipment needs if they are being designed with these systems in mind from the start. These benefits further support targeting the West, Southwest, and South for EV adoption. In combination with their energy profiles, these characteristics make the Mountain West, Southwest, and South most appropriate for an electric-based private transportation system.

95. Badger, 2013, p. 1
Although some will be converted to centralized supercharger stations that serve long-distance EV vehicle trips, the need for consolidated refueling facilities, especially in the form of gas stations, will be greatly diminished in environments with high levels of electric vehicle adoption. Already, there are gasoline retailing trends that are reducing the number of gas stations in the US. A system of distributed, at-home recharging equipment to support that portion of the US vehicle fleet powered by electric powertrains, as well as increased fuel efficiency in other vehicles, further unlocks once necessary gas station sites to be reused and redeveloped for other purposes. Even in urban areas that may continue to rely on gasoline powertrains, real estate pressures for highest-and-best-uses are reducing the number of gas stations.

In 2006, there were 116,855 gas stations operating in the US. Texas and Florida have been identified as places targeted for highly productive EV deployment. When combined with California, these three states account for one-fifth of the nation’s gas stations. In fact, Harris County in Texas, with its 1,397 gas stations, has the second highest number of stations in any US county. These numbers demonstrate the saturation of gas stations in areas targeted for extensive electric vehicle adoption. Many of these sites will likely become available for redevelopment.

Assessing the unique characteristics of gas station sites, in terms of their size, location, and environmental contamination, as well evaluating how each site can be productively reused within the context of its surroundings, can inform how these sites should be redeveloped. Typical and distinctive characteristics of gas stations are that they are sited on small parcels distributed throughout communities. They often sit along major roadways,

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96. Hughes, 2013
97. U.S. Census Bureau, 2008
98. U.S. Census Bureau, 2008
99. U.S. Census Bureau, 2008
Remaining Gas Station Sites

are frequently located at major intersections, and are many times sited at the entrances to business districts. Gas stations are purposely made highly visible from nearby roads. Already, there are a number of former gas station properties that have been redeveloped as a result of changing market pressures and demographic shifts. These can be looked to as models for more extensive redevelopment efforts that deal with entire networks of gas station sites.

Evolving Trends
The gasoline retailing landscape is already changing in ways that create redevelopment opportunities, even before the large-scale introduction of electric vehicles. Mergers among the big oil companies have led to decreased competition and, as a result, have reduced the need for multiple stations when they are owned by the same corporate entity. There has also been a simultaneous trend towards larger centralized stations that are easier to support, in place of many smaller ones scattered throughout an area. Finally, large players like Exxon-Mobile have exited the gasoline retail business entirely, selling all company-owned stations. Though 50% of gas stations in the US are branded with a major oil company, only 0.4% are actually still owned or operated by them. Divestment moves by such savvy, market-aware corporations probably foretells declining feasibility of the current retail gasoline model.

New station owners that have taken over these franchises, as well as older mom-and-pop station owners, are increasingly being squeezed by changing driving habits and environmental rules. The high cost of oil and low profit margins that gas retailers face makes it difficult to rely on gasoline sales alone for profit. Many owners have pursued co-located convenience stores that sell snacks, drinks, and convenience items to boost profits. Stations that attempt to survive only by selling gas and fixing cars at attached repair shops are no longer financially viable. The success of these attached stores hint at an unmet demand for convenience retail and can inform feasible and productive redevelopment uses.

All of these trends have led to the closure of many gas stations. Nationwide, more than 50,000 gas stations have closed since 1991, according to a National Association of Convenience Stores statistic cited by the New York Times. These tens of thousands of closures have often left communities with vacant or abandoned properties, in much the same way that changes in the

100. US Environmental Protection Agency, 2009, p. 1
102. Kaysen, 2012
103. Hughes, 2013
104. Hughes, 2013
106. Hughes, 2013
108. Kaysen, 2012
vehicle fleet's powertrain profile will cause many more to become vacant if redevelopment options are not thought through in advance.

RISK OF ABANDONED STATIONS
The prevalence of gas station sites is part of what makes the possibility of their reuse exciting. If evolving powertrains cause gas stations to go out of business before replacement uses can fill their places, however, then this same prevalence risks creating a number of abandoned properties throughout the country. The widespread integration of these sites within their surrounding communities makes their risk of vacancy more harmful and visible than might be the case at sites that sit in isolation. Because of the high probability of environmental contamination on former gas station sites, their redevelopment has higher costs and higher regulatory hurdles than other types of sites. These obstacles will have to be overcome for redevelopment to succeed.

Abandoned properties are undesirable because they put a drain on police, fire, building, and health department resources; they depreciate property values of adjacent parcels; they reduce property tax revenue; they attract crime; and they degrade the quality of street life.110 Even a single abandoned property that is difficult to redevelop can make it harder to build on surrounding land if it occupies a key site that anchors other redevelopment or is simply in a prominent location.111 Gas station sites, because of their strategic locations along busy corridors and at gateways to neighborhoods, would likely exacerbate this effect on surrounding properties. Divestment in former petroleum sites can also lead to further sprawl as residents and businesses seek to get away from abandoned sites, with their negative environmental, economic, and social effects.112

111. National Vacant Properties Campaign, 2005, p. 9
Remaining Gas Station Sites

Underground storage tank replacement in Cambridge, MA

photo credit: Christopher Rhie
It's important to plan for reuse before more gas station sites become vacant as a result of changing infrastructure needs or market demand for gasoline. The longer a property remains abandoned, the higher the cost of renovation.113

CHALLENGES FOR REDEVELOPMENT: ENVIRONMENTAL CONTAMINATION AND LIABILITY

Before gas station sites can be redeveloped, their environmental contamination must be addressed. This added risk, required environmental expertise, and additional project timelines could be a real disincentive for redeveloping these sites. Developers are often looking for shovel-ready sites,114 which these contaminated properties are not. Uncertainties associated with the costs of site testing, remediation planning, liability protection, and actual cleanup make it difficult for developers to determine whether a project pencils out financially.

