TAKE CHARGE

A ROADMAP TO ELECTRIC NEW YORK CITY TAXIS

NYC TAXI & LIMOUSINE COMMISSION

DECEMBER 2013

Taxi & Limousine Commission

Taxi & Limousine Commission
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Take Charge: A Roadmap to Electric New York City Taxis

A publication compiled by the
Mayor's Long-Term Electric Taxi Task Force

December 2013

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> EXECUTIVE SUMMARY

In his January 2013 State of the City Address, Mayor Bloomberg called for a one-third electric taxi fleet by 2020. To work towards this goal, he commissioned the Long-Term Electric Taxi Task Force to bring together many of the stakeholders who could provide insight into what it would take to meet this goal. A research team that comprised staff from the NYC Taxi and Limousine Commission (TLC) and the Mayor's Office of Long-Term Planning and Sustainability (OLTPS) supported the task force's work and assembled this report.

Electrifying One Third of the Taxi Fleet Would Have a Significant Positive Environmental Impact. Replacing 4,412 of today's taxis with electric vehicle (EV) taxis could have a profound impact on the city's air quality and greenhouse gas emissions. Electric vehicles have zero tailpipe emissions and do not emit pollutants--some of which have been linked to chronic health problems like asthma, emphysema, and heart disease--into NYC's air. Electrifying the taxi fleet would also support the PlaNYC goal of reducing the city's carbon footprint. Replacing one third of existing taxis with EVs would result in an annual well-to-wheels abatement of about 55,000 tons of CO2e, or a decrease in total CO2e emissions from taxis of 18%. It would take the replacement of about 35,000 private vehicles with EVs to realize this level of reduction in CO2e emissions.

Electric vehicle technology has improved significantly in recent years and will likely continue to improve in the future. Major automakers and niche manufacturers are innovating and investing in the EV space, and decreasing battery prices will likely enable them to produce batteries with long ranges at lower prices than they do today. Assuming vehicle and battery prices decline as rapidly as is projected by some industry experts and that the federal EV tax credit remains in place, by 2017 the total cost of ownership (TCO) of an EV taxi could be below the TCO for a comparable non-EV taxi.

A Large Quick Charger Network Would Be Necessary to Support a One-Third EV Taxi Fleet. We project that a network of 350 50kW quick chargers would be needed to ensure that drivers in a one-third electric taxi fleet would have access to chargers when they need them. This suggests that the ratio of quick chargers needed to electric vehicles on the road is approximately 1:13. A phased rollout of both electric taxis and quick chargers would help determine whether real-world charger needs align with this model-generated estimate. It would also provide the market with an opportunity to release technologies, such as reservation systems, that could increase system efficiencies.

Constructing and Operating this Quick Charger Network Would Be Expensive, but Strategies Exist to Narrow the Gap Between Expected Expenses and Revenues. We project that a 350-quick charger network would cost about $20 million per year (accounting for both capital and operating

costs) and could generate approximately $13 million per year in revenue from charging fees from taxi drivers. The projected gap between network costs and revenue from drivers could significantly narrow if:

- Significant economies of scale in installation costs could be realized
- Prices of quick chargers continued to decrease
- Substantial revenue could be generated from non-taxi users, advertising, or vending
- Smart technologies or changes in driver behavior could reduce the number of chargers needed
- A cost-effective technique to mitigate demand charges was implemented

NYC has the Grid Capacity to Accommodate a 350-Quick Charger Network. Based on taxi service areas, fleet garage locations, and driver residence locations, most chargers would need to be located in Manhattan and Western Queens. The largest mismatches between grid capacity and demand for chargers occur in West and Central Midtown in Manhattan and in Long Island City in Queens, but both areas have adjacent areas with additional electric load capacity. There are pros and cons to both on-street and off-street charger siting, and a large network would likely include some of each type of installation.

A Typical EV Taxi Driver Would Need to Quick Charge his or her EV Once During the Shift and Once Between Shifts. With a 35kWh EV battery, we project that the average electric taxi driver would spend a total of about forty minutes per shift charging. This would probably include some charging between shifts and some charging during shifts. The amount of time spent charging would vary from driver to driver depending primarily on how many miles he or she drives during a shift.

Taxi Industry Adaptability. This task force report assumes relatively little change in the taxi industry's operational practices or TLC regulation. This assumption was made out of a belief that an ideal electric taxi program would cause minimal disruption to the industry, and that the industry has chosen many of its current practices based on years of experience and learning about what works well and what does not work well. Changes in TLC regulation or industry practices surrounding lease caps, service refusals, vehicle retirement schedules, responsibility for fuel costs, shift change times, and shift change locations could significantly facilitate EV adoption. In addition, technological advances such as battery swapping instead of plug-in charging and inductive (i.e., wireless) charging could be game changing in their ability to make EVs more easily used as taxis.

Recommendations. EVs present an opportunity to drastically reduce the air quality and carbon impacts associated with NYC's taxi fleet. The City should continue to pursue electric vehicles through a variety of strategies, such as issuing RFIs to vehicle and charger manufacturers to gain additional information on EVs coming to market and to refine estimates on the costs of an infrastructure network. It should explore additional vehicle and infrastructure pilot programs to test vehicles or charging methods different from those being tested in the current pilot program. The City should join with like-minded cities to show the automotive industry what types of EVs our fleets need and look for ways to partner with automakers to provide the next generation of custom-designed NYC taxis. In addition, the City should partner with Con Edison for further research into what it would take to build out the infrastructure needed to serve an EV taxi fleet.

> GLOSSARY + ACRONYMS

CNG – Compressed Natural Gas. A fuel that is sometimes used to power motor vehicles.

DCFC – Direct Current Fast Charger. Also known as a quick charger or level 3 charger. A charger that converts alternating current power to direct current power, enabling it to charge an electric vehicle battery more quickly than other chargers.

DCP – NYC Department of City Planning.

DOT – NYC Department of Transportation.

DOV – Driver Owned Vehicle – A mode of taxi operation in which the driver owns his own taxi vehicle but does not own a medallion. Instead, the driver leases the medallion from an owner or agent.

E-hailing – The act of requesting a taxicab pickup using a smartphone application rather than a hand-hail.

EV – Electric Vehicle. Sometimes called "pure EVs" or "all-electric vehicles." Vehicles that are powered solely by an electric motor and battery and do not have an ICE.

FHV – For-Hire Vehicle. This term is usually used to refer to car service vehicles, which include livery vehicles and black cars.

Fleet – A mode of taxicab operation in which a corporation or an individual who does not personally operate the taxi controls both the medallion and the vehicle to which it is affixed. Drivers who work with the fleet (sometimes called "fleet drivers") lease both the vehicle and the medallion by the week or by the 12-hour shift at a rate that is regulated by the TLC. Fleets maintain a garage where they dispatch drivers, repair vehicles, conduct bookkeeping, and carry out other business activities. The term "fleet" can also refer to a driver who leases a taxi from a fleet garage.

Hack-up – The process of converting a vehicle for taxi use, which includes installation of the meter, rooflight, in-taxi technology system (also known as TPEP), and partition between the driver and rear passenger seats. It also includes vehicle painting and application of required decals.

HEV – Hybrid Electric Vehicle. A vehicle with both an ICE and an electric drive system with motor and battery. HEVs do not support external charging.

ICE – Internal Combustion Engine. A vehicle is referred to as an ICE vehicle when it is fueled by gasoline, diesel, compressed natural gas or bio-fuels and has no electric drive system or charging.

kW – Kilowatt – A unit of electrical power equal to 1,000 Watts.

kWh – Kilowatt hour. A unit of energy equal to 1000 watt-hours or 3.6 megajoules. For constant power, energy in watt-hours is the product of power in watts and time in hours.

Level 2 Charger – A charger that provides 240 volt alternating current charging. A level 2 charger charges an EV's battery in several hours. Charging times vary based on the size of a vehicle's on-board charger.

Level 3 Charger – See DCFC.

Medallion – A license that is required to operate a taxi in New York City. There is a cap on the number of licenses that may only be increased through legislative action. Medallions may be transferred among individuals or corporations.

NYPA – New York Power Authority.

NYSERDA – New York State Energy Research and Development Authority.

OEM – Original Equipment Manufacturer. Also called an automaker.

Owner-driver – A yellow taxi driver who owns his or her own medallion and vehicle.

OLTPS – NYC Mayor's Office of Long-term Planning and Sustainability.

PANYNJ – Port Authority of New York and New Jersey.

PHEV – Plug-in Hybrid Vehicle. A vehicle with both an ICE and an electric drive system with motor and battery. Supports external charging. ICE engine is typically more powerful than the electric drive system.

Quick charger – See DCFC.

TCO – Total Cost of Ownership. This refers to the net cost of purchasing, operating, maintaining, and reselling an asset.

TLC – Taxi and Limousine Commission, an agency of the City of New York.

TPEP – Taxi Passenger Enhancement Program – The technology system that is in every taxi. It includes a

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> INTRODUCTION

In his January 2013 State of the City Address, Mayor Bloomberg called for a one-third electric taxi fleet by 2020. To work towards this goal, he commissioned the Long-Term Electric Taxi Task Force to bring together many of the stakeholders who could provide insight into what it would take to meet this goal. Task force members included:

- Con Edison
- Empire Clean Cities
- Mayor's Office of Long-Term Planning & Sustainability (OLTPS)
- Metropolitan Taxi Board of Trade (MTBOT)
- Natural Resource Defense Council (NRDC)
- New York Power Authority (NYPA)
- New York State Energy Research & Development Authority (NYSERDA)
- New York Taxi Workers Alliance (NYTWA)
- NYC Department of City Planning (NYC DCP)
- NYC Department of Transportation (NYC DOT)
- NYC Taxi and Limousine Commission (NYC TLC)
- Port Authority of New York and New Jersey (PANYNJ)
- Real Estate Board of New York (REBNY)

The Electric Vehicle Task Force first convened in February 2013 to establish its primary objectives and key research questions. At this time, the task force formed three subcommittees based on the individual expertise of participants and the primary areas of investigation required to create a comprehensive plan for electric taxi adoption. The subcommittees were:

- *A Vehicle Committee* to research the current and future electric vehicle market and the economics of operating an electric vehicle as a taxi.
- *A Charging Infrastructure Committee* to (1) research the economics of constructing and operating a quick charger network, (2) model when, where and how often taxis would need to charge, and (3) research what quick charger siting constraints may exist.
- *Taxi Industry Committee* to research current taxi industry operational norms and the challenges and opportunities associated with operating electric vehicles in this unique industry.

In March 2013 the Charging Infrastructure Committee and the Vehicle Committee each convened independently to delve more deeply into specific issues, review preliminary findings, and further refine research questions. A subsequent full task force meeting took place at City Hall in May 2013.

Research and Methodology

A research team that comprised staff from the NYC Taxi and Limousine Commission and the Mayor's Office of Long-Term Planning and Sustainability supported the task force's work and assembled this report. The research team relied on various research methods:

- Individual interviews with task force members and technical experts from organizations including Ricardo Engineering (automotive consultants), Con Edison, the Electric Power Research Institute (EPRI), and the US Department of Energy's Idaho National Labs.
- Review of published reports by universities, government organizations, and private firms.
- Media reporting on electric vehicles and EV infrastructure.
- Information provided directly by manufacturers and installers of electric vehicle infrastructure and electric vehicles.
- Analysis and modeling using TLC electronic trip-sheet (TPEP) data and TLC administrative records.
- Application of Ricardo Engineering's technical findings on taxi electric vehicle total cost of ownership and battery charge times.
- Application of Con Edison analysis of infrastructure capabilities.
- Interviews with taxi drivers, fleet owners/operators, and taxi industry stakeholder groups such as the New York Taxi Workers Alliance (NYTWA), the League of Mutual Taxi Owners (LOMTO), and the Metropolitan Taxi Board of Trade (MTBOT).

- Field observations of gas stations and taxi fleets.
- Observations from ongoing TLC-Nissan Electric Taxi Pilot Program.
- Discussions with other cities engaged in developing electric vehicle infrastructure.

Report Organization

The first section of this report includes several chapters that provide important background information for the study. The second section describes the core analysis of the feasibility of using electric vehicles as taxis and of constructing and operating the charger network to support them. The third section describes regulatory or industry changes that could occur to improve the feasibility of using electric vehicles as taxis and the task force's recommendations. The report also contains an appendix providing additional detail for some sections of the report.

Section I. Background Information

- **Chapter 1. Benefits of Electric Vehicles.** This chapter describes the environmental and other benefits associated with electric vehicles, enabling the reader to understand the motivation for exploring a one-third electric taxi fleet.
- **Chapter 2. Taxi Industry Background.** This chapter describes many aspects of the NYC taxi industry that impact the feasibility of using EVs as taxis. This chapter is especially helpful for readers without extensive specific knowledge of the NYC taxi industry.
- **Chapter 3. Electric Vehicles - Present and Future.** This chapter describes characteristics that would be desirable in an electric taxi and the characteristics of the electric vehicles that are currently available. It also provides some insight regarding the future direction of the electric vehicle industry.

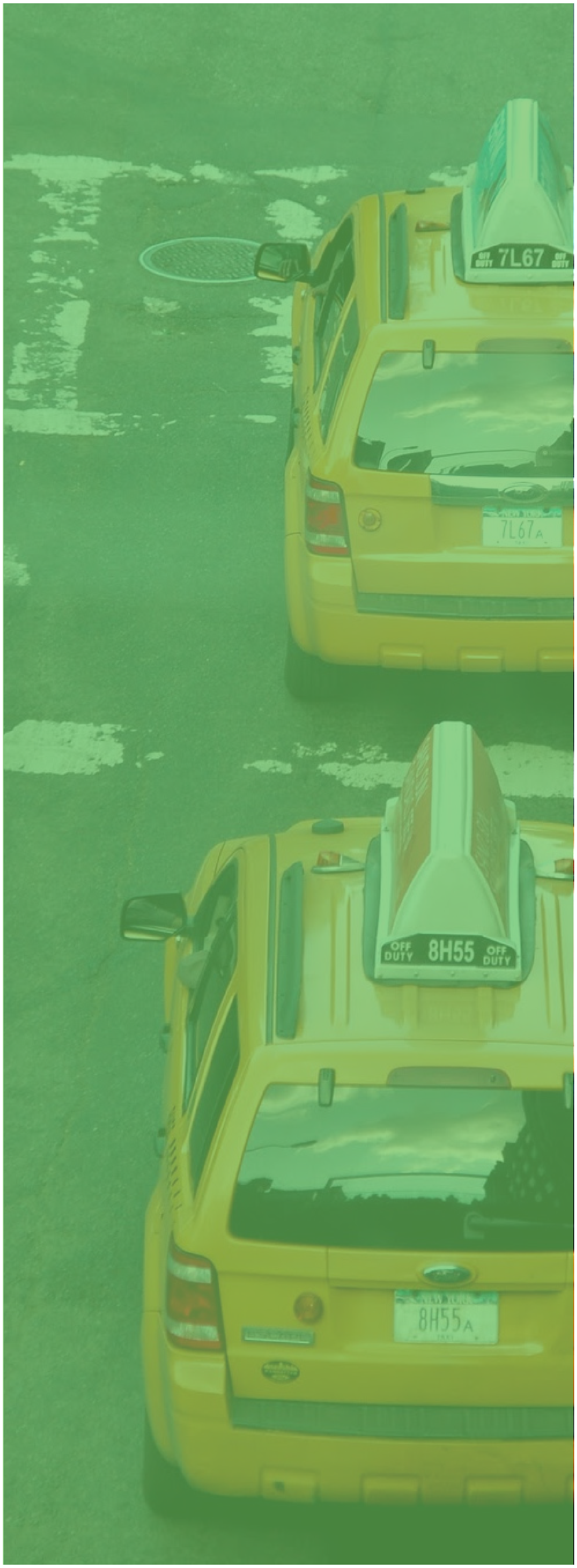
Section II. Feasibility Analysis

- **Chapter 4. Economics of Electric Vehicle Ownership.** This chapter details the total cost of ownership of an electric vehicle when used as a taxi and compares it to the total cost of ownership of a comparable non-EV taxi.
- **Chapter 5. Level of Infrastructure needed to Support Taxi Fleet.** This chapter describes a model that estimates how many quick-chargers would be needed to support a one-third electric taxi fleet. It provides estimates for how often and how long drivers would need to charge and when peak demand at chargers would take place.
- **Chapter 6. Economics of a Charging Infrastructure Network.** This chapter details estimates for how much it would cost to build and operate the quick charger network to support a one-third electric taxi fleet and the revenue that could be generated to support the network.
- **Chapter 7. Electric Vehicle Quick Charger Siting Feasibility Analysis.** This chapter describes initial analysis of the feasibility of siting a sizeable network of quick chargers in the taxi service area.

Section III. Policy and Recommendations

- **Chapter 8. Taxi Industry Adaptability.** This chapter describes changes that could occur in taxi operational practices, TLC regulation, or charging technology that would improve the feasibility of using electric vehicles as taxis.
- **Chapter 9. Task Force Conclusions and Recommendations.** This chapter outlines the task force's recommendations.
- **Appendix.** The appendix includes additional detail on various topics in each chapter.

The widespread adoption of electric vehicles by the yellow taxi industry is a complex endeavor. The work of the government, non-profit and private-sector members of the task force has resulted in a significant improvement in understanding what it would take to meet Mayor Bloomberg's goal.



SECTION I
BACKGROUND INFORMATION

> CHAPTER 1: BENEFITS OF ELECTRIC VEHICLES

In 2007, Mayor Bloomberg released PlaNYC, an unprecedented effort to prepare the city for one million more residents, strengthen the economy, combat climate change, and enhance the quality of life for all New Yorkers.[i] PlaNYC calls for a 30% reduction in the city's greenhouse gas emissions by 2030.[1] This includes a reduction in transportation-related emissions, which were responsible for 22% of the city's greenhouse gas emissions in 2008, by 44%. Passenger vehicles and light trucks represent 74% of the city's total transportation-related greenhouse gas emissions.[ii]

Automobiles and taxis are essential components of New York City's transportation network; however, these vehicles produce tailpipe emissions that significantly impact the environment. Today, New York City's fleet of 13,237 taxis contains a mix of hybrid and internal combustion engine (ICE) vehicles. Electric vehicles could provide an opportunity to decrease the environmental impact of New York City's yellow taxis, contributing to significant improvements in air quality and a reduction in the carbon footprint of the city's yellow taxi fleet.

1.1 Improvements in Air Quality

Replacing one third of today's ICE and hybrid taxis with electric vehicle taxis could have a profound impact on the city's air quality. Unlike conventional vehicles, electric vehicles have zero tailpipe emissions. The New York City Community Air Survey, which included results of monitoring conducted in the summer of 2009, investigated five harmful pollutants and reported that their highest concentrations were found in areas with high vehicular traffic, like Midtown and Downtown Manhattan and sections of the Bronx, Brooklyn, Queens, and Staten Island closest to large freeways.[iii] Many of these pollution concentrations align with areas of that city that have a high density of taxi trips.

Key Findings:

Replacing one third of today's taxis with electric vehicle taxis would have a profound impact on the city's air quality and carbon footprint.

It would result in an annual abatement of 55,640 tons of CO2, or a decrease in total CO2 emissions from the taxi fleet of 18%.

The replacement of a single conventional taxi with an electric vehicle creates an emissions impact that is equivalent to replacing roughly 8 NYC personal cars with electric vehicles.

These pollutants have been linked to chronic health problems like asthma, emphysema, and heart disease, and certain population segments, like young children and senior citizens, are particularly susceptible.[iv] NO_2, for example, is strongly predicted by proximity of heavy traffic and has been directly linked to severe respiratory problems.[v] Electricity generation does generate emissions; however, from a public health perspective it is preferable for these emissions to be released farther away from large population centers, like New York City, that face air quality challenges.

Photo courtesy of Mayor's Office Flickr.

Figure 1.1. What is an electric vehicle (EV)?

Electric vehicles (EVs) are powered solely by an electric motor and battery. They do not have an internal combustion engine like most cars do, instead relying on a re-chargeable battery for power. The all-electric vehicles that are the focus of this report are only one of several types of alternative fuel vehicles on the market. The below table describes the main types of conventional and alternative-fuel vehicles.

Vehicle Types	Description	Example
Internal Combustion Engine (ICE) Vehicles	• Fueled by gasoline, diesel, compressed natural gas, or bio-fuels • No electric drive system or charging	• Ford Crown Victoria
Hybrid Electric Vehicle (HEV)	• Has both an ICE and an electric drive system with motor and battery • Does *not* support external charging • ICE engine typically *more* powerful than the electric drive system • Can use less gas per mile than ICEs	• Toyota Camry Hybrid • Toyota Prius (non-plug-in model) • Ford C-Max Hybrid
Plug-in Hybrid Vehicle (PHEV) (sometimes called "gas-electric")	• Has both an ICE and an electric drive system with motor and battery. • Supports external charging • ICE engine typically *more* powerful than the electric drive system • Typically has smaller battery than an EV	• Ford C-Max Energi • Plug-in Toyota Prius • Mitsubishi Outlander
Electric Vehicle (EV) (sometimes called "pure EVs" or "all-electric vehicles")	• Powered solely by an electric motor and battery (no ICE) • Must be charged externally (plug-in, wireless, or battery swap)	• Nissan LEAF • Tesla S • BYD E6
Range-Extended EVs	• ICE engine has been added to an EV to either recharge the battery or assist in propelling the vehicle • ICE engine typically *less* powerful than the electric drive system.	• BMW i3 EV • Chevrolet Volt

This report focuses on EVs, the only common vehicle type listed that produces zero tailpipe emissions and consumes zero gasoline. It is notable, however, that range-extended EVs or PHEVs could be attractive options for taxi use because the gasoline engine extends the vehicle's range. This could eliminate the need to charge mid-shift and could enable drivers to serve passengers with farther destinations. However, if the battery is fairly small and taxis are running primarily on the gasoline engine, then a large investment in EV infrastructure may not be worthwhile. With PHEVs or range-extended EVs, drivers may need to be incentivized to use electricity with low fuel costs and convenient charge points.

The sources powering New York City's energy grid are another factor making it a promising location for electric vehicle implementation. Nuclear, hydroelectric, and other low-greenhouse-gas-emitting energy sources already create nearly 40% of the energy that New York City consumes.[vi] As the electricity grid becomes more efficient or gravitates towards cleaner energy sources, the emissions associated with powering electric vehicles can decline. The New York State Energy Research and Development Authority (NYSERDA) has deployed or is developing 1,800 MW of wind, solar, hydro, and biomass energy through programs such as its renewable portfolio standards and the NY-Sun Initiative. The introduction of electric vehicles paves the way for reduced emissions and improved air quality.

1.2 Reduced Carbon Footprint

Even after accounting for the energy-production-level emissions associated with electric vehicles, electrification of taxi vehicles would significantly lower the fleet's carbon emissions. With one of the lowest rates of car ownership in the country, New York City's 13,237 yellow taxis represent a more significant portion of the transportation-related emissions than is the case in other cities.[2] A fleet of 13,237 taxis generates approximately 315,491 tons of CO_2 a year.[3] Assuming that the average yearly mileage remained consistent, replacing 1/3 of these taxis with EVs would result in an annual abatement of 55,640 tons of CO_2, or a decrease in total CO_2 emissions of 18%.[4] Whereas this abatement level is possible with just 4,412 electric taxis, it would take 34,857 private vehicles to realize the same reduction in CO_2 emissions.[5] This means that, in terms of emissions, the replacement of a single conventional taxi with an electric vehicle is equivalent to the replacement of roughly 8 NYC personal cars with electric vehicles.

1.3 Resiliency

EV taxis could support the goals of "A Stronger, More Resilient New York," PlaNYC's 2013 comprehensive resiliency plan in two ways.

- Conventional vehicles rely on gasoline. In the event of a fuel shortage, such as the one that followed Hurricane Sandy in October 2012 and kept many taxis off the road, electric vehicles would still have been able to operate because some of the city still had power.[6] By maintaining a nearly 100% gasoline-fueled fleet, we were more vulnerable to service disruptions than we would have been with a fleet powered by a variety of energy sources.[7]
- EVs could also be designed to be usable as mobile power storage units in the event of an emergency, keeping mobile phones and other important devices running for days.

1.4 Additional Benefits

There are three additional benefits that would be realized by introducing EVs into the taxi fleet: visibility, price consistency and energy security.

- *Visibility*: With an average of nearly 500,000 yellow taxi trips a day transporting over 650,000 passengers (roughly 80,000 of whom are tourists), a one-third electric taxi fleet would expose significant numbers of passengers to electric vehicles.[8] Exposing hundreds of thousands of New Yorkers and visitors to electric vehicles could have a significant public education impact and could encourage adoption of EVs by more private automobile owners.
- *Price consistency:* Gasoline prices are tried to the world oil market and can be highly variable. Electricity prices are much less volatile. For example, between October 2010 and October 2012 the national average retail price for a gallon of regular gasoline varied by approximately 40%. In that same period, the national average retail price for a kilowatt-hour of electricity varied by only 11%.[vii] Powering taxis by electricity rather than gasoline can provide more certainty and stability for the industry as to what its operating expenses will be in the coming months and years.
- *Energy Security*: Converting one third of the taxi fleet to electric vehicles would result in nearly 13 million fewer gallons of gasoline being consumed each year. This would support the US Department of Energy's goals of reducing US petroleum imports by one-third by 2025.[viii]

> CHAPTER 2: TAXI INDUSTRY BACKGROUND

Electric vehicles are already performing well in many applications. This report assesses how these vehicles would function in the unique NYC yellow taxi industry. This chapter provides some basic background information about the industry, providing context that will enable the reader to better understand the unique economic and operational challenges and opportunities associated with operating EVs as taxis. It covers the following topics:

- The Taxi Medallion System
- Taxi Business Operational Models
- Taxi Mileage
- Taxi Shift Change
- Taxi Driver Breaks
- Taxi Fueling
- TLC Regulatory Powers

Readers who already have extensive knowledge of the NYC taxi industry may wish to skip ahead to the next chapter.

2.1. The Taxi Medallion System

Key Findings:

NYC taxis have high revenue potential and operate with a valuable license called a medallion. This leads most taxi operators to maximize revenue-generating hours and minimize downtime, limiting time available for charging.

New York City's yellow taxis require a medallion license for operation. Medallion taxis, or yellow taxis, have the right to pick up street-hailing passengers anywhere in the five boroughs. There are 13,237 medallion taxis on the road today, and action by the State Legislature or City Council is required for the creation of new medallions.

The medallion license originated with the Haas Act of 1937, which capped the number of taxis operating in the city. This legislation also established two categories of medallions: fleet and independent. Fleet (also sometimes called simply "mini-fleet" or corporate) medallions are generally owned by multi-taxi fleets or investors. Taxis operating with a mini-fleet taxi medallion are required to operate for 2 9-hour shifts each day. Independent medallions are distinct from corporate medallions in that no individual may own more than one individual medallion and they often have TLC "owner-driver" requirements. Many, though not all, owners of independent medallions are required by TLC rules to personally complete a minimum of 180 nine-hour shifts per year.

Medallion licenses are assets that can be re-sold and traded, and market prices have climbed drastically in recent years. In 2003, the average independent medallion sale took place at

Figure 2.1. Who works in the New York City Taxi Industry?

Drivers

Most New York City taxi drivers fall into one of four categories:

- **Owner-Drivers:** Owner-drivers own both the taxi vehicles they drive and their own medallions. Many lease their vehicles to second-shift drivers for additional revenue.
- **Fleet Drivers:** Many taxi drivers do not own their own medallions or taxi vehicles and instead rent vehicles with medallions on a per-shift basis from a fleet garage.
- **DOV Drivers:** Some drivers do not own their own medallions, but still operate independent of fleet garages. These drivers own their taxicab vehicles but lease medallions, generally on a long-term basis, through an **Agent**. Many DOV drivers operate in teams, with two drivers driving alternate shifts on the same vehicle and sharing vehicle and medallion lease expenses.
- **2nd Shift Drivers.** Many drivers who do not own their medallions or taxi vehicles lease the second shift from an owner-driver or a DOV driver.

Medallion Owners

While some medallions are owned by taxi fleets or by owner-drivers, many medallion owners are more passive investors or retired owner-drivers who earn revenue by leasing their medallions to others. Usually through an **Agent**, an investor or retired-driver medallion owner leases his or her medallion to a **DOV Driver** or to a **Fleet Operator**.

Agents

TLC licenses agents to lease medallions on behalf of investor or retired-driver **Medallion Owners**. Some agents operate taxi fleets, whereas others lease primarily to DOV drivers and do not maintain garages or take an active role in taxi operations.

Fleet Operators

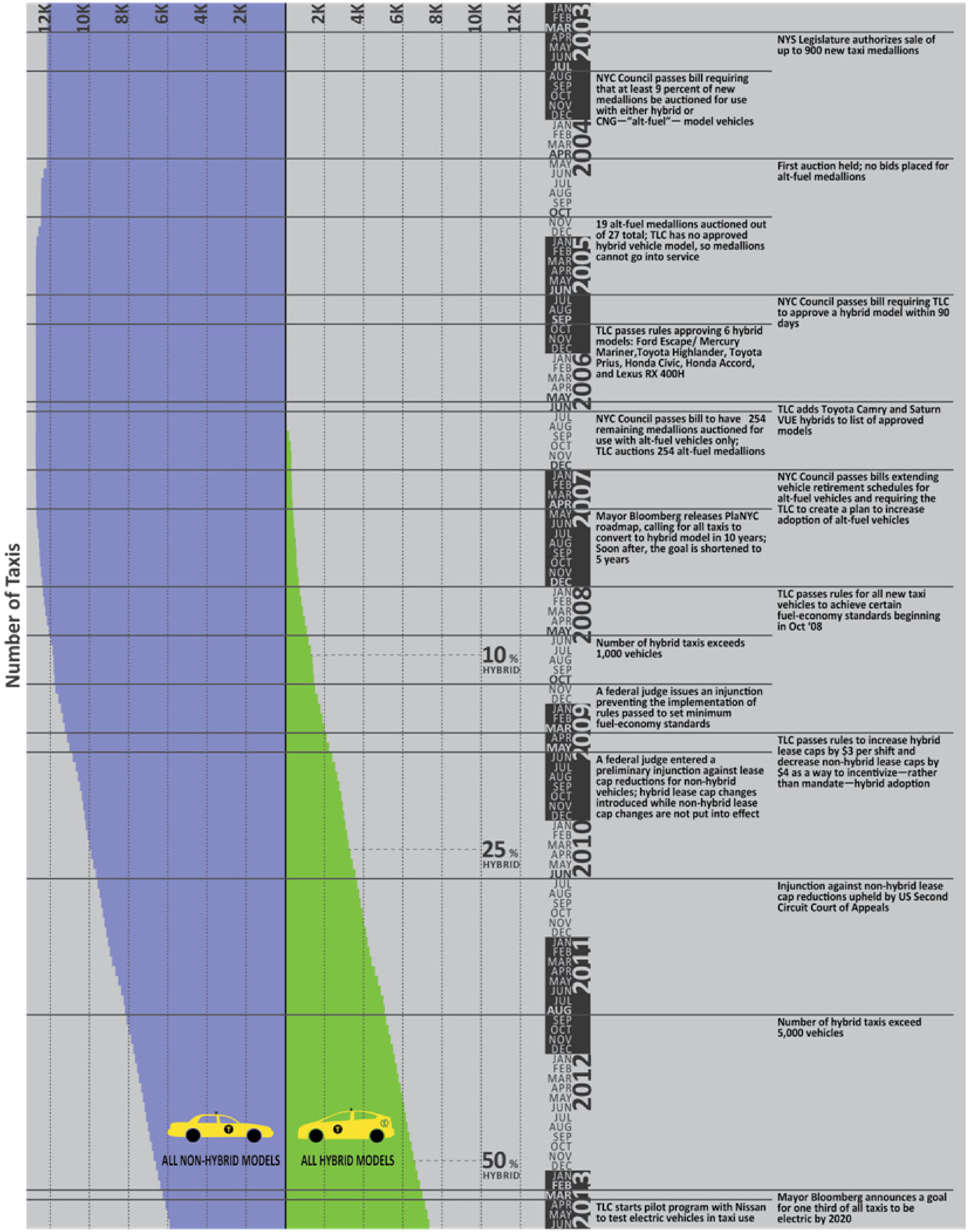
Taxi fleets generally operate garages where they maintain fleets of vehicles that are leased on a per-shift basis to **Fleet Drivers**. While some taxi fleets own both the taxi vehicles and the associated medallions, others lease some or all of the medallions from investor or retired-driver **Medallion Owners**. The TLC also licenses many taxi fleets as Agents.

Who Owns, Leases and Drives NYC Taxi Medallions and Taxi Vehicles?

	Owner-Driver	DOV Driver	Fleet Driver	Fleet Operator	Agent
Owns a medallion?	Yes	No	No	Maybe	No
Owns a vehicle?	Yes	Yes	No	Yes	No
Drives a vehicle?	Yes	Yes	Yes	No	No
Leases vehicle (with medallion) to a primary driver?	No	No	No	Yes	No
Leases vehicle (with medallion) to a second-shift driver?	Often	Often	No	Yes	No
Leases a medallion to vehicle owner?	No	No	No	No	Yes

Trade industry groups represent various segments of the taxi industry. See appendix for more information.

Figure 2.2. Timeline of Hybrid Taxis in New York City



$224,958 and the average fleet sale took place at $260,917. In 2013, independent medallions were sold at prices between $800,000 and $1,050,000 and fleet medallions were sold at prices between $1,000,000 and $1,320,000.[ix] Many medallion owners finance their medallion purchases through loans. This high medallion price signals, at least in part, the strong revenue stream associated with medallion taxi operation. The rate of return from medallion operation compares favorably with other investment opportunities (see appendix for more information). High medallion prices also demonstrate the pressure medallion owners face to keep their taxis in operation, generating lease revenue or fare revenue, in order to make returns on their investments.

2.2. Taxi Business Operational Models

Key Findings:

NYC taxis respond to hails and do not provide call-ahead service. They therefore spend most of their shifts driving either with or without a passenger.

- This means they use more fuel than vehicles that spend significant time parked waiting for a call, which creates demand for longer-range batteries and quick methods of charging.

Taxis are operated either in large fleets or as independent small businesses. Some drivers own their own taxis, but many do not.

