U.S. DEPARTMENT OF
ENERGY

Electricity Delivery
& Energy Reliability

American Recovery and
Reinvestment Act of 2009

Evaluating Electric Vehicle Charging Impacts and Customer Charging Behaviors – Experiences from Six Smart Grid Investment Grant Projects

Smart Grid Investment
Grant Program

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RECOVERY ACT SMART GRID PROGRAMS

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Executive Summary

Under the American Recovery and Reinvestment Act of 2009 (Recovery Act), the U.S. Department of Energy and the electricity industry have jointly invested over $7.9 billion in 99 cost-shared Smart Grid Investment Grant projects to modernize the electric grid, strengthen cybersecurity, improve interoperability, and collect an unprecedented level of data on smart grid and customer operations.

The electric power industry expects a 400% growth in annual sales of plug-in electric vehicles by 2023,[1] which may substantially increase electricity usage and peak demand in high adoption areas. Understanding customer charging patterns can help utilities anticipate future infrastructure changes that will be needed to handle large vehicle charging loads. Under the U.S. Department of Energy's (DOE) Smart Grid Investment Grant (SGIG) program, six utilities evaluated operations and customer charging behaviors for in-home and public electric vehicle charging stations:

- Burbank Water and Power (BWP)
- Duke Energy (Duke)
- Indianapolis Power & Light Company (IPL)
- Madison Gas and Electric (MGE)
- Progress Energy (now part of Duke Energy as a result of a merger in 2012)
- Sacramento Municipal Utility District (SMUD)

While specific project objectives varied, the utilities evaluated the technical performance of the charging systems, the potential grid impacts of charging during peak periods, and the potential need for distribution system upgrades and capacity additions to meet expected electricity demand growth from rising adoption of plug-in electric vehicles. The six SGIG projects evaluated more than 270 public charging stations in parking lots and garages and more than 700 residential charging units in customers' homes.

Major Findings

There are relatively few plug-in electric vehicles on the road today; as a result the six SGIG projects focused on establishing the charging infrastructure with a relatively low number of stations and evaluated a small number of participating vehicles. As expected, project results showed negligible grid impacts from small-scale electric vehicle charging *today*, but gave utilities important insights into the demand growth and peak-period charging habits they can anticipate if electric vehicle adoption rises as expected over the next decade. Utilities face a challenge in determining when their customers purchase electric vehicles, and where and when they will plug-in to satisfy charging needs.

[1] Navigant Research, "Electric vehicle geographic forecasts," http://www.navigantresearch.com/research/electric-vehicle-geographic-forecasts.

Given the current rate of customer electric vehicle adoption, utilities are considering plans for electric vehicle charging programs. For example, BWP analysis showed that with a 25% per year growth in usage at public charging stations, utility investments could have a seven-year payback, which would be a financially attractive business case for some utilities. Table 1 provides a summary of the key project experiences from the six projects.

Table 1. Summary of Key Project Experiences		
Charging Behaviors	i.	The vast majority of **in-home charging participants charged their vehicles overnight during off-peak periods**. Where offered, time-based rates were successful in encouraging greater off-peak charging.
	ii.	**Public charging station usage was low, but primarily took place during business hours and thus increased the overlap with typical peak periods**. Plug-in hybrid owners frequently used the (often free) public stations for short charging sessions to "top off their tanks."
Grid Impacts	iii.	The length of charging sessions and the power required varies based on the vehicle model, charger type, and state of battery discharge**.**
	iv.	The **average power demand to charge most vehicles was 3-6 kilowatts**, which is roughly equivalent to powering a small, residential air conditioning unit.
	v.	However, depending on the model, the **load from one electric vehicle model can be as much as 19 kilowatts,** which is more than the load for most large, single-family homes.
Technology Issues	vi.	**Faster chargers may require more expertise to install in homes and public stations.** Installing a 240-volt charging station, which typically charges 3-5 times as fast as a charger using a standard 120-volt outlet, requires a licensed electrician and occasionally service upgrades.
	vii.	**Public charging station installation had high costs and required substantial coordination** with equipment vendors, installers, and host organizations to address construction, safety, and code requirements.
	viii.	Low usage at public charging stations will require **longer capital cost recovery without substantial growth in usage**.
	ix.	Some utilities found **residential interoperability problems** in communication between smart meters and charging stations. SMUD found that the two devices only connected successfully about 50% of the time during load reduction events.

