FINAL REPORT

WORKSHOP ON

Integrating Electric Mobility Systems with the Grid Infrastructure

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November 6-7, 2019

Boston, MA

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This workshop was sponsored by the Sloan Foundation

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EXECUTIVE SUMMARY

This document is a report on the workshop entitled "**Integrating Electric Mobility Systems with the Grid Infrastructure**" which was held at Boston University on November 6-7 with the sponsorship of the Sloan Foundation. Its objective was to bring together researchers and technical leaders from academia, industry, and government in order to set a short and long-term research agenda regarding the future of mobility and the ability of electric utilities to meet the needs of a highway transportation system powered primarily by electricity. The report is a summary of their insights based on workshop presentations and discussions. The list of participants and detailed Workshop program are provided in Appendices 1 and 2.

Public and private decisions made in the coming decade will direct profound changes in the way people and goods are moved and the ability of clean energy sources – primarily delivered in the form of electricity – to power these new systems. Decisions need to be made quickly because of rapid advances in technology, and the growing recognition that meeting climate goals requires rapid and dramatic action. The blunt fact is, however, that the pace of innovation, and the range of business models that can be built around these innovations, has grown at a rate that has outstripped our ability to clearly understand the choices that must be made or estimate the consequences of these choices. The group of people assembled for this Workshop are uniquely qualified to understand the options that are opening both in the future of mobility and the ability of electric utilities to meet the needs of a highway transportation system powered primarily by electricity. They were asked both to explain what is known about the choices we face and to define the research issues most urgently needed to help public and private decision-makers choose wisely. This report is a summary of their insights based on workshop presentations and discussions.

New communication and data analysis tools have profoundly changed the definition of what is technologically possible. Cell phones have put powerful computers, communication devices, and position locators into the pockets and purses of most Americans making it possible for Uber, Lyft and other Transportation Network Companies to deliver on-demand mobility services. But these technologies, as well as technologies for pricing access to congested roads, also open many other possibilities for shared mobility services – both public and private – that could cut costs and travel time by reducing congestion. Options would be greatly expanded if fully autonomous vehicles become available. These new business models would also affect options for charging electric vehicles. It is unclear, however, how to optimize charging (minimizing congestion on the electric grid) without increasing congestion on the roads or creating significant problems for the power system that supports such charging capacity.

With so much in flux, many uncertainties cloud our vision of the future. The way new mobility services will reshape the number, length of trips, and the choice of electric vehicle charging systems and constraints on charging, and many other important behavioral issues are critical to this future but remain largely unknown. The challenge at hand is to define plausible future structures of electric grids and mobility systems, and anticipate the direct and indirect impacts of the changes involved. These insights can provide tools essential for effective private and public decisions designed to optimize the performance of future mobility and grid systems and for understanding the consequences of choices made. While the participants of this workshop have clearly made deep inroads into the research challenges of this new field, they all agreed that much more should be done.

High priority recommendations for future research work include:

- ***Exploring uncertainty through scenarios that include innovation in electric utilities and mobility:*** Develop a series of plausible scenarios and develop optimization that can minimize costs for each. This could include joint optimization of utility investments, charging station location and ownership and optimization of mobility (vehicle size, routing, dispatch) to minimize trip costs and trip time.

- ***Data ownership and management:*** New technologies can give electric utilities precise, real-time information about all aspects of their systems (generation, transmission, distribution, and consumer consumption). New mobility companies, automated vehicles, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) systems, 5G cellular networks and other systems are likely to transform mobility options. All of these systems generate enormous amounts of data and this raises new questions about who will have access to the data and ensure privacy and security of participants. A careful look at the future of data in electric mobility systems, public access to this data, measures to ensure privacy and security, and related issues would help guide future policy in this fast-moving area.

- ***Electric vehicles in ex-urban and rural areas:*** Most analysis of new mobility systems and electrification focuses on urban transportation issues. It would be valuable to explore options for providing electric transportation services to low density areas and possibly explore options for use of alternative sources of renewable power.

- ***Financing and electric rates:*** A considerable amount of discussion in the workshop focused on how electric vehicle charging systems (and in some cases the electric vehicles themselves) could be financed and how charging locations, timing, and charge rate could be tuned to optimize both mobility and electric grid operations. A number of financing options are available. A complex tangle of federal, state, and local laws and regulation govern ownership and pricing in both electric and transportation. Many may prove to discourage investments and operations that can optimize mobility solutions in the emerging economy. A careful review of the issues described could help.

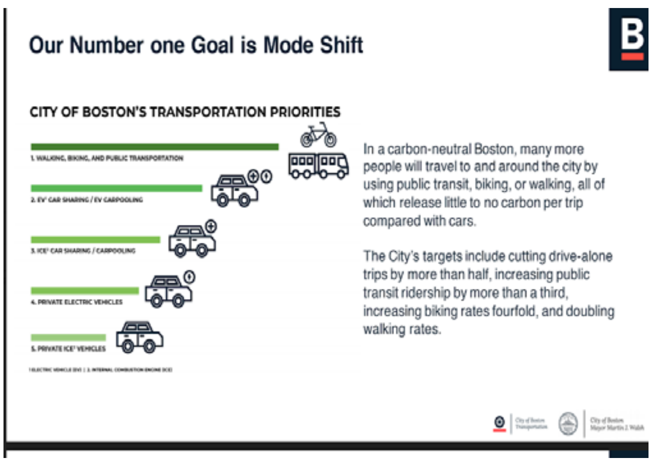
1. SETTING THE STAGE/DEFINING UNCERTAINTY