Many gas station sites are considered environmentally contaminated because of leaks from their underground storage tanks (USTs). Thirty thousand releases are reported from USTs every year,115 revealing the environmental magnitude of this issue. The material and age of many petroleum storage tanks are the cause of most leaks. Until the mid-1980s, most USTs were made of bare steel, which simply corrodes over time and then leaks its contents.116 Because these leaks are not the result of poor operation or negligent care but simply a result of aging facilities, leakage is common throughout the country and not confined to specific properties. Additionally, even after UST sites close, they often continue to contaminate the site until they are redeveloped because facilities with USTs usually leave these buried tanks behind when they close.117 Addressing these leaks is a vital component of most redevelopment projects.

From a developer's perspective, the high cost, potential liability, needed technical expertise, and number of unknowns associated with environmental issues makes contaminated sites less attractive. Developers are hesitant to take on brownfield redevelopment because they can be stuck with the cleanup bill if the previous owners cannot be found or cannot pay.118 These sites become as attractive as non-contaminated sites only in super high-value areas where underdeveloped land is scarce or only to firms with specialized cleanup expertise that gives them advantages over other developers.

Having unknown conditions on a site is one of the most undesirable characteristics for developers, who often have strict financing agreements, specific investor criteria, and guaranteed delivery dates for projects. One

117. Smart Growth America, 2012, p. 1
118. Kaysen, 2012
of the challenges for redeveloping UST sites is that, since federal regulations requiring UST registration didn't occur until the mid-1980s, any tanks taken out of commission before 1974 are not accounted for. Because they are buried, unaccounted for USTs are often not found until excavation begins. These tanks are not found just at abandoned stations but also at stations that had older tanks that were decommissioned before the 1970s. Cleanup costs skyrocket further if contamination is found to have spread to neighboring lots or if it has entered the groundwater.

Though well intentioned, additional regulation around UST cleanup has added even more risk for developers, in the form of unknown timelines. In an effort to assert fairness over who pays for the cost of UST leaks, federal regulations require that cleanup costs be sought from the responsible polluting party before public funding can go towards a cleanup effort. Although well-intentioned, this has hindered the redevelopment of many sites because finding the offending party is difficult or because the responsible party resists payment or is unable to contribute significant funds to the cleanup. As a result, developers can face delays in their construction schedule, which adds greatly to the own cost of redeveloping the property.

Nonetheless, the particular type of contamination found at UST sites comes with some advantages too – or at least conditions that limit its disadvantages. Gas station brownfield sites are often cheaper and easier to clean than larger, more complex brownfield properties because UST sites share a common and known contaminant – petroleum – which has led to the creation of pretty well-established and easily accessible cleanup technology. The most common contaminants at these sites are usually limited to petroleum, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), lead, and other metals. Experts know that oil and groundwater are the most common media affected at these types of sites, and can plan a cleanup accordingly. Remediating leaking USTs is, therefore, known to cost anywhere between $10,000 and $1 million, and the EPA estimates that the average cleanup cost is $125,000. Because the type of contamination on UST sites tends to be easily predicted, the development risk is less than the risk that developers would face at other brownfield redevelopment properties.

Growing awareness, at the federal level, of the importance of supporting remediation of UST sites is also

120. Kaysen, 2012
121. Bartsch, Ward, and Strasser, 2002, p. 15
123. Smart Growth America, 2012, p. 4
making redevelopment easier. Because of their size and the type of contamination, remediation of federally-regulated USTs is typically managed by state programs that were, for a long time, ineligible for EPA brownfield funding. This lack of available funding hampered redevelopment, even though these types of brownfields are prevalent and exist across geographies and in all types of communities. Attempting to remedy this deficiency, the EPA now ensures that a certain amount of money is allocated to funding UST-specific brownfield cleanup every year.

Finally, in thinking about the entire UST issue, because leaks are more likely to occur in older tanks made of bare steel, newer UST sites are less likely to be contaminated and, therefore, easier to repurpose. Gas stations constructed after the mid-1980’s are, therefore, most attractive for redevelopment. Since distributed EV infrastructure and increased gasoline-engine efficiency will reduce demand for gasoline across the board, these newer sites could be targeted for redevelopment first, which would still prevent their vacancy and would still provide opportunity for redevelopment.

CHALLENGES FOR REDEVELOPMENT: SIZE & LOCATION

Gas stations' small footprints present added challenges for redevelopment because reuse options are limited by size and remediation costs can't be spread over a large project. The small and dispersed nature of gas station properties limits their marketability to developers, increases liability concerns, and requires unique assessments and cleanup techniques for each individual site. The size and isolation of the sites incentivizes investors to choose properties that have bigger potential payoffs. In an era of developers seeking large-scale projects that enable them to recoup infrastructure investments, small UST sites are challenging for attracting development.

In addition, the small size of the properties makes obtaining financing and insurance more difficult. Gas station brownfield sites have relatively low environmental impact, as compared to larger and more contaminated sites. This characteristic has historically caused government agencies and redevelopment groups to assign a lower priority to their cleanup. Many programs are designed to favor the most heavily polluted sites, which USTs often are not. UST sites are frequently not eligible for environmental insurance from the private sector or for conventional financing options used to clean other brownfield sites because of their small size and because they are more expensive to clean on a per-acre

128. US Environmental Protection Agency, 2008, p. 1
129. Smart Growth America, 2012, p. 3
131. Smart Growth America, 2012, p. 3
A lack of affordable financing is, therefore, often the biggest barrier to reusing contaminated sites. If government agencies provided funds to support even the environmental assessment of these sites, their redevelopment could be greatly aided because developers would then be dealing with known costs to input into their financial models.