1. Introduction

Early adopters are now bringing plug-in electric vehicles to the roads in small numbers, while manufacturers anticipate steadily rising growth over the next decade. Electric vehicle success will in part depend on whether consumers can plug vehicles in and charge them *when* and *where* they need to. Customers will need charging stations in their homes and readily available in common public locations such as workplaces, parking garages, and parking lots.

To accommodate large electric vehicle charging loads as sales grow, utilities may need to upgrade electric distribution systems, add capacity, and introduce pricing options that encourage off-peak charging so that growing loads do not exacerbate peak demand. Smart grid technologies such as advanced metering infrastructure (AMI) are key enablers of electric vehicle adoption by allowing charging station integration with time-based rates that encourage off-peak charging. AMI metering also allows utilities to analyze charging station usage and charging behaviors based on time of use to inform investment decisions.

1.1 Goals and Objectives for the Six Featured SGIG Projects

Six SGIG projects evaluated electric vehicle charging station technologies and consumer use to provide data that will help each individual utility answer two key questions:

- How long will existing electric distribution infrastructure remain sufficient to accommodate demand growth from electric vehicles, and when and what type of capacity upgrades or additions may be needed?
- When will consumers want to recharge vehicles, and to what extent can pricing and incentives encourage consumers to charge during off-peak periods?

All six projects involved small-scale evaluations of a limited number of charging stations and customers. Four projects installed and tested residential charging units while five installed and tested public charging stations. Table 2 shows where and what type of charging station each utility installed.

Table 2. Types of Charging Stations Evaluated by the Six SGIG Projects

	BWP	Duke	IPL	Progress	MGE	SMUD
California	P					R
Florida				P		
Indiana		P,R	P,R			
North Carolina		R		P,R		
South Carolina		R		P,R		
Wisconsin					P	

P = public charging stations; R = residential charging stations

Projects also evaluated equipment performance and interoperability, operational processes and back-office support, customer acceptance and outreach, business models (e.g., use of third parties versus in-house operations), and pricing alternatives, including time-based rates, cost per hour, cost per kilowatt-hour, and no-cost charging.

In addition to the six projects whose results are discussed in this report, there are several other Recovery Act-funded projects under the Smart Grid Demonstration Program (SGDP) that are evaluating technology, policy, and market issues with electric vehicles and charging infrastructure. For example, **AEP Ohio's project** evaluates the effects of different time-based rate programs on customer charging behaviors and assesses residential, workplace, and public charging locations and impacts on distribution system equipment. The **Los Angeles Department of Water and Power's project** (in which the **University of California at Los Angeles** was a sub-recipient) also evaluates charging behaviors and smart charging strategies and assesses policy options, price-based controls, and distributed intelligence between vehicles, smart chargers, parking garage infrastructure, and cloud computing systems. **Pecan Street Inc.'s project** evaluates customer charging patterns and their impacts on distribution transformers, and assesses electric vehicle adoption and driver behaviors.

1.2 Electric Vehicle Markets Today

Utilities are closely monitoring sales for plug-in hybrid and all-electric vehicles because of their potential impacts on electricity demand and the opportunity they provide for new business. Figure 1 shows a steady increase in monthly sales of plug-in hybrids and all-electric vehicles since 2011, along with a growing number of manufacturers and models that increase customer choice. Though they represent a small portion of the more than 260 million passenger vehicles in the U.S., electric vehicles are expected to grow from nearly 296,000 in 2014 to more than 2.7 million in 2023.[2]

The pace and geographic distribution of future sales are uncertain. Key drivers in some states are new policies and incentives that favor electric vehicle adoption along with state and federal tax credits for electric vehicle purchases. High sales growth is expected first in states like California where policies and incentives are strongest.

[2] Navigant Research, "Plug-in electric vehicles on roads in the United States will surpass 2.7 million by 2023," http://www.navigantresearch.com/newsroom/plug-in-electric-vehicles-on-roads-in-the-united-states-will-surpass-2-7-million-by-2023.