1.1. Revolution in mobility

Several workshop participants, such as Austin Brown, pointed out that the highway transportation system may well be changed in dramatic ways by the emergence of new business models, made possible by modern data-management and communication technologies – including ubiquitous cell phones with built in GPS location. Changes could come quickly. Transportation Network Companies (TNC) like Uber and Lyft still represent only a small fraction of all vehicle miles traveled but, as several presenters pointed out, their market share has grown at a spectacular rate. Still, many other business models could emerge. Mid-sized vans operating on-demand could, for example, pick up passengers and deliver them to transit stops – greatly reducing the "last mile" problem faced by public transportation systems. These fleets could be owned and operated by existing public transportation systems, private firms hired on contract by public systems, or operate entirely independently. Brown is considering offering delivery pickup lockers at transportation transfer points to limit delivery truck trips to residential neighborhoods. The economics of all these systems would be radically changed if fully automated vehicles become a reality, as driver costs are at least ⅔ the total cost of a TNC trip.[1]

Source: Austin Brown, *Sloan Workshop 2019*

The environmental externalities associated with transportation are well known, but recent analysis suggests that the externality costs associated with congestion may be ten times higher.[2] Most urban areas are pursuing strategies to cut congestion costs as an integral part of efforts to lower carbon emissions. Matt Warfield's presentation describes Boston's strategy. He notes that in 2019, 60% of Bostonians lived within a 10 min walk of rail, bus, Bluebike and car share, up from 42% in



Source: Matt Warfield, *Sloan Workshop 2019*

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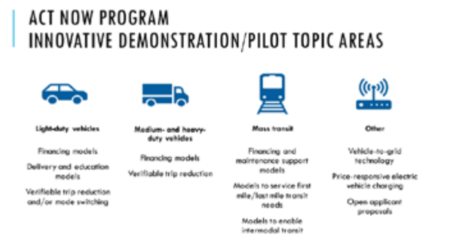
[1] Johnson C. and Walker,J., Peak Car Ownership: The Market Opportunity of Electric Automated Mobility Services, Rocky Mountain Institute, 2016

[2] Anas, A., and Lindsey, R., Symposium: Transportation and the Environment Reducing Urban Road Transportation Externalities: Road Pricing in Theory and in Practice

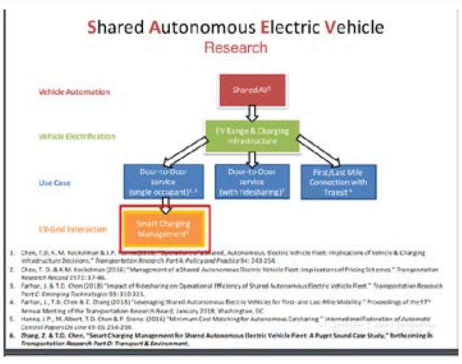
2017. This is an important step in encouraging new mobility solutions for the city. The city is also exploring strategies for better managing parking and use of curb space that can encourage shared vehicles.

Nelson's presentation also emphasized the portfolio of new mobility options being pursued by the city of Boston, of which EV incentives are integral. Boston is working with a multi-state consortium, National Grid, and Eversource, to increase the EV charging infrastructure in Boston by 5000 level 2 and DCFC charging stations. In addition, Boston is exploring ways to provide incentives for charging during the evening through the "Charge forward" initiative.



Source: Galen Nelson, *Sloan Workshop, 2019*

While a variety of approaches are being taken, incentives provided for high-occupancy vehicles, including congestion-based pricing and transportation subsidies designed to encourage mobility access to all urban areas, could dramatically change the attractiveness of alternatives to conventional mobility investments now dominated by single-passenger, owner-occupied vehicles.



Source: Donna Chen, *Sloan Workshop 2019*

As presenter Donna Chen and other speakers pointed out: "Disruptive mobility trends will change the way urban transportation systems interact with the electric grid." Public or private organizations owning fleets of vehicles, for example, will have different patterns of charging location and timing than individual vehicle owners. They will also be able to enter into more sophisticated arrangements with electric utilities. A variety of "use cases" were described and evaluated by presenters.

Fleet owners may well be some of the first large-scale operators of electric vehicles for two reasons: (1) they may be in a better position to finance the higher initial cost of an EV, and (2) their vehicles are operating for a larger fraction of the day allowing them to reduce the cost per mile attributable to charging facilities and additional, including fixed utility costs associated with charging.

Wellik's presentation focused on electric buses that are being adopted in many US cities. She showed that electric buses cost more to purchase ($500-$700K vs $280K for diesel) but cost less to operate (diesel $0.5/mile, electric $0.13/mile) but still have a net annual cost

5.4% more per year than diesels (3.2% more with managed charging strategies). The incremental costs of electric buses will fall as battery costs decrease and production of electric vehicles increases, but she notes that the extra costs of electric vehicles would be offset if emission externality costs are included in the analysis. Liebman's presentation noted similar cost premiums for electric buses but pointed to demonstrations of electric buses in Aspen, Colorado and New York. The Aspen system hopes to achieve 100% electrification by the end of 2019 and believes that fuel and maintenance cost savings can make the system cost effective.