The unique size of a typical gas station site also provides some remediation advantages, just like the predictability of the commonly found petroleum contamination at these sites provides some advantages. Cleaning or disposing of contaminated soil is a large component of any remediation project. Though redevelopment opportunities are constrained by gas station properties’ small acreage, a property’s small size also means that there is less soil to clean or dispose of. Though expensive on a per acre basis, this reduced overall cleanup cost can make remediation and redevelopment more manageable. Developers with less financial capacity that are unable to compete with deep-pocketed firms on larger sites become more competitive on these smaller sites.

133. Smart Growth America, 2012, p. 1
Strategies for Reuse and Redevelopment

Because they serve the same purpose—to refuel vehicles—one of the defining and unique characteristics of all gas stations is that they share fairly uniform design and layout. Gas stations can be found in nearly every built context, from downtown commercial areas to residential neighborhoods. This allows for a variety of redevelopment opportunities tailored to their surroundings' strengths and needs. Gas stations differ from typical brownfield sites in that they are not typically concentrated in industrial areas. They're also usually not big enough to exist independently of their surroundings. This characteristic means that they are prominent sites that can often be used to anchor larger revitalization efforts around them, making them attractive for redevelopment.

In the context of redevelopment, the simplicity of gas station design is one of its virtues. Although the environmental remediation required at gas stations often creates extra risk and has the potential to delay redevelopment, the fact that the structures on gas station sites are small and usually undistinguished means that developers are often unconstrained in what they can propose as replacements. The existing buildings also require little time to demolish, so remediation and redevelopment can begin without an extensive deconstruction process.

The ownership and leasing characteristics of gas stations also make them appealing development parcels. Unlike larger, car-oriented low-density uses like strip malls or buildings with high FARs that incorporate a mix of uses, gas stations mostly have single tenants. This makes it much easier for developers to relocate the occupant, to buy out the tenant, or to time development according to the end of a single lease agreement. When developers must coordinate among many owners or among different lease timeframes, the timeline for redevelopment becomes extended and the process becomes more complicated. Together, the single-tenant

135. Smart Growth America, 2012, p. 4
occupancy and the easily disposed existing structures speed the development process and help make up for the added burden of environmental cleanup.

Beyond these natural advantages that work in favor of redevelopment, there are other approaches that can and should be applied to increase the feasibility of redevelopment. Brownfield properties are usually assessed for redevelopment according to two main criteria: the degree of risk and cost relating to environmental liability and the expected profit from investment in redevelopment. There are ways to tip this balance in favor of redevelopment. Taking a multi-site approach to gas station redevelopment and combining the remediation and redevelopment process into a single project will make gas station sites more attractive for development. These strategies should be incorporated into proposed redevelopment uses and forms intended to replace those gas stations made obsolete by market forces, gains in vehicle efficiency, and the adoption of electric vehicles in certain contexts and regions.

A MULTI-SITE APPROACH

Gas station properties are often so small that assembling multiple parcels into a single, larger development project is desirable for getting the critical scale needed to make redevelopment financially and programmatically feasible. Looking at multiple parcels as a single project increases the efficiency of what would otherwise be several different environmental cleanup efforts. Aggregating properties also creates a parcel of significant enough size to be eligible for certain funding streams and for infrastructure investments. Additionally, tackling many parcels simultaneously reduces overall project risk by pooling individual risk from each site together. Lastly, taking a multi-site approach simply allows for a range of end uses that might not otherwise be feasible on a single, smaller parcel. Because of the many benefits to this approach, aggregating multiple sites should be actively pursued whenever possible when considering the redevelopment of obsolete centralized refueling stations.

When several contaminated parcels are redeveloped together, remediation assessment and cleanup costs can be spread over a larger area, and multiple uses can be coordinated so that needed levels of remediation are minimized. Economies of scale can be gained when many contaminated sites are tested and cleaned together. Core digging equipment to test levels of contamination can be used all at once, for example, and saves the cost of having to bring equipment to an area each time a different site is ready for testing.

Beyond these simple scale issues, though, being able to program different parcels in a coordinated fashion can allow for the placement of uses based on environmental conditions. An area programmed for a residential building will require the highest level of environmental


137. Smart Growth America, 2012, p. 9
remediation, while a site intended for parking can rely on a paving cap to minimize needed cleanup. Placing buildings and uses according to levels of contamination will minimize unneeded cleanup, but this ability to program at a large scale is only possible if the same developer has control over multiple sites. These benefits accrue whether all sites are contaminated or only some are. For example, if redevelopment of an uncontaminated site is occurring in conjunction with redevelopment of a brownfield gas station site, displaced soil from building construction on the clean site can be used to cap the contaminated UST site and would save money otherwise needed to remove and dispose of petroleum-contaminated soil. For multi-site projects made up entirely of brownfield sites, using one site for parking that supports the users of new structures on all of the other sites can at least reduce the amount of remediation needed at that particular parking site.

Multi-site agglomeration also transforms properties that are of low priority when viewed independently into a single, high-priority site able to attract the attention of government agencies that can provide cleanup funding. In 2010, the EPA launched a pilot program called Area-wide Planning Grants to better target financial and technical resources to projects that are conceptualized as large-scale redevelopments with the power to transform entire neighborhoods. At the state level, Ohio, Wisconsin, New York, and Colorado have implemented programs that specifically support this type of unified, area-wide remediation and revitalization, illustrating the growing belief that this approach is the most effective way to achieve robust redevelopment of contaminated petroleum sites. In general, multi-site plans also often draw enough attention and make enough of an impact on their surrounding area to take advantage of public funds relating to infrastructure, affordable housing, education, and economic development.