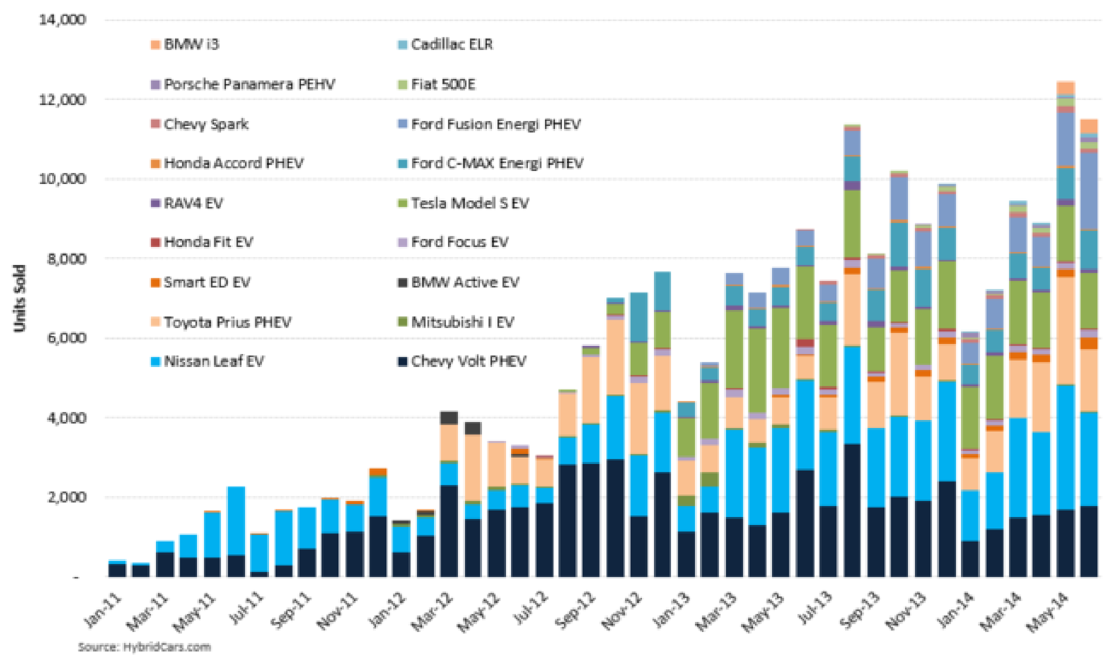

Figure 1. Monthly Sales of Electric Vehicles in the U.S., 2011 – 2014

1.3 Electric Vehicle Charging Equipment

Figure 2. Example of Residential AC Level 2 Charging Station Used by MGE Customers

Electric vehicle charging stations are available in 120-volt, 240-volt, and 480-volt models. Many different models are available with different power levels that determine the speed with which they recharge vehicle batteries. The most common type of charger is a portable 120-volt special charging cord, referred to as AC Level 1 charging, which typically provides 3-5 miles of range per hour of charge. Depending on the size of the battery, and the initial state of charge, this could take 8 to 20 hours to fully charge a depleted battery. Some makes and models—particularly all-electric vehicles or those with larger battery packs—may take about 20 to 60 hours to charge a fully depleted battery at 120 volts. While 120-volt charging is relatively slow, it can often be accomplished with little to no additional cost or installation work if an outlet is already available at home.

Users can cut charging times significantly by installing AC Level 2, 240-volt charging stations. However, these systems can add $600-$3,600 to the cost of in-home charging, depending on the availability of power in the electric panel. Typically, installations require permits and licensed electricians. While not all residential users opt for them, most public charging stations today use AC Level 2 charging stations. Figure 2 and Figure 3 show examples of residential and commercial AC Level 2 charging station in the MGE project.

Figure 3. Example of AC Level 2 Public Charging Station Installed by MGE

The six SGIG projects tested both AC Level 1 and Level 2 charging. DC fast charging, which typically use three-phase 208 or 480 volts, can reduce charging times significantly, but were not tested in these projects. These units require power supplies with 25-50 kilowatts of capacity. Total costs can range from $50,000 to $100,000 per system and require special equipment, installation procedures, and permits. Such units would be ideal for high-throughput, public charging and may eventually become attractive in regions where electric vehicle adoption grows substantially, and customers require fast charging in public locations.