Austin Brown pointed out that Transportation Network Company cars drive three times as far each day as typical vehicles and electric TNC vehicles had significantly different patterns of charging, using sixty times more power from fast electric vehicle charging stations as non-Tesla electric vehicles. One hypothesis for this behavior is that the TNC vehicles are electing to take trips that allow them ready access to charging stations[3].

While there is uncertainty about new mobility service companies, there is also considerable uncertainty about how individual EV owners will behave. One challenge here is that much of the data about EV ownership behavior comes during a period where many EVs had short ranges and EV charging infrastructure was dominated by residential charging. Dr. David Keith found that:

- PHEVs (Plug in hybrid electric vehicles), like EEVs (hybrid electric vehicles), are driven at least as much as gasoline vehicles
- Tesla BEVs (battery electric vehicles) are driven marginally less that gasoline vehicles
- Non-Tesla BEVs (Battery Electric Vehicles) are driven a lot less."

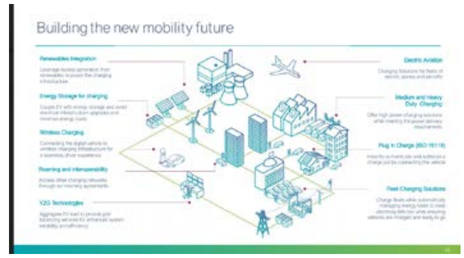
Source: David Keith, *Sloan Workshop 2019*

He observes that the Tesla driving patterns reflect the relatively long range of Teslas now on the road in comparison with other early BEVs. The difference between driving patterns of Teslas and other BEVs "will be falling over time, with more affordable 200+ mi BEVs, and more fast charging stations."

1.2. Revolution in Electric Utilities

[3] https://escholarship.org/uc/item/15s1h1kn

The introduction of large numbers of electric vehicles will create significant new loads for electric utilities that could lead to grid congestion and increasing costs. A number of groups are developing tools that can minimize costs by optimizing the time, location, and rate of EV charging. Several speakers noted, however, that this analysis must consider the rapid changes underway in electric utilities that are affecting both the way electricity is generated and the way electricity is used. There may be sharp changes in timing – when power is generated and when it is consumed. On the supply side, rapid growth in wind and solar energy mean that significant amounts of electricity supply will be intermittent. On the demand side, sharp reduction in fossil fuel use in transportation and in buildings will mean significant new patterns of electricity demand from electric vehicles, heat pumps, and other technologies.



Source: Brett Hauser, *Sloan Workshop 2019*

New technologies for storing electricity and for shifting demand will help accommodate this variability[4]. But traditional strategies for ensuring reliable service at the lowest cost need to be rethought. Integration of the timing of electricity production and use will be essential for ensuring that reliable energy services are delivered at the lowest cost to consumers. Forecasts of both traffic and grid operations (temperature, wind and solar conditions) can add new dimensions of control. As a result, demand management, now a relatively minor part of grid management, is likely to become a major part of electric utility services. Electric vehicles may be able to help address local electric grid congestion problems by changing the time, location, and rate of charging.

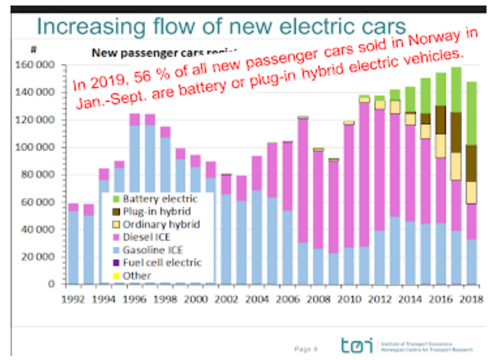
Source: Brett Hauser, *Sloan Workshop, 2019*

The potential demand increase in the next 10-20 years are significant. Electric passenger vehicles could reach 13-26% of today's load[5]. The impact on peak demand could also be significant. Hauser's presentation showed that electric vehicles could lead to a $3.1 trillion investment in new equipment. Wang's presentation reported an estimate by the Sacramento Municipal Utility District showing that 17% of its transformers would need to be replaced to support electric vehicles.

[4] Center for Sustainable Systems, University of Michigan, U.S. Grid Energy Storage Fact Sheet, 2019, http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

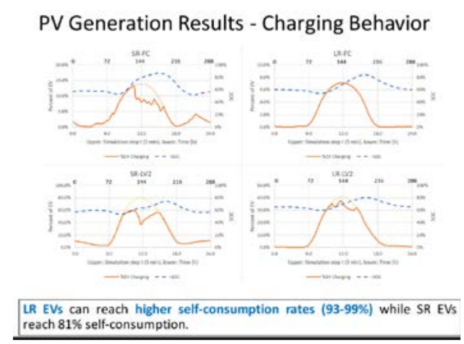
[5] Fox-Penner, et al. 2018

Lasse Fridstrom (Norwegian Center for Transportation Research) described strategies that have led to rapid introduction of electric vehicles in Norway and their plans for the future. This includes a plan to have no sales of cars powered by fossil fuels by 2025. This rapid shift in car markets was driven largely by significant reductions in the taxes paid when purchasing an electric vehicle, and a variety of other incentives including reduced fees on roads and ferries. Introduction of electric vehicles is facilitated by the fact that most car charging occurs at home and most Norwegian homes are electrically heated and have robust connections to the grid.