Tackling properties together also has the benefit of reducing risk, which is one of the biggest disincentives for developers taking on contaminated properties where the full extent of contamination is unknown. Redeveloping multiple sites at once often qualifies developers for environmental insurance policies that are unavailable for cleanup costs of less than $1 million to $2 million. Bundling sites enables the overall cleanup costs to surpass these insurance thresholds. Even disregarding how more attainable insurance can reduce risk, simply putting multiple properties into a single pool for development can reduce the threat of bankruptcy from a single property requiring an exceptionally large cleanup. By pooling sites together, the risk is spread among several sites.

139. Smart Growth America, 2012, p. ii
140. Smart Growth America, 2012, p. ii
141. Smart Growth America, 2012, p. 13
142. Smart Growth America, 2012, p. 9
143. Smart Growth America, 2012, p. 9
144. Smart Growth America, 2012, p. 9
Finally, combining sites opens up redevelopment to a broader range of reuse options. Some uses simply don't physically fit on sub-three acre gas station sites. Even when the agglomeration of an adjacent small gas station site is not possible, creating a unified redevelopment scheme for multiple gas station sites in the same general area can still allow for redevelopment to address multiple, complimentary neighborhood needs. The redevelopment of one of many sites would benefit the others from the positive externalities of environmental cleanup and new construction.

In these cases of site agglomeration and area-wide coordination, interim reuse can play a role in both activating the properties and providing a small stream of income to the developer until the surrounding sites become available and a large-scale project can move forward. Simple reuses for gas station sites, such as using existing structures for storage, parking cars on paved areas, or turning the site into a park, can fulfill a community need until more productive redevelopment plans become feasible. Many gas stations that are temporarily reused stay that way for a number of years and aren't even recognized by the general public as serving an interim use. An example of this type of interim use is the 2009 conversion of an out-of-service gas station in Long Island City, Queens into the Breadbox Café. The developer spent $1 million to convert the defunct station, which sits next to a functioning Getty Station, into an attractive café. Even after spending these funds, however, the development team eventually hopes to tear both structures down when the Getty Station owner is willing to sell in order to construct a high-rise building that will straddle both sites.146

**COMBINING REMEDIATION AND REDEVELOPMENT**

Thinking about remediation and redevelopment as one process rather than as two independent actions has also led to more productive contaminated site reuse practices. Developers and designers should approach future gas station redevelopment projects with this technique in mind. With the launch of EPA's petroleum brownfields program in the early 2000s, the EPA's approach to contaminated sites has changed from focusing solely on ridding environmental contamination to considering the sites from a real estate point of view. The EPA now sees opportunities for economic development and community revitalization through environmental remediation. This approach aligns well with advocacy for gas station redevelopment after centralized refueling stations are no longer needed.

By treating remediation and redevelopment as part of the same process, each component can be tailored to the other's needs. Ultimately, this approach ensures an appropriate risk-based corrective action since cleanup

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145. US Environmental Protection Agency, 2009, p. 3
146. Kaysen, 2012
standards can be tailored to what is actually intended to come next. Every bit of contamination does not need to be removed if it doesn’t pose a threat to future users, and being required to remove all contamination can be a big disincentive for reuse.\textsuperscript{149} A parking lot constructed on top of petroleum-contaminated soil, for example, can contain pollution and prevent people from exposure without requiring the contamination to be fully removed.\textsuperscript{150} This approach replaces a much more expensive “dig and haul” cleanup approach that would be unnecessary if the property was intended to be paved over anyway.\textsuperscript{151} Envisioning future uses before remediation begins saves money for whoever is cleaning the property – whether developer, former property operator, or government agency – and thus demonstrates the importance of proposing gas station property reuses before they are no longer needed.

Jointly pursuing these complimentary processes at the same time also just makes it more likely that sites will be redeveloped, and this is advantageous in itself. Developers find projects attractive if they are likely to move forward at a regular pace without hang-ups midway. It saves them money and increases certainty about their project. From a municipal and governmental point of view, fostering faster redevelopment of contaminated sites also makes sense. A National Vacant Properties Campaign study in St. Paul shows that clearing vacant buildings saves $4,697 in maintenance and security costs over 20 years but that rehabilitating the building saves $7,141.\textsuperscript{152} This realization shows that facilitating redevelopment as part of any brownfield environmental cleanup is in the interest of municipalities, as well as developers.

Since the US EPA changed its approach from cleaning to reusing brownfields in the early 2000s, there have been dedicated funds designed to help developers re-purpose and redevelop contaminated brownfield petroleum properties. Those seeking to redevelop gas station sites should harness this money. The federal brownfield petroleum program is jointly managed by two EPA offices: the Office of Brownfields and Land Revitalization (OBLR), which has overseen the brownfields program since its inception, and the Office of Underground Storage Tanks (OUST), which specifically promotes the cleanup of leaking USTs. Together, these offices award and manage grants for assessment and cleanup, and they encourage landowners and developers to pursue smart growth strategies as part of their redevelopment.\textsuperscript{153}

\begin{footnotes}
\item[149] Bartsch, Ward, and Strasser, 2002, p. 46
\item[150] Bartsch, Ward, and Strasser, 2002, p. 46
\item[151] Bartsch, Ward, and Strasser, 2002, p. 46
\item[152] Goetz et al. 1998, as cited in National Vacant Properties Campaign, 2005, p. 6
\item[153] US Environmental Protection Agency, “Opportunities”, 2011, p. 1
\end{footnotes}
Opportunities for Reuse and Redevelopment