- This creates a unique purchase decision dynamic because the economic incentives of vehicle purchasers only sometimes align with those of drivers. There would probably be no one-size-fits-all approach to incorporating EVs into the taxi industry.

In many cities taxis respond to both hails and call-ahead requests. In NYC medallion taxis focus on street hails and do not respond to calls for pickups from a central dispatch company. Livery cars (also known as car service vehicles), black cars (also sometimes called car service vehicles), and luxury limousines provide call-ahead service in New York City, while yellow taxi drivers spend much of their shifts cruising to find street-hailing passengers. Yellow taxis cruise primarily in the Manhattan Central Business District. They also serve taxi stands at high-volume locations, such as Grand Central Terminal, Pennsylvania Station, LaGuardia Airport, and JFK Airport.

Understanding the three primary taxi business models will help the reader better understand many of the operational and economic forces driving this analysis. Yellow taxis in New York City generally operate in three distinct business models:

Fleet: In a fleet operation, a corporation or an individual who does not personally operate the taxi owns both the medallion and the vehicle to which it is affixed. Drivers who work with the fleet lease both the vehicle and the license by the week or by the 12-hour shift at a rate that is regulated by the TLC. Fleets maintain a garage where they dispatch drivers, repair vehicles, conduct bookkeeping, and carry out other business activities. Often taxi drivers change shifts at fleet garages. The highest concentration of fleet garages is in Western Queens. There are also concentrations of garages in Western Brooklyn and the Bronx. Although there are some fleets that continue to maintain garages in Manhattan (concentrated on the West Side), their numbers have shrunk as the industry has migrated to Queens. Fleets operate about one third of taxis.

Driver Owned Vehicle (DOV): In a DOV operation, the driver owns his own taxi vehicle but does not own a medallion. Instead, he or she leases the medallion from an owner or agent to be able to operate his vehicle as a yellow medallion taxi. Often the DOV drivers work in teams (sharing the driving time, medallion lease expenses, and vehicle expenses) or the primary DOV driver “sub-leases” his vehicle and medallion to other drivers. About one third of taxis are operated as DOVs.

Owner-Driver: An owner-driver operating a medallion taxi owns both the medallion license and the vehicle to which it is affixed. While he or she may authorize additional drivers, the owner is, with some exceptions, responsible for personally keeping the car in service for at least 180 shifts each year. Owner-drivers operate about one third of taxis.

2.3. Taxi Mileage

Key Findings:

NYC taxis typically drive 70,000 miles per year and 114 miles per shift. Therefore:

- The electric vehicles that would be best suited for taxi use would likely have longer ranges than many existing EVs.
- Quick-charging will likely be necessary to power these high-mileage, time-constrained vehicles.

The high mileage taxi drivers log each shift significantly impacts the vehicles, battery sizes, and charging equipment would be needed to serve an EV taxi fleet. Beginning in December 2008, all New York City taxis were required to record and transmit electronic trip records and GPS data through the Taxi Passenger Enhancement Program (TPEP). These records record the time, location, and metered fare of all taxi trips. Much of the data presented in this and other chapters is based on TPEP trip-sheet data. TLC also collects mileage readings at each taxi's inspection. According to TLC inspection data, the average taxi drives about 70,000 miles per year.

The vast majority of New York City taxis are double-shifted. In fact, only 1,312 medallions, or 9.9% of the total taxi fleet, are single shifted.[9] According to TPEP trip-sheet and inspections data, the median New York City taxi drives 114 miles each shift (See Figure 2.3).

2.4. Taxi Shift Change

Understanding how, when, and where taxis perform the shift change will help the reader understand (1) some of the operational issues taxi operators would face in adopting electric vehicles and (2) some charging network challenges that the City should expect with a large fleet of electric taxis.

TLC rules do not regulate exactly when shift changes take place; however, lease caps imply the existence of a "day shift" and a "night shift." Many fleet garages choose to maintain 5 AM and 5 PM shift changes, and analysis of TPEP data shows that this model carries through to most of the industry. Figure 2.4 shows the share of medallions changing shift by hour.

There is wide variation in amount of time taxis take to change shift. Figure 2.5 shows the number of minutes that passed on a sample day between the final drop-off of one driver's shift and the first pickup of the next driver's shift.

Key Findings:

90% of taxis are double-shifted and many, though not all, shift changes occur in a tight timeframe.

- This limits the amount of time available to charge and highlights the need for quick charging and large vehicle batteries.

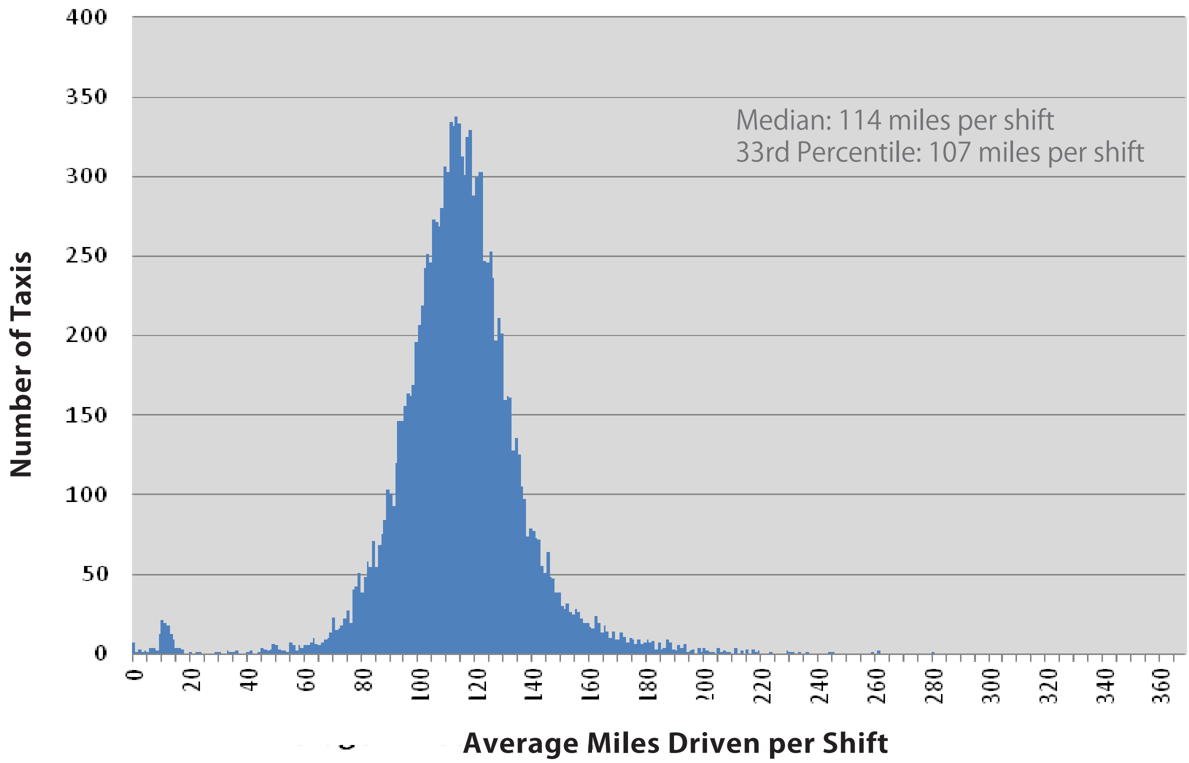
Currently taxi shift changes cluster at specific times of day.

- This could cause clustering at chargers and drives up the number of chargers needed. It presents opportunities for technological innovation and/or industry adaptability to make more efficient use of charging infrastructure.

We believe afternoon shift changes are generally more rushed than morning shift changes because they occur during a period of peak passenger demand. However, this rush does not translate into very short times between shifts. This is probably due to rush hour traffic and the time drivers need to travel from their final fares to their shift change locations and from shift change locations to fare-rich areas of the city. The morning shift change tends to be less rushed, possibly because there is lower demand for taxis in these early morning hours.

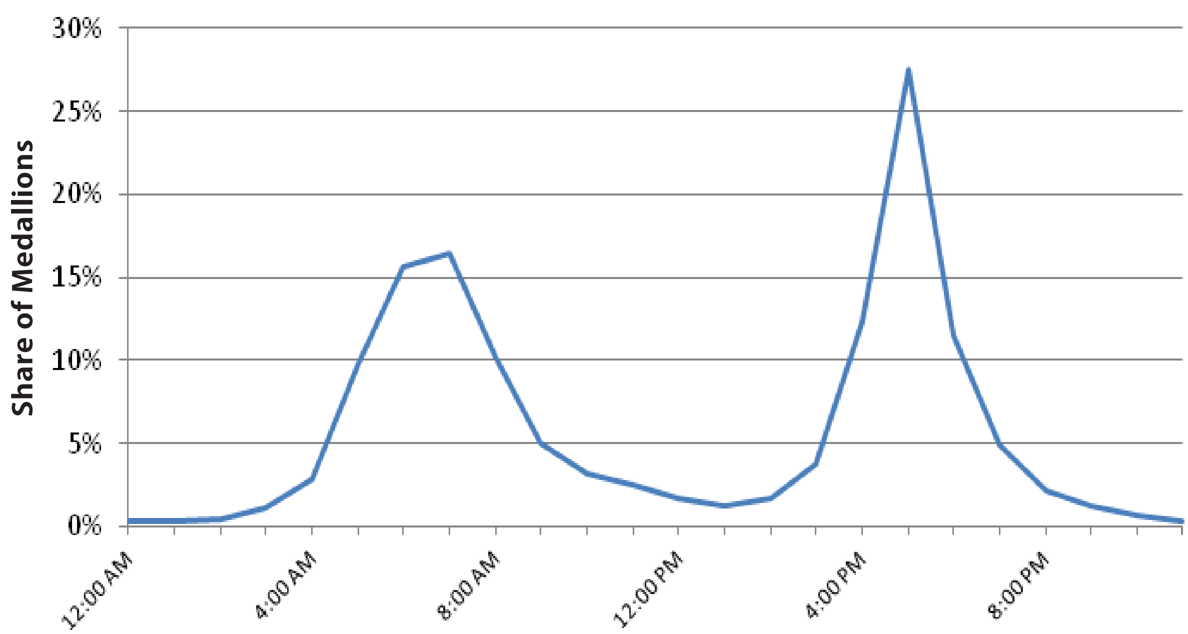
There are several ways that drivers and fleets manage the transition between shifts. Some fleets require drivers to return vehicles to their garages at the end of each shift to settle up finances and hand the vehicle over to the driver working the next shift. Other garages allow drivers to perform off-site shift changes, handing over the vehicle in-person at a gas station or at a location near the drivers' homes. Sometimes drivers park the taxi at a designated swap location. At this location the next driver picks the vehicle up whenever he is ready to begin his shift, eliminating the in-person rendezvous and saving time for both drivers.

Figure 2.3. Miles Driven by NYC Taxis, Per Shift



Source: TLC analysis of September 2012 TPEP Trip-sheet data.

Figure 2.4: Medallions Changing Shift by Hour



Source: TLC analysis of January 2013 TPEP trip-sheet data.

Figure 2.5: Minutes Between Shifts

	AM Shift Change	PM Shift Change
<20 minutes	0.2%	4.9%
21 to 45 minutes	0.4%	15.1%
46 to 60 minutes	1.4%	11.7%
1 hour +	98.1%	68.3%

Source: TLC analysis of January 2013 TPEP trip-sheet data. For the purpose of this table, the AM shift change includes changes that occur between 5 am and 8 am and the PM shift change includes changes that occur between 4 pm and 7 pm.

2.5 Taxi Driver Breaks

Key Findings:

Most taxi drivers take some breaks that could potentially be used as charging opportunities.

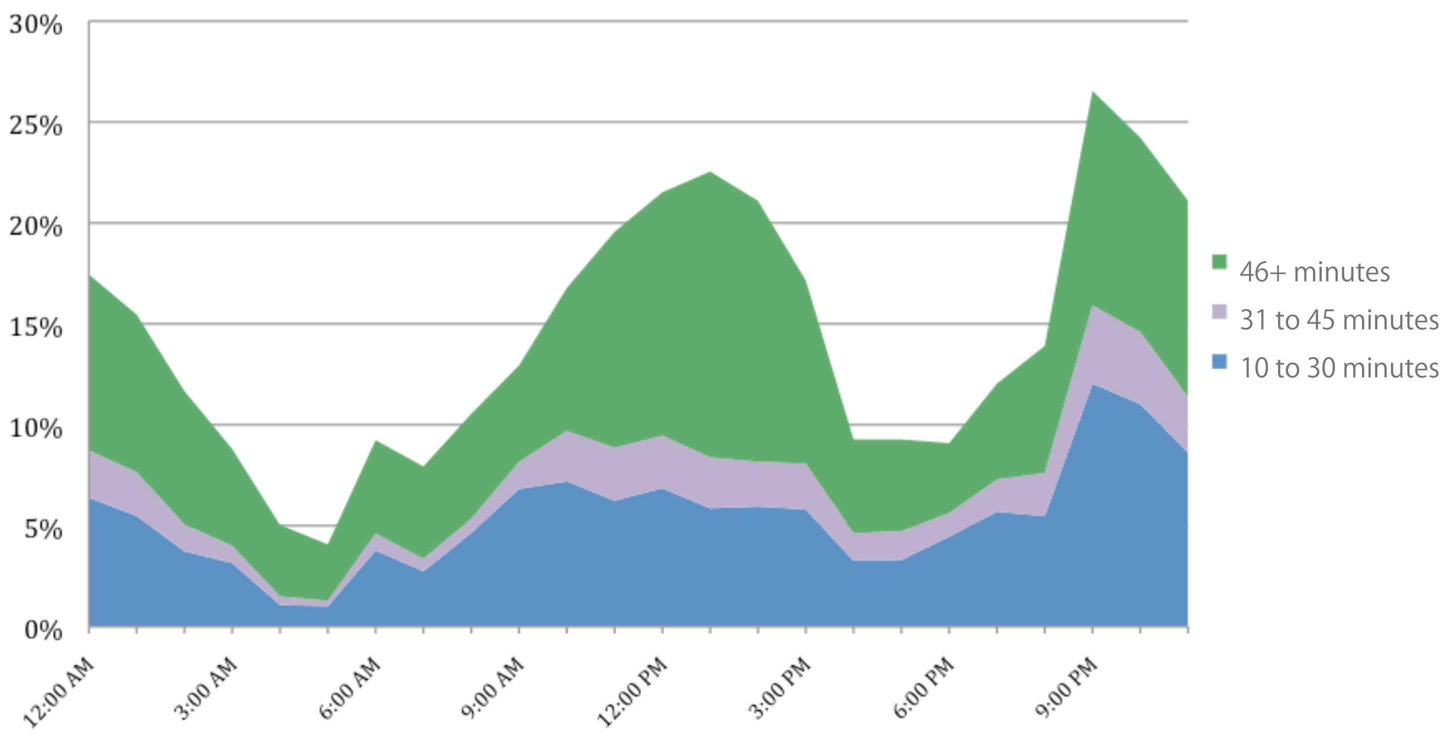
There would still be time costs for drivers needing to charge during the shift or between shifts.

Understanding taxi driver break patterns helps us identify challenges and opportunities for taxi drivers to charge their electric vehicles. With the majority of the taxi fleet operating in two 12-hour shifts, drivers must take breaks during those shifts to use the bathroom, eat meals, and stretch their legs. For an electric vehicle operating as a taxi, a mid-shift break could also double as a charging opportunity. Using one week of TPEP trip-sheet data and a sample of 1,259 taxis with sufficient data to perform this analysis, the TLC investigated the frequency and duration of these breaks.

In this study, TLC measured the duration of a break as the time between dropping off a passenger and picking up the next passenger. This means that a portion of the time identified as a "break" was probably spent driving to the breaking location and/or cruising for the first street-hailing passenger after the break. When applied to electric vehicles, this means that not all time recorded as a break is available charging time.

Longer breaks are more likely than shorter breaks to be successfully re-purposed as charging opportunities.

Figure 2.6: Medallions Taking Breaks Each Hour



Source: TLC analysis of January 2013 TPEP trip-sheet data.

- In 63% of the sampled vehicles, the driver typically took at least one 30+ minute break per shift.
- In 41% of the sampled vehicles, the driver took at least one 45+ minute break per shift.

A vehicle with a 35kWh battery can charge from 10% to 80% in about 30 minutes.[x] Therefore existing longer breaks can provide an opportunity to multi-purpose time once spent at lunch, prayer, or using the restroom as time also spent charging. Figure 2.6 shows the share of medallions on the road during each hour that took a break within that hour. The highest concentrations of breaks appear to take place around lunchtime and late at night.

2.6 Taxi Fueling

Key Findings:

Taxi drivers do not currently spend a lot of time fueling.

- Time currently spent fueling does not represent a significant amount of time that could be re-purposed for charging.

With most taxis travelling over 200 miles per day, frequent refueling is necessary. Handing over a vehicle with a full tank of gas to the next driver is a common convention in the industry, so many taxi drivers buy gas after every shift. It is common for drivers to refuel immediately before shift change, and many New Yorkers have noticed high concentrations of taxis at gas stations in the hours before the shift change. TLC investigated whether existing time spent at gas stations could be re-purposed as time spent quick-charging.

To test this hypothesis, TLC conducted 12 weekday field observations from 3:30 to 6:00 PM at 10 gas stations in Manhattan and Queens. The field observations surrounded the 5:00 PM shift change, which we believe represents the busiest period for taxis at gas stations. We found that the average gas station visit for a taxi driver (which included waiting in line to get to a pump, time spent fueling, and time spent lingering after fueling) lasted a total of 6.25 minutes. In the observed sample, 70% of taxis were able to enter the station and proceed directly to the pump, while the remaining 30% had to wait in line first. Therefore although the lines of taxis at gas stations at shift change times are eye-catching, in actuality most taxi drivers typically spend little time fueling. Therefore time spent charging would be an additional time cost for drivers and not merely a replacement of time spent buying gas.

2.7 TLC Regulatory Powers

A private business wishing to green its fleet may do so simply by purchasing electric vehicles. TLC, however, does not own or operate the taxi industry in New York City. TLC regulates the industry, and understanding the scope of its regulatory powers is helpful to understanding the mechanisms through which it could encourage EV adoption. The purpose and powers of the TLC are outlined in the New York City Charter.[xi] Two aspects of TLC regulation are particularly relevant to electric vehicles: regulation of the taxi vehicle and regulation of the economics of taxi operation.

Key Findings:

TLC regulates taxi vehicle specifications, but cannot mandate fuel economy.

TLC regulates taxi fares and lease caps. Therefore TLC rules significantly impact revenue streams of taxi drivers, fleets, and medallion owners. TLC could use regulatory tools to change the economics of the industry to better align with EV operation.

Regulation of taxi vehicle. For the yellow taxi industry, TLC sets specifications for vehicles, which include measurements, maximum vehicle age, and equipment standards. It currently requires that all vehicles being put into taxi service be new vehicles. The TLC does not, however, have the ability to set fuel economy standards.

Regulation of economics of taxi operation. The TLC also regulates many of the costs borne by both licensees and passengers. This includes taxi fares and lease caps (i.e., the maximum rates a medallion and/or vehicle owner may charge a driver to use the medallion and/or vehicle for a shift or a week). While TLC rules do not regulate the timing of shift changes, lease cap rules do imply the existence of a day shift and a night shift.

2.8 Conclusion

The yellow taxi industry characteristics described in this chapter provide useful context for the analysis in this report. There are various elements of the taxi industry that pose challenges to EV adoption:

- A vast majority of taxis are operated two shifts per day, which limits the time that could be used for low-cost level 2 charging or quick charging without impacting revenues.
- Drivers cruise for fares, which drives up the number of miles logged per shift and the battery range and/or number of charges needed to complete a shift.
- Many taxi drivers do not own the vehicles they drive, which creates a unique purchase decision dynamic because the economic incentives of vehicle purchasers (vehicle purchase, repair, and maintenance costs) only sometimes align with those of drivers (fuel costs, passenger and driver experience).
- Because NYC taxis typically operate 70,000 miles per year and 114 miles per shift, the electric vehicles that would suit taxis would likely have longer ranges than most existing EVs.
- Quick-charging will likely be necessary to power these high-mileage, time-constrained vehicles. It is more expensive and difficult to install than level 2 charging.
- Shift changes currently cluster in certain times of day, which could lead to clustered demand for vehicle chargers.

There are also elements of the existing taxi industry that could facilitate EV adoption:

- Approximately 10% of taxis are currently single-shifted. These vehicles would have sufficient time to level 2 charge between shifts and could more flexibly structure their shifts to avoid seeking a charge at peak times.
- Most taxi drivers take some breaks that could potentially double as charging opportunities.
- TLC rules, such as those governing fares and lease caps, significantly impact revenue streams of taxi drivers, fleets, and medallion owners. TLC could use regulatory tools to change the economics of the industry to better align with EV operation.
- Taxis drive an average of 70,000 miles per year. If circumstances arise in which the costs per mile of charging an EV are significantly lower than the costs per mile of running on gasoline (e.g., gas prices increase and/or charging can be delivered inexpensively), the taxi industry would experience significant reductions in operating costs by adopting EVs.
- The taxi industry is incorporating new technologies, such as e-hailing, that could increase the efficiency of the system and reduce cruising miles.

Subsequent chapters take these underlying conditions into account in outlining the path to a one-third electric taxi fleet.

The EV Taxi Pilot Program

On April 22, 2013, the TLC launched a pilot program to evaluate the use of electric vehicles as taxis in New York City. Using Nissan LEAF vehicles, this program will help the TLC learn more about incorporating EV charging into a driver's day, putting the significant wear and tear of taxi use on an EV, and maintaining battery range even with frequent quick charging. Although the Nissan LEAF is not an ideal vehicle for taxi use in terms of vehicle size or range, it provides an excellent opportunity to explore the feasibility of electric vehicles as taxis.

All pilot program participants were given a level 2 charger for use at their homes or garages, which charges the vehicle in approximately 8 hours. In addition, they were given access to two quick chargers in Manhattan, which bring the battery from 0% to 80% in around 30 minutes. Taxi owners were incentivized to participate in the program with free use of the Nissan LEAF vehicle, retirement extensions on their current vehicles, and small stipends to cover additional expenses.

This pilot will be evaluated based on data from several sources. The TLC has been monitoring the vehicles' daily activity through TPEP trip-sheet data and quick charger portals. Additionally, Nissan and the Idaho National Labs will be monitoring data related to battery life, driver habits, and vehicle range. Conversations with fleets and drivers participating in the pilot program will also be key in helping to identify the pros and cons of operating EVs as taxis.

Initial findings show that owner-driver participants have adapted well to their new vehicles. In the first three months of the pilot, EVs completed more than 2,000 trips. Owner-driver participants have been generating revenue that is on par with their past earnings and have been completing a number of trips per hour that is comparable to the trip volume they handled with their conventional taxis.

The owner-driver participant who has been in the program the longest has found a routine for driving the EV taxi that works for him. He level 2 charges at home to begin his shift with a 100% charge. He picks up a fare at the airport on the way to Manhattan and works for about 5 hours before doing a 30-minute quick charge. This quick charge usually powers him for the remainder of his shift. He has been able to complete his shift and return home off just two charges of his 24kWh battery per shift by conserving range. He does this by cruising less than he did before and by turning down passengers with far-away destinations whose trips he could not complete without running out of charge. (There is an exception to TLC refusal rules for the pilot.) Limited battery range (especially on hot summer days), time spent charging, and quick charger equipment malfunctions have been the primary challenges participants have been experiencing. Initial results show that there is potential for an EV --especially a vehicle with a longer range than the LEAF--to be used successfully as a NYC taxi.

> CHAPTER 3: ELECTRIC VEHICLES: PAST + PRESENT

The integration of electric drive-train technology into today's conventional vehicles is a common and increasing trend around the world. Original equipment manufacturers (OEMs) are incorporating electric power into many of their vehicle models such as hybrids, plug-in hybrids, and fully electric vehicles (EVs). While the taxi industry has now broadly accepted hybrid technology (57% of taxis were hybrids as of August 2013, a share that has grown steadily), plug-in hybrid vehicles and fully electric vehicles are not yet in use as taxis and comprise a small share of the overall vehicle market.

An essential component of assessing the feasibility of incorporating electric vehicles into the taxi fleet is understanding what vehicle characteristics the industry needs in order to meet both its own needs and those of passengers. It is also important to understand whether a vehicle with these characteristics is available now or is likely to be in the future. To address these issues, this chapter begins with a discussion of what characteristics an electric vehicle would ideally have in order to be well suited for taxi use. It next lists the electric vehicles that are currently available. It concludes with a discussion of where the electric vehicle industry is headed in the future and how this impacts the likely ease of adoption of electric vehicles as New York City taxis.

3.1. Desirable Characteristics for an Electric Taxi

When considering which EV models would be suitable for taxi use, one should consider both the vehicle's size and its range.

Vehicle size. Once the NV200 Taxi of Tomorrow assumes the status of the Official Taxicab Vehicle, which will depend upon when and whether the City is successful at defending the program in court, taxi vehicles will be required to have an EPA interior volume index of at least 130 cubic feet.[xii] Even if the program is not able to go forward due to the litigation, then pre-existing minimum vehicle size requirements will continue to be in place. Additionally, taxis are required to have four doors and there is a passenger expectation that they will have seating capacity for five people – four passengers plus the driver. Some taxis (50% by 2020 according to a recent legal agreement between the City and disability advocates) must also be accessible to individuals who use wheelchairs. These characteristics and size specifications are rare in current electric vehicle models. The only current EV model we have identified that has an interior volume of over 130 cubic feet is the Toyota RAV4 EV;[xiii] however, if TLC wanted to allow more EVs to be used as taxis, it could change its regulations to permit smaller EVs to be used as taxis. There is precedent for this practice. In the past the TLC had special size specifications for hybrid vehicles to facilitate their adoption when there were fewer large hybrid models available.

Vehicle range. TLC records show that current medallion taxis typically travel about 200 miles per day or 114 miles per shift.[xiv] There is one currently available EV, the Tesla Model S (which has an EPA range of 208-265 miles

Key Findings:

The ideal electric taxi would be able to cover a shift in a single charge, have plenty of space for passengers, the driver, and luggage, and be competitively priced with other vehicle options.

EV technology has improved a great deal in recent years and is projected to continue improving for the next decade.

Although none of the electric vehicles available today is a perfect fit for the taxi industry, the industry is dynamic and new EVs that are better-suited for EV taxi use are likely to come to market.

Photo courtesy of Nissan.

Figure 3.1. Pure Electric Vehicle Models that are Currently Available, Selected Characteristics

Make/ Model	MSRP**	MSRP after Federal Tax Credit	Motor Size	Battery Size	Range	Quick Charge Capable	On-Board Charger	Interior Volume****
2013 Nissan LEAF	$30,100*	$22,600	80kw	24kWh	75 miles	Yes	6.6kw***	116.4
2012 BYD E6	$52,500	$27,500	75kw	Unknown	122 miles	Yes	-	-
2014 Tesla Model S (60kWh)	$73,070*	$65,570	225kw	60kWh	208 miles	Yes	10kw	125.6
2014 Tesla Model S (85 kWh)	$81,070	$73,570	270kw	85kWh	265 miles	Yes	10kw	125.6
2012 Mitsubishi MiEV	$29,825*	$22,325	49kw	16kWh	62 miles	Yes	-	97.9
2014 Ford Focus EV	$35,200	$27,700	107kw	23kWh	76 miles	No	6.6kw	103.9
2013 Toyota RAV4 EV	$49,800	$42,300	115kw	41.8kWh	103 miles	No	10kw	144.6

**MSRP includes the option cost necessary to equip the vehicle for quick charging (QC)*
*** MSRP does not include any tax credits or incentives. All MSRPs exclude destination and handling charges.*
****On-board charger increases from 3.3kw to 6.6kw when option for quick charger is included. An on-board charger is device in an EV that directs energy from a Level 2 charger into the vehicle battery, and higher kW on-board chargers enable faster Level 2 charging.*
*****Interior volume equals a vehicle's passenger volume plus cargo volume.*

What determines an EV's operating range? Many factors, such as a vehicle's weight, tire size, motor size, aerodynamics, auxiliary power draw (defrosters, heat, A/C), and driver's driving habits, contribute to the vehicle's range. While all of these factors can be changed slightly to maximize a vehicle's range, the factor that has the most significant impact on vehicle range is battery size. Larger batteries allow vehicles to travel farther on each charge, but they drive up the vehicle purchase price.

depending on the battery size selected[xv]) that would be able to complete most taxi shifts without a mid-shift charge. Other currently available EV models would need mid-shift charges to be able to complete most taxi shifts. As batteries decrease in price and manufacturers learn more about consumer preferences, more longer-battery-range vehicles are likely to enter the market.

3.2. Characteristics of Currently-Available EVs

With the above characteristics in mind, we have done research on the current EV models available. Figure 3.1 presents the seven vehicle models that come closest to suitability for taxi use.[10]

Figure 3.1 helps demonstrate several important concepts for understanding the challenges of using EVs as taxis at this time:

- The range-price trade-off
- Varying charging capabilities
- Vehicle size considerations

Range-Price Trade-off. Figure 3.1 illustrates some tradeoffs between vehicles. For example, the Nissan LEAF is available at a price comparable to the purchase price of some of today's taxis, but offers a range that is relatively low. While the Tesla Model S (60kWh battery) offers a range that would be excellent for taxi use, the MSRP of $73,070 is much higher than taxi owners would likely be willing to pay for a vehicle. The higher-end features in the Tesla (a luxury vehicle) are part of why the Tesla costs so much more than the LEAF. However, the very large battery in the Tesla also drives the price difference.[11]

As a point of comparison, the Ford Crown Victoria (which is out of production but was a very popular taxi model) sold for $26,950. The Toyota Camry Hybrid, currently the most popular hybrid taxi, sells for $26,140. The NV200 Taxi of Tomorrow (TOT) has an MSRP of $29,700 in 2013 (this includes most hack-up equipment). The only EVs on the market today that have a similar price point are the Nissan LEAF and the Mitsubishi MiEV.

Varying charging capabilities. A limitation of some of the currently available taxis stems from how they are engineered to charge. All EVs have the capability to charge at Level 2 home and public chargers, but not all vehicle models support quick charging. For example, the Nissan LEAF and the BYD E6 have the ability to quick charge, while neither the Ford Focus EV nor the Honda FIT EV supports quick charging. Taxi drivers currently spend very little time fueling. Time spent charging in some cases translates into lost fare revenue.

What about EV tax credits? Currently, the federal government is offering a tax credit of up to $7,500 for purchases of electric vehicles with a battery larger than 5kWh. The initial credit is for $2,500, with an additional credit of $417 for each kWh over the initial requirement of 5kWh, up to a total tax credit of $7,500.[xvi] By law the credit phases out when manufacturers reach 200,000 EVs sold, and manufacturers are not close to reaching this level of sales. As of July 2013 GM had sold just over 43,000 EVs, while Nissan (the 2nd-largest seller) had sold nearly 18,000. How long this tax credit will continue to be available will therefore depend primarily on market adoption rates.

Therefore it is important for an electric vehicle that will be used as a taxi to have quick-charging capabilities.[12]

Vehicle size considerations. Even assuming TLC modified its vehicle size specifications to enable more EVs to qualify for taxi service, the small size of most current EVs could be a barrier to their adoption by the taxi industry. Figure 3.2 compares the passenger volume, cargo volume, and total volume of some EV models and some popular current taxi models.

What about battery swapping? One major issue for any of the EV models shown in Figure 3.1 is the time needed to charge. For taxi drivers, "time is money" and some drivers--especially those who do not see charging time as equivalent to rest break time--will see time spent charging as a major deterrent to adopting an EV. Even on a 50 kW quick charger, a LEAF takes 30 minutes to charge from 0% to 80%. Larger batteries offer longer ranges, but this also increases the time it takes to charge the battery. It is possible to make a charger that charges the battery more quickly (e.g., a 100 kW charger), but this drives up equipment costs somewhat and demand charges significantly. Another solution, which currently only Tesla supports (but has not yet introduced into the market), is battery swapping. See Chapter 8: Taxi Industry Adaptability, for more information on battery swapping.

Most taxi owners currently choose vehicles with larger passenger volumes than are available in the currently available EVs (except for the Toyota RAV4 EV). The two most popular taxi vehicles in the existing fleet, both of which have gone out of production, are the relatively large Ford Crown Victoria and Ford Escape Hybrid. Taxi owners putting new vehicles into operation in 2013 have been selecting primarily Toyota Camry Hybrids, Ford C-Max Hybrids, and Toyota Prius V Hybrids.

Vehicle size is far from the only factor driving vehicle purchase decisions. However, driver comfort, passenger comfort, and adequate space for luggage are all important considerations for TLC and for taxi owners selecting a vehicle, and vehicle size could prove to be a barrier to EV adoption. The Nissan NV200 Taxi of Tomorrow has a roomy 142 cubic feet of interior volume. If this vehicle becomes available in an electric version in the United States, it would provide excellent space for the driver, passengers and luggage. In addition, if TLC wanted to allow more EVs to be used as taxis, it could change its regulations to permit smaller EVs to be used as taxis. There is precedent for this

Figure 3.2. Vehicle Size, Electric Vehicles and Popular Taxi Vehicles

Vehicle	Passenger Volume (ft^3)	Cargo Volume (ft^3)	Total Interior Volume (ft^3)
EVs:			
Nissan LEAF	92.4	24	116.4
Tesla Model S	94	31.6	125.6
Mitsubishi MiEV	84.7	13.2	97.9
Ford Focus EV	90.7	13.2	103.9
Toyota RAV4 EV	108.2	36.4	144.6
Honda FIT EV	89.3	12	101.3
Current Taxis (# on road):			
Ford Crown Victoria (4,415)	114.2	20.6	134.8
Ford Escape Hybrid (4,054)	99.5	27.8	127.3
Toyota Camry Hybrid (2,128)	102.7	15.4	118.1
Toyota Highlander (448)	145.7	42.3	188.0
Toyota Prius V (268)	97.2	34.3	131.5
Ford C-Max (228)	99.7	24.5	124.2

Source: TLC 2013 Licensing information and OEM websites.

practice. In the past the TLC had special size specifications for hybrid vehicles to facilitate their adoption when there were fewer large hybrid models available.