2. Overview of the Featured SGIG Projects

Six SGIG utilities are evaluating in-home and/or public charging equipment and consumer charging behaviors for plug-in electric vehicles:

- Burbank Water and Power (BWP)
- Duke Energy (Duke)
- Indianapolis Power & Light Company (IPL)
- Madison Gas and Electric (MGE)
- Progress Energy (Progress, now part of Duke Energy as a result of a merger in 2012)
- Sacramento Municipal Utility District (SMUD)

2.1 Burbank Water and Power (BWP)

Utility and Project Overview: BWP provides electricity and water services to more than 51,000 residential, commercial, and industrial customers in the city of Burbank, California, which has a population of more than 108,000. As of July 2013, BWP market research showed a total of about 30,000 electric vehicles in California, including about 99 in Burbank.[3]

BWP's SGIG project has a total budget of almost $51 million, including DOE funding of $20 million. The project includes system-wide deployment of advanced metering infrastructure, communications networks, and systems for meter data management; more than 50,000 smart meters; customer systems including in-home displays and programmable communicating thermostats; distribution automation equipment for more than 100 feeders; systems for integrating customer-owned ice storage systems for load management; and 11 public charging stations.

Charging Station Evaluations: Eleven 120- and 240-volt stations were installed at six locations, including three privately-owned and three city-owned parking lots. Nine of the stations are in downtown locations and each draws about the same amount of power as residential central air conditioning units. Project objectives include evaluation of charger load characteristics, pricing options for charging and customer responses, charger demand response capabilities, and the impacts of charging on utility infrastructure and operations.

While a relatively small part of the overall SGIG project, BWP's charging station activities contribute to the city's sustainability goals and the community's response to California's Zero Emission Vehicle mandate (which sets a target for zero-emission vehicle purchases and provides incentives to increase consumer demand for electric vehicles).

[3] BWP, August 2013 Status Report – Electric Vehicle Charging Demonstration Program, August 2013

2.2 Duke Energy

Utility and Project Overview: Duke Energy, headquartered in Charlotte, North Carolina, provides electric service to 7.2 million electric customers and gas services to about 500,000 customers in the Southeast and Midwest. Duke is also an energy supplier and operates more than 57 gigawatts of electric generating capacity and a natural gas distribution infrastructure in Ohio and Kentucky.

Figure 4. Example of an AC Level 1 Residential Charging Station Installed by

Duke's SGIG project has a total budget of almost $556 million, including DOE funding of $200 million. The project includes deployment of advanced metering infrastructure, communications networks, and systems for meter data management; more than 1 million smart meters; customer systems such as in-home displays, web portals, and time-based rate programs; distribution automation equipment such as automated feeder switches, capacitors, and line monitors; and residential and commercial electric vehicle charging stations in North and South Carolina and Indiana. Figure 4 and Figure 5 provide examples of Duke's residential and public charging stations.

Charging Station Evaluations: Duke's "Charge Carolinas" project includes 150 residential stations North and South Carolina, while its "Plug-IN" project includes 85 residential and 47 commercial stations in Indiana.[4] Charging station evaluation objectives include: assessing the performance and customer acceptance of vehicle charging equipment; analyzing load profile data to determine grid impacts; assessing installation and maintenance costs for the utility and customers; and achieving a better understanding of future infrastructure needs from projected increases in demand for electric vehicles over the long term.

Figure 5. Example of an AC Level 2 Commercial Charging Station Installed by Duke

2.3 Indianapolis Power and Light Company (IPL)

Utility and Project Overview: IPL provides retail electric service to more than 470,000 residential, commercial, and industrial customers in Indianapolis, Indiana, and other nearby communities. IPL operates four power plants with more than 3 gigawatts of capacity.

[4] Duke was a sub-recipient for a federal grant for the state of Indiana on this project. This effort was not funded under the SGIG program.

Figure 6. Example of a 240-Volt Commercial Charging Station Installed by IPL

IPL's SGIG project has a total budget of almost $49 million, including $20 million in DOE funding. The project includes deployment of advanced metering infrastructure, communications networks, and systems for meter data management; more than 10,000 smart meters; customer systems such as home area networks, web portals, and programmable communicating thermostats; distribution automation systems such as automated feeder switches, capacitors, voltage regulators, and equipment monitors; and more than 170 electric vehicle charging stations. Figure 6 shows a commercial charging station installed by IPL. Figure 7 shows a map of the Indianapolis-area charging station locations.

Charging Station Evaluations: IPL evaluated more than 170 residential, commercial, and public electric vehicle charging stations (240 volts) in 114 locations. Evaluation objectives include gaining insights into the potential impacts on distribution systems; understanding customer expectations and vehicle charging patterns; testing new equipment and time-based rates for encouraging off-peak charging; and determining customer acceptance of electric vehicles and their "range anxiety" when depending on public charging.