Acknowledging the environmental challenges and understanding the benefits of a multi-site, multi-stage approach to brownfield redevelopment creates a more informed framework through which to propose redevelopment opportunities for current gas station sites. While these reuse options are tailored specifically to suburban contexts, where at-home EV charging would significantly diminish the need for centralized stations, and while they are anticipated to be implemented most commonly in the regions of the West, Southwest, Midwest, and South that are best poised for large-scale EV adoption, these proposed reuses can be applied across the country. Especially in light of existing gasoline retailing trends and the closure of many gas stations in the past two decades, these redevelopment options are relevant nationwide. It should be noted that not all reuse options are appropriate for all sites, and the unique context of each refueling station changes the appropriateness of each reuse option. Ultimately, any reuse option that clears the financial and liability threshold of reusing a brownfield site can be implemented on gas station sites. Nonetheless, the following specific reuse options are explored for gas station sites left vacant by changes in the retail gasoline market, increases in fuel efficiency, and a move towards distributed electric charging equipment: alternative fueling stations, public spaces and resources, residential buildings, retail space, and offices.

ALTERNATIVE FUELING STATIONS
Because the US's vehicle fleet is expected to rely on a mix of powertrains in the future, some existing gas station sites will need to be retrofitted to support other alternative fuels. Some will be turned into EV supercharger centers, with their retail and entertainment components, to support long distance charging. Because of the greater efficiency of at-home chargers, EV station conversion makes sense only along long-distance corridors or at retail-entertainment centers that draw from a large geography. Thus, these EV station conversions
possible reuse

options

alternative fueling stations

public spaces and resources

residential buildings

retail

office space

credit: Andrew Turco

should only occur at highway rest-stop facilities or adjacent to entertainment-retail-civic centers.

Unlike EVs, however, vehicles running on natural gas, ethanol, hydrogen, and biodiesel will likely require nearly all of their refueling to occur at central depots, much like today’s gasoline-powered cars do. These powertrains can’t as easily rely on a distributed re-powering system like EVs can since they all depend on some form of liquid fuel. Electricity can be easily delivered via existing wires, but liquid fuel must be transported by pipe or truck, which makes it hard to distribute outside of centralized facilities. There may be some exceptions. If, for example, natural gas can be dispensed from home heating oil tanks or a system of distributed biofuel production facilities can also directly refill vehicle tanks, then these particular powertrains may adopt a modified refueling system. Many of the characteristics that make current gas station sites appropriate for their current use, though, will also make them relevant for these other fuels. Locating these retrofitted stations along major roadways, at major intersections, and at convenient community locations, as well as making them highly visible to drivers, will be just as relevant for alternative fuel depots. Additionally, environmental exposure would likely be minimized since much of the site would remain paved and would, therefore, make remediation cheaper.

Federal agencies have already begun to think about how to site alternative fuel stations on former gas station sites. The EPA’s Office of Underground Storage and the US’s Department of Energy’s National Renewable Energy Laboratory (NREL) are conducting analyses to assess where alternative fueling facilities can be located on gas station sites. Just as EVs infrastructure makes the most sense to be sited in suburban areas of the West, Southwest, South, and Midwest, the National Renewable Energy Laboratory is assessing where these alternative fuels are most likely to be adopted so they can recommend the corridors along which retrofitted fueling stations should be constructed.

In converting these gas station sites to alternative fuel stations, certain combinations of fuels make sense to be placed in the same location. The NREL states that the most economical way to make hydrogen is to reform it from natural gas. Ethanol and biodiesel share the same kinds of storage tanks and dispensers, so similarly, these two fuels should be placed together at centralized fueling stations. The one form of alternative powertrain infrastructure that should not be collocated with others is electric charging equipment. According to the NERL, electric charging equipment requires some distance from other liquid and gaseous fuels to eliminate the potential that a spark from the electrical system could

154. Johnson and Hettinger, 2011, p. 1
155. Johnson and Hettinger, 2011, p. 1
156. Johnson and Hettinger, 2011, p. 2
157. Johnson and Hettinger, 2011, p. 2
158. Johnson and Hettinger, 2011, p. 2
ignite these other fuels. For the most part, electric charging equipment will be distributed among drivers’ homes, so this shouldn’t be an obstacle to multiple powertrains operating within the same region.

Many of the current trends affecting existing gasoline stations will likely be amplified in these retrofitted facilities since they will be constructed with additional revenue streams in mind. The increasing reliance on convenience stores will likely continue, and alternative fuel sites can expand on this trend by providing more area for retail space that includes more diversity in the types of goods and services sold. By providing more retail square footage, the station operator earns more revenue and the surrounding community gains access to essentials within a short distance of other uses, like homes or offices.

Finally, there are environmental design and energy improvements that can be undertaken at current gas stations that should also be applied to revamped alternative fuel stations. Considering standard gas station design includes a large overhead canopy to protect customers from the elements, these pre-existing structures could be retrofitted with solar panels in high solar capacity regions to increase the share of clean power sources. The energy generated by these panels provides an extra revenue stream for station operators, and as importantly, it serves to further distribute alternative energy infrastructure into the suburban environment.

Because gas station sites already house infrastructure equipment, the installation of panels at these sites likely wouldn’t stir up opposition within communities, and their placement on top of canopies would put them largely out of site. Following similar sustainable design goals, the amount of pavement at typical gas station sites could be shrunk in order to reduce runoff and the heat island effect. But these changes are differences in the way these stations would be specifically constructed. Functionally, alternative fuel stations would very closely mirror the gas stations they replace.