Source: Lasse Fridstrom, *Sloan Workshop, 2019*

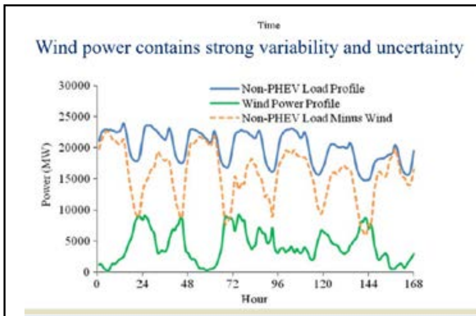
In most conventional utilities, prices have been lowest at night when electric loads are low, and this has been the basis of the fixed "time of day" rate charges used in some utilities today. Chen's analysis shows, however, that there is significant day to day variability in the shape of utility loads. Her presentation included an analysis of a utility's load curve which showed that conventional evening peaks occurred 31% of the time but there were no significant peaks 31% of the time, sharp "spike peaks" 16% of the time, and peaks at unusual times for the remaining 22%. These patterns could change dramatically in a future when costs may be lowest when solar or wind energy is available.



SR=short range electric vehicles, LR= long range, FC= fast chargers, LV2= Level 2 chargers

Source: Donna Chen, *Sloan Workshop, 2019*

Jianhui Wang's presentation showed how a utility with a significant amount of wind power can affect load shapes and optimum strategies for charging. Donna Chen's presentation focused on the way electric vehicle charging could be affected when they are operated in a utility using large amounts of solar energy. The large batteries available for long-range electric vehicles could provide a close match to the availability of solar energy. The methods used to optimize charging are described in following section.



Source: Jianhui Wang, *Sloan Workshop, 2019*

2. OPTIMIZATION CHALLENGES

The ultimate goal of a highway transportation system is to move individuals and freight from their origins to their destinations as safely and quickly as possible at the lowest possible cost – including externality costs such as congestion and damage to the environment.

When considering electric vehicles, cost optimization must also be applied to the electric grid. This requires analysis both of patterns of mobility (e.g. data on trip origins and destinations) and operation of electric utilities. The cost of electricity delivered to customers depends on the location of the customer and the time of day. Utilities must recover cost of both capital investment and operating costs (including fuel costs and line losses). The way utilities actually recover these costs is discussed in the next section. Several presenters explored ways that overall utility costs (and customer costs) could be minimized with sophisticated rate structures. They assumed low cost information technologies that allow greater control over utility operations and make it possible to shape the electric use of individual customers. These tools are essential for helping utilities manage increasingly complex generation portfolios and managing utility-scale storage and customer demands.

Electric vehicles should be easier to manage than many other electric loads and can even provide a range of services directly useful for grid stability – such as frequency and voltage regulation. A presentation by Kempton argued that electric vehicles could provide bulk grid-scale electric storage without affecting the charge levels available to customers. He estimates that if half of all cars were electric they could provide enough storage to power the entire US grid for 11 hours and that a single Chevy Bolt could power a typical US house for 40 hours.

Challenges	Opportunities
Uncontrolled charging of large-scale EVs can affect the safe and economic operation of power systems in the following aspects: × Increased electricity T&D losses and higher peak load. × Increased voltage deviations. × Transformers loading. × Business models. × Increased price volatilities.	If appropriate charging/discharging strategies are adopted, EVs can contribute to power system operation in various ways. ✓ Load valley filling. ✓ Line congestion management. ✓ Demand response. ✓ Frequency regulation. ✓ Increase renewable penetration. ✓ Vehicle-to-grid (V2G).

Source: Jianhui Wang, *Sloan Workshop 2019*

Presentations by Annaswamy, Chen, and Wang outlined sophisticated optimization models that address the challenge of integrating large numbers of electric vehicles into the grid. They all show that care in system design and operation can result in significant improvements, but all emphasize that much more work needs to be done.

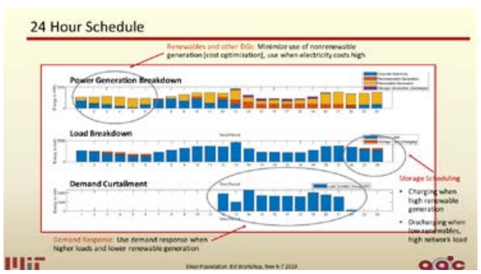
Wang's optimization focused on strategies for adjusting "prices of electricity at public charging stations to influence the spatial distribution of EV charging loads to mitigate their impacts to the grid." The optimization had two objectives:

- Objective one: minimize the EVs' total traveling time.
- Objective two: minimize the EV owners' payment for the charging services.

His model showed that with optimal pricing, the cost to EV customers is reduced by 2.6%. The real power losses are reduced by 4.5%. He also explored a rate structure which used "model predictive control" which anticipates future demand. This reduced charging costs by 13.44% and power loss by 15.78%. When run for a utility with high wind capacity, the model showed how the control system could accommodate wind variability by shifting charging to times when wind output was high and minimizing charging during periods of low wind.

Chen addressed a similar set of optimization challenges but included an analysis of new mobility providers and optimal location of charging facilities. The model had four main components:

- Trip generation: use local travel demand model to generate origin/destination demand
- Charging station generation: site selection to ensure sufficient coverage
- SAEV fleet generation: size of fleet needed to serve demand
- Operation: continuous daily operation based on station and fleet configuration.