3.3 Battery Prices

EV technology has improved a great deal in recent years and is projected to continue improving for the next decade. Declining battery prices will improve the affordability of longer-range EVs. For example, analysts estimate that the current price for a battery pack is between $500 and $875 per kWh. Forecasts predict that the pack price will decrease to between $225 and $700 per kWh in 2017, and will continue to decline through 2022 (See Figure 3.3). While there are some disagreements among analysts as to what the current and future prices of batteries are, there is broad consensus in the industry that the price will significantly drop in the coming years.

Since the battery is the most expensive component of the vehicle, the advancement in battery technology will drastically decrease the price of EVs over time. For example, using the Bloomberg New Energy Finance estimates, a 24 kWh battery in 2013 costs $21,000, but in 2017 that same battery is projected to cost $10,800. This steep reduction in price will strengthen the economic case for EVs in the taxi industry. In addition, if gasoline prices increase significantly but electricity costs remain relatively stable, EVs will become relatively more attractive.

Declines in battery prices or increases in battery density could help remedy the size issue that exists in the current EV selection.

- If battery costs continue to decrease, OEMs could increase battery sizes so that they could power a larger vehicle for a reasonable range without driving vehicles costs too high. However, the downside of larger batteries is they increase the weight of the vehicle, negating some of the increased range added by the larger battery.
- Increases in battery density--the amount of range per unit of battery mass--would present a greater opportunity. Denser batteries would allow OEMs to increase battery capacity without adding the weight that negatively impacts vehicle range.

3.4 The Future of Electric Vehicles

Whereas the previous section focuses on existing EV availability, this section provides insight into what EV availability might look like over the next 10 to 15 years. The City already has a long-term contract with Nissan North America for a supply of taxis and supporting parts for the next five years, with the option to extend the contract if there is no superior vehicle available (the "Taxi of Tomorrow" program). This includes a commitment to examine an EV version of the NV200 Taxi. However, it is worthwhile to consider product planning from other auto manufacturers for several reasons:

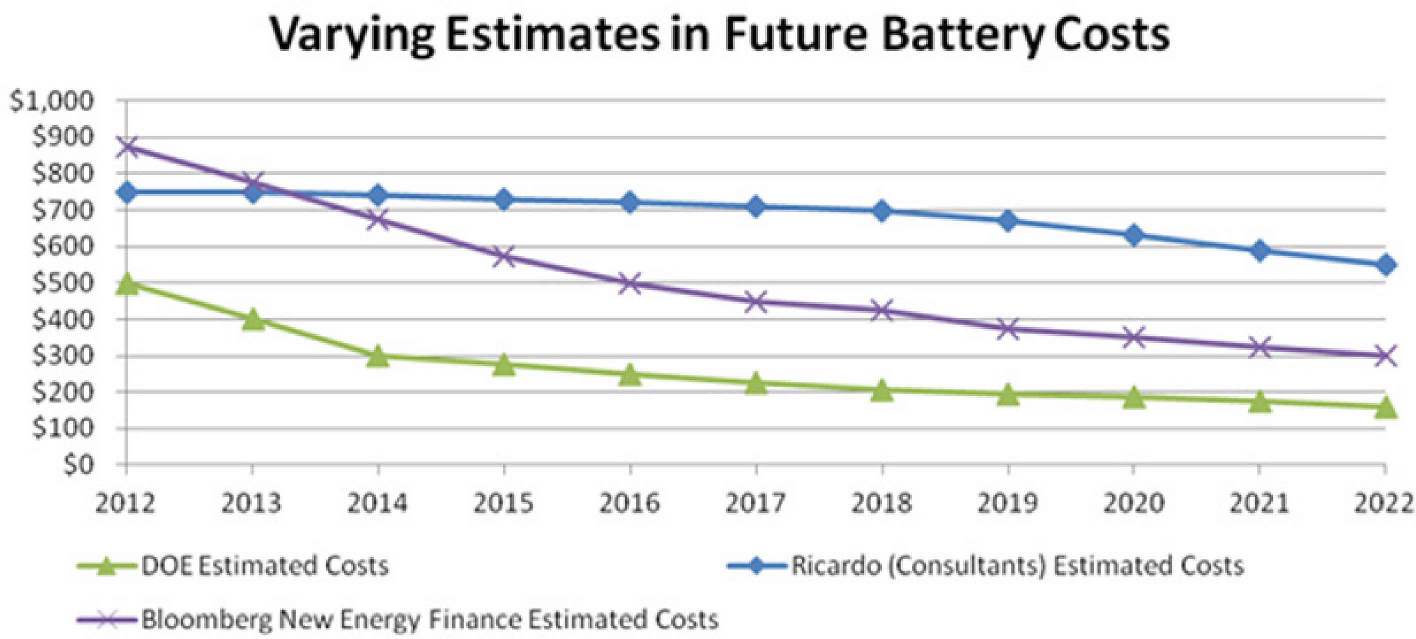
1. Because in five years the NV200 Taxi could be replaced with a superior vehicle, if one is available.
2. To preserve the City's ability to pilot new technologies.
3. To allow for planning for EV infrastructure that would be suitable for a range of vehicles and vehicle technologies beyond taxis.
4. Because the Taxi of Tomorrow program is currently on hold pending the resolution of litigation. If the City is not ultimately successful in defending the program in the courts, then the program will not be able to go forward and all taxi owners will be able to purchase vehicles other than the NV200 Taxi.

To that end, we contacted several Original Equipment Manufacturers (OEMs) to discuss likely directions for future electric vehicles. While none of the OEMs was willing to go on the record about specific vehicle plans or detailed product planning developments, some were willing to have general discussions about their corporate philosophy on EVs and where they believed the market would develop

EVs and Resiliency

Mitsubishi sees a place for EVs in disaster relief and recovery. EVs could be used as power storage units in the event of an emergency because they are fully mobile, do not use gasoline, and when fully charged hold enough electricity for typical consumers to keep their mobile phones, computers and other similar devices running for days.

Figure 3.3. Battery Price Cost Estimates and Projections



**Department of Energy Report – Net Zero Cities: Transportation Energy Technology Futures at the DOE*
***Bloomberg New Energy Finance – Battery Innovation: Incremental or Disruptive?*

by the early 2020s. We had discussions with Nissan North America, Mitsubishi Motors, Ford Motor Company, and BYD.

3.4a. Mitsubishi Motors

Existing EVs. Mitsubishi Motors is an OEM based in Japan with a small presence in the U.S. market. Worldwide, it is one of the 20 largest automobile manufacturers. It does not currently have any vehicles in the NYC taxi fleet. Its current EV solution is the iMiEV (pronounced eye-meev), a small pure EV. Its marketing and sales plan is similar to that of its direct competitor, the Nissan LEAF, in that it is expected to be a suitable commuter car or second car for customers living in high-density areas.

Future EVs.

The next EV model to be offered by Mitsubishi will likely be the Outlander, an SUV-style four-door vehicle that is comparable to the Toyota Highlander or Nissan Pathfinder. It may be a suitable size and configuration for taxi use. The gasoline-powered version of this vehicle is available in the U.S. now, and a plug-in hybrid electric vehicle (PHEV) version with a small 12-kWh battery and a gas tank is expected to be forthcoming in the near future.

Corporate Philosophy on EV. Mitsubishi Motors publicly states that it is fully committed to EV solutions. The company is currently engaged in a taxi demonstration project and a police car demonstration project in Japan using Level 3 quick-chargers. The release of the Outlander is consistent with Mitsubishi's continued commitment to cater to the market for sport-utility and off-road vehicles as well as pure-plug-in EV urban vehicles. Given that they are releasing both a pure EV model and a PHEV model, they do not appear to favor one approach over the other. Because of charging infrastructure challenges and range anxiety expressed by U.S. consumers, utilizing both approaches will allow Mitsubishi to hedge its investment in EV platforms. Its assumption is that if a consumer has only one car, and she is interested in EV, it will most likely be a PHEV. If the same consumer has multiple cars, then there is an easier transition to pure EV because a "backup" vehicle mitigates range anxiety.

3.4b. Ford Motor Company

Ford Motor Company is a major worldwide automaker and is one of the "Big Three" American car companies. It currently commands more than 65% of the New York City taxi market, although its share is shrinking as its Crown

Victoria and Escape HEV, which together make up 63% of the NYC taxi market, have both been discontinued and generally are being replaced with other makes and models. Ford was one of the highest-scoring presentations in the Taxi of Tomorrow Request for Proposals (proposing an ICE version of its Transit Connect), but it did not win the competition.

Existing EVs. Ford currently offers several EV options. The Focus is available as a pure plug-in EV. The C-MAX Energi and Fusion Energi are PHEVs. The mix of models and fueling options is consistent with Ford's corporate philosophy of offering multiple platforms for each fuel choice.

Future EVs and Corporate Philosophy on EV. Ford has not committed to becoming a pioneer in electric vehicle technologies, although the company devotes resources to the development of improved battery technologies. It believes that responding to market and consumer demands takes precedence over attempts to create market demand by promoting proprietary EV-specific solutions.

Ford's goal is to preserve maximum flexibility by developing multiple power sources for its existing lines of vehicles. No matter what power source a customers want (gasoline, ethanol, CNG, HEV, PHEV, or pure EV), Ford wants to be able to offer it. To that end, Ford does not plan to offer specific EV-only platforms as competing OEMs do. Rather, it will adjust to market demand when deciding which vehicle platforms to offer as EVs. The company's philosophy could be captured as "a great car that happens to be an EV" rather than "a great EV." This does not mean that every future platform will be offered in every fuel configuration. Packaging and weight issues remain with battery installation, so it is likely that Ford will make electric versions available of vehicles that are similar to those offered as EVs now: small sedans (C-MAX class), medium-sized sedans (e.g., Fusion), crossover vehicles, and SUVs.

Ford does not see taxi purchasers as significantly different from other types of consumers. Its assumption is that almost every EV consumer wants a vehicle that gets a range of about 200 miles per full charge and can be charged to full or near-full capacity in about 15 minutes. The company believes consumers want to minimize the difference between the EV driving experience and the liquid petroleum driving experience.

Ford is also focused on issues surrounding battery life and believes that consumers will reject EV solutions in which the battery life gradually declines over the lifespan of the vehicle, gradually reducing range as time goes on. It believes that consumers prefer a battery that retains its charge capacity for the expected typical lifespan of the vehicle and will understand if the battery rapidly loses its ability to hold a charge at the time when it will be traded in or sold. Ford believes that most consumers will be able to avoid incurring battery replacement costs.

Given Ford's concerns about consumer preferences and battery life, it is likely that the company will offer more PHEV than EV solutions in the next several years.

3.4c. Nissan North America

Nissan North America is a major manufacturer of passenger and commercial vehicles. The New York City area is one of Nissan's strongest markets in the U.S. and at present HEV Nissan Altimas make up about 2% of the New York City taxi fleet. The Nissan NV200 Taxi (the "Taxi of Tomorrow") was selected as the City's Official Taxi Vehicle for at least a five-year period starting in October 2013. Although some medallion owners have already voluntarily purchased the vehicle, its status as the Official Taxi Vehicle has been delayed due to ongoing litigation. An HEV version of the NV200 Taxi will be available by the end of 2015.

Existing EVs. The Nissan LEAF is a pure EV plug-in vehicle that was launched simultaneously in the United States, Europe, and Japan. It is being used in the Nissan-TLC Electric Taxi Pilot Program and is helping the City and the industry test the concept of EV use in NYC taxis. Nissan sells this mass-produced consumer vehicle in all 50 states, and it has exceeded Nissan's expectations for the number of consumers who use it as a primary vehicle rather than a secondary or commuter vehicle. This is leading Nissan to re-assess some of its assumptions about consumer EV adoption.

Future EV Solutions. Nissan has not formally announced its next EV platform in the United States, but it is expected

Photo courtesy of NYC Mayor's Office Flickr.

to be a version of the NV200 Taxi vehicle that was selected as the Taxi of Tomorrow.[13] Nissan's Taxi of Tomorrow proposal anticipated the eventual introduction of an eNV200 Taxi, and the City's contract with Nissan contains provisions to formally adopt such a vehicle if it becomes available during the term of the contract. Nissan is planning to test an eNV200 prototype as a taxi in London later in 2013 via a pilot program. Although the European NV200 base vehicle has some differences from the U.S. version, London's test should provide useful information about an eNV200 Taxi's suitability for New York. It is also possible that Nissan's luxury vehicle brand, Infiniti, will also offer an EV platform in the near-term future; however, the company has thus far not made any public commitment to do so.

Corporate Philosophy on EV Nissan seeks to become the worldwide leader on EVs in the automotive industry and devotes considerable resources to achieving this goal. It believes that pure EV plug-in vehicles are the most direct way to achieve this goal. However, as part of a general corporate goal of "Right Vehicle, Right Price," Nissan will not exclude research on alternatives such as PHEVs and range-extended EVs if that is what consumers are demanding. Because even incremental improvements in emissions get Nissan closer to its emissions goals, it is interested in improvements in battery technology as well as weight reduction, improved engine efficiencies, and other engineering solutions to problems of range and pollution. Nissan currently offers 8-year warranties on batteries, and under normal consumer use expects the battery to last for the vehicle's entire life.

Nissan's preferred approach to EV design is not to "electrify" an existing platform. Instead, it believes that in order for an EV to be successful, the company must take a holistic approach and design the total vehicle from the ground up to be an EV. It believes that if a vehicle is designed specifically as an EV, it will be the best EV it can be.

In conjunction with vehicle design, Nissan seeks to educate consumers on the advantages of EV and actively works with government and private entities to build out the infrastructure that is needed to support its vehicles. Nissan does not consider EV to be "exotic" or something that requires a wholesale change in consumer behavior to adopt. The company is comfortable with the idea that an EV might not be the ideal solution for every consumer in every circumstance. Nissan wants to "change the playing field" by educating consumers about why they do not need to have range anxiety and matching the right customer to the right EV.

Nissan believes that taxi purchasers have wants and needs that are very different from those of other consumers, largely because their livelihoods depend on the vehicle's being reliable. Given Nissan's involvement in the Taxi of Tomorrow project, one should expect that the company will be able to capitalize on its research and experience in the taxi industry.

3.4d. BYD (Build Your Dreams)

BYD is a manufacturer of consumer vehicles and buses based in China that seeks to expand its market to the United States. BYD intends to limit its entry into the U.S market to fleet customers who operate as what they consider to be "high utility" customers; that is, those whose vehicles drive 100 or more miles per day (e.g., limousines, buses, and taxis). BYD does not plan to offer any vehicles to private customers other than fleets because they believe that it is a better strategy for growth in the U.S market to deal with the a smaller number of large-scale purchasers (fleets) rather than a larger number of single-vehicle purchasers (personal consumers).

They believe that "high utility" customers are the most natural EV marketplaces because they have the greatest potential to capitalize on the advantages of electric power. Given that BYD does not yet have an infrastructure to sell and service vehicles in the United States, this focus on fleets allows the company to mitigate the risk of an expensive build-out of dealerships and distributors to cover the relatively modest EV sales in the U.S. thus far.

Existing EVs The BYD e6 is BYD's mid-sized crossover hatchback EV and is similar in style to a Toyota Prius. Approximately 600 BYD e6 vehicles are currently used in the city of Shenzhen, China as taxis, and the manufacturer believes that these vehicles would be suitable for taxi use in New York. BYD also offers the F3 sedan, which is similar in style to a Toyota Corolla.

BYD vehicles use an iron phosphate battery that they claim offers significant advantages over competing technologies. They report that it lasts for 7,200 charge cycles and has a daily "range" (not single-charge range) of over 200 miles. However, these claims assume that the end user conforms to BYD's assumptions about duty cycle behavior and that the operator will adjust his or her behavior to charge small amounts throughout the day. BYD vehicles are currently being field-tested as taxis in Bogota, Colombia and NYC will be able to learn more about driver behavior change from the results of this project.

BYD vehicles also carry an on-board 30kW charger, which speeds Level 2 charging and would therefore reduce the costs of a charger network. BYD hopes that eventually consumers will be able to charge at any location with electricity, such as service stations or other businesses

Future EVs. The F6 platform, a full-size sedan, may be offered as a plug-in EV in the future. BYD believes that PHEV vehicles are transitional and that pure EVs are the clear future solution. While the company is developing some PHEV platforms, it does not prioritize the gasoline engine components and is including them to assuage range anxiety. BYD does not plan to engineer vehicles to automatically transition from the e-machine to the gas motor when the battery's power has been exhausted. It will require the user to press a button to activate the alternate power sources so that users will eventually learn that they do not use the gas motor very often and become more comfortable with the pure EV experience.

Corporate Philosophy on EV. BYD believes that changing driver behavior is a core part of engendering widespread adoption of EV. Some of the basis for this theory comes from its experience with taxis in Shenzhen, where they claim a rapid change in drivers' charging behavior took place once the drivers determined that running on electricity was cheaper than running the vehicle for equivalent mileage using gasoline. BYD reports that these taxi drivers do not rely on a large quick charge at the beginning and end of the shift, but rather take frequent breaks throughout the day to "top off" the battery. The analogy BYD uses is that high-intensity smartphone users do not expect a charge to last a full day, so instead they grab a charge wherever they can (e.g., at a coffee shop, the airport, etc.) to "grab a few bars" and ensure continuous service.

By using this periodic top off method, BYD claims that its taxis get a 180-200 mile "range" per shift today using existing battery technology, as long as drivers do frequent small charges during the shift. Its philosophy is that "behavioral change enables the technological breakthrough." Therefore BYD is relying on behavioral changes rather than technological advances in battery storage to drive its product planning.

3.4e. Summary

Information vehicle manufacturers provided signals several important directions for automobile manufacturing:

- Several major manufacturers plan to continue to make significant investments in developing EVs or vehicle platforms that may be used as EVs.
- Most manufacturers we spoke with are working on EVs, PHEVs, and range-extended EVs. It is unclear whether these vehicle types will continue to be produced side by side in the coming years, or if one strategy will come to dominate the market.
- Some OEMs focus on using technology to minimize the degree of behavioral change required of drivers to adopt EVs. They aim to make the technology fit the people. Others focus on bringing about changes in human behavior so that people better fit the technology.
- Although private consumers continue to be the primary market most manufacturers are targeting for EV adoption, BYD's interest in "high utility" vehicle users and Nissan's work with NYC on Taxi of Tomorrow give some reason for optimism that an OEM will produce a vehicle that is a good fit for NYC taxi use.

3.5. Conclusion

Electric vehicle technology has improved significantly in recent years and will likely continue to improve in the future. Major automakers and niche manufacturers are innovating and investing in the EV space, and decreasing battery prices will likely enable them to produce batteries with longer ranges at lower prices. In addition to monitoring pre-existing trends in the EV industry, there is a significant opportunity for New York City to join with other cities to demonstrate to automakers that there is demand for EVs designed as taxis. New York City's taxi market has brought about significant innovation from automakers in the past (e.g., the Ford "Stretch" Crown Victoria and the "Taxi of Tomorrow" project), and it could do so again in partnership with other cities interested in incorporating more EVs into their taxi fleets.

SECTION II

FEASIBILITY ANALYSIS

> CHAPTER 4: ECONOMICS OF ELECTRIC VEHICLE OWNERSHIP

Key Findings:

The total cost of ownership (TCO) for an EV-suitable taxi may be competitive with a comparable non-EV vehicle, particularly if battery prices continue to decline, the federal tax credit for EV purchase remains in place, and charging is available at a competitive price.

The cost of purchasing and operating electric vehicles as taxis is an essential consideration in determining what it would take for a significant share of the taxi fleet to operate electric vehicle. There are six primary factors that determine the cost of owning and operating an electric vehicle:

1. Vehicle purchase price
2. Maintenance and repairs
3. Battery replacement
4. Years vehicle is in service
5. Residual value
6. Cost of fuel (electricity)

This chapter discusses each of the costs in turn and compares them to the likely price that a taxi operator would face if he or she were to operate a non-electric vehicle. By quantifying the difference in costs between operating an EV taxi versus a non-EV taxi, we can understand (1) when there is likely to be a "value gap" that would need to be overcome through policy change or outside funding in order to incentivize taxi owners to adopt EVs, and (2) when EVs would be a natural choice for taxi owners without policy intervention. Figure 4.1 summarizes the value gap estimates detailed in the remainder of the chapter:

There are several important assumptions surrounding this analysis:

- This analysis assumes an electric taxi with a 35kWhr battery. We selected a 35kWhr battery because that is the battery size we believe would be necessary for the taxi fleet to continue to operate in the currently dominant schedule of two 12-hour shifts in which drivers log approximately 115 miles per shift.[14] Based on TLC shift modeling (See Chapter 5: Level of Infrastructure Needed to Support Taxi Fleet) and preliminary findings from the Nissan-TLC Electric Taxi Pilot, with a 35kWhr battery a typical driver would be able to complete a shift with one charge prior to shift changeover and one charge during the shift.[15]
- This analysis assumes relatively few operational changes on the part of the taxi industry. Although charging would need to be integrated into the shift and shift changeover procedures, this analysis

Figure 4.1. Summary Vehicle Owner 5-Year Value Gap for Operating an EV

	2017	2020	2025
Vehicle purchase price premium for EV	None	($3,000)	($4,400)
Maintenance and repairs savings for EV	($3,611)	($3,611)	($3,611)
Battery replacement costs	$9,940	$7,000	$5,600
Additional residual value for EV	($4,250)	($4,250)	($4,250)
Value gap	$2,079	($3,861)	($6,661)
Federal tax credit	($7,500)	($7,500)	($7,500)
Value gap after tax credit	($5,421)	($11,361)	($14,161)

Source: Ricardo Engineering estimates for maintenance and repairs and vehicle body costs. McKinsey estimates for battery prices. EPRI estimates for battery resale values.

assumes that the taxi fleet continues to operate under the currently dominant schedule of two 12-hour shifts. If there were more significant alterations to taxi industry operations (e.g., a switch to shorter shifts, sufficient e-hailing activity to significantly reduce cruising), then a different battery size and value gap calculation could be made.

- This analysis assumes a 5-year service life for the taxi.

EV purchase prices and battery replacement costs are the two biggest drivers of the cost of owning an EV. Published reports are fairly uniform in their projections that battery costs will decrease in the future; however, they diverge in their estimates for what current battery costs are and how quickly they will decline. This chapter features vehicle and battery replacement costs based on McKinsey analysis that predicts relatively steep declines in prices.[xvii] These numbers represent what McKinsey characterizes as the best-case battery prices that could be achieved if large-format batteries were manufactured at scale.[xviii] To provide additional information on more conservative battery price projections, we include battery price projections from Ricardo Engineering in footnotes.

4.1. Vehicle Purchase Price

Vehicle purchase price is a key component of understanding what the value gap would be between operating an EV taxi and operating an alternative non-EV taxi. Predicting the future price of a vehicle that is not yet available is an imprecise task; however, there are a couple of facts surrounding this prediction that are particularly worth noting:

- Battery prices are a key driver of the purchase price of electric vehicles, particularly in the case of vehicles with larger batteries (as we model here).
- Battery prices are projected to decline over time. There are varying estimates as to (1) what battery costs currently are and (2) what the rate of decline in costs will be.

Assuming an EV taxi with a 35kWhr battery, using McKinsey projections for battery prices and Ricardo Engineering projections for the costs of other vehicle parts, we generated the vehicle price projections in Figure 4.2.

Figure 4.2 Electric Vehicle Purchase Price Projections

2017 [16]	2020	2025
$33,730	$31,390	$30,990

Source: McKinsey battery price estimates and Ricardo Engineering estimates for other vehicle component costs for a hypothetical electric taxi with 35kWhr battery

We anticipate that an electric taxi with a large, 35kW battery would cost about $34K in 2017, but would decline in price to about $31K by 2025.

There is currently a $7,500 federal tax credit available to purchasers of electric vehicles. Although this tax credit is currently set to disappear once certain EV sales volumes are reached, it is likely that this tax credit will continue to be available to EV purchasers in the near future.

4.2. Vehicle Maintenance

Maintenance and repair costs constitute an operational cost that is generally lower in electric vehicles than in other vehicles. This savings is driven by the fact that EV owners do not need to purchase and devote labor associated with various vehicle consumables (i.e., FEAD belts, engine air filters, engine oil, engine oil filters, transmission fluid, transmission oil filters, spark plugs, and coolant changes) that other vehicles need. Over the course of five years of taxi operation, the owner of an electric vehicle would spend about $3,500 less in maintenance and repairs than would the owner of an alternative vehicle.

4.3. Battery Replacement

Electric vehicle batteries degrade over time, diminishing the share of the battery that is available to power the vehicle. The more frequently a battery is recharged and the more quickly it is charged (i.e., quick-charged rather than Level 2 charged), the more quickly it degrades. Although technically a battery with a degraded capacity can continue to power a vehicle, at a certain point the range becomes small enough that it becomes operationally difficult to continue to use this battery. This analysis assumes that after a battery is degraded to 80% of its original capacity, it needs to be replaced.[17] Battery replacement would be a significant driver of the costs of operating an electric vehicle as a taxi.

Based on the assumption that a double-shifting electric taxi would need to do 4 quick charges per day, Ricardo Engineering estimates that the battery would degrade to 80% capacity in approximately 2.76 years, or after 2,850 charges.[18] Therefore to complete 5 years of taxi service, a typical taxi would need to replace its battery once. The same level of uncertainty exists regarding the price of a replacement battery as exists regarding the purchase price of an electric vehicle. Figure 4.3 presents estimates of the costs of replacing a 35kWhr battery in 2017, 2020, and 2025.

Figure 4.3. Battery Replacement Costs

2017 [19]	2020	2025
$9,940	$7,000	$5,600

Source: McKinsey estimates based on hypothetical 35kWhr EV taxi battery.

Any operational practice that would reduce the number of charges per day that the battery goes through, such as single-shifting or reduction in miles driven (e.g., through cruising reduction due to e-hailing or more shift changing in Manhattan) would prolong the life of the battery and could potentially prevent an owner from needing to replace the battery. This would significantly decrease the cost of owning and operating an EV.

What about battery leasing?

Another economic model for EVs that may emerge is battery leasing rather than battery purchase. Enabling consumers to purchase only the electric vehicle up front while offering them a lease on the battery could facilitative EV adoption because:

- The leasing model smoothes the costs associated with operating an EV. Purchasing only a vehicle and not a battery reduces up-front costs to vehicle purchasers and eliminates the mid-vehicle-life layout for a replacement battery when it degrades beyond an acceptable level for taxi use.

- The leasing model reduces uncertainty. Entering into a battery lease agreement in which the vehicle owner is guaranteed a battery with a certain capacity at a set price over a set time period reduces the uncertainty and perceived risk of adopting an EV. The owner would not need to worry that his battery could degrade more quickly than expected because he has entered a contract to have an ongoing level of service for a set time period.

4.4. Years of Vehicle Service Life

Currently TLC regulations require that taxi vehicles retire from taxi service after between 3 and 7 years, depending on (1) the type of vehicle, and (2) how the vehicle is operated. This cost analysis assumes a 5-year vehicle life, which was selected based on the timeframe during which we project 2 batteries would be degraded to the point at which replacement would be warranted. This is slightly less time than the average required retirement date in the existing taxi fleet (5.2 years)[xix] but longer than many taxis actually stay on the road in practice (see appendix for more details).

That some taxis leave service prior to their scheduled retirement dates suggests that vehicle durability will be a key determinant of the number of many battery cycles electric vehicles last. From an economic perspective, an ideal retirement "age" for an electric vehicle might not be an age, but instead the point at which two batteries have been degraded (so long as the vehicle continues to meet safety requirements). This would enable operators to take full advantage of each battery's usable life, eliminating the possibility that a years-based retirement schedule would leave owners with "wasted" battery capacity at the end of the vehicle's service life.

4.5. Residual Value

Due to the newness of the market there is not a lot of information on resale values of EV vehicles and/or their battery packs; however, it is reasonable to assume that there will be some residual value at the end of the vehicle's taxi service life. The residual value of EVs is projected to be higher than that of comparable non-EVs, driven primarily by the value of the battery pack. The additional residual value expected for EVs is expected to be about $2,750.

There is also likely to be value in the battery that the vehicle owner sells in the middle of the vehicle's life. This

Opportunity: Battery Reuse

A battery with 70% capacity still has a lot of functionality even if it is no longer up to the rigors of taxi operations. Batteries can provide backup energy for buildings during outages and help address intermittency issues with solar and wind energy. They can also reduce the costs of providing quick charging. Selling the battery can not only make the city's energy cleaner and more reliable, but also can also generate new revenue for taxi owners.

Of course there are many challenges to realizing the value of second-life batteries. To understand the potential value, the City undertook a research survey with the Electric Power Research Institute (EPRI), a non-profit think tank for the energy and utility industries. EPRI identified five major factors that influence batteries' potential value, several of which can be influenced by taxi taskforce stakeholders. For example, ensuring that taxi batteries can be reused in local buildings increases their value and minimizes the expense of transporting used batteries, which EPRI identified as a cost driver. Likewise, measuring wear during taxi use could help pre-determine battery capacity and reliability and increase their value.

While these are issues that will be faced by the larger electric vehicle market, the relatively homogenous taxi fleet is an attractive controlled environment for identifying possible solutions. Compared to the wider vehicle market, taxis have more defined usage and operate using predominantly just a few vehicle models. Because there are so many taxis, they could create a local market for second-life batteries. Over five years, a one-third electric taxi fleet would create enough battery capacity to provide backup power to over 15,000 homes. Finding a second life for batteries, while not a prerequisite for taxi electrification, demonstrates the significant economies of scale e-taxis offer and the larger benefits they could bring the city.

battery could generate an estimated $1,500 in revenue. Therefore we estimate that the total value from reselling the EV and the battery in the middle of the vehicle's life is $4,250.[xx]

4.6. Fuel

Fuel comprises a large share of a taxi's operating costs. Most analyses comparing the total cost of ownership of an EV to that of alternative vehicles show fuel costs savings from driving an EV. The calculation is a relatively straightforward comparison of how much it costs in electricity (usually priced at the local level 2-charging residential rate) to drive a certain number of miles versus how much it costs in gasoline to drive that same number of miles. One cannot make a similar comparison in the case of electric NYC taxis because the round-the-clock operation means that there is relatively little opportunity to slow charge and most charging will have to take place at quick chargers.

There is not a prevailing market price for quick charging. To our knowledge, there are no profitably-operating, non-subsidized networks of quick chargers in the United States.[20] Because of the many costs that go into constructing and operating a quick charge network (see Chapter 6. Economics of Infrastructure Network), the operator of a quick charge network would not simply take the price that it pays per unit of electricity and charge customers this amount plus a profit margin. The price would also have to incorporate demand charges for electricity, the cost (if any) of renting the land the charger is on, and paying off the costs of purchasing and constructing the charging stations.

Based on the cost figures found in Chapter 6, a 350-unit quick charger network would cost about $20 million per year.[21] With 4,412 taxis doing an average of 616 shifts per year, the quick charger network could break even charging taxi drivers $7.35 per shift (or half that amount per charge). If the charging network were profit-driven, the price to charge would likely be higher.[22]

Given improving fuel efficiency in non-EV vehicles, even assuming increases in gas prices, charging drivers about $7.50 per shift might not generate savings enough to incentivize them to want to drive EVs instead of other options.[23] In Chapter 6 we estimate that drivers would be incentivized to drive an EV if their per-shift cost to charge were $5. Not charging break-even prices for charging leaves the charger network operator with a value gap; however, this model construction leaves drivers (whom we model as a separate entity from taxi owners, although they are sometimes the same person) without any value gap.

By setting quick charging prices at a level that holds driver well-being neutral in terms of his time and fuel expenses, we are then able to isolate two distinct value gaps: (1) the charging infrastructure value gap described in Chapter 6, and (2) the vehicle owner value gap described in this chapter. Isolating these gaps helps us envision policies to fill in these gaps (e.g., a subsidized infrastructure network or tax credits for vehicle purchase). The model could be constructed differently to hold one of the other parties constant (e.g., set charging prices at a break-even rates for the infrastructure network and then determine what direct subsidy to drivers would be needed to make them whole on their fuel and time costs), but we believe identifying vehicle and infrastructure network value gaps provides a more straightforward mechanism for policy development and implementation. Therefore fuel costs are not included in the calculation of the vehicle owner value gap. Please see the appendix for further explanation about how various taxi industry participants' financial responsibilities are accounted for in this model.

4.7. Conclusion

We can bring the information from sections 4.1 through 4.5 together to calculate the total savings a taxi owner would experience over the course of 5 years for operating an electric taxi with a 35kWh battery compared to a non-EV taxi.

Figure 4.4 shows that, before accounting for tax credits, the size of the 5-year value gap is $2,000 in 2017 and shrinks to an overall gain to the owner of over $6,000 by 2025. If the federal tax credit remains in place, the gap is even narrower and the total cost of ownership of an EV would be about $14,000 less than a comparable non-EV in 2025.

If the estimates in Figure 4.4 are correct and a vehicle meeting necessary specifications becomes available, then in 2017 a taxi owner would have a slight incentive to adopt an EV over an alternative vehicle. Of course, it may require more than a $5,400 reduction in total costs of ownership over 5 years to incentivize taxi owners to make a significant operational change. To make electric vehicle purchase even more attractive to taxi owners in

Figure 4.4. Summary Vehicle Owner 5-Year Value Gap for Operating an EV

	2017	2020	2025
Vehicle purchase price premium for EV [24]	None	($3,000)	($4,400)
Maintenance and repairs savings for EV	($3,611)	($3,611)	($3,611)
Battery replacement costs	$9,940	$7,000	$5,600
Additional residual value for EV	($4,250)	($4,250)	($4,250)
Value gap	$2,079	($3,861)	($6,661)
Federal tax credit	($7,500)	($7,500)	($7,500)
Value gap after tax credit	($5,421)	($11,361)	($14,161)

Source: Ricardo Engineering estimates for maintenance and repairs and vehicle body costs. McKinsey estimates for battery prices. EPRI estimates for battery resale values.

the near future, policies could be put in place to improve the economic case for adopting an EV. For example, New York City could join with other cities to demonstrate to automakers that there is demand for EVs designed as taxis, catalyzing an automaker to design a vehicle that is well suited for the taxi industry both operationally and economically. There are also several non-policy events that could further improve the economics of EV adoption:

- Automotive manufacturers could sell electric vehicles and replacement batteries at prices below cost (and below prices projected here) to (1) meet emissions targets, (2) generate earnings in an emissions credit market, or (3) meet other strategic business objectives.
- Battery prices could decrease to lower levels than are projected by McKinsey or Ricardo.[25]
- A vehicle could be custom-designed ("optimized") for the taxi duty cycle, making it run more efficiently and get more range as a taxi as compared to vehicles that were not custom-designed as taxis. Optimizing for the taxi duty cycle[26] could render a battery smaller than 35kWh sufficient to meet industry needs, thereby reducing vehicle purchase and battery replacement costs.
- Batteries could withstand quick charging better than is expected and may not need to be replaced during the vehicle's time operating as a taxi. (Research on the impact of frequent quick charging is in early stages.)
- Taxi industry operations could change to reduce cruising and other non-revenue miles (e.g., e-hailing, more within-Manhattan shift changing), reducing the size battery needed to power each shift.