**PUBLIC SPACES AND RESOURCES**

Because gas stations sit on small properties and are easily accessible, these parcels can provide good reuse opportunities for the introduction of pocket parks, community centers, and other neighborhood amenities that otherwise have few places to locate. Two of the criteria for the distribution of the Small Business Liabilities Relief and Brownfields Revitalization Act funds are based on how remediation and reuse will create parks, new public landscapes, and recreational areas and how redevelopment funds will reduce environmental and health threats. The significance of explicitly including open, green, recreational space in the funding criteria suggests the important role that the current land use pattern of gas station sites could play in creating a network of public open spaces in urbanized or underserved areas. Although these sites’ conversion to new public landscapes

159. Johnson and Hettinger, 2011, p. 2

wouldn’t create a big, singular natural space that could support large-scale activities, the scattered distribution of gas station sites could be advantageous in that their conversion to new public landscapes could provide important breathing space within a variety of micro-neighborhoods. In much the same way that street plaza conversions in New York City have carved out valuable public space in areas that did not previously appear to have room available for parks, the conversion of gas stations to public landscapes could create a similarly vibrant network of small, easily transformed parks.

Not all gas station properties sit within markets that have strong enough economic conditions to support full-scale redevelopment or reuse. This is especially true in less dense suburban areas where there are other greenfield sites available for development. Even in these situations, however, clearing, cleaning, and converting these properties into new public landscapes can improve the quality of life for residents while also increasing the value of surrounding properties. One study that looked at 3,000 house sales from 1980 to 2003 found that homes near vacant lots that had been cleaned and greened increased in value by 30%.161 Philadelphia has taken the approach of greening many abandoned lots in order to create green corridors, and similar approaches to gas station reuse could create green corridors elsewhere.162 This type of conversion could increase storm-water absorption, decrease runoff, and reduce the heat island effect when the extensive paved areas of gas stations are removed.

These landscape conversions would likely have the greatest impact in dense areas where there are otherwise limited green spaces and where most residents do not have their own private yards. Because of their charging infrastructure, though, electric powertrains are best tailored for use in the suburbs, and in these contexts, many residents have their own private green spaces around their homes. In this environment, other public uses would likely bring greater benefit since open space is not otherwise hard to locate in these contexts.

The US EPA recommends non-profit offices, government offices, libraries, schools, firehouses, health clinics, and public infrastructure as public reuse options for former gas station sites. Many of these reuses are pursued today. The Palm Springs Visitors Center in Palm Springs, California is an example of a former Tramway Gas Station that has been repurposed in a relatively straightforward way to serve a public good. Unless multiple parcels can be combined, however, some of these suggested reuse options would not be suited to standard gas station sites. This is another reason to think about multiple-parcel redevelopment approaches when thinking about gas station reuse.

Some of the suggested smaller-scale public use options are feasible on single sites and could be made more rel-
A former gas station in Palms Springs, CA was converted into the Palm Spring Visitors Center.

A re-conceptualized library could differ from the classic model and act more as a public coffee shop where people can work and connect to the internet. Especially in suburban areas where there are few common civic or commercial spaces where residents experience spontaneous interaction, this type of gas station site reuse could anchor the community. This use comes with a number of potential benefits, including the provision of public workspace close to residences, which could thereby reduce commutes; the delivery of internet access to those who might not otherwise have access; and the creation of a central gathering point for people in the community to interact outside of retail experiences.

Other potential public facilities beyond traditional civic buildings and parks would introduce uses that reflect more contemporary needs. In residential neighborhoods where car ownership is low, these stations could be converted into car-share facilities. Maintaining the convenience store would allow the primary income generator to remain, and the car share station would still provide the attraction that brings people to the store, in much the same way that gas pumps do. Being able to pave most of the site for parking would also reduce environmental cleanup costs. Because gas stations are usually sited along major roadways and at important intersections, these sites would be logical places to place car-share vehicles that can then easily access the transportation network. Furthermore, these car share lots could incorporate EVSEs and provide the “at-home” solar charging space for these vehicles, thereby furthering the deployment of alternative power sources in suburban contexts.

RESIDENTIAL BUILDINGS
Residential reuse of gas station properties is appealing because redeveloping station sites in this way provides an opportunity to construct new housing in al-
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ready built-out areas or in settings that have existing commercial uses. This approach leads to either more housing or mixed-use environments. Targeting the right types of gas station sites that are at the gateways to commercial districts creates new homes closer to jobs and other regularly accessed destinations.163 From a developer’s perspective, the same site on the corner of major intersections that makes gas station properties attractive as gas stations also makes them great places to build condos.164 These types of properties have extensive view corridors and two street-facing sides for windows. The small size, high threshold for environmental cleanup, and necessary rezoning required to convert gas stations into residential use, however, is a large disincentive and obstacle for carrying out this kind of reuse outside of very high-demand residential markets. Gas station owners can sometimes realize more profit from redevelopment than from continued gas station operation in high-value real estate markets, but developers likely aren’t willing to pay similar dollars outside of major cities.