Source: Anuradha Annaswamy, *Sloan Workshop, 2019*

One early observation is that vehicles with larger batteries offer utilities expanded options for charging strategies that minimize costs. Using her model to determine optimum charging locations and times, she found that "Managed charging can save 34% in electricity costs for long range vehicles." She was also able to design a system that used long-range EVs to capture 93-99% of the photovoltaic output generated by the utility. This strategy, however, increased with zero-occupant vehicle miles traveled.

Her analysis also includes the impact of shared automated vehicles which can greatly increase options for optimizing electric vehicle charging. She points out that in addition to eliminating driver costs, shared automated electric vehicles offer options for:

- "Strategic relocation (supply/demand mismatch)
- Automated charging
- Reduced maintenance
- Reduced range anxiety."

Anuradha Annaswamy presented a model which also explored methods for using demand side management and other methods to minimize costs in a next-generation utility. Her method focuses on a "general distributed optimization algorithm" which enables:

- "Easier and parallelized computations
- Lower communication requirements (between units and/or overall)
- Maintains privacy of cost functions problem."

Her presentation included an analysis of optimum power operations for electric-powered trains traveling on the Boston, New York route. Considerable savings could be achieved by using her optimization tools to select power sources.

3. POLICY ISSUES

Three strategies have been proposed for increasing the sophistication of demand side management for electric vehicles. These are:[6]

- Direct load control, where the utility has the ability to directly control the electricity demand and has the right to discontinue it.
- Dynamic pricing arrangements that provide a price signal directly to customers so they can voluntarily react to the prices.
- Participation through an aggregator in electricity markets where price signals incentivize DSR activity.

Presenters discussed the merits of these alternatives and also explored the provision of EV charging services to rural areas

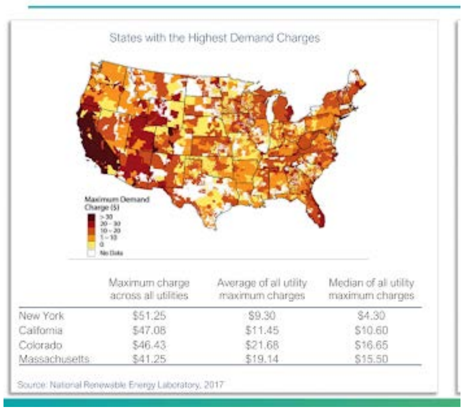
3.1. Rate Design

Even if a joint optimization of mobility and grid operations can be calculated, it is unclear how the recommendations can be implemented. Options for adjusting the timing of demand for electricity are expanded enormously by dramatic reductions in the cost of collecting, communicating, and processing information. Real time pricing and pricing forecasts can shape markets but may prove difficult to implement. Mobility service company ownership of large fleets of electric vehicles and electrified public transportation services may make sophisticated control schemes more feasible.

A number of the simulation models discussed earlier assume a sophisticated set of utility rates that encourage customers to charge electric vehicles in a way that minimizes integrated system costs. The demand charges actually employed by utilities today is much less sophisticated.

Kontou's presentation showed the enormous variation in the structure of utility rates around the country. 44% have flat demand charges, 47% of utilities have no demand charges and 9% have time of use demand chargers. 47% of the US population and about half of highway miles are in a utility service territory with no demand charges.

[6] EIA, Global EV outlook 2019
https://webstore.iea.org/download/direct/2807?fileName=Global_EV_Outlook_2019.pdf



Source: Eleftheria Kontou, *Sloan Workshop, 2019*

While demand charges are clearly justified by the economics of existing utility operations, she points out that they are a major barrier to investment in charging facilities. Kontou's presentation notes that these charges amount to 46% of EV charging bills. She notes that a large part of the problem is the low utilization rate of both public and private charging facilities. Costs per customer can be greatly reduced if a charging facility paying a fixed demand charge can spread the cost over a number of customers. Hauser's presentation showed details the demand charges and time of day rates some utilities are currently using. While all send price signals that can reduce grid congestion, none approach the sophisticated time-of-day explored in the modeling exercises.

Wang and Annaswamy suggest rate structures that are even more sophisticated than real time pricing by considering how anticipated demand (consumer demand less intermittent renewable production) can further improve the operation of EV charging. As shown earlier, Wang shows that significant cost savings can be achieved. His presentation also explored ways that EV charging aggregators and fleet owners could be encouraged to participate in rates that incorporate his "model predictive control" pricing mechanisms and the travel cost to EV customers is reduced by 2.6%. One challenge is finding a way to manage the risk aggregators face since actual demand (and production costs) may not match forecasts. He suggested using "information gap decision theory" to address this issue. Annaswamy proposed using "structured market derivatives" to facilitate aggregators to adopt more sophisticated pricing mechanisms.

3.2. Utility Ownership

Hauser's presentation argued that utilities have a number of clear advantages:

- Expertise in electrical infrastructure
- Control rates (many shifting to time of day rates)
- Grid integration (experience with DSM)
- Consumer access including disadvantaged communities
- Can optimally locate charging
- Renewable integration
- Storage
- Access to other charging networks through roaming agreements
- Instantly authenticate and authorize a charge just by connecting the vehicle

Utility ownership is, however, controversial[7]. Many argue that utility ownership would stifle competition and innovation. Fleet operators and mobility service companies may be able to manage the up-front costs of fast charging systems and enter into sophisticated arrangements with utilities.