> CHAPTER 5: LEVEL OF INFRASTRUCTURE NEEDED TO SUPPORT ELECTRIC TAXI FLEET

Due to the 24-7, around-the-clock nature of most taxi operations in New York City, fast-charging is basically a given in the equation to making electric taxis feasible operationally. From a TLC study on the fueling habits of taxi drivers, we have discovered that drivers spend very little time each shift devoted to fueling (on average about 6.25 minutes per session including time waiting, fueling, and loitering after/before fueling). Also, from a separate TLC analysis of trip data to discover break time habits, we found that 63% of drivers in our sample took at least one 30-minute break per shift, but only 11% of drivers took two or more 30-minute breaks per shift (for more details, see Chapter 2: Taxi Industry Background). For electric taxis to work efficiently without disrupting normal driver habits too much, fast charging will be necessary. It is likely that break time will have to be coupled with charging events to reduce time off the road and lost fare revenue. The existing rarity of a driver's taking multiple long breaks in a shift means that an ideal EV taxi vehicle would be built to allow most drivers to have just one 30-minute charge during an average shift.

Based on the assumption that one quick charge per shift would be acceptable to the taxi industry, the question then becomes, "How many chargers would be needed to satisfy charging demand from over 4,400 electric taxis?" Although the main factor in determining how often an electric vehicle will need to charge—and thus how many chargers, overall, would be need to support a sizeable electric fleet of vehicles—is the number of miles travelled, simply calculating the number of charges needed per vehicle based on electric vehicle ranges and multiplying by the total number of electric vehicles will not provide a fair answer to the question. There are other elements to consider—namely, when the vehicles will seek to charge (the temporal element), and where the vehicles will seek a charge (the geographic element). Each of these elements can lead to considerable degrees of clustering, which could increase the need for chargers during a specific time

Key Findings:

Number of Chargers

- We estimate that a network of 350 50kW quick chargers would be needed to ensure that drivers in a 1/3-electric taxi fleet would have access to chargers when they need them.
- This suggests that the ratio of chargers needed to electric vehicles on the road is about 1:13.
- Therefore EV adoption in the taxi fleet would require a significant infrastructure investment.
- A phased rollout of both electric taxis and quick chargers would help determine whether real-world charger needs align with this estimate, or if they are higher or lower.

Time Spent Charging

- With a 35kWh EV battery, we project that the average electric taxi driver would spend a total of about 40 minutes per shift charging. This would include some charging between shifts and, for most, some charging during shifts. The amount of time spent charging would vary from driver to driver depending primarily on how many miles he or she drives during a shift.
- Although charging time during and between shifts would be significant for most drivers, it is not an amount of time that would be impossible to incorporate without significant revenue impacts.

of day or at a specific place. To determine the effects of the temporal element on the number of electric taxi quick chargers needed, we developed a model that uses current taxi shift structures to calculate the number of chargers needed by time of day. The geographic element--how these chargers need to be distributed throughout the city--is discussed separately in Chapter 7: Electric Vehicle Quick Charger Siting Feasibility.

This chapter contains seven sections that describe the methodology used to estimate the number of quick chargers needed and the results of the model:

1. Model Overview: The effects of shift structures on charging habits
2. Methodology: Selecting which taxis should be modeled as electric vehicle adopters
3. Methodology: Calculating how often, how long, and when taxis will need to charge
4. Results: Number and duration of charges per shift
5. Results: Identifying peak times for charging
6. Strategies to make an economically efficient level of infrastructure operationally successful
7. Conclusion

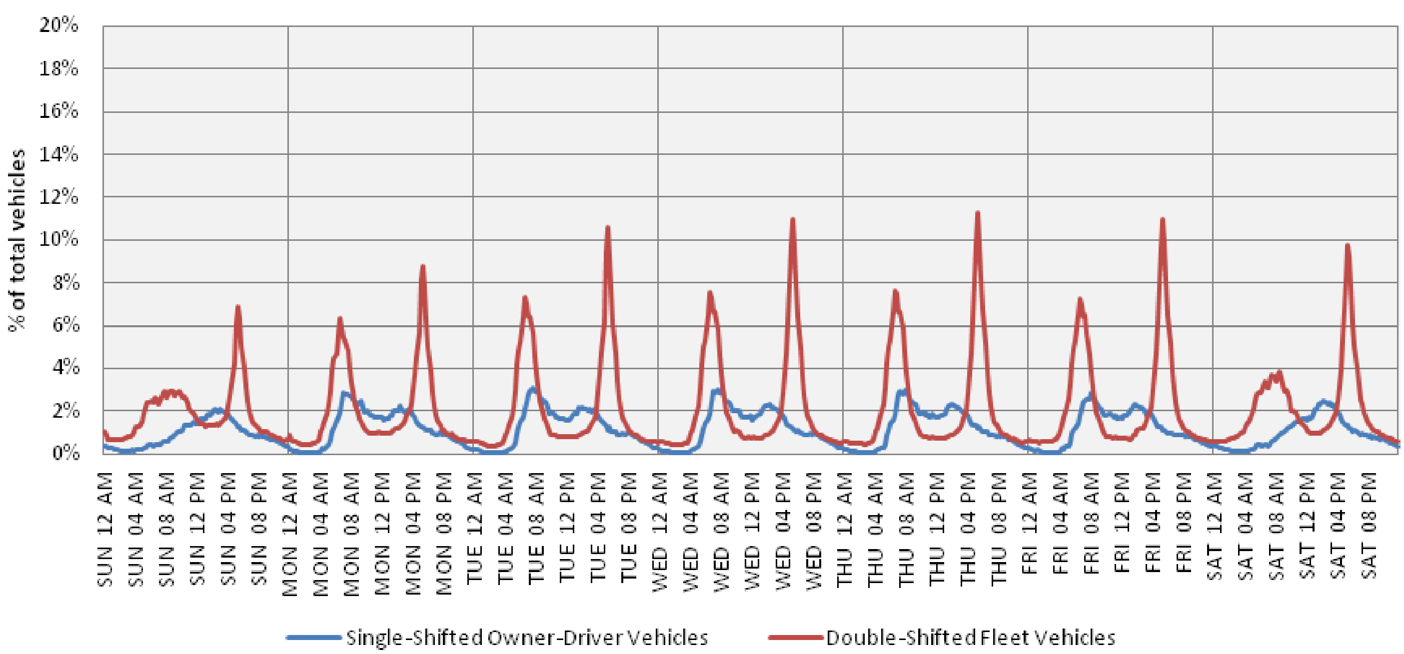
Readers interested in a "bottom line" number of chargers estimate can skip to Section 5.5. Readers interested in the assumptions and modeling that went into generating this estimate should read the entire chapter.

5.1. Model Overview: The effects of shift structures on charging habits

We built a micro-simulation model that aims to incorporate the effects of the mostly uniform shift structures existing in the NYC taxi industry today into our estimate of the level of infrastructure that would be necessary to support an electric fleet of taxis. By taking into account current behaviors in the taxi industry, we modeled when taxis are likely to seek a charge. This gives us particular insight into when we might see temporal clustering in charging demand and spikes in the number of chargers needed to meet this demand while avoiding queues at chargers.

The foundation of the model is the overall structure of taxi shifts in which drivers operate today. Figure 5.1 shows shift structure distributions for vehicles operated under two different taxi models: fleet vehicles and single-shifted owner-driver vehicles. Fleet vehicles tend to start their shifts around a centralized time for both the AM and PM shifts.

Figure 5.1: Distribution of shift start times for single-shifted owner-driver and double-shifted fleet vehicles



Source: NYC TLC TPEP trip-sheet data, 2012

This is especially true on weekdays, when on average, 39% of vehicles operated under this model start their evening shifts in the 5:00-6:00 PM hour, with over 11% starting in just the 5:15-5:30 block alone.

The morning shift start times are also clustered to a degree, but less so than the evening shift. In the morning shift, 28% of fleet vehicles begin weekday AM shifts in the 6:30-7:30 PM hour, on average. This has serious implications for electric vehicle charging, as taxis that all start at the same time will likely all run low on battery power and seek a charge around the same time as well.

5.2. Methodology: Selecting which taxis should be modeled as electric vehicle adopters

One step in developing the micro-simulation model was to determine which taxis' actual trip and shift behavior would be included in the model. We used two factors--number of shifts per day and number of miles per day--to determine which taxis would be the most-likely-fit EV adopters.

Single-shifters: From the perspective of minimizing temporal clustering at chargers, the most easily adaptable taxis for electric taxi adoption under current shift structures are single-shifted taxis. These taxis are operated at staggering shifts (instead of the more clustered shift start times found in the fleet model), resulting in charging events that are more staggered. Figure 5.1 shows that, on average, no more than 10% of single-shifted owner-drivers begin a shift in the same hour and no more than 4% start in any single 15-minute interval. However, single-shifting is relatively uncommon in the taxi fleet as a whole; only 10% of the 13,237 medallions in service operate under this model. Still, if this entire group were to adopt electric vehicles, it would bring the city a full 30% of the way towards the goal of over 4,400 electric taxis by 2020.

Low-mileage double-shifters: Given the inevitability that a fair share of the 4,412 electric taxis would be operating under a double-shift model, we sought to predict which double-shifted taxis would be the most likely EV adopters. We thought that the taxis that logged the lowest mileage--and therefore would need to spend the least time per shift charging--would be the next most likely group of EV adopters. Even with lower-mileage double-shifted taxis, temporal clustering takes place. However, the number and height of clustering peaks that occur within each shift is lower than it would be with higher-mileage double-shifted taxis.

On average, taxis travel around 120 miles per shift. For the lowest-mileage double-shifted taxis, the average shift mileage is around 100 miles.[27] With a 35kWh battery assumption,[28] we expect a realistic range of 118 miles per full charge (see Chapter 4: Economics of Electric Vehicle Ownership, for more information on the effects of the taxi duty cycle on expected battery ranges) or 83 miles per actual 10% to 80% charge (prior to any battery degradation). This means that vehicles, on average, would only require around one intra-shift charge per shift and one charge between shifts.

In the model, we assumed that 1,300 of the taxis adopting EV are those taxis that currently operate under the single-shifted owner-driver operation model. The remaining 3,112 taxis in our model are those that operate in the low-mileage double-shifted operation model. There are at least 3,112 low-mileage double-shifted taxis that are operated by owner-drivers or DOVs. Therefore even if a particular industry segment, such as fleets, did not adopt EVs, there are enough single-shifted owner-drivers and low-mileage double-shifted DOVs and owner-drivers to meet the goal of a one-third electric taxi fleet.

5.3. Calculating how often, how long, and when taxis will need to charge

Another step in developing the micro-simulation model was to determine how often, how long, and when taxis will need to charge. Using taxi trip-sheet data from 2012, we determined shift structures for the population of likely EV-adopting taxis (as identified above). We calculated average taxi shift start times, shift end times, and shift lengths over the year, and summarized them by day in fifteen-minute increments. We then converted these averages into a probability that a taxi will start a shift at a given time, operate for a given duration, and end at a given time. Converting the averages to a probability allows us the flexibility to scale the model up or down according to a variable number of electric taxis on the road.

In addition to assumptions about which taxis adopt EVs and the assumption, reflected above, that there is little change from existing shift change times or shift duration, we make several other behavioral and operational assumptions in the model:

- *Quick charging*: We assume that taxis will charge exclusively using quick chargers and that they will maximize efficiency by only charging up to 80%.[29] This is a common assumption for analysis of quick charging because power flow decreases significantly from fast chargers after a vehicle's battery reaches 80% of capacity, meaning each additional percentage point of power takes longer and longer to achieve. Because we assume exclusively quick charging, we therefore begin each taxi shift in the micro-simulation with the vehicle battery at 80% of charge.
- *Rate of battery use:* Taxis within the model lose charge at a rate determined by the size of the battery and the distance traveled. Preliminary data from the TLC-Nissan Electric Taxi Pilot provided a taxi-specific vehicle range in miles for a 24 kWh battery, which we scaled to different battery sizes to determine which battery would give the range needed. For the purposes of this model, we converted the range in miles to minutes on the road using taxi trip-sheet statistics on the number of shift miles typically driven in a given amount of time.
- *Battery size:* We assume an electric taxi with a 35 kWh battery to minimize the number of times a driver must stop to charge.[30]
- *Driver decision to charge:* We assume that taxi drivers will put off charging as much as possible, so we assume in the model that half of all drivers will wait until they are at 10% of the total battery capacity before seeking a charge. We assume that the other half of drivers will be slightly more cautious and will split equally between charging at either 15% or 20% of the total battery capacity.[31]

Incorporating these assumptions, using actual trip-sheet data on taxi shift start and end times and miles traveled within the shift, the model removes taxis from the "road" based on when they meet one of two conditions: (1) the taxi has reached the state-of-charge of 10-20% and thus seeks a charge to continue driving, or (2) a taxi's shift is not long enough to require an intra-shift charge and the taxi is removed at whatever state-of-charge exists at the end of the shift.

After removing taxis from the "road" in the model, we place them in a charging pattern, which we assume to be 30 minutes – the time it takes a 50 kW quick charger to charge a 35 kWh battery from 10% to 80% state-of-charge. For each time period, the model calculates both the number of new taxis arriving for a charge as well as the number of taxis remaining after arriving at a previous time period. After entering the charging pattern, we return taxis to the "road" at 80% state-of-charge 30 minutes following the time interval at which they entered the charging pattern. The cycle of stepping through battery power continues until either a taxi leaves the "road" for a second intra-shift charge or a taxi leaves the road because it has completed a shift according to its shift start time and duration.

5.4. Results: Number and duration of charges per shift

We project that the average electric taxi driver would spend a total of about 40 minutes per shift charging. This would usually include some charging between shifts and some charging during shifts. The amount of time spent charging would vary from driver to driver depending primarily on how many miles he or she drives during a shift. On the low end, 41% of drivers would only need to charge between shifts, spending, on average, less than half an hour charging. On the high end, about 6% of drivers would spend at least an hour charging each shift. Although charging time during and between shifts would be significant for most drivers, it is not an amount of time that would be impossible to incorporate. This is especially the case given that the break behavior we have discovered, in which 63% of drivers take one 30-minute break or more each shift, mirrors the number of drivers in our model who would need to charge at least once in a shift (58%). For more detail on the model's projections for the number of charges that would need to take place during and between shifts, please see the appendix.

5.5. Results: Identifying peak times for charging

Since we calculate both the times of day taxis seek charges and the duration of those charges, we can determine when during a week of taxi service we might be likely to experience peak charger demand due to temporal clustering. Figure 5.2 shows in detail the total charging demand for Wednesday shifts, the day with the highest peak demand.

Planning a charger network to accommodate the highest peaks of demand would not be economically sensible, as chargers would, on average, sit unused around 15 hours each day. Lowering the number of chargers to 350 would satisfy about 95% of all demand (i.e., 95% of the time a driver needs a charger, one is available), and each charger would be in use by taxis 15 hours each day, on average. Figure 5.3 shows the amount of charger demand that 350 chargers would cover.

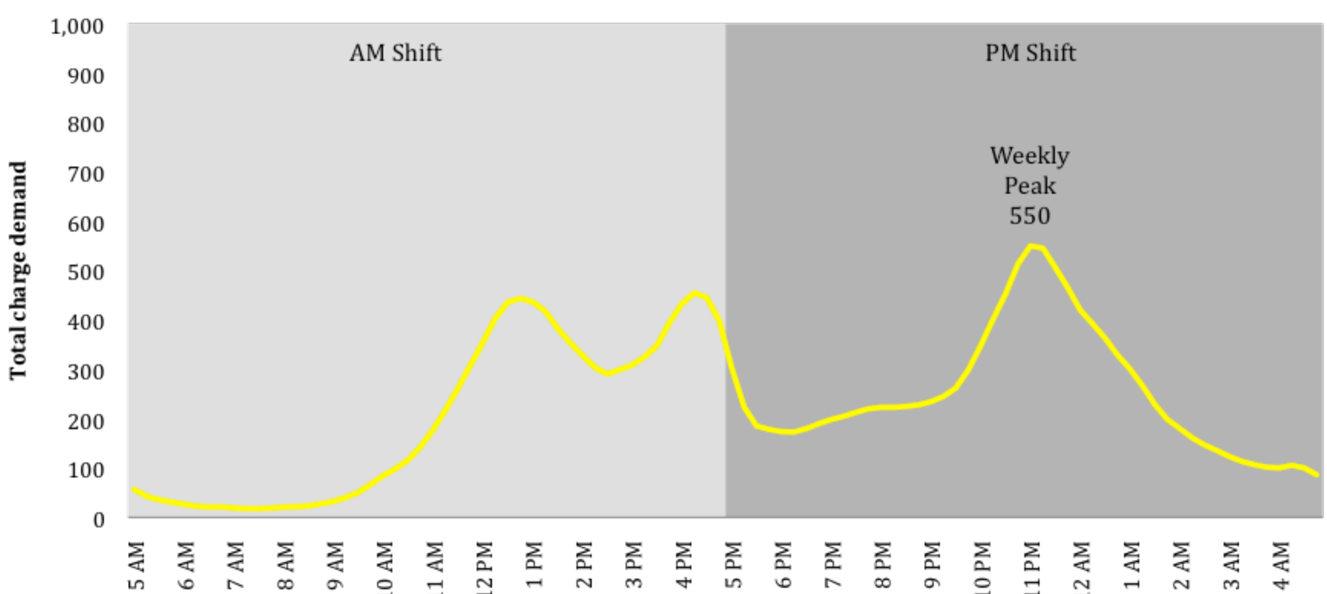
The peaks that this number of chargers would not accommodate occur in the afternoon and before the evening shift change in the AM shift and during the late-night portion of the PM shift. The afternoon and late-night peaks are a product of clustered shift starts, which lead to later clustering at chargers as batteries get low on energy. The evening shift change peak is the product of an acutely clustered shift change that occurs roughly between 4:30 and 6:00 PM and the large number of drivers needing to charge before handing over their vehicles to the next driver.

5.6. Strategies to make an economically efficient level of infrastructure operationally successful

Meeting drivers' charging needs with 350 chargers—rather than the 550 that would be required to meet the absolute peak demand—assumes some driver adaptability in planning when to charge. Technology could assist drivers in making these adaptations. For example, one technique to help mitigate the operational impact of building an efficient but below-peak level of infrastructure would be developing a "smart" charger network that communicates to drivers the availability of nearby chargers and even makes reservations. This type of system could allow drivers to fit charge events into their shifts more smoothly by reminding drivers of nearby available chargers, drawing more drivers to charge in non-peak times and reducing demand at peak times. Variable time-of-day pricing could also incentivize drivers to charge away from peak demand times.

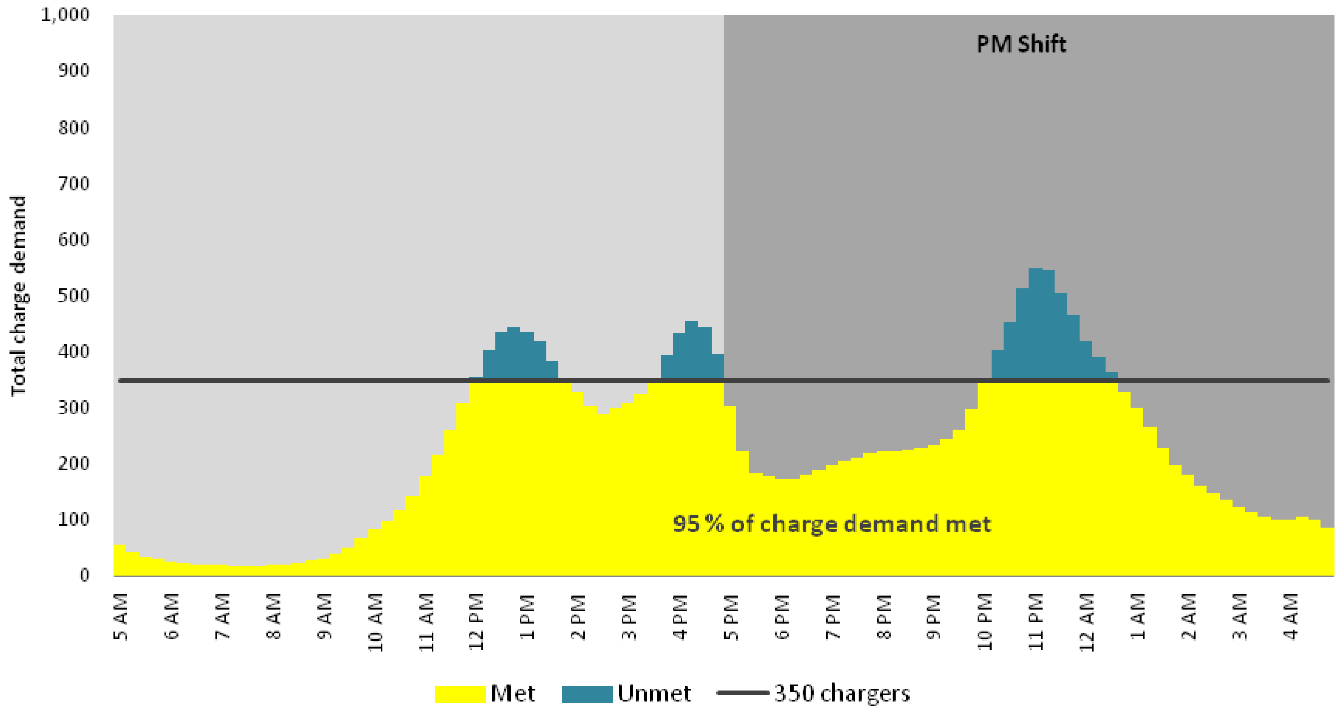
Incremental changes in shift behavior could also help mitigate the peak charger demands. Figure 5.4 shows the effects on peak charging of a small change in existing shift structures for double-shifted vehicles. In this scenario, we adjusted the shift structure so that one quarter of those vehicles that now change drivers between 4:30 and 6:00

Figure 5.2: Total charger demand (Wednesday detail)



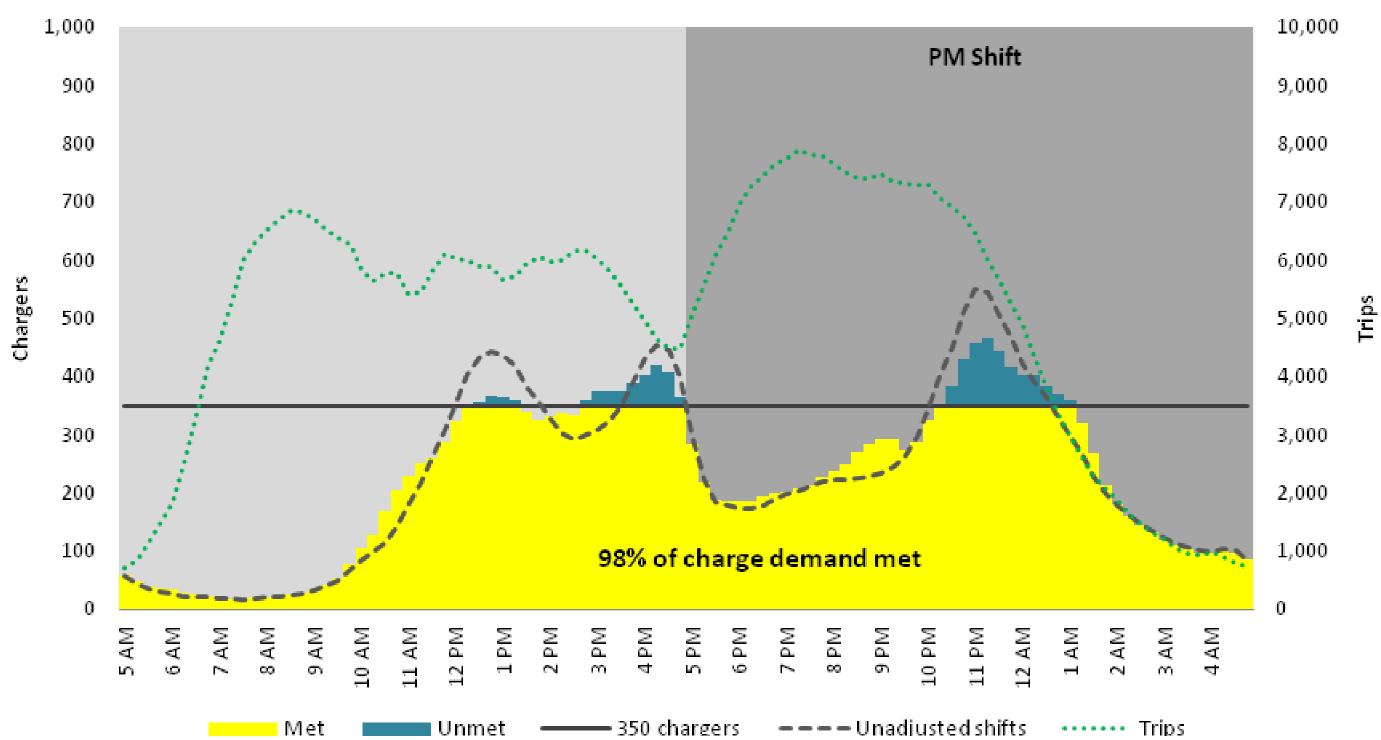
Sources: NYC TLC TPEP trip-sheet data, 2012; Ricardo Engineering charge-time matrix

Figure 5.3: Charger demand met by 350 chargers (Wednesday detail)



Sources: NYC TLC TPEP trip-sheet data, 2012; Ricardo Engineering charge-time matrix

Figure 5.4: Charger demand met by 350 chargers with slightly staggered shifts (Wednesday detail)

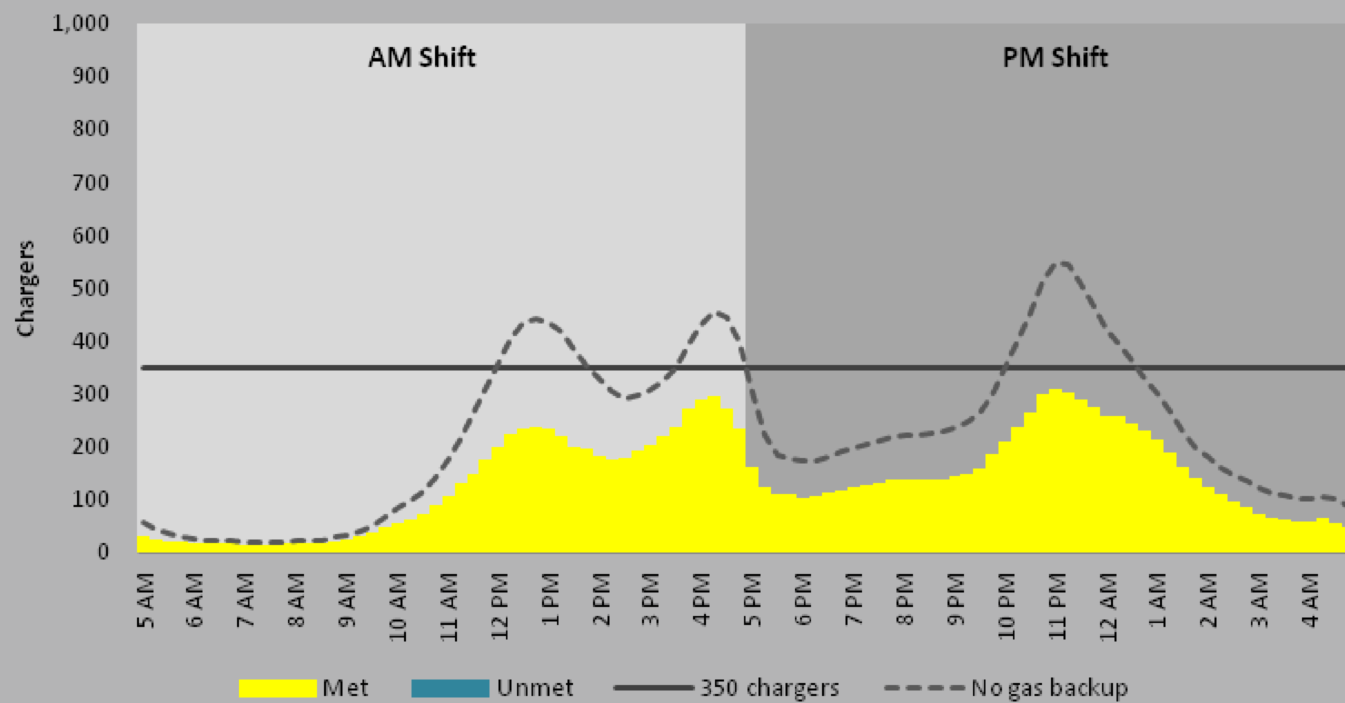


Sources: NYC TLC TPEP trip-sheet data, 2012, Ricardo charge-time matrix

Figure 5.5. Alternative Scenario with Range-Extended EV

Our analysis of charger demand assumes an all-electric vehicle. Range-extended EVs have an electric engine with a gas engine backup. Using range-extended EVs as taxis could help decrease charging needs and even the battery size needed in the vehicle. We considered a scenario using a hypothetical vehicle that has a 16 kWh battery and a gas backup tank that is large enough that the total distance the vehicle could travel without refueling equals the real-world taxi range that an EV taxi with a 35 kWh battery would get.* As compared to the all-EV scenario, this configuration would reduce the length of each charge event to 15 minutes (instead of 30). This lowers peak demand for chargers. In this scenario, 350 chargers would meet all of charge demand with a little extra capacity.

Charger demand met by 350 chargers using extended-range EV (16 kWh battery + gas backup tank)



Sources: NYC TLC TPEP trip-sheet data, 2012, Ricardo charge-time matrix

** With 94 miles of real-world taxi range on a vehicle with a 35 kWh battery (after degradation) and approximately 43 miles of real-world taxi range on a 16 kWh battery, a gas backup tank that could hold enough fuel to power the vehicle for at least 50 miles would be necessary.*

PM would change between 3:00 and 4:00 PM and one quarter would change between 7:00 and 8:00 PM. Under this scenario, the peak demand drops from 550 to 466 chargers, and the percentage of charge demand that is met by 350 chargers increases from 95% to 98%. Due to lower trip volumes for the late-night period (the average trips from 2012 are shown in green in the figure), drivers have more time without passengers, which leaves more room for a natural staggering of charge events away from the peak projected here.

Faster chargers than the 50 kW speed we assume in the model could also help reduce charger demand. A 100 kW charger could charge a 35 kWh battery from 10 to 80% in 15 minutes—half the time it takes a 50 kW charger to do so. Since much of the peak is a product of the overlap of new vehicles arriving to charge while other vehicles are still charging, a faster charger could reduce the peak need lower than the 350-charger threshold. The drawbacks to faster chargers, however, are higher purchase price and, more significantly, higher demand charges on the infrastructure operator.[32]

5.7. Conclusion

Building the appropriate amount of infrastructure to meet the needs of over 4,400 electric taxis is likely to be costly. Even after assuming a larger battery size of 35 kWh, most drivers will still have to charge their taxis at least once during their shifts and once between shifts. Therefore a large network of fast chargers would be necessary to accommodate an electric fleet of any size. From our modeling, we have learned that current shift structures are likely to create peak times when drivers will seek to charge. Building a network to meet this peak would increase program costs, so seeking ways to mitigate the peaks will be necessary to a successful and economically feasible rollout of electric taxis.

We believe that a network of 350 fast chargers would be sufficient to serve an electric fleet of the size proposed by Mayor Bloomberg. Ensuring that the network of chargers is a "smart" network with reservation capabilities will be essential to smoothing out the peaks in demand. In addition, faster chargers or slight changes in shift behavior could also enable the City to provide sufficient charging infrastructure for taxis with a smaller investment. It is also notable that the 4,412 electric taxis proposed would not all begin service on the same day. Therefore the City would be able to scale infrastructure up with the taxis as taxi owners adopt these vehicles while assessing the true demands for charging and the ability of drivers to adapt to this new component of operation.

> CHAPTER 6: ECONOMICS OF AN INFRASTRUCTURE NETWORK

Key Findings:

We project that a large quick charger (QC) network would cost more to construct and operate than could be generated in revenue from EV taxi drivers, but the gap is not insurmountably large.

The economics of a QC network could improve as compared to these estimates if:

- Significant economies of scale in installation costs were realized
- Prices of quick chargers continued to decrease
- Significant revenue could be generated from non-taxi users, advertising, and vending
- Smart technologies or changes in driver behavior reduced the number of chargers needed
- A cost-effective technique to mitigate demand charges was implemented

Understanding the economics of operating a quick charging infrastructure network is an important component of assessing what it would take to have a significant share of the taxi fleet operate electric vehicles. It requires quantifying three main items:

1. Cost of purchasing and installing quick chargers
2. Cost of operating quick chargers
3. Revenue that quick charger network could generate

This chapter investigates each of these items in turn and ends with an estimate of the size of the value gap--the difference between revenue and expenses--that would exist for such a network. This helps us understand what level of grant support or other intervention would be needed to incentivize an entity to construct and operate the network. Due to the newness of the technology and the high levels of uncertainty surrounding estimates for expenses such as installation costs, the estimates in this chapter should be viewed as informative but by no means definitive.

To preview, Figure 6.1 shows the estimated size of the value gap.