Residential reuse often requires the assembly of multiple gas station parcels because of the small size of petroleum brownfields.165 In environments where there is a market for vertical, apartment-style residential construction, the small size of the parcel can be mitigated by the density and economic return of more units that can be placed on such a small site. In many suburban-style environments, though, the small scale of any residential structure on these properties wouldn’t justify the economics of cleanup costs. Particularly high cleanup costs are a result of stricter environmental regulations for residential reuse. Because people are exposed to the environment of their homes more than any other location, regulations mandate higher standards of cleanup for residential reuse. For the most part, locating residential development on uncontaminated spaces is a more cost effective approach, especially outside of very expensive urban markets. Even the EPA acknowledges that conversion to residential use may be prohibitively expensive due to the cost of achieving needed environmental standards.166 Proposed residential building design may also need to be modified as a result of site conditions. The property may not support the construction of a basement, underground parking, or other subsurface structures because of the risk of vapor intrusion from contaminated soil below.167

Beyond the added cost of the remediation, the highest and best use of these sites according to the market is often not as residential but as commercial space. According to a report on recycling gas stations by the Midwest-Northeast Institute, redeveloping gas station sites into
housing without a subsidy is difficult because the sites are often simply more valuable as commercial spaces.\textsuperscript{168}

Finally, gas station properties are often zoned for commercial use through their function as retail refueling stations. Therefore, these sites must often be rezoned for residential use, or the redevelopment project must be mixed-use in order to avoid violating zoning restrictions. Although this obstacle exists, it is easy to overcome since municipalities often partner in the redevelopment process of brownfield sites in order to help obtain necessary cleanup funding and would, therefore, likely coordinate rezoning with the desired redevelopment plan.

These disincentives for residential reuse only recede in cities where residential property values are high enough to outweigh the extra cost and liability during the development phase. For example, multiple former gas station properties in Manhattan have been converted to residential use. In October 2013, there were only 117 stations left in Manhattan, down 44% from 2004 when there were 207, according to statistics from the New York City Bureau of Fire Prevention, as cited by the New York Times.\textsuperscript{169} The fact that gas stations are relatively land intensive and inherently low density for the amount of service they provide means that the property owners can make significantly more money by developing the property into another use. As James Dario Jr.,\textsuperscript{168} Bartsch, Ward, and Strasser, 2002, p. 35
169. Hughes, 2013

Residential redevelopment will likely be common in places with high real estate values that can justify vertical construction but not in typical suburbs. This example shows a BP Station on Houston Street in New York City with a proposed mixed-use redevelopment.
a real estate broker interviewed by the *New York Times*, said, a BP Amoco station on Atlantic Avenue in a prime part of Brooklyn might have sold for $1 million to $2 million as a gas station, but it instead sold for $13 million as a residential development parcel. This is not a phenomenon unique to gas stations. Other low density car-related uses like parking lots and car washes are also frequently redeveloped for higher value uses. Nonetheless, the economics of these types of conversions are likely to be different in average suburban communities.

**RETAIL**

Retail already plays an important role in the profitability and success of gas stations, and this should inform future uses. Although most drivers stop at stations primarily for gas, the owners earn their profits primarily from items bought in the attached convenience stores. Seventy-one percent of gas station sales are from motor fuel, but these sales account for a mere 36% of profit. And the importance of these non-gasoline sales is only growing. The number of gas stations with attached convenience stores grew 4.1% between 2002 and 2007 to a total of 97,508 gas stations nationwide. This is a large proportion of the roughly 116,000 stations in operation in the US. Along with this growth in the number of convenience store has come an enormous increase in the value of sales at these stores. During the same 2002-2007 period, sales at gas station convenience stores grew from $187 billion to $336 billion. This is an 80% growth in sales value. The existing strength of retail at these sites shows that redevelopment for further retail uses would be reasonable and also reinforces the notion that those properties converted to EV supercharging centers would benefit from the incorporation of retail centers.

The state-level distribution of per-capita sales at gas station convenience stores also suggests that certain areas of the country are underserved by retail and would, thus, be particularly appropriate for retail redevelopment. In more rural areas, like the upper Midwest, the upper West, the rural Northeast, and states like West Virginia, people spend significantly more money at gas station convenience stores than they do in states with higher densities, such as California, New York, New Jersey, Massachusetts, and Maryland. This pattern suggests that gas station convenience stores in rural areas are actually serving as critical retail outlets, and it suggests pent-up demand for retail uses. Since these states with the highest per-capita sales also have fewer big cities than the states with the lowest per capita sales, these convenience stores are also likely achieving these sales in more suburban and rural contexts, where there are fewer large downtowns and where people already drive to get to their retail destinations. One prediction from this assessment is that there might still be a healthy

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170. Gregor, 2007  
Small convenience retail components of gas stations can be both profitable and important in urban areas too. In St. Louis, a developer who wanted to demol-
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ish a 1968 Phillips 66 station was unable to do so because of its architectural significance. As a result, the developer undertook a $1 million restoration in 2012 to reuse the 3,200 square feet of usable space to house a Chipotle and Starbucks. This project shows that gas station sites are feasible and financially justifiable as non-gasoline retailing sites, even without the attraction of gasoline refueling and even without expanding the usable retail square footage. Replacing a gas station with a fully built-out retail structure that takes advantage of the property’s entire footprint, however, would lead to even more financial profitability. Gas stations that are already part of a commercial district or retail environment can be designed to take advantage of street fronts or sidewalks to create a desirable street-level, public-facing space that completes the streetscape that it is part of.

Similarly, many gas stations inside or adjacent to residential neighborhoods or along feeder roads in suburban residential communities could be converted to community-oriented retail uses. This type of reuse could serve to bring services closer to residential populations, both reducing VMT for residents and providing a central gathering place within a neighborhood. Especially considering travel for errands is the most common type of private vehicle trip, taking advantage of the proximity of these sites to residential land use could reduce the distances that suburbanites have to travel for basic goods and services. At the same time, site owners could likely find interested business operators as a result of gas stations’ prominent locations at the corners of intersections and along busy thoroughfares, which are attractive to small businesses.

OFFICE
Commercial reuse that includes some combination of retail and small office space could also be feasible on these former gas station sites. Office use, like retail, doesn’t need to meet the same standards of cleanup as residential reuse does. The reduced remediation standards lower the cost of redevelopment. These remediation-cost differences also further stress the importance of tailoring cleanup plans with intended redevelopment projects.