3.3. Rural charging infrastructure

While most EV discussions focused on EV use in urban areas, Araujo's presentation explored options for charging infrastructure in rural areas of the intermountain west areas and the Regional Electric Vehicle Plan for the West (REV) initiative. This 8-state consortium aims to put charging stations every 25-50 miles on road networks spanning 7300 miles as part of a "tourism economy" initiative. This will require a total of 600-1200 stations. As of November 2019, 317 DC fast chargers installed (Tesla has 221). Installation is facilitated by the fact that Public Utility Commissions in Idaho, Colorado and Utah do not limit sale of electricity in charging stations. Nevada Energy can own and operate charging stations as part of the rate base.

4. THE PATH FORWARD: PRIORITY RESEARCH CHALLENGES

Based on the panelist presentations and the ensuing discussion, the following research topics emerged as priorities:

1. ***Exploring uncertainty through scenarios that include innovation in electric utilities and mobility***

While the participants explored some dimensions of this issue, many critical questions remain open. Forecasts are highly uncertain since much of the future depends on technical innovations, policy decisions, and the way people will behave in response to new mobility options. The wisest way forward will be to develop a series of plausible scenarios and develop optimization that can minimize costs for each. This could include joint optimization of utility investments, charging station location and ownership and optimization of mobility (vehicle size, routing, dispatch) to minimize trip costs and trip time.

The scenarios explored should include:

- A range of new mobility scenarios including expanded use of shared vehicles, fleet owners providing first and last mile services with on-demand vans, transportation network companies, and redesigned public transportation systems. The scenarios should include different levels of market penetration of electric vehicles and penetration of innovative systems focusing on the behavioral issues involved in making shared vehicles more attractive than single passenger vehicles. These

[7] NYSERDA (2015) Electricity Rate Tariff Options for Minimizing Direct Current Fast Charger Demand Charges. Report Number 16-02.

scenarios should include cases where Connected and Autonomous Vehicles (CAVs) become practical.

- A range of hybrid scenarios that bridge the gap between ‘now’ and ‘future’ frameworks where both ‘manual’ and autonomous vehicles exist on the road.

- A range of scenarios for potential future transportation demand based on the cost and performance of new mobility systems (e.g. induced demand, trip timing and trip length). This should include scenarios where policy has allowed people now poorly served by transportation (disabled, low-income) to better meet their travel needs.

- A range of standardization and interoperability scenarios for highway charging from plug-in, to some hybrid scenario, to overhead pantograph, to overhead wireless inductive charging.

- A range of scenarios for the location and use of electric vehicle charging (linked to scenarios for vehicle ownership).

- A range of assumptions about congestion pricing and other methods for controlling urban congestion. Automated vehicles should be able to provide very granular data about a range of road conditions.

- A range of possible ‘transition’ optimization scenarios pertaining to rate design and EV charging utilization scenarios for current utilities with flat demand charges (or no demand charges) as the number of EVs and charging stations increase.

- A range of new freight delivery models focusing on innovative urban delivery strategies.

- A range of behavioral, societal, and policy scenarios in encouraging electrified TNC over electrified public transit options, that is, the types of infrastructure system planning scenarios: hybrid, solely transit, solely TNC.

- A range of electric utility generation scenarios including rapid shifts to low carbon energy sources and varying assumptions about the cost and availability of grid-scale storage, use of electric vehicles as grid resources, and the extent of interconnection possible. These analyses should be regionally specific.

- A range of assumptions about electrification in markets outside of transportation including a rapid shift of building fuel use to electric heat pumps and new industrial processes based on electricity.

2. *Data ownership and management*

New technologies can give electric utilities precise, real-time information about all aspects of their systems (generation, transmission, distribution, and consumer consumption). New mobility companies, automated vehicles, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) systems, 5G cellular networks and other systems are likely to transform mobility options. All of these systems generate enormous amounts of data and this raises new questions about who will have access to the data and ensure privacy and security of participants.

There are many tradeoffs in this space. The safety of travelers would, for example, be enhanced by systems that could monitor their travel and detect emergencies, but these systems raise obvious privacy issues. Optimizing the operation of both the grid and mobility systems depends on this data – for example by forecasting patterns of travel demand and the availability of wind and solar resources. The design and operation of public transportation systems, including the charging strategies used by these systems, would benefit from this data.

But the vast majority of the needed data is proprietary – owned by companies that operate vehicle fleets, cellular phone networks, contractors operating tolls on highways, vehicle companies gathering data from private vehicles (including detailed information about highway conditions), and many others. There is great uncertainty about the nature of this data now and in the future and little clarity about the rules that govern its management. A careful look at the future of data in electric mobility systems, public access to this data, measures to ensure privacy and security, and related issues would help guide future policy in this fast-moving area. Interoperability of data structures is also important.

3. *Electric vehicles in ex-urban and rural areas*

Most analysis of new mobility systems and electrification focuses on urban transportation issues. While 80% of Americans living in urban areas and the urban share of the population is growing worldwide, many of these people live-in low-density areas where conventional public transportation and public charging strategies are not economically justified under current conditions. This is certainly also true for the 1 in five Americans who don't live in urban areas. Soaring urban housing prices mean that low-income families are being forced to live further from their places of employment. It would be valuable to explore options for providing electric transportation services to low density areas and possibly explore options for use of alternative sources of renewable power.