6.1. Cost of purchasing and installing quick chargers

Figure 6.1. Charging Network Value Gap Calculation

Cost per charger per year	$58,000	See section 6.2e of this chapter.
Number of chargers	350	Estimated in Chapter 7.
Total costs per year	$20.3 million	Calculated
Total revenue per year	$13.4 million	Estimated in section 3 of this chapter.
Value gap per year	$6.9 million	Calculated

6.1a. Cost to purchase quick chargers Although level 2 chargers are relatively inexpensive (about $2,000[xxi]), quick chargers are fairly expensive pieces of equipment. Fortunately, less expensive models have been introduced in recent years. There are many companies manufacturing quick chargers, including Nissan, Aerovironment, Schneider Electric, Coulomb, Eaton, Fuji, and Blink. 50 kW quick chargers are the most common quick chargers produced at this time, and they are assumed to be the equipment of choice in this analysis. A 50 kW charger can charge a 24kW battery (e.g., Nissan LEAF) from 0% to 80% in about 30 minutes.[33]

A bulk purchase of quick chargers would likely result in lower prices, but existing information on the price of quick chargers

Key Findings:

We estimate that quick chargers would cost $35,000 each. They have been declining in price and represent a relatively small share of the overall infrastructure network costs.

helps us understand the approximate level of investment that would be needed. We obtained information on the costs of chargers from various companies (see appendix for details). Assuming continued competition, price decreases, and discounts for bulk purchasing, we estimate that quick chargers for a large New York City taxi program would cost $35,000 each.

6.1b. Cost to install quick chargers The cost to install quick chargers, particularly in dense urban environments, comprises a significant and sometimes majority share of the costs of a quick charging infrastructure project. Installation costs depend on a variety of factors, including:

- The availability of 480V electrical service at the site. A 50 kW quick charger needs 480 volts of 3-phase electric service delivered at 65-80 amps. This is commonly available in large buildings, but less common on sites that do not already have a significant electrical draw.[xxii] If existing electrical service is not located

Figure 6.2. Cost Estimates for Quick Charge Installations

Type of Site[34]	Notes	Cost
Easier Interior Garage: 480V, 3-phase service is already available.	This is the least costly scenario. Electrical service in the correct voltage is already provided, no concrete work is required and unit is simply bolted to the floor. Variation in price depends on the ease of rigging and length of feeder to unit.	$5,000 - $15,000
Harder Interior Garage: 208V, 3-phase service of sufficient capacity available.	This is the next least costly scenario. Electrical service is available, but it is low voltage and must be stepped up with a transformer and associated switches must be added indoors.	$15,000-$25,000
Easier Surface Lot Exterior Location on Private Site: 480V or 208V power available.	This site has sufficient electrical service capacity available inside a nearby building (e.g., Seward Park Co-Op), and this power is used for an outdoor charger. A transformer might be needed.	$20,000-$40,000
Harder Surface Lot Exterior: location on private site, 208V is available.	This type of site, which might include an outdoor parking lot or garage, needs new Con Edison service or an upgrade of existing service with a step-up transformer. Costs for new service where service already exists would be incurred by the charger network/property owner (not by Con Edison). Some outdoor switchgear, asphalt/concrete work, bollards, a utility meter, and coordination with Con Edison would be required.	$40,000-$75,000
Easier Sidewalk Location: 480V or 208V power from adjacent building is available.	This is the easier curbside site, in which the charger is installed on a public sidewalk and power is drawn from an adjacent building with spare capacity. Sidewalk locations are more complex than other sites and require greater coordination.	$30,000-$50,000
Harder Sidewalk Location: No service is available.	This is the toughest site, in which new Con Ed service dedicated to the charger must be installed. The standard 208V service would require a step-up transformer to bring service to 480V. In addition, this site type would also require switchgear, asphalt/concrete work, bollards, and coordination with Con Edison.	$50,000-$85,000

Source: Site review and analysis by Quantum. This table does not include costs borne by Con Edison.

Figure 6.3. Charger Installation Costs

	Installation Cost	% Chargers this Site Type
Easier Interior Garages	$10,000	35%
Harder Interior Garages	$20,000	10%
Easier Surface Lot	$30,000	5%
Harder Surface Lot	$57,500	5%
Easier Sidewalk Location	$40,000	35%
Harder Sidewalk Location	$67,500	10%
Average Cost	$31,000	

near the charger site, additional costs for running electrical power from the source to the charger, purchasing and installing a step-up transformer, or from introducing new service could also be incurred.

- The amount of surface material (e.g., sidewalk) that must be disrupted for the installation.
- The complexity/crowdedness of the space underground below the installation (e.g., other utilities).
- Ease or difficulty of obtaining permits and required inspections.
- The proximity of the installation to trees. When trees or tree roots that need to be protected are near a charger, it can increase the difficulty and costs of excavation.

To understand costs of installation beyond what could be gleaned from the limited information about existing charger installation costs (see appendix for information on existing charger costs), the NYC Mayor's Office of Long Term Planning and Sustainability Planning and Sustainability worked with Quantum, a company that installs quick chargers, to generate cost estimates for hypothetical parking garage, surface lot, and sidewalk locations. Their findings are summarized in Figure 6.2.

Key Findings:

Quick charger installation costs are highly variable between $5,000 and $85,000 depending on the site. We project an average cost per charger installation of $31,000.

Significant research would be necessary to site quick chargers in a way that minimizes overall network costs, including installation costs, electricity costs, and land costs, while still meeting program objectives.

Aerovironment, a company that installs chargers nationwide, provided representative installation costs in ranges similar to those provided by Quantum. They quote a typical curbside charger installation at $50,000, an interior garage installation at $25,000, and a surface lot in an urban area at $45,000.[xxiii]

Before a thorough assessment of available sites and interested charger hosts has been completed, it is difficult to know how often we would be able to locate suitable sites in each of the six installation categories noted above. Although the goal of a site selection process would be to find as many low-cost sites as possible, in some cases we may need to select higher-cost sites to meet other program goals (e.g., having a good distribution of sites throughout the city, locating chargers near driver amenities). We therefore model a scenario with a mixture of easier and more difficult sites (see Figure 6.3).

The distribution of site types was based on very basic assumptions about the types of sites we would likely find for quick chargers. For example, we believe that few surface lots would be available in the areas with greatest need for chargers (i.e., the Manhattan CBD), so we model a small share of chargers in these locations. In the Manhattan CBD it also may be difficult to locate sufficient curbside parking spaces to meet the need for chargers, so we model that a large share of chargers would be sited at private or public interior parking garages (see Section 6.2c for discussion of land cost challenges for some of these sites). Based on the assumed cost and site type distribution in Figure 6.3, we project that the average cost of a quick charger installation would be $31,000.

In a large infrastructure rollout, installers would benefit from some economies of scale that could potentially reduce the cost below these numbers. This could particularly be the case if chargers were installed in clusters rather than on a one-by-one basis.

6.2. Cost of operating quick chargers

In addition to quick charger purchase and installation costs, there are costs associated with operating quick chargers. These include:

- Maintenance and repairs
- Connectivity and data transfer
- Land
- Electricity

This section describes each of these operational costs in turn and provides estimates for likely expenses.

6.2a. Maintenence and Repairs

Key Findings:

Quick charger maintenance and repairs would cost $1,500 to $2,500 per charger per year and represent a relatively small share of the costs of operating a charger network.

Quick chargers require both routine maintenance and periodic repairs. The primary maintenance activity that would need to occur each year is filter cleaning two to three times per year. The primary repair activity that would need to occur periodically would be replacing the charger's plugs and cords or a broken screen. Replacing the charger's plugs and cords would be necessary occasionally due to everyday wear, but would most likely need to occur more frequently because of intentional vandalism or customer misuse/accidents. Outdoor locations would most likely require more repairs than indoor locations. A charger manufacturer provided us with a range of likely maintenance and repair costs for both indoor and outdoor locations (see appendix for details on maintenance and repairs needed).

Using quotes from the charger manufacturer and an assumed distribution between indoor and outdoor sites and higher- and lower-maintenance sites, we estimate average annual maintenance costs per charger of about $2,000. See Figure 6.4.

6.2b. Connectivity and Data

Quick chargers in use by the taxi fleet would need to have network connectivity (sometimes called "EV Data") so that the owner can (1) control who may and may not access the charger, (2) bill users for accessing the charger, and (3) have robust reporting on activities at the charger.[xxiv] Aerovironment quotes an annual connectivity cost of $240.[xxv] Nissan quotes an annual connectivity cost of $420 and an annual network maintenance cost of $1,050.[xxvi] GE quotes $120 to $265 per year for connectivity depending on functionality.[xxvii] Assuming that the network would need the highest-level network functionalities available but that it would benefit from some economies of scale, we estimate connectivity costs of $500 per charger per year.

6.2c. Land

Key Findings:

The cost of land for quick chargers is highly dependent upon actual sites selected. We estimate an average of $1,300 per charger per year, though this cost could vary widely depending on site selection.

Significant research would be necessary to site quick chargers in a way that minimizes overall network costs, including installation costs, electricity costs, and land costs, while still meeting program objectives.

Another operational cost associated with quick charging is the expense of purchasing or renting the land on which the charger and, if necessary, a step-up transformer reside. In addition to space for equipment, space for vehicles to park while charging and waiting to charge would also be necessary. Depending on where chargers reside, the costs may be either opportunity costs only or also entail explicit costs to the charging network operator.

Figure 6.4. Projected Quick Charger Maintenance and Repair Costs

	Maintenance/ Repair Cost	% Chargers this Maintenance/ Repair Level
Indoor, low estimate	$700	22.5%
Indoor, high estimate	$1,500	22.5%
Outdoor, low estimate	$2,300	27.5%
Indoor, high estimate	$3,100	27.5%
Average Cost	$1,980	

Non-taxi-industry private parking garages or lots: Unless a parking garage owner is able to directly charge the driver a market-rate parking fee for using a charger on his land, the charging network owner would likely need to pay the property owner a rental fee in exchange for dedicating a spot to quick charging and forgoing regular parking revenue for this space. As a point of reference, monthly parking spots advertised online were listed at approximately $175 in Long Island City and $400 per month in Manhattan neighborhoods south of Central Park; however, real estate experts report that monthly parking may cost as much as 50% more than this in these locations.[xxviii] [35] The operational reality of many private garages in NYC makes monthly parking rates a less-than-ideal indicator of the cost of private garage space. Many parking facilities in New York City are valet style and essentially "bury" monthly-parked cars deep underground. For a taxi charging system, space with chargers would most likely need to be easily accessible for drivers to drive into, plug in, and exit. These spaces nearer the ground level and front of the garage are of premium value to garage operators, and the value they would assign to leaving these spots vacant for quick charging would likely be higher than the revenue for a typical monthly parking spot.

Taxi-industry-owned private lots: About one third of taxis are operated as fleets, and fleets maintain garage premises where they conduct their business. (As noted in Chapter 2, owner-drivers and DOV operators generally park their vehicles either on-street or at their private homes. Most taxis are double-shifted, so time spent parked is relatively minimal). At fleet facilities, drivers sometimes park during the shift change. These facilities are also locations where taxi drivers and fleet owners conduct their financial transactions and where fleet mechanics work to maintain and repair vehicles. TLC requires that fleets maintain off-street parking space at or near the business premises to store the lesser of (1) 25 vehicles, or (2) 50% of daily-leased vehicles plus 5% of longer-than-daily-leased vehicles. Garages typically have more than one hundred vehicles, so the amount of parking they maintain is likely in the neighborhood of 25 spots.

From TLC observations and conversations with fleet operators, taxi garages are crowded spaces at shift change time and many drivers cannot even fit their vehicles into the garage to change shifts. They instead park on-street somewhere near the garage. Therefore space in garages is at a premium and not all space could be re-purposed to quick charging because some space would need to remain for vehicles under repair or for other purposes. Still, a fleet interested in operating electric vehicles and allowing its drivers to charge on premises would have some already-owned or already-leased land where chargers could be installed. Garages are significantly less crowded at non-shift-change times, so fleets could accommodate EV charging onsite more easily at times of day other than the shift change. Some taxi garages also own gas stations, which provide additional land already "within the industry" that taxi owners could potentially re-purpose for charging.

City-owned land: The City of New York could make its own land available as sites for quick chargers. This could include City-owned surface lots, parking garages, or curbside spaces currently used at taxi stands, taxi relief stands[36], or public parking.

- *Taxi stands and taxi relief stands*: There are approximately 215 taxi stands with approximately 650 parking spaces throughout the city. There are approximately 50 taxi relief stands with approximately 150 spaces throughout the city. These sites do not currently generate revenue for the City and some are underutilized, so re-purposing some of these locations for charging may be an attractive option.

- *Public parking:* For spaces currently used as public curbside metered parking, the opportunity cost of re-purposing these spaces into charging sites translates into about $11,000 per space in annual revenue to the City.[37] There is also public curbside parking that is not metered where one can park free of charge. Re-purposing revenue-generating spaces into charger spaces may be less attractive than other options for chargers from a fiscal point of view; however, in some cases these spaces may be in locations that are operationally ideal for charging (e.g., cost of charger installation/ operation would be low relative to other locations) and therefore they would be selected.

The City is already installing level 2 chargers in ten of its public parking garages and many of the garages used by City-owned vehicles.[xxix]

In addition to City-owned land, a taxi charger program could be incorporated into lands that the City does not own directly but over which it has some development control. The City could look into incorporating space for quick chargers into development deals it is working on, just as it integrates other features that would benefit the community into these types of plans.

Using a projected distribution of charger site types and the costs of acquiring these sites, we estimate an average annual land cost of about $1,300 per charger (see Figure 6.5). The actual distribution of site types and therefore land costs would be dependent upon site feasibility/cost assessments and which property owners participate in the program.

6.2d. Electricity The cost of electricity is another key operating cost for a quick charger. There are two types of electricity costs that would need to be covered by the network: demand charges and energy usage charges.

- *Energy usage charges:* Energy usage charges are the typical per-unit cost of electricity that most people think of when considering electricity costs. They are measured in kilowatt hours (kWh) and they reflect the quantity of electricity the property drew from the system over the course of the month.
- *Demand charges:* Demand charges are an additional charge a customer pays that reflects the highest energy draw the customer makes on the system within any one-half hour period during the month. Demand charges reflect the maximum rate (measured in kW) at which the property is pulling electricity off the grid. The electrical utility, Con Edison, charges these fees because it must build the system out to have capacity to serve whatever "spikes" in demand for electricity a customer has, even if the customer's demand for electricity is lower than this level most of the time.[xxx]

Strategy to Reduce Infrastructure Network Costs: Next-Generation Charging Equipment

Improvementsin charging equipment could also help drive down network costs. For example, the Electric Power Research Institute (EPRI)—in a partnership with NYPA, Con Edison, the NYC Mayor's Office, the Eaton Corporation, and Enertronics—is developing a medium-voltage transformer system for DC fast charging that would tap into medium-voltage power to reduce the equipment costs, installation costs, and demand charges associated with quick-charging. The charging equipment and installation costs could be 20% below those projected here, representing a savings of about $13,000 per charger or $4.6 million for a network of 350 chargers. This new technique could also reduce demand charges by 25%. This would represent a savings of $5,000 per charger per year or $13 million over 5 years for the entire network.

Quick chargers are able to charge vehicles relatively quickly because they pull electricity off the grid and into the vehicle's battery at a fast rate. However, this fast energy draw generates a demand charge because, unless the quick charges all happen to take place at times when the customer's use of other electric-powered equipment has plummeted, it spikes the customer's overall demand. According to calculations by Con Edison, the demand charge for a 50 kW charger would range from $1600 to $1800 per month or $20,000 per year.[38] Demand charges are unaffected by the number of times the charger is used. So long as the charger is used at least once in the month, the demand charge associated with that spike in electrical draw will be assessed and this month the demand charge will persist for 18 months even if no further charge events occur in this time. Demand charges are lower for slower quick chargers (e.g., 25 kW) than they are for 50 kW quick chargers because they can never spike demand as high as 50 kW chargers do; however, the tradeoff is that they would charge vehicles more slowly.

Key Findings:

Electricity costs would be $45K per charger per year (assuming 23 charges per day, 365 days per year). Because they occur every year, these costs represent a significant share of the costs of the operating a quick charger network.

Technologies or techniques that could reduce electricity costs (e.g., energy storage systems like GreenStations, integration with building energy management systems) could make a significant positive impact on the economics of the network.

Unlike demand charges, energy usage charges are assessed based on the amount of electricity consumed. Therefore the electricity costs per charger vary depending upon how many times each day they are used and how much time each vehicle spends charging. To charge from 10% to 80%, a vehicle with a 35 kWh battery would need to charge for approximately 30 minutes at a 50 kW charger.[xxxi] This "full charge" would cost about $3.85 in electricity. Not all charges would be "full" 10% to 80% charges. According to the estimates in Chapter 5, in our network each 50 kW charger would be in use for an average of 9 hours per day (23 charges lasting an average of 23 minutes). The average charge would therefore cost somewhat less than $3.85. We estimate that the average charge would cost $3.00 in usage charges. At this price, with each charger doing an average of 23 charges per day, 365 days per year, the energy usage charges would be about $25,000 per charger per year. [39]

These estimates may be on the high end because they do not account for some efficiency that could be gained by "pooling" several quick chargers in one location. This is because when an EV is connected to a 50 kW quick charger, it does not draw 50 kW the entire time. Therefore if five chargers were located in the same place, it would probably not ever trigger a demand charge equal to 250 kW because EVs would all start charging at staggered times and would not hit the 50 kW peak at the same time. This lower peak would result in a lower per-charger demand charge than is modeled here.

Figure 6.5. Land Costs for Quick Charger Network

	Annual Land Cost	% Chargers in this Location Type*
Fleet-owned property	$0 (opportunity cost to fleet owner)	25%
Private garage or lot	$4,800 ($400/mo. x 12 months)	15%
City-owned lot	$0	10%
Taxi stand	$0	40%
Other curbside location: formerly unmetered	$0	5%
Other curbside locations: formerly metered	$11,000 in meter revenue foregone	5%
Weighted Average Cost		$1,270

** Actual distribution would be dependent upon site assessments and property owner interest in program*

Figure 6.6. Summary Costs of Quick Charging Infrastructure Network

	Average Cost	Cost per Year	Notes
Charger purchase*	$35,000 (up front)	$4,900	See Section 1a.
Installation costs*	$31,000 (up front)	$4,340	See Section 1b.
Maintenance/repairs	$1,980/year	$1,980	See section 2a.
Data and connectivity	$500/year	$500	See section 2b.
Land	$1,270/year	$1,270	See section 2c.
Demand charges	$20,400/year	$20,400	See section 2d.
Energy usage charges	$25,000/year	$25,000	See section 2d.
Total	--	$58,390	

** Assumes 5-year equipment life, 30% of value of charger and installation work remains after 5 years.*

Key Findings:

We estimate that a quick charger network could generate approximately $13 million in revenue per year from driver fees each year. This estimate is sensitive to the costs of other fuels (i.e., gas prices) and the extent to which drivers see time spent charging as a re-purposed break time or a lost revenue opportunity.

This revenue level is lower than the annual costs of the quick charger network. Therefore policies or programs to increase revenue (e.g., selling charging to non-taxi EV users, selling advertising space, vending, or grants) would be needed to fund the network.

6.2e. Summary Costs of Infrastructure Network

The below table summarizes the total costs per year to install and operate a quick charger. Although some manufacturers rate quick charging equipment as having a 10-year service life, these estimates assume that, due to the high level of use these chargers would experience and their public accessibility, the useful life would be closer to five years. However, we do assume that 30% of the value of the charger and the installation remain at the end of the 5-year service period.[40]

Due to the newness of the technology and the high levels of uncertainty surrounding estimates for expenses such as installation costs, the estimates in this chapter should be viewed as informative but by no means definitive. In particular, installation costs will vary widely depending on the network installer's ability to secure access to lower-cost host sites. There are also a variety of strategies that could be employed to reduce some of these costs. For example, New York State offers a tax credit of up to $5,000 per EV charger installation.[41]

6.3. Revenue that a Quick Charger Network Could Generate

Determining how much revenue the charger network could generate requires accounting for the need to incentivize taxi owners and drivers to purchase and lease electric taxis over alternative vehicles. As is discussed in Chapter 2: NYC Taxi Industry Background, taxi drivers currently only need to fill up with gas once per shift. At shift change--the busiest time of day at gas stations serving taxi drivers--waiting for an available fuel pump and filling up typically takes only 6 minutes. In contrast, we anticipate that the average amount of time charging per shift will be about forty minutes, with virtually all taxis needing to charge before shift change handover and about 60% needing an additional charge mid-shift (see Chapter 5: Level of Infrastructure Needed to Support Taxi Fleet).

If a taxi driver were driving gasoline-powered vehicle, in 2017 he or she might be driving the NV200 Taxi of Tomorrow. This vehicle is expected to get 28 miles per gallon by 2017, which in a taxi shift of about 125 miles requires 4.4 gallons of gasoline. If gasoline costs were $4.50, this would mean drivers would be spending about $20 per shift on gasoline.[42]

To incentivize drivers to switch from a single 5-minute gasoline fill-up to approximately forty minutes of charging in one to two sessions per shift would require pricing charging competitively and making it as convenient as possible. As discussed in Chapter 2: NYC Taxi Industry Background, taxi drivers do take breaks; however, charging would require that they modify the location, duration and time of these breaks and at times deal with issues like lines at the charger. To entice drivers to make the shift, we project they would need to save the equivalent of one fare per shift, or $15, and could therefore pay $5 per shift for charging. See Figure 6.7.

If New York City were to have a one-third electric taxi fleet, these 4,412 taxis would do an average of 616 shifts per year. If the charging network could charge drivers $5 per shift, this would generate $13.4 million in revenue per year. There are several important caveats to this estimate:

- The actual level of incentive that taxi drivers would require to switch from gasoline-powered vehicles to EVs is unknown, so the $5 figure could be too high or too low. It is dependent on gas prices and the many factors that affect the convenience of charging
- The charging network could be made available to the public or to other non-taxi fleets, which could generate additional revenue. However, adding additional users to the universe of electric vehicles relying on the chargers could impact the number of chargers that are needed and the costs of installing and operating the system. One option to mitigate the impact public or non-taxi use would have on the size of the charging network needed would be to have rules or incentives for non-taxi customers to use the chargers at off-peak times.
- Charging is not the only potential revenue source for a charging network. Advertising space in New York City is valuable and offering charger faces to advertisers could be a significant revenue stream to the network. For example, Citibank is paying $41 million over the course of 5 years to be the title sponsor of New York City's bike-share program. This entitles them to advertising on 600 stations, 10,000 bicycles, membership keys and the NYC Bike Share website.[xxxii] Although advertising on quick chargers might not generate a Citibike level of advertising revenue (particularly if chargers are not in highly-visible public spaces), figures from Citibike provide some sense of the scale of revenue that sponsorship opportunities in NYC can generate.

6.4. Projected Value Gap for a Quick Charger Network

Combining the estimates from sections 6.1 through 6.3 enables us to estimate the approximate size of the value gap that would exist for a charging network of the size we believe would be necessary to serve a one-third electric taxi fleet.

If the charging network had an annual cost of $58K for each of 350 chargers and it could generate $13 million per year in revenue, an additional $6.9 million per year would be

Figure 6.7. Charging Revenue from Taxi that a Quick Charger Could Generate

Number of electric taxis	4412	1/3 of taxi fleet
Charging fee tolerance per shift	$5	Estimated amount driver could be charged to incentivize EV over gas-powered vehicle
Average shifts per year per taxi	616	Assumes 50 weeks/year; 1/3 of taxis are single-shifted and 2/3 are double-shifted
Revenue per year	$13.4 million	

Figure 6.8. Charging Network Value Gap Calculation

Cost per charger per year	$58,000	See section 6.2e of this chapter.
Number of chargers	350	Estimated in Chapter 7.
Total costs per year	$20.3 million	Calculated
Total revenue per year	$13.4 million	Estimated in section 6.3 of this chapter.
Value gap per year	$6.9 million	Calculated

needed to break even. As was mentioned at the beginning of this chapter, due to the newness of the technology and the high levels of uncertainty surrounding estimates for expenses such as installation costs and the amount drivers could be charged for charging, the estimates in this chapter should be viewed as informative but by no means definitive.

6.5. Conclusion

We project that a large quick charger (QC) network would cost more to construct and operate than could be generated in revenue from EV taxi drivers, but the value gap is not insurmountably large. There are opportunities to shrink or eliminate this gap by addressing both revenues and costs:

Costs could be reduced from the levels described in this chapter if:

- Significant economies of scale in installation costs were realized.
- Prices of quick chargers continued to decrease.
- A cost-effective technique to mitigate demand charges were implemented.
- Smart technologies or changes in driver behavior reduced the number of chargers needed.

Revenues could be higher than the levels described in this chapter if:

- We have underestimated taxi drivers' tolerance for time spent charging. If drivers do not see time spent charging as an economic loss (e.g., they enjoy the break time), they would be willing to spend more for charging than is modeled in this chapter.
- Gas prices were to increase to levels above those used in the projections in this paper. Higher gas prices would reduce the perception of charging time as a sacrifice because it would represent a significant fuel cost savings. This would increase the amount drivers would be willing to pay to charge.
- Significant revenue could be generated from non-taxi charger users (e.g., other private fleets, City fleets, or the public).
- Significant revenue could be generated from advertising on chargers or from convenience stores/ restaurants catering to drivers charging their vehicles.

> CHAPTER 7: ELECTRIC VEHICLE QUICK CHARGER SITING FEASIBILITY

Key Findings:

NYC has the grid capacity to accommodate 350 quick chargers.

Based on taxi service areas, fleet garage locations, and driver residence locations, most chargers would need to be located in Manhattan and Western Queens.

The largest constraints in grid capacity when looking at demand for chargers occur in West and Central Midtown in Manhattan and in Long Island City in Queens, but both areas have adjacent areas with additional electric load capacity.

There are pros and cons to both on-street and off-street charger siting, and a large network would likely include both types of installations.

In Chapter 5 we estimate that a network of 350 quick chargers would be needed to support a one-third electric taxi fleet. In this chapter, we pivot towards geography and begin to explore how a network of this size could be sited throughout New York City. We look at both the demand and supply geographically, thinking about where taxis operate—and, thus, where taxis are likely to be when they seek a charge—and where the city's electrical grid is currently projected to best handle additional load. Our approach is mostly macro-level, as we look broadly across the city at where we could place chargers. We do not attempt to offer a site-by-site plan for where to place chargers; however, we do explore more general site types and offer a few specific sites as case-study examples of where charges might be accommodated.

This chapter contains 6 sections that broadly consider the feasibility of siting hundreds of quick-charging stations in NYC:

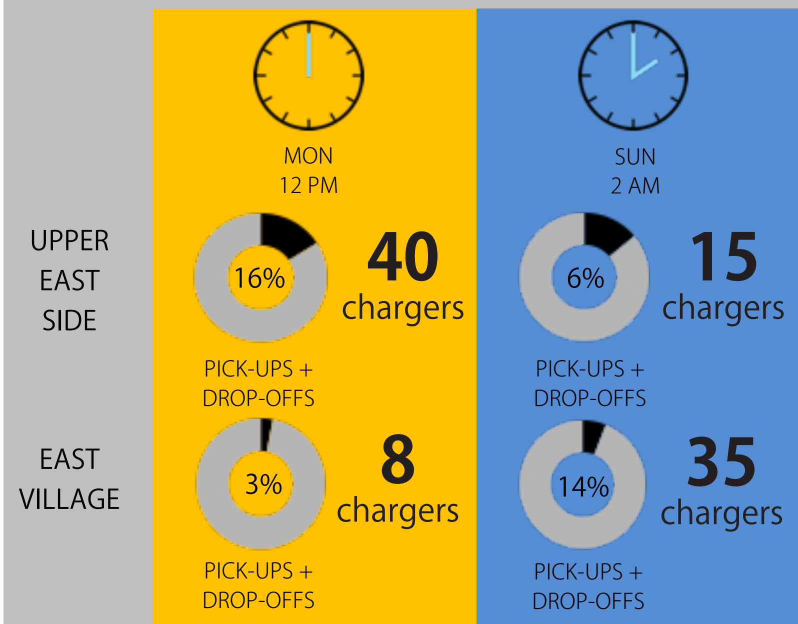
1. Geographic Allocation of Chargers: Overview
2. Geographic Allocation of Chargers: Examining where taxis operate (demand-side)
3. Geographic Allocation of Chargers: Fitting a charger network into a grid with limited capacity (supply-side)
4. Site Types: Overview
5. Site Types: Off-street versus on-street locations
6. Conclusion and Recommendations

The supply side of this chapter is based on information from Con Edison's long-term forecasts. These forecasts are based on common views and assumptions about customer and industry trends. They develop a 20-year outlook on customer behavior and energy usage that serves as the basis for their long-range plans. The forecast for energy use reflects Con Edison's views on the local economy, employment, demographics, and also considers shifts in energy use patterns. Understanding these trends in the way consumers use electricity helps the utility to prepare its system for continued demand growth. This approach is consistent with the New York Independent System Operator's view of the future. Con Edison expects

Figure 7.1. NYC Districts and Airports with Baseline Number of Chargers (57 chargers)

Source: NYC DCP GIS layers

Figure 7.2. Example of Allocated Chargers in Two Districts



On the average Monday at lunch time, about 16% of taxis are either picking up or dropping off passengers in the Upper East Side. At the same time, about 3% of taxis are making trips to/from the East Village. For Sundays in the early morning, the pattern switches: about 6% of taxis are making trips to/from the Upper East Side at this time, while 14% are making trips to/from the East Village. We calculated that during both of these time periods, about 250 taxis might be seeking to charge. On Monday afternoon, the Upper East Side would need 40 chargers to satisfy demand, given the distribution of trips. However, on Sunday morning, only 15 chargers would be necessary to meet demand. In the East Village, only about 8 chargers would be needed on Monday afternoon, but 35 chargers would be necessary on Sunday. To satisfy both demands, we looked at weekly peak demand to distribute chargers.

the transportation sector to be a source of increased electric consumption as electric-vehicle technologies improve and are adopted by consumers.

7.1 Geographic Allocation of Chargers: Overview

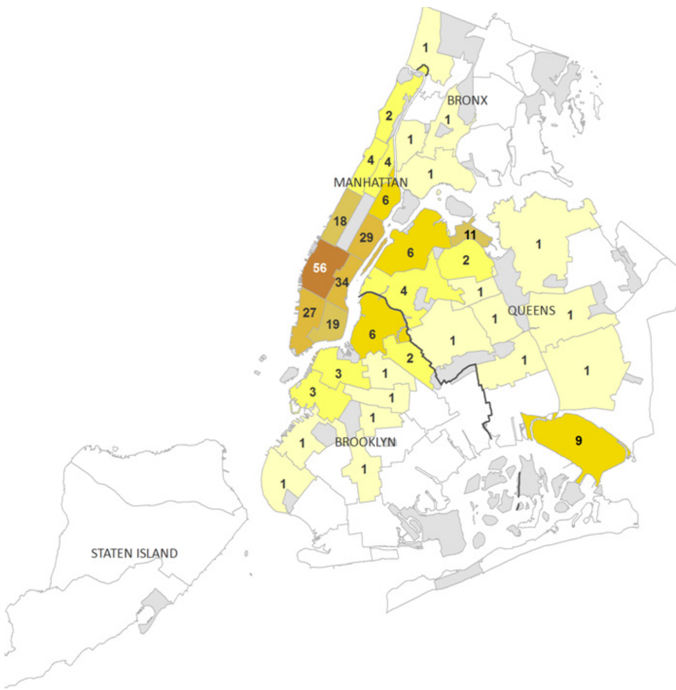
The geographic placement of vehicle charging infrastructure will have to meet two overlapping and somewhat contradictory needs: chargers should be distributed enough to ensure a taxi is never too far from a charger, while also concentrated enough in areas with high taxi volumes to reduce queuing and increase the overall efficiency of the charging network. In addition to the temporal clustering which we describe and model in Chapter 5: Level of Infrastructure Needed to Support Taxi Fleet, a degree of geographic clustering is also likely to occur. Given that over 90% of yellow taxi pick-ups today occur in Manhattan, there will certainly be a clustering of charging demand in the broadest sense—most chargers will probably have to be located in Manhattan because of the nature of yellow taxi service. In addition to geographic clustering based on where taxi service takes place, we believe that there is also likely to be clustering in areas of the city where fleet garages are located and where many owner-drivers live, since these are areas where vehicles are stored or switched and would likely be places where drivers will want to charge either before or after completing a shift.

As we begin to estimate the geographic demand for charger placement, we must also consider the current constraints on the supply-side of the equation. Con Edison believes the city could easily handle a network of 350 vehicle chargers without additional area substation infrastructure reinforcement; however, they point out that there are some areas of the city where the supply resources are reaching their maximum capacities under the current 20-year load relief plan. By looking at how much charging infrastructure the grid could handle in each area of the city, we attempt to match the supply and demand in a way that will satisfy drivers' demand for charging while respecting the projected limits of the electrical grid.

7.2. Geographic Allocation of Chargers: Examining where taxis operate (demand-side)

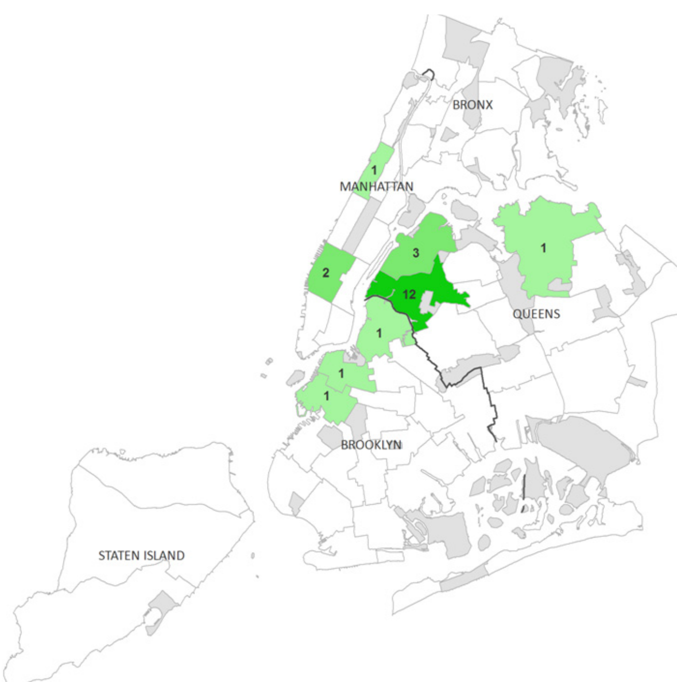
On the demand side of electric vehicle charging, there are

Figure 7.3 Chargers Allocated Based on Level of Taxi Pickups and Drop-offs (262 chargers)



Source: NYC TLC TPEP 2012 trip-sheet data, NYC DCP GIS layers

Figure 7.4 Chargers Allocated Based on Fleet Garage Locations (22 chargers)



Source: NYC TLC Licensing records, NYC DCP GIS layers

two main considerations in determining where chargers would need to be placed. The first is the need to create a continuous network of chargers to ensure charger availability across the city. Under current TLC rules, drivers may not refuse service to passengers travelling within the five boroughs of New York City, to Westchester or Nassau Counties, or to Newark Airport.[xxxiii] In order to continue to provide the same level of yellow taxi service with electric vehicles, drivers must be confident that they can travel anywhere within the city[43] and have the ability to charge afterwards, if necessary. We set a baseline of one charger in each of the city's 55 Public Use Microdata Areas (PUMAs)[44] — areas that roughly follow the boundaries of the City's 59 Community Districts — and at the LaGuardia and JFK airports. For the purposes of this report, we will refer to PUMAs as "districts." Districts are, on average, 5.5 square miles in area; if chargers were centrally located in each district, drivers would never be farther than a few miles away from a charger. Figure 7.1 shows each of the city's 55 districts, in addition to the airports.