In some American cities, start-up office spaces and shared office spaces have emerged in otherwise outdated non-Class A office buildings that no longer appeal to established tenants and don’t meet large corporations’ floor plan needs. Though these buildings don’t often meet the requirements of larger tenants, they provide a supply of cheaper space to small businesses and start-ups that don’t need typical office configurations and may only have a few employees. The Cambridge Innovation Center, for example, which rents space to individuals or companies in a refurbished office build-

175. Kaysen, 2012
176. US Environmental Protection Agency, 2009, p. 8
ing in Cambridge MA, divides its spaces into units as small as 60 square feet. A number of these types of spaces could easily fit on most gas station sites. While this model is common in urban areas like Cambridge, MA, it could expand into the suburbs and could take advantage of small gas station sites that are much too small for typical office buildings but could succeed as small, right-size startup spaces. The location of gas station would also make these small office spaces easy for workers to access.

178. Cambridge Innovation Center website, 2014
CONCLUSION

The US is transitioning to a mixed-powertrain vehicle fleet, and the existing infrastructure that has supported traditional combustion-engine automobiles for decades will no longer be needed in the same capacity that it is today. Gas stations rely on the need for centralized storage and distribution of liquid fuel. Electric vehicles, however, create the opportunity for distributed “refueling” equipment. As a result, there are opportunities to incorporate this new EV-enabling infrastructure into the built environment that change the way we think about and reuse more than 115,000 existing gas station sites.

Electric vehicles’ refueling needs differ from those of combustion-engine vehicles in a few critical ways. Electric vehicles’ comparatively limited range means that recharging must occur more often than gasoline refueling happens. The source of energy for an EV motor is electricity, which can be much more easily accessed from a variety of land uses and buildings than liquid fuels, such as gasoline, can be. The combination of these unique characteristics demands rethinking of the way a fleet comprised of EVs should be supported. Charging can happen outside of centralized stations since electrical connections are widespread; it has to be very convenient to meet the need of frequent recharges; and it has to be incorporated into other uses so that the extended time of charging doesn’t become an obstacle.

Vehicle travel patterns show that cars are often parked at home overnight for extended periods of time and that Americans’ average daily travel distances can be powered by single overnight charges. Therefore, at-home chargers become the best way to support an EV fleet. Because charging is so critical to this powertrain’s operation, the feasibility of charging opportunities and locations plays an outsized role in determining where EVs can be effectively deployed. At-home charging is significantly easier if the house and vehicle can be directly connected each night, which is possible mainly where single-family homes and private driveways are prevalent. This largely limits productive EV use to suburban environments.

Suburbs are the home to a vast majority of Americans who rely on autos for most of their mobility needs. Thus, targeting EV deployment to these particular development contexts will also trigger the most significant change to the profile of the US’s vehicle fleet. Since the prime motivation for the introduction of electric vehicles is their ability to reduce carbon emission, this suburban application helps the powertrain reach its goal.

The deployment of a complete charging infrastructure at suburban homes has further-reaching repercussions than carbon emission reduction from automobiles. Retrofitting homes with equipment that incorporates on-site solar energy generation and a smart grid system linking solar panels, the electric vehicle, and the home’s
grid energy supply allows the EV to act as a mobile battery storage unit. This function, in turn, allows the EV to balance energy load and introduce solar power into a metropolitan area's energy mix. In this way, at-home EV charging infrastructure not only supports a greener auto fleet but also supports a greener overall energy mix.

Because of this potential to not only change the carbon profile of automobiles but also of grid-supplied energy, targeting the deployment of EVs and these at-home chargers to regions of the US where they will make the most impact can exaggerate this effect. An analysis of regions by power supply emissions shows that the Rockies, Midwest, and South have the dirtiest energy production and could, thus, benefit the most from this greening of the energy system. At the same time, high solar capacity would also make the solar component of at-home systems a large part of the energy supply if distributed across a landscape. The Southwest, West, and South have the highest solar potential in the US and could, as a result, also be appropriate for EV deployment. Taking all of these factors into account paints a picture of where EV adoption should be focused. The suburban West is where EV adoption would be both feasible and provide the greatest emissions benefit. Suburban areas of the Southwest, South, and Midwest would also benefit greatly.

This system of distributed EV charging would greatly reduce the need for gas station facilities. Since recharging can be most effectively accomplished at home and at a few strategically-placed central charging facilities, many gas station sites will be available for redevelopment. Retail gas stations across the country are already being buffeted by a number of trends that have caused tens of thousands of outlets to close in the past twenty years. Because gas stations' environmental condition makes them onerous to redevelop and because vacancy has a number of negative externalities, devising a strategy for their redevelopment before greater EV adoption is important. The redevelopment potential of these sites is also a huge opportunity.

Redevelopment of these sites will be particularly important in areas where high levels of EV infrastructure installation will diminish the need for gasoline. Best reuse options focus on provisioning new public facilities, expanding existing retail uses, and introducing a new, small-scale office typology into the suburban environment. Public reuse options take advantage of gas stations' geography within many neighborhoods and their accessibility to large populations and roadways. The best of these reuse options include new networks of re-conceptualized libraries that provide portals to internet access and dispersed workspaces, as well as the location of shared equipment, like car share vehicles. Beyond these more public-oriented uses, the increasing dependence of gas stations on retail sales shows that a systematic conversion of these sites to more fully engage retail opportunities for capturing drivers during the time it takes for them to recharge their electric vehicles would likely be feasible and productive.
SOURCES


Cambirdge Innovation Center. “Your Office - Done As You’d Like It.” <cic.us>. 8 May 2014.