4. *Financing and electric rates*

A considerable amount of discussion in the workshop focused on how electric vehicle charging systems (and in some cases the electric vehicles themselves) could be financed and how charging locations, timing, and charge rate could be tuned to optimize both mobility and electric grid operations. A number of financing options are available including personal ownership of charging systems and personal decisions about charging patterns, fleet operators – including public transportation systems, aggregators, and electric utilities. During the workshop, several pricing mechanisms were proposed that would encourage adopters to adopt charging behaviors that would facilitate this optimization. There are clear risks in adopting pricing schemes that depend on forecasts that may be in error. Methods included "model predictive control," and "structured market derivatives."

Electric pricing can also provide incentives for investments in both grid-level storage and use of electric vehicles to provide storage and other services. The net cost analysis should include avoiding new investments in distribution systems (lines and substations). There should also be a way to give credit to systems that can increase system reliability (e.g. during power outages).

Pricing for transportation systems is also uncertain. There is interest in congestion pricing of roads, an interest that may increase rapidly if electric vehicles and automated vehicles lead to sharp reductions in gasoline taxes, parking, and other fines. At the same time, there is growing interest financing highways through contracts with companies that earn income through tolls – including tolls that reflect real-time congestion. These fees could also help shape travel and charging behavior. There is also strong interest in shifting conventional public transportation systems to systems that can provide equitable access to mobility for the disabled and low-income users.

A complex tangle of federal, state, and local laws and regulation govern ownership and pricing in both electric and transportation. Many may prove to discourage investments and operations that can optimize mobility solutions in the emerging economy. A careful review of the issues described could help move to a new generation of rules.

APPENDIX 1: WORKSHOP PARTICIPANTS

SPEAKERS

Last Name	First Name	Title	Affiliation
Annaswamy	Anuradha	Senior Research Scientist	Massachusetts Institute of Technology
Araujo	Kathleen	Director	Boise State University
Brown	Austin	Executive Director	UC Davis
Cassandras	Christos	Professor	Boston University
Chen	Donna	Assistant Professor	University of Virginia
Fox-Penner[8]	Peter	Director, ISE and Professor of Practice, Questrom School of Business, Boston University	Boston University
Fridstrøm	Lars-Erik (Lasse)	Senior Research Economist	Institute of Transport Economics (TØI)
Griffin	Joseph	Control Firmware Engineer	SunPower Corporation
Hauser	Brett	CEO	Greenlots
Keith	David	Assistant Professor	Massachusetts Institute of Technology
Kempton	Willett	Professor of Marine Science and Policy	University of Delaware
Kontou	Eleftheria	Assistant Professor	University of Illinois at Urbana-Champaign
Liebman	Michael	Senior Associate	Rocky Mountain Institute
Lutchen	Kenneth	Dean of COE	Boston University
Nelson	Galen	Chief Program Officer	Massachusetts Clean Energy Center
Paschalidis	Yannis	CISE Director	Boston University
Van Hentenryck	Pascal	Professor	Georgia Institute of Technology
Wang	Jianhui	Associate Professor	Southern Methodist University
Warfield	Matt	Planner	Boston Transportation Department

[8] *PFP COI Disclosure 12-8-18*
CONFLICT OF INTEREST DISCLOSURE
Dr. Fox-Penner holds equity in Energy Impact Partners, a utility-backed energy investment and innovation firm, and consults for Energy Impact Partners and The Brattle Group on energy technologies. Dr. Fox-Penner also conducts research in areas of interest similar to the business interests of Energy Impact Partners and The Brattle Group. The terms of this arrangement have been reviewed by Boston University in accordance with its financial conflicts of interest in research policies.

Wellik	Tyler	Graduate Student Researcher	University of Texas, Austin

OTHER PARTICIPANTS

Last Name	First Name	Title	Affiliation
Ackerman	Rachel	Senior Manager	Massachusetts Clean Energy Center
Andrianesis	Panagiotis	Research Associate	Boston University
Anto	Mana	Graduate Student	Boston University
Arthur	David	Chief of the Energy Analysis and Sustainability Division	USDOT Volpe Center
Buddharaju	Jyothsna	Senior Director, Strategic Initiatives	Boston University
Caramanis	Michael	Professor, Systems and Mechanical Engineering	Boston University
Castrillon	Julio	Research Assistant Professor	Boston University
Chang	Emily	Graduate Student	Boston University
Chen	Ray	CODES lab under Prof.Cassandras	Boston University
Cohen	Max	Graduate Student	Boston University
Devine	Samantha	Climate Advisor	City of Boston
Dutta-Koehler	Madhu	Associate Professor	Boston University
Gevelber	Michael	Associate Professor	Boston University
Guan	Yue	PhD candidate	MIT
Hatch	Jennifer	Research Fellow	Boston University
Houshmand	Arian	PhD Candidate	Boston University
Jermain	David	Associate Director	BU Institute for Sustainable Energy (ISE)
Kelly	Henry	Non-Resident Senior Fellow	BU - ISE and University of Michigan
Kittner	Noah	Assistant Professor	University of North Carolina at Chapel Hill
Lian	Scott	General Engineer	Volpe Center, USDOT/OST-R
Liu	Rui	Graduate Student	Boston University
Mehdipour	Noushin	Graduate Student	Boston University
Mintz	Julia	Graduate Student	Boston University
Mitjans	Marc	Graduate Student	Boston University
Pechak	Olena	Graduate Student	Boston University