Building off this baseline level of coverage (put in place to reduce range anxiety), we next looked at locations where the city is likely to need more than a single charger in order to satisfy the demand for charging from electric taxis. We project the likely demand for chargers in each area of the city by looking at two main factors: where taxi drivers operate during their shifts and where taxis are between shifts.

To determine where taxis are while in service, we examined the locations of all taxi pick-ups and drop-offs in 2012. For each weekday, we calculated in 15-minute time periods the distribution of pickups and drop-offs completed across each of the 55 districts and at the airports. We matched trip starts and ends with charger demand as calculated in Chapter 5 to map demand at each time of day and each area of the city. Because different areas of the city are busier with taxi activity at different times of day, this matching process often resulted in demand for many chargers in one location at one time of day and then demand for many chargers in another location at another time of day (for an example, see a comparison of charger demand in the Upper East Side and the East Village by time of day in Figure 7.2).

Chargers are fairly permanent installations, so we would not expect to be able to move chargers' locations to adjust to the geographic shifts in demand that occur at different times of day. Instead, as a measure of demand throughout the week, we used the weekly peak in charger demand for each zone to allocate the overall peak number of chargers we think would be necessary to satisfy total demand.

We calculated in Chapter 5 that around 350 chargers would be needed to satisfy electric taxi demand. In allocating chargers, we assume that after assigning each district with a base of one charger, around 90% of the remaining chargers should be sited to accommodate where taxis operate during their shifts and 10% should be sited to accommodate where vehicles are between shifts. Figure 7.3 maps out the service-based demand for chargers by district. The largest concentration of charger demand based on taxi service locations is in the district representing Clinton, Chelsea, and Central Midtown, where 56 chargers beyond the baseline single charger would be needed to put chargers in place at a level that is proportionate to the level of taxi pickups and drop-offs taking place. Additional districts with large concentrations of chargers include East Midtown (34 chargers), the Upper East Side (29), and the area representing Greenwich Village, Tribeca, and the Financial District (27).

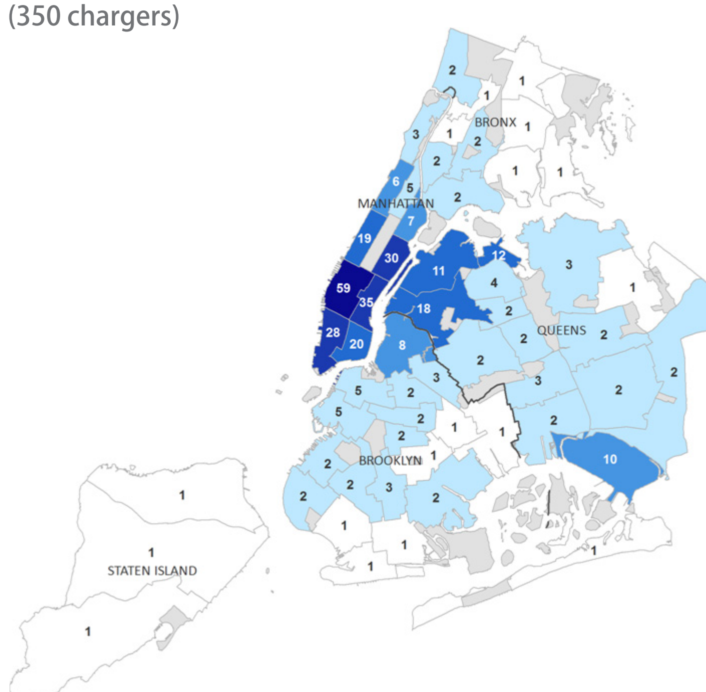
Figure 7.5 Chargers Allocated Based on Owner-Driver Residences (9 chargers)

Source: NYC TLC Licensing records, NYC DCP GIS layers

In looking at where taxis are between shifts, we considered both fleet and DOV/owner-driver operations, looking at the locations of fleet garages and the residences of owner-drivers. For fleets, we counted the number of fleet-affiliated vehicles in each district, and for owner-drivers, we counted the number of drivers in each district. Of the 350 chargers we allocated, we assume that 22 would be sited near fleets to accommodate fleet vehicles and 9 would be sited in areas with high concentrations of taxi driver residences to accommodate owner-driver and DOV vehicles.[45]

Figures 7.4 and 7.5 map the fleet- and owner-driver-based demand for chargers between shifts. For chargers allocated for fleet vehicles, the top area is the district representing Long Island City, Sunnyside, and Woodside in Queens, with a total of 12 vehicle chargers allocated. Most fleet garages are located in one of these three neighborhoods. Much smaller concentrations of fleet-based chargers are located in the districts representing Astoria (3 chargers) and Clinton,

Figure 7.6 Total Chargers Allocated to Districts and Airports (350 chargers)



Source: NYC TLC TPEP 2012 trip-sheet data, NYC TLC Licensing records, NYC DCP GIS layers

Chelsea, and Central Midtown (2 chargers). For chargers allocated based on areas where owner-drivers live, additional chargers would be needed in districts in Northwest and Southeast Queens and in Southern Brooklyn. One additional charger would be allocated to six districts in Queens and to three districts in Brooklyn.

Figure 7.6 summarizes the projected total number of chargers needed based on the recommended distributions in Figures 7.1 through 7.4. The area of the city that would need the largest concentration of electric vehicle chargers is the district representing Clinton, Chelsea, and Central Midtown, with a calculated concentration of nearly 60 chargers. Other districts with large numbers of allocated chargers include East Midtown (35 chargers), the Upper East Side (30), and the area including Greenwich Village, Tribeca, and the Financial District (28). Outside of Manhattan, the largest concentration of chargers would need to be in the area including Long Island City, Sunnyside, and Woodside (18 chargers). Twelve chargers would be needed to serve LaGuardia Airport and ten chargers would be needed to serve JFK Airport.

Figure 7.6 represents only an informed projection of where demand for charging would take place. A real-world infrastructure rollout would occur over the course of several phases. We would then be able to use data on the popularity of chargers at various locations in the first phase of charger rollout to inform how we should geographically distribute later phases of charger installations.

7.3. Geographic Allocation of Chargers: Fitting a charger network into a grid with limited capacity (supply-side)

On the supply-side of the equation, there are a few limitations on where charging infrastructure can be placed. Con Edison, the utility company that delivers electricity to all of New York City (except for the Rockaway Peninsula), must ensure that the grid is stable on even the most demanding energy days of the year. These peak days usually occur in the summer months when the outside temperatures are highest and when many customers are running air-conditioning units throughout the day. Con Edison developed projections of which power distribution networks have capacity to add 50kW electric vehicle chargers and how many chargers each network could safely accommodate from an area substation perspective[xxxiv]. Although overall the city's electrical grid can handle 350 50kW electric vehicle chargers, there are a few areas of the city where existing area substation capacity is more restricted to accommodate the additional charger load given projected peak load conditions over the long term.

Figure 7.7 shows the current projected capacity for charging infrastructure in all power networks in Manhattan and the power networks in Brooklyn and Queens where we project some concentration of chargers would be needed. Networks outlined in red are areas where there is limited excess area substation capacity, but where Con Edison recommends against siting chargers to avoid additional infrastructure reinforcement and associated capital expenditures.

7.4. Relationship between Projected Demand for Chargers and Grid Capacity

Overall, much of the capacity for electric vehicle chargers exists in the more residential areas of Manhattan. In general, Con Edison recommends that chargers be sited in these areas because they have excess area substation capacity that would be needed to support those chargers.[xxxv] Along the East Side of Manhattan—comprised mostly of residential neighborhoods—most power networks from East Harlem (Triboro network) down through the East Village (Cooper Square network) have capacity for 40 or more chargers. The greatest capacity exists in the Triboro and Randalls Island networks, each of which has capacity for up to 100 50kW chargers. For some areas of the city where we have calculated a large demand for chargers—namely, in the Upper East Side and East Midtown—there is sufficient capacity from an area substation perspective to provide for (and even above) the calculated demand. In addition to the East Side, there is excess capacity in the network supplying power to Washington Heights for up 100 50kW chargers, though there is far less demand for charging infrastructure in this area.

Figure 7.8 shows the intersection of supply and demand, aggregating the recommended number of chargers from Con Edison and the demand for chargers by district and showing the balance between the two. Unfortunately, many of the networks with limited capacity overlap with areas of the city where significant numbers of chargers would be beneficial to electric taxi drivers. The only power networks within the Clinton, Chelsea, and Central Midtown districts with capacity are the Chelsea, Fashion, Empire, and Greeley Square networks. Together, these four power networks can accommodate up to 160 chargers, easily covering the 59 chargers that we allocated to this area. Although there is enough grid capacity, these chargers would need to be placed within a fairly limited geographic area. Within this area, there is availability in the Chelsea and Fashion power networks for up to 60 and 40 chargers, respectively. Placing a large number of chargers within the Fashion network could contribute to considerable amounts of congestion, given that this area is quite small (this network spans the area roughly banded by 5th Avenue, 8th Avenue, W. 26th Street, and W. 30th Street, an area covering about one-eighth of a square mile). The same issue exists for the Empire and Greeley Square networks since these networks are even smaller than the Fashion network; together these networks have capacity for an additional 60 chargers. Therefore, most of the chargers would need to be placed in the Chelsea network (which would just meet the demand for 59 chargers). The space constraints in this area could also influence the types of charger configurations that would be possible in these areas.

In addition, Con Edison recommends that no quick chargers be placed in the Borden and Sunnyside power networks, the networks that cover Long Island City and Sunnyside, Queens. If this recommendation were ignored, Con Edison estimated that these networks, combined, would still only have sufficient capacity for eight quick chargers. In estimating demand, we have calculated that nearly 20 chargers should be placed in this area of Queens, since the area is home to many taxi fleet garages and taxi drivers. Fortunately, the adjacent power network, the Long Island City network, has additional capacity and could be a backup location to accommodate the chargers needed to support fleet- and owner-operated vehicles

Additional constraints exist when siting chargers at the airports. The Port Authority of NY and NJ (PANYNJ), which manages the New York City area airports, has advised that there is not sufficient power at their facilities to install any number of quick chargers.[xxxvi] Con Edison has corroborated this insufficiency, advising TLC that only 20 quick chargers could be accommodated at LaGuardia Airport under Con Edison's current 20-year Load Relief Plan—and only if the power is supplied from the Long Island City and not the Jackson Heights network.[xxxvii] This limits the area in which the chargers can be placed at LaGuardia. In addition to power-related constraints, there are also space constraints at the airports—particularly in the airport taxi holds—that could pose challenges to charging at airports. One way to help alleviate airport power and space issues could be to create a "virtual taxi hold line" in Astoria, where excess grid capacity exists. Those drivers that charge in this area could be given tickets to advance them to the front of the taxi line at the airport (known as "shorties" or "expedited procedures") to encourage them to charge just outside of LaGuardia. This approach could help manage space and energy constraints, but would require agreement on specifics between the Port Authority, the City, and any involved private landholders.

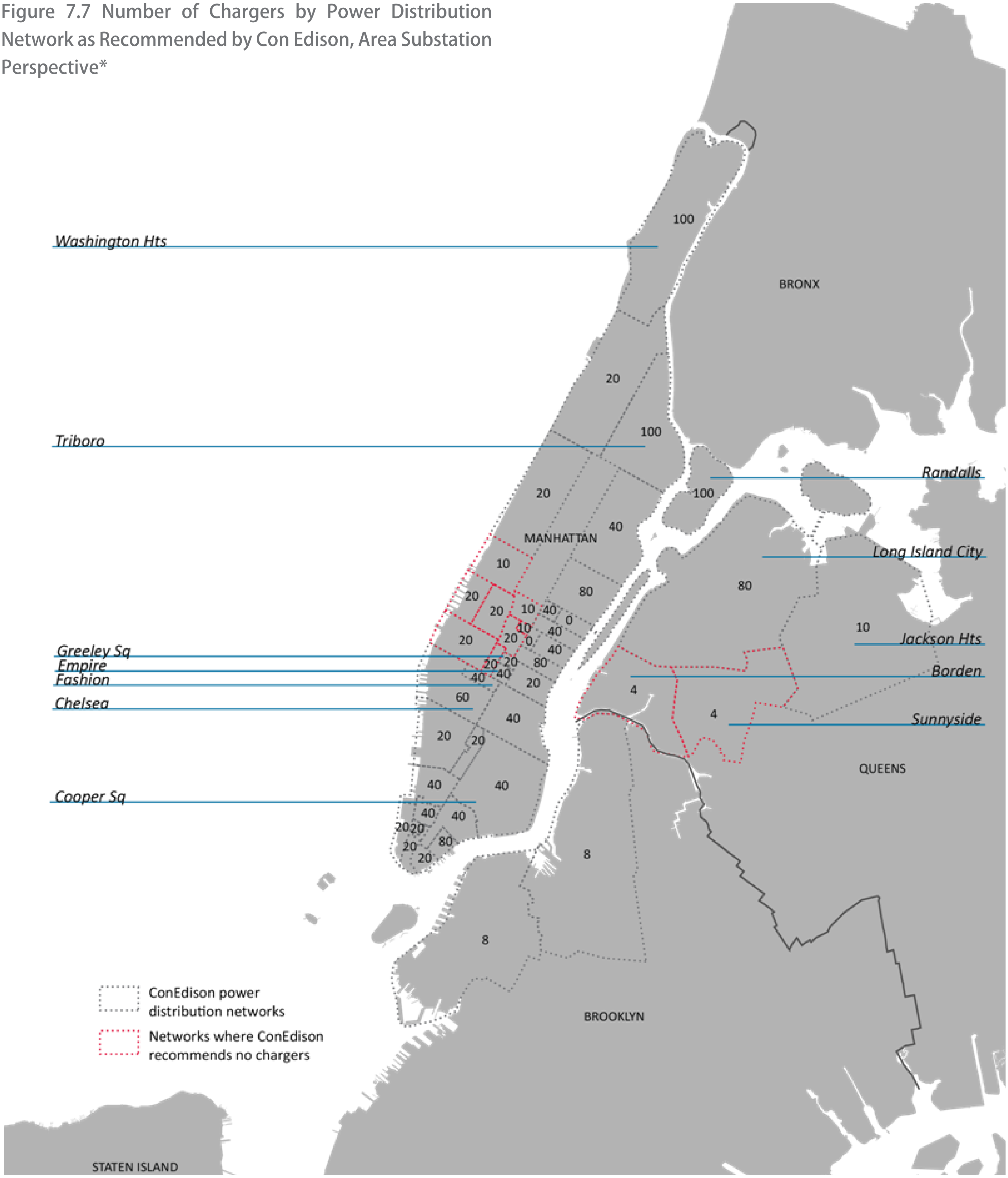
7.5. Site Types: Overview

Although the current electrical grid can handle the number of quick chargers calculated as necessary to support an electric taxi fleet of over 4,400 vehicles, choosing specific sites for chargers will remain quite difficult. Much of the difficulty in choosing sites has to do with the highly variable costs of installation, which are very site-specific (for some estimates on installation costs, see Chapter 6: Economics of an Infrastructure Network). In addition, different site types offer pros and cons in terms of vehicle access, feasibility of construction, and ability to power the charger using an existing electrical service. We examined the two main site types: on-street and off-street, breaking off-street sites into several sub-types, including parking lots, parking garages, taxi fleet garages, and EV-specific fueling sites.

7.6. Site Types: Off-street versus on-street locations

Off-street and on-street locations both have their pros and cons (see Figure 7.10 for a condensed itemization). Each type of location could become very expensive, depending on whether or not additional transformers and electrical lines would be needed to support the chargers. Even for single-charger installations, it is likely that most sites would require at least one additional transformer to provide the voltage needed to quick-charge an electric vehicle. However, once transformers are added, the incremental costs for each additional charger become much smaller because a cluster of three transformers could likely support up to 25 50kW chargers.[xxxviii]

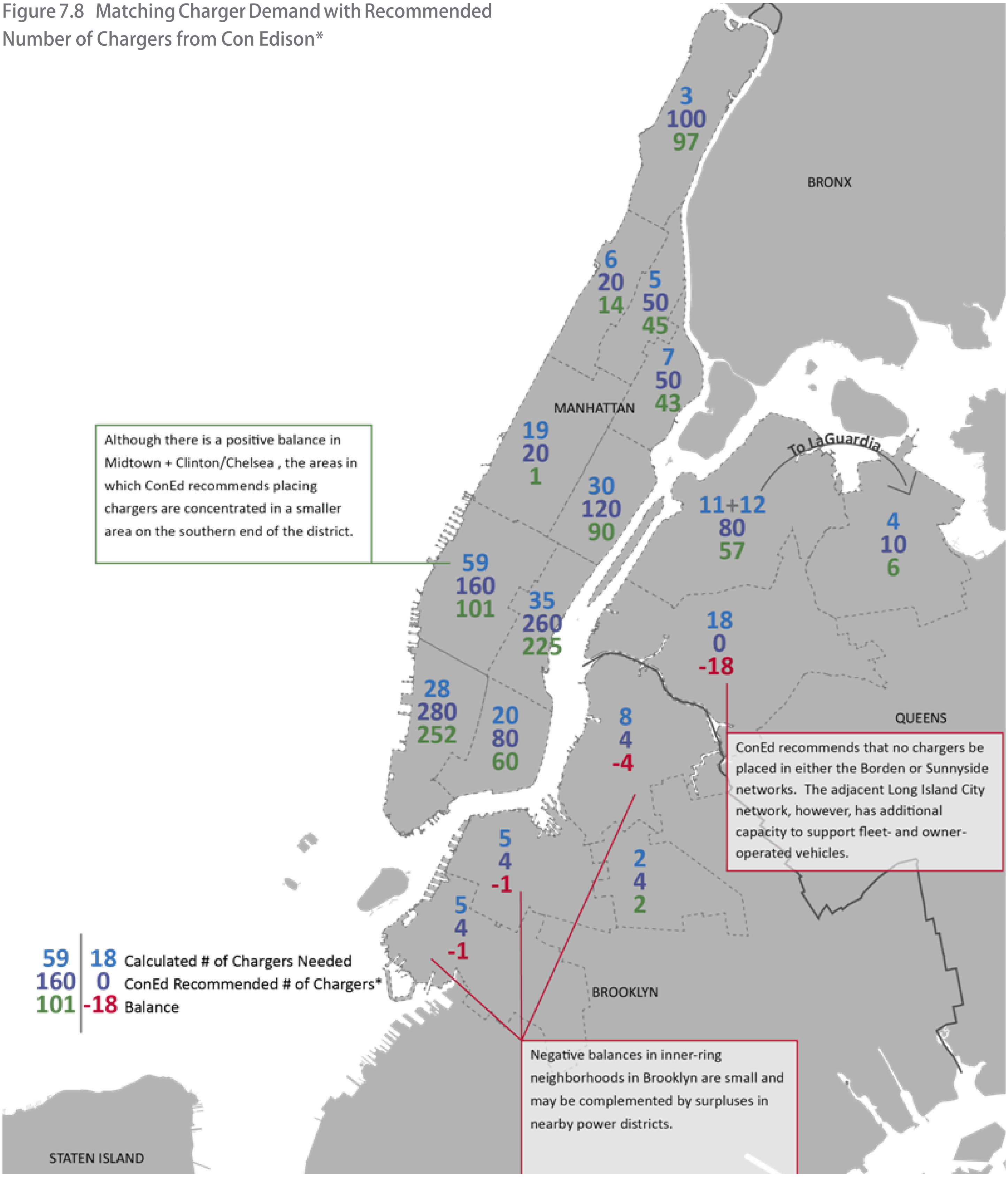
Figure 7.7 Number of Chargers by Power Distribution Network as Recommended by Con Edison, Area Substation Perspective*



Source: Con Edison, NYC DCP GIS layers

**The above analysis and numbers are for 50kW fast chargers, based on the current 20-year Load Relief Plan (2013-2032) issued on March 5, 2013 by Con Edison.*

Figure 7.8 Matching Charger Demand with Recommended Number of Chargers from Con Edison*



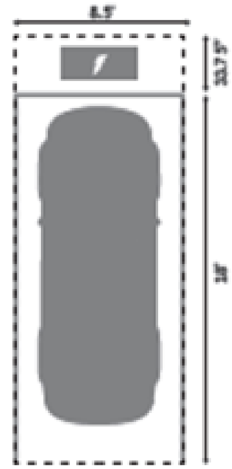
Source: Con Edison, NYC TLC TPEP 2012 trip-sheet data, NYC TLC Licensing records, NYC DCP GIS layers
**The above analysis and numbers are for 50kW fast chargers, based on the current 20-year Load Relief Plan (2013-2032) issued on March 5, 2013 by Con Edison.*

Opportunity: Charger Clusters

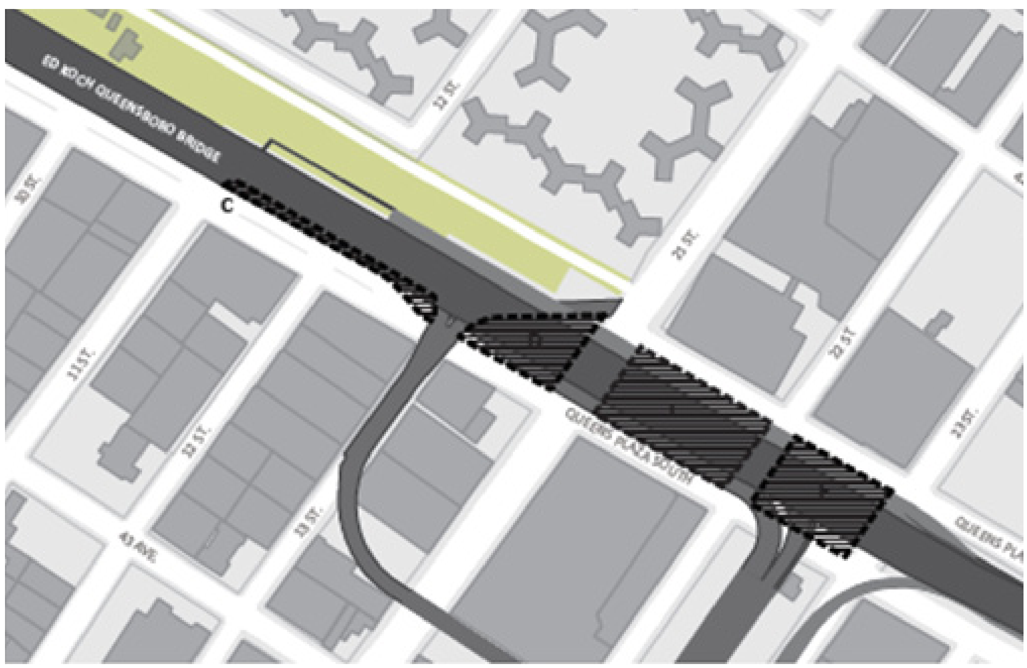
In addition to the financial benefit clustering chargers provides to the economics of operating a charger network, clustering chargers makes sense from a human perspective. As compared to single chargers, arrays of chargers are most likely to justify accessory amenities, such as restrooms, food vendors, and prayer or resting space for drivers to use for the 30 minutes they wait while their vehicles charge. Creating spaces that are attractive to drivers is likely to help encourage them to adopt electric taxis. The vast network of available and under-used city-owned land—approximately 140 million square feet of space beneath NYC's elevated transit infrastructure—could provide significant area for charging EV taxis.[46] The proximity and connection of this network to NYC's roadways and transit system could provide efficient access to charging for NYC's taxi fleet. The open air spaces under transit infrastructure could provide an alternative to the current strategy of housing chargers in enclosed spaces such as building garages.

Figure 7.9 Potential Charging Sites: Queensboro Bridge

Manhattan
Approx. Area/Total Spaces
A: 6,615 sq.ft./11
B: 5,107 sq.ft./12



Typical charging space layout
177 sq. ft.



Queens
Approx. Area/Total Spaces
C: 15,444 sq.ft./67
D: 36,945 sq.ft./75
E: 75,169 sq.ft./227
F: 54,421 sq.ft./160

Sources: DoITT Open Data, 2013; NYC DCP 2012, The City of New York, 2012
Credit: Susannah Drake, Urban Design Fellow, Design Trust for Public Space, prepared as part of the Under the Elevated *Project*

Figure 7.9 Off-Street vs On-Street Charger Siting

OFF-STREET		ON-STREET	
Pros	Cons	Pros	Cons
- Some buildings already have 480 V service necessary for 50 kW quick chargers. - Indoor charger installations are generally less expensive than curbside installations. - Indoor and/or private locations can offer more security and protection from the elements than can outdoor/public locations.	- Off-street parking spaces are very valuable in Manhattan, especially during business hours. - Many off-street parking facilities are valet-only, making it logistically difficult for a driver to enter to charge. - Multiple property owners add to the difficulty of managing and operating a network of chargers. - Advertising would be less visible and therefore less valuable on indoor chargers.	- Site assembly may be easier because the City owns the streets. - Current taxi relief stands exist on-street throughout Manhattan, providing space that could be re-purposed for charging. - Drivers can easily drive by curbside chargers and view whether they are available or occupied. - Advertising would be more visible and therefore more valuable on on-street chargers.	- Bringing new service to on-street locations can be difficult. Power equipment needs to be stored somewhere and sidewalks can be crowded. Connecting to the power supply of adjacent building may be costly or difficult. - Queues for chargers may encourage double-parking and congestion. - On-street installations are generally more expensive than indoor installations.

Given the high demand for on-street parking in New York City and the space limitations on city sidewalks, off-street facilities may be better able to accommodate multiple chargers than on-street facilities. Off-street facilities also may have existing infrastructure on which to build, helping control installation costs. If a charger installation requires Con Edison to add new capacity where there is existing service, so long as chargers' electricity is billed to the existing building and not as a separate service on the same property, costs of the upgrade could be covered by Con Edison if the upgrade is considered necessary. Otherwise, the customer would need to share Con Edison's cost for upgrading the service.[xxxix]

There are a few on-street sites that are wide and have large shoulders and therefore may be well positioned to accommodate arrays of chargers. Many of these wider streets are adjacent to NYCHA public housing, and if these on-street locations could be matched to power sources on NYCHA properties (which are city-owned), economies of scale similar to those described for off-street charger clusters could potentially be achieved. Figure 7.12 shows a few example sites, including one on-street location meeting the above-mentioned description.

Another factor that must be considered in any charger siting process is queuing. It would be problematic if taxis waiting to charge double-parked or otherwise blocked vehicular or pedestrian circulation. One avenue for addressing queuing is to build space to queue into site design. Another avenue to mitigate queuing could be mobile technology. For example, drivers could use a mobile app to see which chargers are vacant or about to become vacant because another taxi is nearing the end of its charge. This would direct taxis towards chargers without a wait. A charger reservation system could also mitigate queuing by discouraging drivers from visiting chargers that are fully booked and drawing them towards chargers with availability.

In addition to different types of physical locations, the type of owner for different properties can also affect the feasibility and cost of siting quick chargers in New York City. For a discussion of the pros and cons of various site ownership options, please see the appendix.

7.7. Conclusion and Recommendations

Based on of our initial exploration into where to site electric vehicle quick chargers, it appears that NYC grid could handle the addition of 350 electric vehicle quick chargers.

Figure 7.10 Off-street Subtypes

Parking lot (surface)	- Easiest to run new power lines under surface lots	- Not many parking lots available in areas where chargers are needed most - Surface lots are low-energy, so most would require upgrades to service service and demand charges may be significant
Parking garage	- Ubiquitous in Manhattan where chargers are needed most - Operated mostly by just a few companies - Some have sufficient 480V service to support quick chargers already	- Can be costly to install quick chargers given space constraints - Access to self-parkers/charging vehicles may be difficult since many garages are valet-only
Taxi fleet garage	- Almost a necessity for any fleet with a sizeable number of electric vehicles - Most fleet garages are in Long Island City, so close to many taxis	- Demand charges can be more burdensome for smaller garage to handle - Question of whether fleet-sited chargers would offer access to non-fleet EV taxis
Fueling station	- Familiar model for refueling - Currently allowed under Zoning Code in most places, except certain Commercial Zoning Districts	- Number of stand-alone gas stations in Manhattan has dwindled in recent years because real estate is more valuable under other uses

Source: http://www.nyc.gov/html/dcp/html/greenbuildings/index.shtml

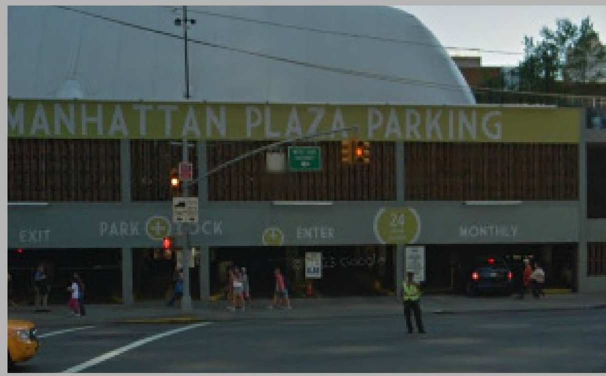
Although there are some constraints on the number of chargers that could be placed in certain areas of the city, those constraints are not widespread or completely insurmountable. The largest constraints between supply and demand occur in West and Central Midtown in Manhattan and in Long Island City in Queens, which have adjacent areas with additional electric load capacity. This report focuses on the grid's capacity to serve the needs of a 1/3-electric yellow taxi fleet. If other fleets (e.g., Boro Taxis, FHVs) or individual residents adopt EVs at increasing rates, this would place further demands on the electric grid. Although there is capacity for more than 350 50kW quick chargers (see Figure 7.7), to ensure smooth implementation future planning of a charger network to serve taxis would have to be done in concert with planning for projected non-taxi needs. In considering different site types, there are a few imperatives that have emerged. First, we must better understand the true feasibility of on-street charging. This would involve working with the NYC DOT, Con Edison, and the Public Design Commission to explore how this would best work, considering street space constraints, franchise/concession issues, and the goal of designing spaces that could make charging both convenient and amenity-rich for drivers. Further exploration into how electricity for street-side spaces could be matched with adjacent properties is also necessary, requiring further research by the City and Con Edison.

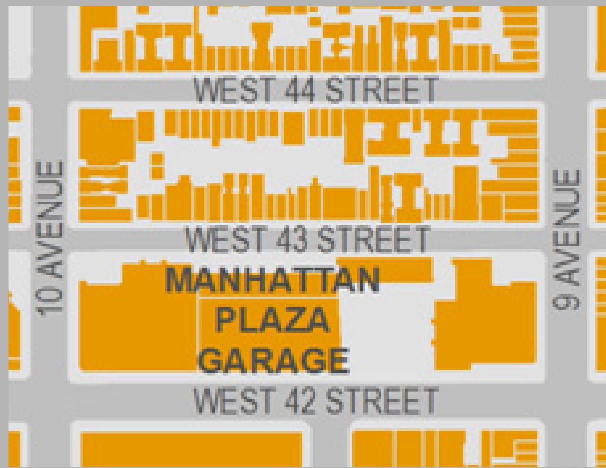
For off-street locations, we should explore options to incentivize new buildings to create spaces that are "EV ready." There are many current examples of how the City has revisited existing codes to allow and even encourage the adoption of environmentally friendly innovations. The Department of Buildings and the Mayor's Office of Long-Term Planning and Sustainability (OLTPS) are already working to make 10,000 new parking spaces ready for level 2 chargers. In December 2013, New York City Council took a significant step towards attaining this goal when it passed legislation that ensures that 20% of new off-street parking in New York City will have the electrical capacity to support chargers.[xl] City Planning's Zone Green text amendment clarifies that electric vehicle charging is allowed in all parking facilities and that battery swapping is allowed in Commercial Districts.

In addition to the changes already made to allow and encourage EVs, the City could pursue even more changes. City Planning, through the Zoning Code, incentivizes developers to include affordable housing by offering an increase in floor area; a similar incentive could be provided to developers who include EV infrastructure in their plans. Instead of retro-fitting spaces to allow for quick-charging, new buildings could begin to include charging stations as an integral part of a building from the beginning. This would help reduce energy costs because space could be made for additional transformers in anticipation of the additional electrical load. This strategy may be especially useful in new large developments like the Hudson Yards development in West Midtown. This area is projected to be deficient in substation capacity over the next 20 years, and new substations built to support the new office towers could be sized to support multiple quick chargers to support an electric taxi fleet. It is not uncommon for new substations to accompany large developments. The World Trade Center reconstruction is connected with a new substation downtown for 1 World Trade Center.[47]

The City should continue to explore infrastructure issues by encouraging the development of additional charger locations throughout Manhattan. Through additional infrastructure, we can begin to learn more about how on-street charging could work, how a network of chargers could be managed efficiently, and how considerations like design and amenities could make charging attractive to taxi drivers.

Figure 7.12 Example Sites





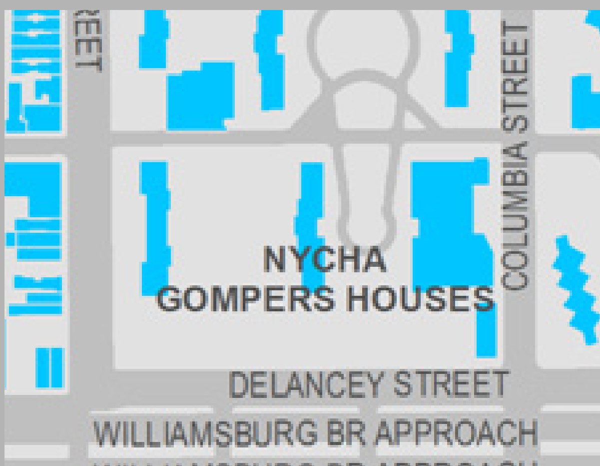
LOCATION : **W 42 St. | Manhattan**

Between 9th Ave. & 10th Ave.
OFF-STREET

OWNER : PRIVATELY OWNED

ADEQUATE SERVICE? : YES

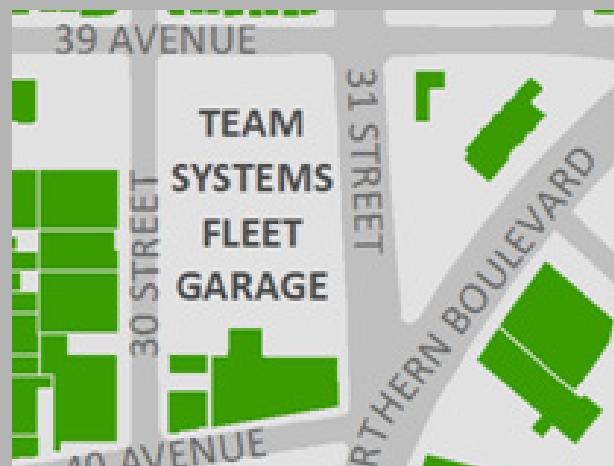
SITE DETAILS : *Manhattan Plaza Garage, owned and operated by Related Management, is a current host to one of the quick chargers installed for the TLC-Nissan Electric Taxi Pilot. The service upgrade performed by Related Management for the pilot would allow for additional chargers to be added to this site. Large property owners like Related could be helpful in finding space*



Delancey St. N. | Manhattan

Between Pitt St. & Columbia St.
ON-STREET
CITY-OWNED
UNKNOWN

A possible way to accomplish on-street charging would be to look to wider streets with additional space. Delancey St N is a wider street where on-street parking is currently laid out in a perpendicular configuration. Its proximity to the Gompers Houses could allow the City to connect to an existing service, avoiding the need to pay for new service. How power could be brought to on-street locations is still a big unknown.



40th Ave | Queens

Between 30th St. & 31st St.
OFF-STREET
PRIVATELY OWNED TAXI GARAGE
YES

Team Systems is a taxi fleet garage in Long Island City (LIC) with over 300 taxis. Currently, service is adequate at this site to support 1 or 2 50kW quick chargers. It is in the Borden power network, in which Con Edison recommends placing only 4 chargers total. Although the network could support 4 chargers at this garage, it is likely that many garages would want to have access to quick chargers. Placing a cluster of chargers in the nearby LIC power network

SECTION III

POLICY + RECOMMENDATIONS

> CHAPTER 8: TAXI INDUSTRY ADAPTABILITY

Key Findings:

Changes to TLC regulations, taxi industry business practices, or technology could facilitate the application of electric vehicles to taxi service.

- Changes to TLC regulations could include changing lease caps, retirement schedules, the required taxi service area, or the split of expenses between owners and drivers.
- Changes to taxi industry practice could include changing shift change times, shift change locations, or amount of time spent cruising for fares (e.g., through e-hailing).
- Changes in technology could include battery swapping or wireless charging.

This task force report assumes relatively few changes in the taxi industry's operational practices or TLC regulation. This assumption was made out of a belief that an ideal electric taxi program would cause minimal disruption to the industry, and that the industry has chosen many of its current practices based on years of experience and learning about what works well and what does not work well.

This assumption significantly impacts the ease of adoption of EVs as taxis. As an example, mileage-driving aspects of the current taxi industry—the 12-hour shift schedule, the prevalence of shift change occurring outside Manhattan, and taxi cruising patterns—create the need for a relatively large battery to accommodate high-mileage shifts without excessive visits to a charging station. This drives program costs. If any of these mileage-driving practices were to change, it could reduce the battery size needed (or even the number of charging stations needed) and therefore make owning and operating EVs as taxis more economically advantageous.

It is possible that taxi operational practices, TLC regulation, or charging technology could change to even better accommodate the economics and practicality of the use of electric vehicles as taxis. This chapter discusses some of these potential changes.

8.1. Changes to TLC Regulation

TLC regulation of lease caps, retirement schedules, the required taxi service area, and the split of expenses between owners and drivers impacts the viability of operating electric vehicles as taxis. This section describes the current regulations and how they could be changed in ways that may encourage or facilitate EV adoption. Before any of these changes were to be proposed to the Commission, additional analysis and consideration beyond the scope of this report would be required.

8.1a. Lease Caps

Lease caps represent an area in which TLC regulation could change to improve the viability of using EVs as taxis. TLC currently regulates the lease cap, or the maximum amount that a medallion owner or agent may charge a driver for leasing the taxi for a shift or a week. For DOV leases, TLC sets weekly lease cap rates. For fleet leases, TLC sets both daily and weekly leases and the cost of the lease varies based on day of the week and whether it is the 12-hour day shift or the 12-hour night shift (see appendix for these lease rates). TLC rules do not define what hours constitute a day shift or a night shift, but the dominant industry practice is that the day shift runs from 4 or 5 am to 4 or 5 pm and the night shift runs from 4 or 5 pm to 4 or 5 am. A common explanation for this shift change timing is that it enables the night shift driver and the day shift driver each to get to drive during one of the day's rush hour periods.

There are two potential changes to lease cap regulation that could improve the viability of an electric taxi program: shorter shifts and encouraging more weekly leases:

Shorter shifts: If TLC were to change the lease caps to encourage shorter (e.g., 8-hour) shifts, this could potentially facilitate EV adoption because it would be more likely that drivers could complete this shorter shift on a single charge. This could reduce the size of the battery needed in the vehicle and may be attractive to drivers who do not want to charge more than once per shift. Eight-hour shifts could potentially be implemented in a way that would be revenue-neutral to medallion owners by holding total daily lease revenue constant and just dividing it into three shifts rather than 2. This could potentially be done in a way that drivers would also favor by having lease caps that vary by shift (as is the case today) such that the typical hourly wage (fare revenue minus lease costs) remains the same.

Encouraging more weekly leases: In discussions with the industry, we learned that shift change locations vary from fleet to fleet and driver to driver. In some fleets, the driver must always return the vehicle to the fleet at the end of his shift. In other fleets, the drivers are permitted to shift change wherever they please. The practice of shift changing at fleet exists for various reasons, including some fleets' desire to see the condition of the vehicle between drivers and the desire to settle up finances on a daily basis. However, shift changing at the fleet imposes time costs on the driver. This is especially the case when the driver must travel in traffic to a fleet in Queens, Brooklyn, or the Bronx and find street parking when there is not enough parking at the fleet garage. A driver beginning his shift also faces time costs due to non-Manhattan shift changing because he often must drive from the garage to Manhattan to find his first fare.

Some industry stakeholders told us that the practice of shift changing at non-fleet locations, such as a rendezvous point in Manhattan, is more common when the drivers are on weekly rather than daily leases. The latter practice also may be more convenient in terms of EV use because it can prevent the driver from logging extra miles traveling to and from the fleet garage. TLC regulations may encourage daily rather than weekly leasing by setting a weekly lease rate that generates less revenue for medallion owners than they would get by charging for seven individual daily rates. If TLC wanted to encourage weekly leasing--and potentially the efficiencies associated with it—it could adjust weekly leases to generate as much revenue for medallion owners as do daily leases. Of course, the downside of this is that some drivers currently benefit from the "discount" they receive by taking on the taxi for a full week.

8.1b. Service Refusals

TLC service refusal rules represent an area in which TLC regulation could change to improve the viability of using EVs as taxis. Current TLC regulations prohibit taxi drivers from refusing to transport a passenger based on his or her destination so long as the desired destination is within the City of New York, Newark Airport, Nassau County, or Westchester County.[48] This policy is important to ensure that all New Yorkers have access to taxi service. From the perspective of an electric vehicle program, however, this policy introduces challenges. Drivers seeking to maximize the miles they can drive before re-charging their batteries may let their batteries run down fairly low, for example, to 10% before they go "off-duty" and look for a charger. At 15% charge (when a driver would reasonably still be cruising for passengers), an EV taxi with a 35 kWh battery might only have about 18 miles of charge left. This would be plenty of charge to enable the driver to make several more typical 2.9-mile taxi trips and then head to a charger. Unfortunately, this might not be enough charge to get the driver from Columbus Circle to the Staten Island Mall or from Harlem to JFK Airport. If the driver were to accept these trips, as he would be required to do under current rules, he would be at risk of running out of charge or needing to stop for a charge while he has the passenger with him (which would not be acceptable to passengers--particularly to those on the way to the airport!)

Therefore if the City wanted to encourage drivers to get the most mileage possible out of each charge (which makes sense from an efficiency point of view), some modification of the service refusal policy may be necessary.

- For the electric taxi pilot, drivers are permitted to refuse service based on destination when they would not be able complete the trip and return to a charger without running out of charge. Electric vehicle trackers can log the vehicle's state of charge, so if a similar policy were in place for a broader rollout of EVs, TLC could audit for abuse of this exception.
    - The downside of this policy is that passengers

could feel unfairly refused and that passengers traveling to farther away destinations would have access to fewer of the city's taxis. An indicator light system could help address the feeling of being unfairly refused by showing passengers when a taxi is unavailable for longer trips due to low charge.

- Electric vehicles could have a different required service area than taxis currently have.
  - This downside of this policy is that passengers traveling to farther away destination would have access to fewer of the city's taxis. It also may be confusing to passengers if different types of yellow taxis have different required service areas. Markings could help address this issue.
- Medallion owners who wish to operate as "specialist taxis" could adopt electric vehicles. For example, airport specialist taxis could exclusively shuttle passengers to and from the airports. If plentiful charging were available at the airports, EV drivers specializing in serving airport trips would know that they would always be returning to a location with a charger so they could maintain a high enough level of charge to serve between the pickup point and the airport or the airport and the required service area.

Each of these options has its drawbacks. A careful weighing of the pros and cons of modifying the TLC refusal policy would probably be necessary to successfully integrate fully-electric EVs into the fleet.

This report assumes that the taxi fleet would use all-electric vehicles. Another option to consider that would eliminate the need to reexamine refusal policy would be a fleet of plug-in hybrid vehicles or range-extended EVs. If these vehicles were put into service and their gas backup tanks were sufficiently large, then electric taxis could continue to be required to serve the existing required service area with little rule modification. Gas backup tanks would also serve other purposes, such as reducing range anxiety.

8.1c. Retirement Schedules

TLC's authority to regulate taxi retirement schedules represents an opportunity to improve the economic case for EVs. TLC regulates how long a taxi may be in service before it must be "retired" out of taxi service. Currently taxis must be retired after three to seven years of service, depending on vehicle type and mode of operation. As is discussed in Chapter 4: Economics of Electric Vehicle Ownership, many vehicles leave taxi service prior to their required retirement dates. However, other vehicles may be well-maintained and/or durable and able to last longer than their retirement dates permit.

TLC could encourage adoption of electric vehicles by permitting them to remain in service without a specific retirement date so long as they continue to meet TLC and DMV safety and emissions inspection standards. This could improve the economic case for EVs by allowing owners to keep them in service for longer than they would be permitted to keep other vehicles in service, reducing the frequency with which the taxi owner has to bear the expense of replacing a vehicle.

8.1d. Responsibility for Fuel Costs

TLC's ability to regulate which parties are responsible for which vehicle expenses represents an opportunity to incentivize EV adoption. Most taxi drivers currently pay for their own fuel. Although TLC permits fleets to provide

fuel and charge drivers a higher lease cap in exchange, anecdotally we believe most drivers continue to pay for their own fuel.

Two of the current challenges of EV adoption are the relatively high vehicle purchase prices (for vehicles with large batteries) and the high price of battery replacement. These "downsides" are borne by medallion owners and vehicle owners. One of the benefits of EVs over other vehicles is that fuel costs can be lower with EVs. Whereas owner-drivers and DOV operators are already incentivized to seek vehicles that reduce their fuel costs, fleet operators have less incentive to do this because they do not typically pay for fuel.

If medallion owners were required to cover fuel costs, they may be more incentivized than they are today to buy vehicles with lower fuel costs. They would have an opportunity to realize the financial upside to EV ownership. Of course, the existence of this upside would depend upon the price at which charging could be provided.

8.1e. Fare

Another regulatory tool TLC could use to increase the viability of EV adoption is the taxi fare. TLC regulates the rate of fare and periodically increases it to account for factors including inflation and changes in the expenses faced by taxi drivers and medallion owners. NYC taxis perform nearly 500,000 trips per day, or about 180 million trips per year. Each taxi typically performs about 36 trips per day (this average includes "zero" trip totals for taxis that were not on the road on a given day). A fifty-cent fare increase would generate approximately $6,500 per year per taxi, or $33,000 over the course of 5 years. This additional revenue could defray transition costs associated with purchasing and operating electric vehicles or could help fund the infrastructure network.

Many NYC taxi passengers express some willingness to pay for cleaner vehicles. In a TLC survey of 2,982 taxi passengers conducted between July 23 and July 30, 2013, 50% of passengers said they would be willing to pay 25 cents extra to ride in a taxi that has zero tailpipe emissions. 37% of passengers said they would be willing to pay 50 cents extra and 24% said they would be willing to pay $1.00 extra.

8.2. Changes to Taxi Industry Practices

Although TLC regulates many elements of the taxi industry, many operational practices are left to the discretion of taxi owners and drivers. If the taxi industry were interested in adopting electric vehicles, it could voluntarily change some of its business practices to better accommodate these vehicles.

- *Shift change times:* As is described in Chapter 5: Level of Infrastructure Needed to Support Taxi Fleet, some of the most significant peaks in charger demand are driven by the relatively uniform shift change times. The taxi industry could change its shift change times to a more staggered fashion, with some EV taxis changing in the noon/midnight hour, some changing in the 2 pm/2am hour, etc. Doing so could significantly mitigate the peaks in demand for chargers, reducing the level of infrastructure needed and overall program costs. Although not as significant as changing the shift change schedule, the taxi industry has demonstrated adaptability as drivers have adjusted to purchasing gas outside of Manhattan as the number of gas stations in the central business district has declined.

- *Shift change locations:* Earlier in this chapter we discuss how TLC could modify the manner in which we regulate lease caps to incentivize more weekly leasing and more frequent shift changing in Manhattan. Even without any change to the lease cap or necessarily higher rates of weekly leasing, fleets wishing to facilitate the adoption of EVs could do so by permitting more drivers to shift change at non-fleet locations. This could be at a charging station in Manhattan, for example, or some other Manhattan location that eliminates the need for the drivers to spend time driving and parking at their fleet garages. This would reduce miles traveled, allowing drivers to devote more of their battery's charge to driving passengers. It would also save drivers time, which would enable them to earn more revenue or work fewer hours.

- *E-hailing:* E-hailing is a technology that enables passengers to electronically hail a taxi using their smartphones. Passengers indicate in their smartphone apps where they need taxi pickups, and available drivers are able to see where these hailing passengers are. TLC is currently piloting this technology, and many hope that this technology will improve the efficiency of taxi operations by better matching passengers needing a ride to drivers offering a ride. The pilot program is in its early stages and we do not yet know how prevalent e-hailing will become or if these hoped-for efficiencies will be gained. However, if e-hailing significantly improves the matching of drivers to passengers, it could cut down on the number of miles drivers "spend" cruising for fares and could make the range concerns associated with EVs less significant.[49]

8.3. Changes to Charging Technology

It is possible that technological improvements could significantly improve the feasibility of using electric vehicles as taxis. This task force report assumes that plug-in quick charging will be the predominant mode of charging EV taxis' batteries. We made this assumption because plug-in charging is the most common method for re-charging electric vehicle batteries. Two other technologies that could gain prominence and that could significantly improve the viability of using EVs as taxis are inductive charging and battery swapping.

8.3a. Battery swapping.

Battery swapping is a technology in which instead of waiting to re-charge a depleted battery, the driver simply swaps out the depleted battery for a new one. This swap takes place at a "swap station" where the driver takes the vehicle, allows a robot to do the swap, and then drives off with a full battery. This swap takes place in just a few minutes and could take place at a speed that is competitive with the speed of a fill-up at a gas station.

Several companies have been operating in the battery swap industry. Better Place is probably the best-known company to have developed and implemented a battery swapping network. They set up battery swap stations in Israel, Denmark, the Netherlands, China, Hawaii and Japan. Each station cost approximately $500,000.[xli] In May 2012 Better Place filed for bankruptcy and was purchased by Sunrise Group.[xlii] Better Place's struggles came from various sources, including unexpected roadblocks from local authorities when the company sought to site swapping stations. Probably more significant was that there were not enough automobile manufacturers building electric vehicles that were compatible with their swapping stations to provide enough customers to recoup costs of the infrastructure networks.[xliii]

Automaker Tesla is also entering the battery swapping arena. In June 2013 they unveiled a battery swap option for their Model S cars. Their vehicles already offer long ranges, and they are touting the battery swap option as an amenity to facilitate long trips. They plan to charge $60 to $80 per battery swap and for each swap station to cost $500,000. They will begin by installing these stations on the I-5 corridor in California and the Boston-DC route on the East Coast.[xliv] The battery swap stations Tesla is currently planning are made only to work with Tesla vehicles.[xlv]

If there were a taxi-suitable EV that was compatible with battery swapping technology, it would pose several advantages:

- Taxi drivers would not need to adapt their break and meal times or locations because they would only need to make a quick visit to a swapping station to "refuel" rather than wait for a quick charge. Operationally a battery swap visit would be very similar to a gas station visit.
- The charging network operator would not need to find sites for hundreds of quick chargers. It would instead need to find sites for several battery swap stations. (Of course, battery swap stations are larger than quick charge stations and may require significant storage space—either above- or below-ground—to store the high volume of swappable batteries needed to power a fleet of taxis. There would be challenges associated with siting these as well.)
- Taxi owners would not need to be concerned with having to make a lump sum battery replacement payment because they would most likely not own a battery but would instead be paying some sort of subscription service or per-mile charge in exchange for using communal batteries.[50] Currently there

is not a battery swap-compatible vehicle that appears feasible for the taxi industry; however, in the dynamic EV field it is possible that one could come into play and introduce this exciting new option for EV taxis.

8.3b. Inductive or "Wireless" Charging

Inductive charging is another technology alternative to plug-in charging that could improve the feasibility of electric vehicle adoption in the taxi fleet. Inductive charging uses an electromagnetic field from a coil embedded in the ground to transfer charge to the battery pack of a compatible EV.[xlvi] An EV seeking to charge using an inductive charger does not need to plug into anything. Instead, the driver positions the vehicle over the inductive charger and the charging occurs automatically. Inductive charging equipment could be installed underground in areas where taxis stop frequently, such as taxi stands, the airport taxi holds, and at traffic lights on common taxi routes. This charging would not cost taxi drivers any time because it would occur automatically at locations they frequent, and could potentially eliminate or greatly reduce the amount of time they need to spend quick charging.

Although inductive charging systems can be designed to function at faster speeds, the most prevalent commercial models are Level 2 setups. These systems, which are designed for home or public garages, currently cost between $3,500 and $4,000. This setup includes three components: the on-vehicle receiver/coil, the garage-floor transmitter (which transfers the electricity to the vehicle), and the garage installation that transmits power from the building to the wireless charging system.[xlvii] Qualcomm Halo is currently piloting its inductive charging technology in London, with several installations in both private and public areas across the city. Qualcomm Halo is also working on dynamic inductive charging, which would enable EVs to wirelessly charge while they are in motion.[xlviii] If this technology comes to fruition, it could be game-changing for the viability of EV use as taxis. It could eliminate the need for drivers to stop and charge at all and could enable the operation of vehicles with much smaller (less expensive) batteries because charging could happen on an ongoing basis throughout the shift.

8.4. Conclusion

Changes to TLC regulations or taxi industry business practices could ease the adoption of electric vehicles as taxis. Future analysis could investigate the pros and cons of these changes for the taxi industry and the public, modeling the likely impact of various changes on factors that impact the viability of EV taxis. For example, we could analyze the extent to which changing the required taxi service area would impact mileage, and in turn the battery size and amount of charging time needed for an EV taxi. We could investigate the extent to which changing lease caps to encourage more weekly leasing would impact the popularity of weekly leasing, shift change locations, and in turn mileage. This would also impact the battery size and amount of charging time needed for an EV taxi.

There are also many factors impacting the viability of using EVs as taxis, such as the development of viable battery-swapping or wireless charging models, which are driven primarily by forces beyond the TLC and the taxi industry. Electric vehicle prices and battery prices significantly impact the viability of EVs, but are driven by factors including global commodity prices, technological advances, and business strategies of multinational automakers.

TLC and the NYC taxi industry can attempt to influence these trends that are outside of our direct control by facilitating pilot programs to test new technologies and inform the EV industry of the needs of the NYC taxi industry. Reports like this one can inform these outside players of some of the challenges and opportunities surrounding EV adoption in the taxi industry, potentially inspiring innovation and customization to make EVs and EV charging equipment that are attractive in the NYC taxi market and similar markets around the world.

> CHAPTER 9: TASK FORCE CONCLUSIONS + RECOMMENDATIONS

Replacing one third of taxis with electric vehicle taxis would have a profound impact on the city's air quality and carbon footprint. It would result in an annual abatement of 55,640 tons of CO_2, or a decrease in total CO_2 emissions from the taxi fleet of 18%. The replacement of a single conventional taxi with an electric vehicle creates an emissions impact that is equivalent to replacing roughly eight NYC personal cars with electric vehicles.

This report provides some preliminary information on what it would take to use electric vehicles as taxis. It broadly finds:

- NYC has the electrical grid capacity to site the 350 chargers we believe would be necessary to serve a one-third electric taxi fleet.
- The economics of constructing and operating this charger network suggest that although there is probably a gap between the costs of the network and the revenue it could generate solely from taxi driver fees, this gap could most likely be overcome through a combination of additional revenue sources (e.g., charging fees from non-taxi EV drivers, advertising, vending) and strategies to reduce costs (e.g., new charger technology).
- If EV prices continue to decline as some experts project and manufacturers continue to introduce greater variety of vehicle types and battery sizes, then by 2017 the total cost of ownership of an EV taxi could be competitive with the total cost of ownership for other taxis.

The City should take the following next steps to work towards the goal of a one-third electric taxi fleet:

Electric Vehicle Market Assessment

1. The City should issue a request for information (RFI) to vehicle manufacturers to learn more about what types of vehicles they have in the pipeline that may be suitable as EV taxis. The City should request not only information on vehicle product planning, but also ideas for innovative, alternative

Photo courtesy of NYC Mayor's Office Flickr.

economic models for supplying vehicles to the taxi industry that would facilitate EV adoption.

2. The City should continue to monitor the market environment for EVs and whether automakers are announcing future releases of taxi-suitable EVs.

3. The City should seek a partnership with an automaker to provide the next generation of custom-designed NYC taxis. NYC may find a partner in this endeavor that is interested in producing electric vehicles for use as taxis.

Electric Vehicle and Charger Testing

4. The City should assemble a thorough evaluation of the ongoing TLC-Nissan LEAF Electric Vehicle Pilot Program, taking advantage of qualitative and quantitative findings from this early pilot to inform future pilots and broader policies surrounding EVs. The City should also monitor the results of the London eNV200 taxi pilot for lessons that could be applied in NYC.

5. The City should explore additional vehicle and infrastructure pilot programs that would provide us with more information on what technologies would work well in the taxi industry. Additional pilots could include different vehicle types, such as pure EVs with longer battery ranges than the 2012 Nissan LEAF, plug-in hybrid electric vehicles, or range-extended EVs. Additional pilots could also include wireless charging systems or battery-swapping systems.

6. The City should explore the feasibility of using EVs in other industries, such as the for-hire vehicle industry or Boro Taxi fleet, in which a greener fleet would have a significant air quality and carbon impact. The City should assist for-hire vehicle bases wishing to incorporate EVs into their fleets by putting them in touch with electric vehicle and electric vehicle charger manufacturers who are interested in working with fleets.

Harness Its Relationship with Nissan

7. The City should continue to work with Nissan as it develops an electric version of the NV200 Taxi for the United States so that this product is as well-suited for the NYC taxi industry as possible.

Legal and Regulatory Changes

8. The City should work to modify the NYC Administrative Code to ensure that EVs qualify as vehicles that may be used with restricted alternative fuel medallions.

9. The City should work to modify TLC rules, such as vehicle size requirements, to accommodate EVs.

10. The City should consider creating a set of 8-hour shift lease caps, which could potentially accommodate EVs better than would the current 12-hour shifts.

11. The City should consider changing lease caps to encourage more fleet weekly leasing, which could potentially reduce the time costs drivers face when traveling to the fleet at the beginning and end of each shift.

12. The City should consider developing guidelines for whether and how EV charging stations could be installed on public sidewalks.

Further Research

13. The City should pursue a partnership with Con Edison to undertake the detailed analysis necessary to determine feasibility of curbside quick charging. This partnership should also include the NYC Department of Transportation's working with Con Edison to develop a full site plan for a sample area where a cluster of chargers might be installed. This would help both organizations learn in-depth what issues would arise with installing charger clusters.

14. The City should research what the revenue potential for a quick charger network would be from advertising, vending and non-taxi EV user fees.

Pursue Funding

15. The City should seek funding sources to begin to build out a charger network that could serve taxis, private users, and other fleets. It could pursue policy tools, such as tax abatement for property owners that make quick chargers available. It should pursue grants from the federal government and state organizations, such as NYSERDA, to build out a charger network and incentivize EV adoption by the taxi industry.

16. The City should continue to support citywide efforts to expand EV infrastructure, especially quick-charging.

APPENDIX

Appendix to Chapter 2

Trade Groups Representing the Taxi Industry. There are several industry trade groups that represent the interests of different taxi industry segments. They liaise with the TLC staff, TLC Commissioners, and elected officials to promote policies to align with the interests of their membership:

- Committee for Taxi Safety (CTS): CTS largely represents agents who lease to DOV drivers.
- Greater New York Taxi Association (GNYTA): GNYTA largely represents yellow taxi fleet operators.
- League of Mutual Taxi Owners (LOMTO): LOMTO represents primarily owner-drivers. It is also a credit union specializing in lending for medallions.
- Metropolitan Taxi Board of Trade (MTBOT): MTBOT largely represents fleet operators. Their membership also includes a growing DOV segment.
- New York Taxi Workers Alliance (NYTWA): NYTWA is the largest driver advocacy group. Their membership includes fleet drivers, DOVs, and owner-drivers.

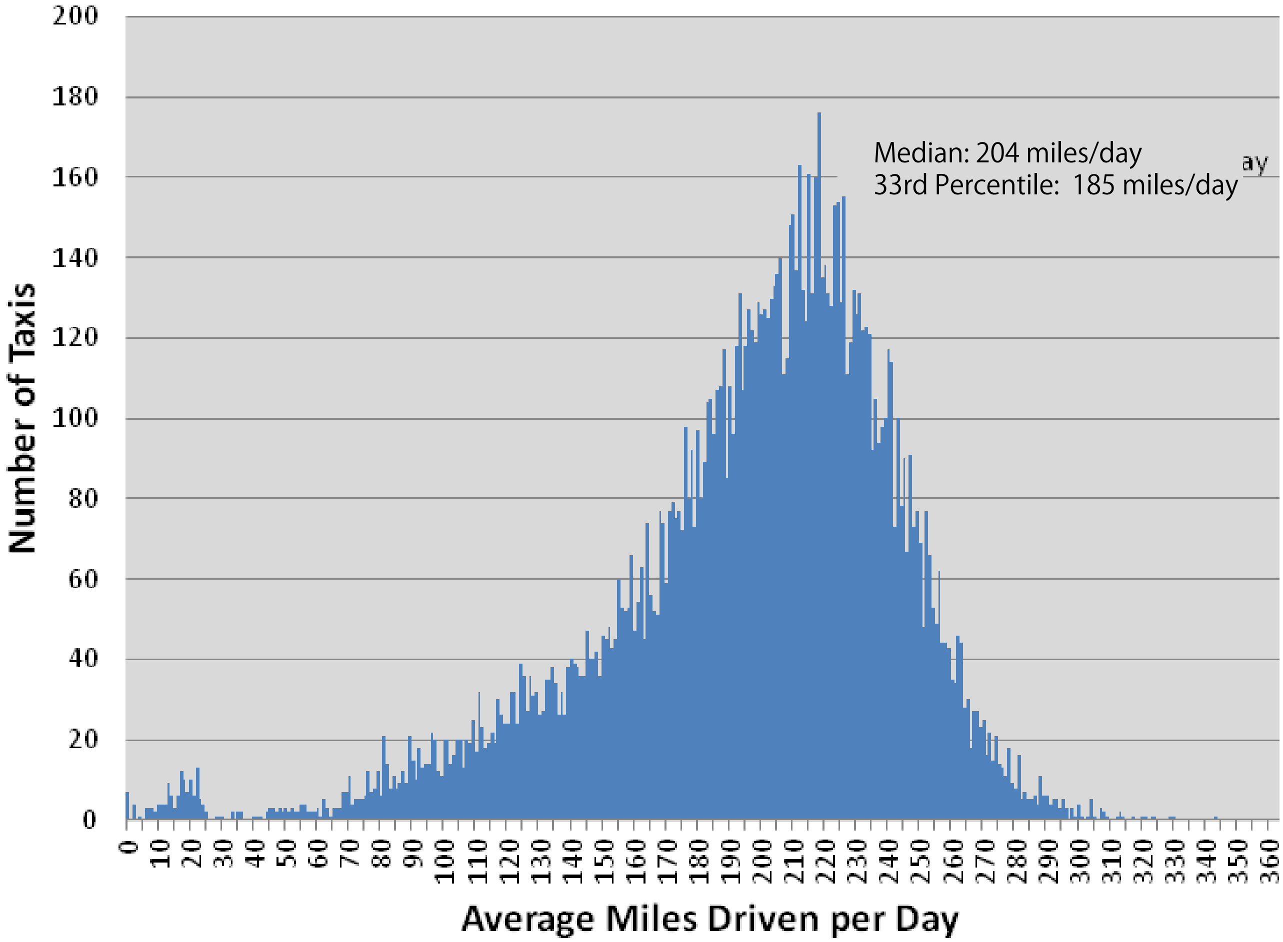
Rate of Return from Taxi Medallions. The rate of return from medallion operation compares favorably with other investment opportunities. Figure A2.1 below compares the return on a medallion purchased in 2004 with comparable investments in the S&P 500 or in a leading corporate bond fund. The purchase price of a fleet medallion in 2004 was $313,731. As the analysis below demonstrates, an investor who purchased a fleet medallion in 2004 would have realized an annualized return on investment (ROI) equal to 19.9% each year from 2004 to 2013. This figure includes the annual lease income of $37,000, as well appreciation in the value of the medallion. Excluding medallion value appreciation still yields an annual 8.6% ROI from lease revenue alone. Compared with the S&P 500 (5.9% annual ROI) and the Dow Jones Corporate Bond Index (1.1% annual ROI), the operation of a fleet medallion provides a competitive rate of return.

Of course, the ROI of any individual medallion owner will depend on the price that medallion owner paid for his or her medallion.

Figure A2.1. Return on Investment for NYC Taxi Medallions and Other Investments

	Medallion (w/ cap. app.)	Medallion (w/o cap. app.)	S&P 500	DJI CorporateBond Index
Principal	$313,731	$313,731	$313,731	$313,731
Capital Appreciation	$786,269	$0	$119,554	$29,804
Dividends/Operating Income	$305,250	$305,250	$71,147	$0
Total Gains	$1,091,519	$305,250	$190,701	$29,804
Percentage Gain	347.9%	97.3%	60.8%	9.5%
Annualized Gain	19.9%	8.6%	5.9%	1.1%

Figure A2.2. Miles Driven by NYC Taxis, Per Day



Source: TLC analysis September 2012 TPEP trip-sheet data.

Appendix to Chapter 4

Figure A4.1. Scheduled Retirement Dates for Taxis

	Medallion Type		
Vehicle Type	Fleet Unrestricted	Independent Unrestricted	All Medallions
Conventional	4.3	5.1	4.6
Hybrid	5.9	6.8	6.2
Wheelchair-Accessible	4.8	6.3	5.2
Overall			5.2

Figure A4.2. Average Actual Years of Service Life for NYC Taxis

Scheduled Years to Retirement	Actual Years to Retirement		
	Conventional Vehicles	Alt-Fuel Vehicles	Accessible Vehicles
3	2.75		
4	3.75	3.75	3.25
5	4.75	3.08	3.42
6	5.66	4.00	4.08
7	5.66	6.08	4.17

Figure A4.3. Taxi Industry Participant Financial Responsibilities

Industry Stakeholder	Purchases and Maintains Vehicle	Pays for Fuel and Cares About How Much Time is Spent Charging	How this Stakeholder's Concerns are Captured in the Model
Fleet driver	No	Yes	- The fleet driver is primarily concerned with fuel costs and time costs (i.e., time he spends charging or traveling to a charger rather than collecting fares). - By setting charging costs at a rate that saves him enough money to compensate for time spent charging (See Chapter 6), he is incentivized to participate in the EV program.
Fleet owner	Yes	No (typically)	- The fleet owner does not typically pay for fuel costs. He is primarily concerned with vehicle purchase and maintenance costs and with having vehicles that drivers are willing to lease. - The vehicle gap calculated in Chapter 4 represents the economics that will drive his decision-making process, which accounts for all vehicle expenses other than fuel.
Owner-driver/DOV	Yes	Yes	- An owner-operator or DOV operator is both a driver and an owner. - These participants would need to be incentivized to join an EV program in both roles. - By setting charging costs at a rate that saves the owner-driver/DOV enough money to compensate for time spent charging, he is incentivized to participate in the EV program in his driver role. - The vehicle gap calculated in Chapter 4 represents the additional set of economics--vehicle purchase price, operating costs, and lease-ability--that will drive his decision-making as a vehicle purchaser.