Porter	Chris	Principal	Cambridge Systematics, Inc.
Ren	Justin	Associate Professor and Dean's Research Fellow	Questrom and BU - ISE
Ruhamanthi	Jaddivadi	Graduate Student	MIT
Samaranayake	Samitha	Professor	Cornell University
Spiller	Beia	Lead Senior Economist	Environmental Defense Fund
Stanton	Maureen	CISE Center Administrator	BU - CISE
Stocker	Adam	Researcher	TSRC, UC Berkeley

APPENDIX 2: WORKSHOP PROGRAM

Integrating Electric Mobility Systems with the Grid Infrastructure

Agenda: Day 1- November 6, 2019

9:00am-9:30am	**Breakfast**
9:30am-9:45am	**Kenneth Lutchen:** Dean of the College of Engineering, BU **Ioannis Paschalidis:** Director of CISE, BU *Welcome Remarks*
9:45am-10:00am	**Christos Cassandras:** Head of the Division of Systems Engineering, BU **Peter Fox-Penner:** Director of the Institute for Sustainable Energy, BU *Introduction*

Session 1: Assessing the Impacts of New Mobility Models and New Technologies on Electric Vehicle Charging

10:00am-10:20am	**David Keith**, MIT: *Real-World Patterns of Hybrid and Electric Vehicle Driving in Massachusetts*
10:20am-10:40am	**Donna Chen**,UVA: *Shared Autonomous Electric Mobility: Smart Charging Opportunities and Challenges*
10:40am-11:00am	**Michael Liebman**, RMI: *The Wheels on the Bus Go Cha-Ching: How Market Based Solutions Can Drive Clean, Efficient and Equitable Mobility*
11:00am-11:20am	**Morning Break**
11:20am-11:40am	**Lars-Erik (Lasse) Fridstrøm**, Institute of Transport Economics: *The Anatomy of Electric Vehicle Market Uptake: Targets, Incentives and Greenhouse Gas Abatement in Norway*
11:40am-12:00pm	**Matthew Warfield**, Boston Transportation Dept: *Mode Shift and Accelerating the Transition to Electric Vehicles*
12:00pm-1:00pm	**Lunch**

Session 2: Current Research on Modes of Electric Grid Integration

1:00pm-1:20pm	**Anuradha Annaswamy**, MIT: *Demand Response Using Trains and Automobiles*
1:20pm-1:40pm	**Jianhui Wang**, SMU: *Electric Vehicle Grid Integration: Challenges and Solutions*
1:40pm-2:00pm	**Tyler Wellik**, UT Austin & **Joseph Griffin**, SunPower Corp: *Leveraging Intelligently Charged Electrified Transit to Support a Renewable Energy Grid*
2:00pm-2:20pm	**Mid-Afternoon Break**
2:20pm-2:40pm	**Willett Kempton**, UD: *Integrating Electric Vehicles into the Grid as Storage Resources*
2:40pm-3:00pm	**Eleftheria Kontou**, UIUC: *Electricity Rates for Electric Vehicle Direct Current Fast Charging in the United States*
3:00pm-3:20pm	**Afternoon Break**

Session 3: New Approaches to Integrating Mobility and Grid Optimization

3:20pm-3:40pm	**Austin Brown**, UC Davis Policy Institute for Energy, Environment, and the Economy: *Policy Options to Improve Electrification of TNCs*
3:40pm-4:00pm	**Kathleen Araújo**, BSU: *Advancing the Intermountain West's Electric Vehicle Corridor: Critical Infrastructure and Policy Blueprinting in Early Adoption*
4:00pm-4:20pm	**Pascal Van Hetenryck**, GA Institute of Tech: *Socially Aware Mobility Systems*
4:20pm-4:40pm	**Late Afternoon Break**
4:40pm-5:00pm	**Brett Hauser**, Greenlots: *Accelerating Transportation Electrification and the Implications for the Utility Grid*
5:00pm-5:20pm	**Galen Nelson**, MassCEC: *Clean Transportation: New Kid on the Grid Edge Block*
5:20pm-5:30pm	**Peter Fox-Penner**, Dir. of the Institute for Sustainable Energy, BU: *Closing Remarks*
5:30pm-6:30pm	**Reception**

Integrating Electric Mobility Systems with the Grid Infrastructure

Agenda: Day 2 - November 7, 2019

8:30am-9:00am	**Breakfast**
9:00am-9:15am	**Henry Kelly:** Non-Resident Senior Fellow, Institute for Sustainable Energy, BU *Opening Remarks*
9:15am-10:30am	**Breakout Groups**

Group 1: Assessing the Impacts of New Mobility Models and New Technologies on Electric Vehicle Charging

Chair: Henry Kelly: Non-Resident Senior Fellow, Institute for Sustainable Energy, BU
Scribe: Emily Chang

Group 2: Current Research on Modes of Electric Grid Integration

Chair: Christos Cassandras: Head of the Division of Systems Engineering, BU
Scribe: Arian Houshmand

Group 3: New Approaches to Integrating Mobility and Grid Optimization

Chair: Peter Fox-Penner: Director of the Institute for Sustainable Energy, BU
Scribe: Jennifer Hatch

10:30am-10:45am	**Break**
10:45am-11:15am	Breakout Group Reports
11:15am-12:00pm	Plenary Discussion
12:00pm	Christos Cassandras: Head of the Division of Systems Engineering, BU *Closing Remarks*