Appendix to Chapter 5

Details on Number of Charges per Shift

Number of Intra-shift Charges. Based on the model, we calculated that 53% of electric taxis would require only one intra-shift charge, with 6% of taxis requiring a second intra-shift charge. 41% of taxis would not require an intra-shift charge at all. On average, taxis would spend just 19 minutes within each shift charging. This average is low primarily due to the fact that 41% would not require a mid-shift charge. Drivers who do need a mid-shift charge would spend 33 minutes, on average, at the charger.

Number of Inter-shift Charges. Those taxis that we remove from the "road" because they have completed a shift according to their shift start times and durations next enter a separate charging model, which we created to calculate charge times between shifts. Since we assume that each taxi begins a shift with at least 80% battery power, we must calculate the necessary charge time following a shift when a driver must ensure battery power is sufficient to operate the vehicle for another shift. The current prevailing behavior for double-shifted taxis is to fill up the gas tank at the end of the shift, so we assume that all inter-shift charging occurs immediately following a shift. In this model, we assume that "full" equates to 80% of the battery.[51]

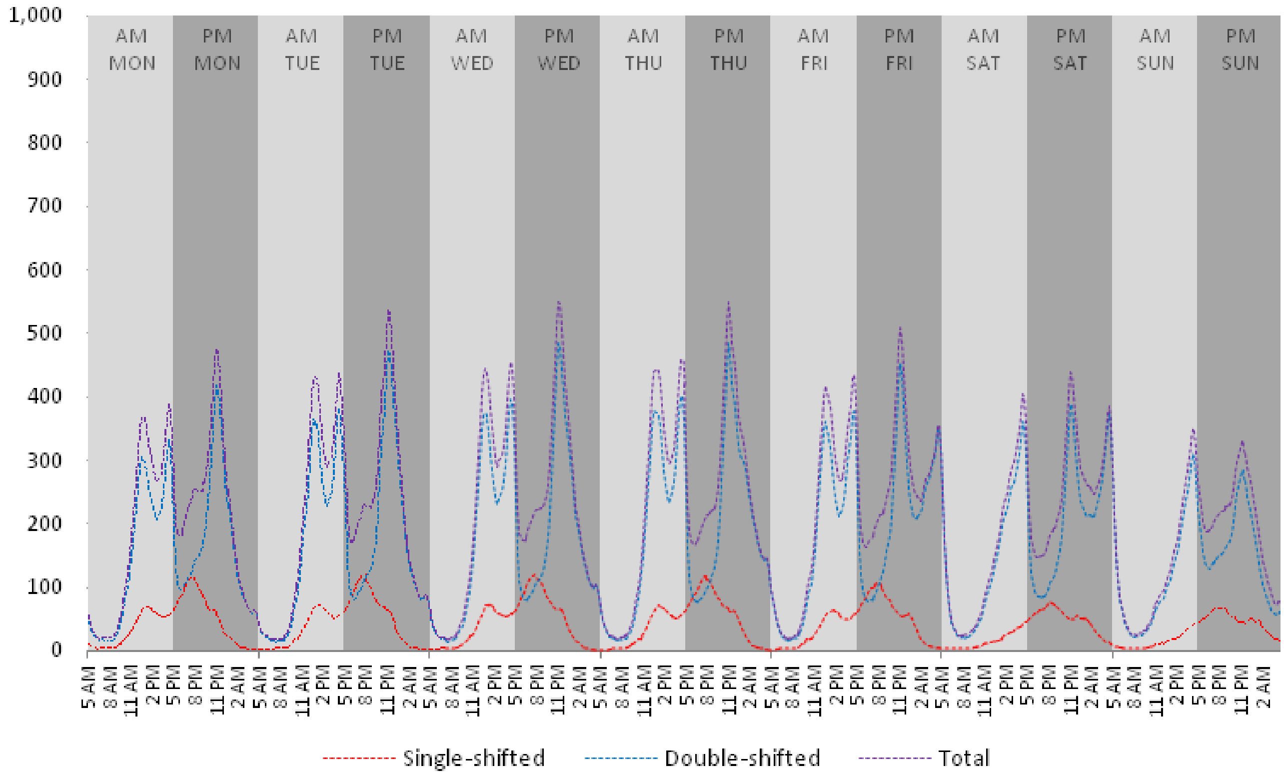
For inter-shift charges, instead of subjecting each taxi to a uniform charge of 30 minutes, we calculate necessary charge times based on the state-of-charge of each taxi at the time it leaves the "road." For some taxis, a five-minute charge will return a taxi to "full"; for other taxis close to the low 10-20% battery range, charge time may be equal up to 30 minutes. Ricardo Engineering calculated a matrix of charge times for various battery sizes that we used to calculate how long a taxi must spend charging between shifts. On average, we calculated that drivers would spend 22 minutes charging between shifts. In combination, we anticipate that drivers would typically spend around 40 minutes for both intra- and inter-shift charges.

Identifying peak times for charging. Figure A5.1 shows a week of charger demand from each operation model—single-shifted owner-drivers and low-mileage double-shifted taxis.

For the single-shifted cohort of taxis, the peak charger demand occurs on Tuesday between 7:45 and 8:00 PM (the daily peak is generally highest on weekdays between 7:45 and 8:00 PM) with a total demand of 121 single-shifted vehicles seeking a charge. For the double-shifted cohort, a peak of 485 vehicles seeking a charge occurs on Thursday between 11:00 PM and 11:15 PM. In general, weekday peaks occur during this time period. Double-shifted vehicles require more peak chargers per vehicle primarily because of the high number of vehicles that begin the evening shift at around the same time period on weekday afternoons.

When combining the two cohorts, the high charger demand of the double-shifted vehicles weighs heavily on the total demand, even though the high peak of the double-shifted vehicles occurs during a softer peak among single-shifted vehicles. In combination, the high peak demand during the week again occurs on Wednesday between 11:30 PM and 12 Midnight with a total demand of 550 charges. Tuesday and Thursday have a similar high peak demand during the same time period.

Figure A5.1. Projected charger demand for 4,412 electric taxis by mode of operation



Sources: NYC TLC TPEP trip-sheet data, 2012, Ricardo charge-time matrix

Appendix to Chapter 6

Cost to purchase quick chargers. We obtained information on the costs of chargers from various companies to generate an estimate that quick chargers for a large New York City taxi program would cost $35,000 each. The information on charger pricing is as follows:

- Nissan's branded quick charger first became available in 2013 and is relatively low-priced. The starting MSRP for this 50kW quick charger is $15,500,[xlix] and a recent quote for the value of a Nissan quick charger unit including add-ons necessary for public operation (e.g., data capabilities to enable access control and customer billing) is about $24,000. A Nissan quick charger has been installed at the Manhattan Plaza Garage in Midtown Manhattan to support the 2013 Nissan-TLC Electric Taxi Pilot Program.
- Aerovironment's EV50 50 kW quick charger was recently quoted at $45,000 to $55,000. This quick charger was installed at the Seward Park Cooperative in Manhattan's Lower East Side to support the 2013 Nissan-TLC Electric Taxi Pilot Program.
- Green Charge Networks (GCN) has installed a DC Fast Charger at a 7-Eleven on Francis Lewis Boulevard in Queens. This charger is integrated with Green Charge Networks' GreenStation, which is an energy storage system that locally stores energy during periods of low use and augments grid power with stored energy during peak demand. This system mitigates demand charges ($25+ per kW in the summer) and the amount of underground infrastructure improvements that are needed to support the quick charger. GCN reports that in general the payback period from such a system is between 3 and 6 years. They have found that hardware costs for DC Fast Chargers range between $15,000 and $35,000 depending upon the manufacturer, and they expect these costs to decrease as production and installation ramp up.[l]
- Fuji manufactures a 25 kW quick charger that costs $28,000.
- Schneider Electric manufactures a 50kW quick charger with a base price of $25,000.

Costs of Existing Charger Installations. Ecotality has commissioned 80 quick chargers as part of its work with the US Department of Energy's Idaho National Labs. The cost of these installations ranged from $6,000 for a simple Arizona installation (where there was easy access to power and little ground disruption) to $48,000 for a San Diego installation that required significant underground work.[52] They opted not to go forward with some installations they considered because installation costs topped $100,000. Chicago has 26 quick charging stations that generally cost under $20,000 in installation expenses. They worked closely with their utility to find locations where costs could be minimized, and sited the chargers primarily in retailers' surface parking lots. Relative to suburban or rural installations (in which a unit might be installed on grass at a location close to electric service and with little other utility infrastructure underground), New York City installations would most likely require significant disruption of surface materials and higher complexity of underground work.

The cost of quick charger installations is highly variable depending on the site, and since it is still a relatively rare form of infrastructure, cost data are not readily available. There are currently only two quick chargers in Manhattan and three in New York City:

- Parking garage example: The installation work for the quick charger at the Manhattan Plaza Garage cost an estimated $65,000, but this estimate is on the high side for this type of installation because Manhattan Plaza brought enough electrical service to the site to serve 4 quick chargers rather than the one that was immediately being installed. Without the additional power being brought to the site, the installation might have cost about $40,000. This example highlights, however, the economies of scale that could accompany installing several quick chargers in a single location.[li]

- Surface parking lot examples: The installation of a quick charger at the Seward Park Co-Op cost $20,000 to $40,000.[lii] There is also a quick charger in a 7-11 parking lot on Francis-Lewis Blvd. in Queens.

The City also received a quote for a curbside quick charger. The installation of a curbside charger near Union Square was estimated to cost $55,000.[53]

Figure A6.1. Quick Charger Maintenance and Repair Cost Projections

	Annual Maintenance and Repair Costs [liii]	Maintenance and Repairs Performed
Indoor, low estimate	$700	- 2 easy filter cleanings/year - Replace plugs and cords every 5 years - Occasional broken screen or re-cleaning
Indoor, high estimate	$1500	- 3 more labor-intensive filter cleanings/year - Replace plugs and cords every 2 years - Occasional broken screen or re-cleaning
Outdoor, low estimate	$2,300	- 2 easy filter cleanings/year, occasional re-cleaning - Replace plugs and cords every 5 years - Replace screen once per year - Wrap on charger to allow for better restoration after vandalism or damage
Indoor, high estimate	$3,100	- 3 more labor-intensive filter cleanings/year, occasional re-cleaning - Replace plugs and cords every 2 years - Replace screen once per year - Wrap on charger to allow for better restoration after vandalism or damage

Source: Quotes provided to OLTPS by charger manufacturer.

Nissan also offers a 1-year maintenance plan for their charger for $2,695/year[liv] and Aerovironment estimates annual preventative maintenance costs of $1,250.[lv]

Appendix to Chapter 7

Site Types: Ownership

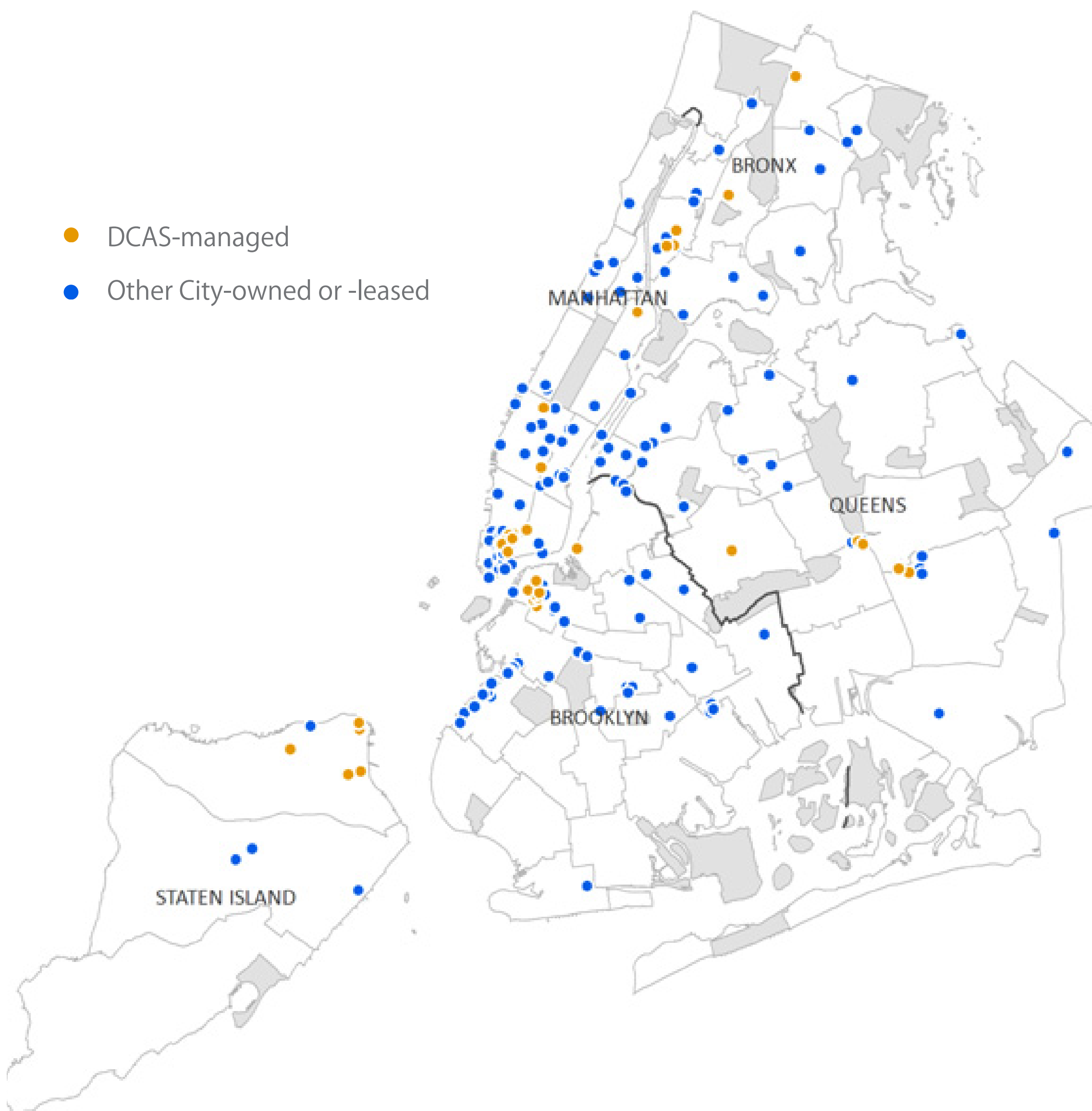
In addition to different types of physical locations, the type of owner for different properties can also affect the feasibility and cost of siting quick chargers in New York City. To build a large network of chargers, negotiating with many different property owners could be time-intensive and lead to highly variable costs from site to site. From TLC's experience in siting chargers for the Nissan-TLC Electric Taxi Pilot Program, working through legal agreements and coordinating construction with different property owners can be time-intensive.

From an ownership perspective, on-street locations could be easier to handle than off-street locations. This is because all street space is owned by the City of New York. However, regulatory issues--particularly street furniture rules--exist surrounding on-street siting. This means a revocable consent agreement would have to be arranged for any objects (chargers or supporting infrastructure) located on the sidewalk. In addition, electric vehicle chargers have not been approved in a wholesale fashion as street furniture objects. This approval process would require review by the NYC Departments of Transportation and City Planning and by the Public Design Commission, which could take anywhere from four to six months.[54] However, once a particular charger design and layout goes through the public process, it does not need to be approved separately for each individual site. The operator of the network would also need to obtain a franchise or concessions agreement with the City in order to sell charges to drivers on public property. Franchise agreements can carry longer terms (20+ years) and can be offered to a preferred company selected through an RFP (Request for Proposals), but the City must identify the charger network as a public service to enter into this type of agreement. For a concessions agreement, an RFB (Request for Bids) would be necessary, and the terms of this type of agreement would likely be shorter than those in a franchise agreement.[lvi]

For off-street locations, finding a few large property owners could be logistically preferable to working with many smaller property owners because fewer individual negotiations would need to be carried out. The City is one such landholder, and working through the NYC Department of Citywide Administrative Services (DCAS), the city agency that manages City-owned facilities, could be easier than working through a private entity (unless that entity has a large interest in propagating the charger network).

Figure A7.1 shows City-owned or leased spaces throughout NYC. Unfortunately, most of the DCAS-managed properties are located in downtown areas in Manhattan and Brooklyn and not dispersed evenly throughout the city. Many of the other properties are spaces where the City is leasing office space. For these spaces, the relationship between the City and the property owner could be advantageous from the perspective of brokering a deal to support electric vehicle charging equipment. Other quasi-public-sector lands, such as those owned by the Port Authority of New York and New Jersey or the Metropolitan Transit Authority (MTA), may also be good candidates for siting chargers.

Figure A7.1. City-Owned and Leased Property



Source: NYC DOF, NYC DCP GIS layers

At least some of a large quick-charging network would likely be located on private land or in private buildings. This is due to the limited availability of city-owned land in the Manhattan Central Business District and the fact that it is unlikely that all quick chargers could be located at on-street locations. Working through groups like the Real Estate Board of New York (REBNY) in the future could help bring a centralized focus to deploying a large charger network across many disparate locations.

Appendix to Chapter 8

Figure A8.1. Medallion-and-Vehicle (Fleet) Lease Caps

		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Weekly
AM	Standard	$105	$105	$105	$105	$105	$105	$105	$630
	Hybrid vehicle	$108	$108	$108	$108	$108	$108	$108	$648
PM	Standard	$115	$115	$120	$129	$129	$129	$115	$737
	Hybrid vehicle	$118	$118	$123	$132	$132	$132	$118	$755

Figure A8.2. Lease Caps Used in DOV Segment

	Medallion-only	All-in (medallion + vehicle + other expenses)
Standard	$952	$1,227
Hybrid	$994	$1,269

Please see the TLC rules at *http://www.nyc.gov/html/tlc/html/rules/rules.shtml* for more details on lease caps.

> ACKNOWLEDGEMENTS

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Bethany Bowyer, NYC Office of the Mayor
Bhairavi Desai, New York Taxi Workers Alliance
Brian Asparro, Green Charge Networks
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John Newman, McKinsey
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> NOTES

[1] This 30% reduction is based on levels of greenhouse gas emissions measured in 2005.

[2] According to the City's 2010 report on electric vehicle adoption, only 44% of households in New York own cars, compared to 90% nationally.

[3] This calculation is based on a non-EV taxi that gets 24 MPG, drives 70,000 miles per year, and OLTPS models for carbon emissions per unit of gasoline consumed.

[4] This decrease is 18% rather than 33% because we account for the carbon emissions that take place at the point of electricity generation.

[5] This calculation is based on average annual mileage of 70,000 for a New York City taxicab and 8,900 for a private vehicle in New York City.

[6] Of course disruptions to electrical service could keep EV taxis off the road. In these cases gasoline-fueled vehicles would continue to be able to provide service. A fleet containing a mixture of EVs and other vehicles may be best equipped to maintain some level of service in the case of various types of emergencies.

[7] We could increase the resiliency of the charger network itself by installing backup power sources for chargers and by distributing chargers across many of Con Edison's power networks.

[8] According to a 2011-2012 TLC passenger survey conducted on the screens in the back of taxicabs, 13% of taxi trips are tourism-related.

[9] In this analysis we define a medallion as single-shifted if it was driven by only a single hack license number for at least 90% of days in 2012. We consider all other medallions double-shifted.

[10] For an EV to be used as a NYC taxi it must, of course, be available in the United States and in New York State. OEMs make the decision about whether to sell a vehicle in the US based on various factors, including projected market demand for the vehicle, availability of dealer networks, availability of charging infrastructure, and the costs of modifying and testing vehicles to meet US requirements. There are many models of EVs, such as the Renault Fleunce ZE, that are sold abroad but that are not currently available in the United States.

[11] Tesla has announced that it will develop another EV by 2016 or 2017 that will be smaller than the Tesla Model S and cost half as much. Tesla has hinted that this vehicle would cost less than $40,000 and have a 200-mile range. Clifford Atiyeh. "Tesla Confirms Smaller, Cheaper Model for 2016 or 2017--Code Name: "Blue Star." Car and Driver. June 6, 2013. http://blog.caranddriver.com/tesla-confirms-smaller-cheaper-model-for-2016-or-2017-code-name-blue-star/

[12] While quick charging is the fastest option for charging an EV, the increasing size of on-board chargers is greatly decreasing the amount of time it takes to charge a vehicle on a level 2 charger. The 2012 Nissan LEAF without the quick charge option has a 3.3kWh on-board charger. This will charge its 24 kWh battery to 100% in approximately seven hours. A Nissan LEAF with the quick charge option has a 6.6 kWh on-board charger and can charge the 24kWh battery to 100% in just 3-4 hours. The Toyota RAV4 EV has a 41.8 kWh battery and 10kWh on-board charger that will charge this large battery to 100% in five hours. Increasing the on-board charger size decreases the level 2 charging time significantly, but still does not offer the charging speed offered by a quick charger.

[13] As part of the Taxi of Tomorrow development process, Nissan has spent several years working closely with TLC and with the taxicab industry to document the duty cycle of New York City taxis and has developed a vehicle to deal specifically with that industry's needs. The NV200 platform is appropriate for use as a New York City taxicab and could be an excellent option for an EV taxi in terms of vehicle size and other features. We do not have confirmation of other key characteristics planned for an eNV200 Taxi, such as vehicle range or price.

[14] Preliminary findings from the TLC-Nissan Electric Taxi Pilot are showing a "NYC taxi range" in the summer of 80 miles off a full 100% charge with a 24 kWhr battery, or about 118 miles with a hypothetical 35kWhr battery. (Due to battery degradation over time and the projection that only 70% of battery range will truly be used--10% charge up to 80% charge--the "full battery range" will rarely be taken advantage of by drivers.)

[15] This may be more than enough battery capacity for some drivers, but we selected this size so that (1) the vehicle would be able to continue operating without excessive charger visits even after some battery degradation, and (2) drivers could complete shifts that are longer than their average shift without excessive charger visits. A 35kWh battery that has degraded

by 20% has a 28kWh capacity, or 94 miles. At each charge, we expect the driver to take advantage of approximately 70% of the battery capacity, or 66 miles. In 2 charges per shift, this allows for 132 miles per shift.

[16] Estimates are based on McKinsey projections and assume battery pack prices per kW hour of $284 in 2017, $200 in 2020, and $160 in 2025. Estimates vary between analysts. For example, Ricardo Engineering projects higher battery prices per kW hour of $525 in 2017, $447 in 2020, and $313 in 2025. This results in vehicle purchase prices of $55,290 in 2017, $51,203 in 2020, and $44,140 in 2025.

[17] 70-80% is a standard cutoff for battery degradation in the automotive industry. Drivers are likely to notice a reduction in range at 80%. Personal communication with David Barnes of Ricardo Engineering, July 17, 2013.

[18] The rate of battery degradation depends on the battery chemistry. Some battery technologies are more resistant to charge degradation than others. Personal communication with Ricardo Engineering on September 3, 2013.

[19] Estimates are based on McKinsey projections and assume battery pack prices per kW hour of $284 in 2017, $200 in 2020, and $160 in 2025. Estimates vary between analysts. For example, Ricardo Engineering projects higher battery prices per kW hour of $525 in 2017, $447 in 2020, and $313 in 2025. This results in battery replacement prices of $31,500 in 2017, $26,813 in 2020, and $18,750 in 2025.

[20] Some manufacturers are moving towards offering free quick charging. For example, Tesla is building a highway-focused "supercharger" network of 120kW quick chargers for Tesla Model S owners to use free of charge on inter-city trips. http://www.teslamotors.com/supercharger

[21] This includes amortized charger purchase price, installation costs, maintenance/repairs, data and connectivity, land, and electricity costs. See Chapter 6 for more details.

[22] As a point of comparison, a taxi driver doing a 120-mile shift in a Ford Crown Victoria, a Nissan NV200, or a Toyota Camry Hybrid would pay about $28, $19, and $10, respectively, in direct fuel costs but would experience very low time costs for fueling.

[23] In the case of fleet-operated taxis, the vehicle purchase decision rests with the fleet owner rather than the driver. The driver, not the fleet owner, typically pays for fuel. In this case, theoretically a fleet owner could purchase electric vehicles for his drivers to use even if the time-spent-fueling vs. cost-of-fueling tradeoff was not attractive for drivers. However, to do so could leave fleet owners open to problems finding drivers who want to drive the EVs. In addition, TLC would not promote an EV program that negatively impacted driver revenue.

[24] This does not include the $7,500 federal tax credit that is currently available to EV purchasers.

[25] McKinsey analysis projects fairly rapid battery price declines, whereas Ricardo Engineering projects much slower declines. Whereas Ricardo's 2020 battery price per kilowatt hour (kWh) projection is $447, McKinsey projects price per kWh may fall to $200 in 2020. Whereas Ricardo's 2025 battery price per kilowatt hour (kWh) projection is $313, McKinsey projects price per kWh may fall to $160 in 2025. ("Battery technology charges ahead" by Russell Hensley, John Newman, and Matt Rogers. McKinsey Quarterly, July 2012.) http://www.mckinsey.com/insights/energy_resources_materials/battery_technology_charges_ahead) Ricardo explains that these lower projections are driven by the McKinsey model's making a number of assumptions regarding the reuse of existing capital plant that Ricardo does not believe are sustainable in reality. Ricardo's assessment is that much of the currently "mothballed" capacity will not be directly reusable in the future without significant additional investment. In addition, the lowest cost battery is not necessarily the best suited to meet mass and package volume requirements for vehicle use. For example, lead acid batteries can be found for $80/kWhr, but they do not work well in EVs. There is likely to be a multi-dimensional set of tradeoffs between battery chemistry, energy density, charging rate, and degradation for vehicle applications. The reduced cost of the cheapest battery is likely to be offset by increased costs elsewhere in the system. TLC personal communication with David Barnes at Ricardo Engineering. July 16, 2013.

[26] Existing electric vehicles' performance has been optimized for various duty cycles, leading to better energy performance when driven in these conditions.

[27] We calculated average shift mileage for taxis by tabulating revenue mileage collected in TPEP trip-sheet data, multiplied by a revenue-miles-to-total-miles conversion factor that we calculated from tri-annual inspections data recording

revenue mileage and total mileage. The charging needs of taxis falling into the low-mileage group, but whose charging is above the average of 100 miles, are also incorporated into the model.

[28] 35kWh is the "nominal" pack capacity. The usable capacity is smaller.

[29] Assuming that 100% of charging will take place at quick chargers is a conservative estimate because some taxis will find ways to do Level 2 charging between shifts. The most likely candidates to incorporate some Level 2 charger are the one-tenth of the taxi fleet only drives one shift per day. If these drivers have off-street parking in a home driveway or garage, they may install Level 2 chargers and charge between shifts. However, many drivers park their vehicles on the street, which makes Level 2 charging logistically much more difficult.

[30] We selected a vehicle battery size based on the dual considerations of (1) cost and (2) taxi operational requirements. If a vehicle with a longer range became available and affordable for the taxi industry, it is possible that most taxis could complete entire shifts on a single charge and that quick charging would occur primarily in longer between-shift sessions. Although this could be operationally preferable to more frequent charging, it would likely increase the height of charger demand peaks at shift changes and therefore the number of chargers needed to meet demand.

[31] There are alternatives to this assumption. For example, drivers may charge when they feel like taking breaks regardless of their vehicles' states of charge. If drivers charge when they want breaks rather than when they run low on charge, this may have some smoothing effect on the peaks in demand for chargers because it could mitigate the demand-peaking driven by relatively uniform shift change times. Whether charging is billed per unit of time or per charge would impact drivers' tendency to charge based on their own personal needs or based on the vehicle's state of charge, with time-based billing favoring the former.

[32] Currently Tesla is installing 100kW and 120kW chargers for its vehicles to use (http://www.teslamotors.com/supercharger). Aerovironment also makes very fast chargers (http://evsolutions.avinc.com/products/fleets/charging_fleets_a); however, we do not know other manufacturers' comfort levels with these charging speeds or whether superfast charging negatively impacts the battery.

[33] 25kW chargers are also on the market, but we assume 50kW for this analysis because fast quick charging is important in the taxi industry. It is also possible to make chargers that work faster than 50kW chargers. These chargers would be costlier to purchase and would generate higher demand charges, but would decrease time costs for drivers. Vehicles would have to be designed or modified to support charging at higher speeds.

[34] Assumptions: No work done on overtime, 50kW charger purchase not included, no sales tax, all work performed by licensed electrical contractor and includes permitting, inspection and Certificate of Approval, no sub-metering, no correction of any existing violations, and no telecommunications.

[35] Another point of reference is ZipCar. One Manhattan garage operator charges ZipCar $300 per month per car to park in its garage; however, the price a garage charges ZipCar for a space is not perfectly analogous to the price that would be charged for EV charger space. This is because (1) ZipCar spaces are easily usable by other vehicles when the ZipCar is absent, (2) garage operators can move ZipCars as needed, enabling them to adjust placement based on space concerns, and (3) ZipCars only need one space each, whereas in garages with smaller parking spaces an EV charger would take up two spaces - one for the charging equipment and one for the charging vehicle.

[36] Taxi relief stands are stretches of curbside land at which taxis may park free of charge to take a break. They may leave the vehicle. In contrast, taxi stands are stretches of curbside land where taxis may park while waiting to be approached by a passenger wishing to make a trip. The driver must remain with the vehicle and be ready to transport a passenger. In NYC, a very small share of taxi stands are staffed by a dispatcher.

[37] Assumes $3/hour midtown metered rate is charged 13 hours/day, 6 days/week, and 52 weeks/year, with 90% occupancy during revenue-generating hours.

[38] Con Edison estimates provided on August 12, 2013 assumed a 50 kW quick charger charging a vehicle with a 60 kWh battery from 10% to 80% charge and 15 charges per day per charger. TLC adjusted these estimates to generate costs of charging a 35kWh battery 23 times per day. An EPRI report informed Con Edison's work on the amount of energy required to provide this charge, including additional energy used by the vehicle's battery cooling and management system during the rapid charge cycle. Source: "Direct Current Fast Charger System Characterization: Standards, Penetration Potential, Testing, and Performance Evaluation." Electric Power Research Institute (EPRI). December 2011.

[39] We investigated whether purchasing electricity wholesale, as the City does through NYPA, could reduce electricity costs relative to the retail prices quoted here. OLTPS analysis found that the total electricity costs would be very similar whether power was purchased through NYPA or through Con Edison. This is driven by the fact that although energy usage charges are lower through NYPA than through Con Edison, demand charge rates are higher.

[40] The charger may still be usable after some refurbishment or its parts may have value after the charger as a whole is taken out of service. The infrastructure underlying the installation--trenching, wires--may be useful for installing the next charger.

[41] The NYS credit is valid against corporate tax, corporate franchise tax and personal income tax. The credit expires after December 31, 2017. A federal tax credit for EV infrastructure put in place in 2012 only applies to charger placed in service before January 1, 2014. Burton, David. "New York Enacts Electric Vehicle Recharging Station Tax Credit to Compliment the Federal Tax Credit." The Tax Equity Telegraph. May 10, 2013. http://www.akingump.com/en/experience/practices/global-project-finance/tax-equity-telegraph/new-york-enacts-electric-vehicle-recharging-station-tax-credit.html

[42] Ricardo Engineering used US Energy Information Administration (EIA) 2013 Annual Energy Outlook data to project a 2020 NYC retail gasoline cost of $4.48 per gallon. www.eia.gov/forecasts/aeo/er/early_prices.cfm. If gas prices increase to levels that are higher than this projection, the economics of EV as compared to gasoline-powered vehicle improve.

[43] In this report, we do not quantify what amount of charging infrastructure may be needed in Westchester or Nassau County, as trips to these places represent less than one percent of all trips; however, some level of charging infrastructure would ultimately need to be considered for these places in order to maintain current service requirements.

[44] PUMAs are a geographic unit created by the U.S. Census Bureau for the tabulation of socio-economic data. In NYC, PUMAs closely approximate the City's 59 Community Districts. A comparison of the two geographies is available at http://www.nyc.gov/html/dcp/pdf/census/puma_cd_map.pdf

[45] We based this split on the proportion of single-shifted and double-shifted taxis we incorporated into our modeling of electric taxis in Chapter 5, where approximately 30 percent of the taxis modeled as adopting EV are single-shifted and 70 percent are double-shifted.

[46] *Under the Elevated: Reclaiming Space, Connecting Communities* is a project of the Design Trust for Public Space in partnership with the NYC Department of Transportation. The project is developing strategies to maximize the function, use, and spatial qualities of the millions of square feet of space underneath New York City's bridges, elevated highways, subways, and rail lines. *Under the Elevated* will culminate in early 2014 with the launch of a set of design, programming and policy recommendations.

[47] The map represents capacity based on current 20-year Land Relief Plan (2013 - 2032) issued on March 5, 2013 by ConEdison.

[48] There is slightly more nuance to this policy. Please see Section 54-20 of the TLC Rules for more information. http://www.nyc.gov/html/tlc/downloads/pdf/2011rulebook_ch54.pdf

[49] Of course, taxis that spend less time cruising may spend more time parked, which could potentially impact the supply of available parking. Taxis currently have a passenger for about 60% of the miles they drive and do not have a passenger for about 40% of the miles they drive. These non-passenger miles represent cruising, commuting, and personal use. Source: TLC TPEP electronic trip-sheet records and TLC Safety and Emissions inspection records.

[50] Assuming no subsidy, the overall expense associated with batteries over the course of the vehicle's life with a swapping model would probably be similar the expenses that would be associated with a traditional battery ownership model. They would simply be spread out over a longer time period.

[51] Although the convention of each driver handing over the vehicle to the next driver with a full tank of gas is sensible from a fairness point of view, this convention could change if circumstances called for it. To test the impact of changing this convention for EVs (i.e., no need to hand over taxi at a "full" 80% charge), we modeled other possible conventions for minimum shift changeover battery states of charge. Other conventions (e.g., 50% = "full") did not significantly impact the number of charges each taxi had to do in a shift or the number of chargers needed to accommodate the fleet, so we used the 80% convention in the model.

[52] Additional costs for this installation were borne by the San Diego utility.

[53] Price provided by Aerovironment and does not include cost of permits or work that Con Edison would perform to support the installation.

[54] http://www.nyc.gov/html/dot/html/infrastructure/revconif.shtml

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Unless otherwise noted, all photos by NYC TLC staff