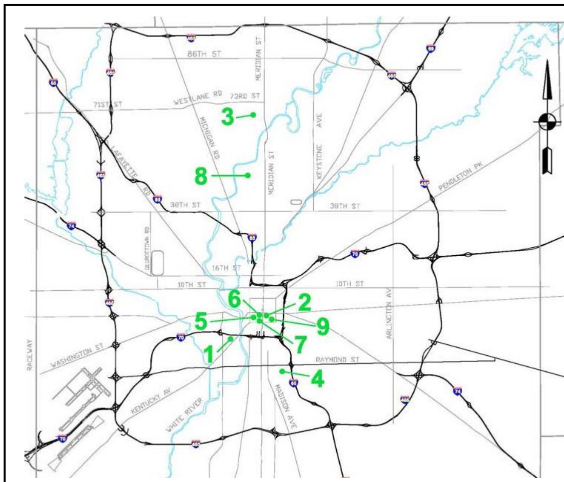

Figure 7. Indianapolis Locations of 9 Public Charging Stations

The project includes 89 residential units at individual homes and 51 fleet installations at 14 commercial locations, including IPL's operations center, car dealerships, local universities, and the Indianapolis Department of Public Works. The project also included 22 installations at 9 public locations including parking garages, a library branch, university, and community center. In addition, the project included 10 secondary or back-up installations at 3 locations including a manufacturing facility and the Indianapolis Zoo.

2.4 Madison Gas and Electric (MGE)

Utility and Project Overview: MGE serves 141,000 electric customers in Madison, Wisconsin and several surrounding Dane County communities. MGE also serves about 147,000 natural gas customers in Dane, and six neighboring counties. The total population served exceeds 300,000.

MGE owns and operates electric power plants and purchases additional resources from the Midwest Independent System Operator.

MGE's SGIG project has a total budget of about $11 million, including DOE funding of about $5.5 million. The project includes deployment of advanced metering infrastructure, communications networks, and systems for meter data management; about 4,500 smart meters; distribution management systems; 19 public charging stations, in addition to 6 existing ones; and advanced metering at 26 residential charging stations.

Charging Station Evaluations: MGE's charging stations are located at ten different public locations and have two outlets per station: one for charging at 120 volts, the other for charging at 240 volts. Both outlets can be used by customers simultaneously. Evaluation objectives include assessing technical performance and customer acceptance of charging equipment; pricing options to encourage of-peak charging; and grid impacts. Figure 8 shows the metering system used to collect charging data from MGE customers.

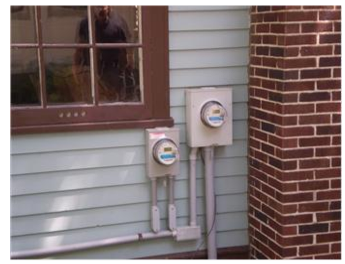

Figure 8. MGE Metering System for Collecting Charging Data

MGE conducted education and outreach activities to inform vehicle owners, auto dealerships, and host entities for the public charging stations about how to use the systems safely and how patterns of charging behavior can affect grid operations and electricity costs.

2.5 Progress Energy

Utility and Project Overview: Progress Energy serves more than 3 million customers in North and South Carolina and Florida. In 2012, Progress Energy merged with Duke Energy.

Progress Energy's SGIG project has a total budget of more than $520 million, including DOE funding of $200 million. The project includes deployment of advanced metering infrastructure, communications networks, and systems for meter data management; 160,000 smart meters; customer systems such as 190,000 load control devices, time-based rate programs, and customer web portals; distribution automation equipment for more than 2,400 feeders such as automated switches, capacitors, and voltage regulators; and more than 300 AC Level 2 electric vehicle charging stations. Figure 9 show a residential charger.

Figure 9. Residential Charger Installed by Progress Energy

Charging Station Evaluations: Residential chargers were installed at 188 locations in North and South Carolina, while public charging stations were installed at 46 locations in North and South Carolina and 68 locations in Florida. Evaluation objectives include: collecting and analyzing charging data and assessing patterns of charging behaviors; assessing charging station installation and maintenance costs; and determining market readiness of vehicles, stations, and supporting grid infrastructure, consumers, and local conditions.

2.6 Sacramento Municipal Utility District (SMUD)

Utility and Project Overview: SMUD serves about 620,000 residential and commercial customers in Sacramento, California and surrounding communities in Placer County. SMUD has a summer peak demand of about 3 gigawatts, driven largely by residential and commercial air conditioning. SMUD serves a total population of more than 1.4 million. Figure 10 shows a service territory map.

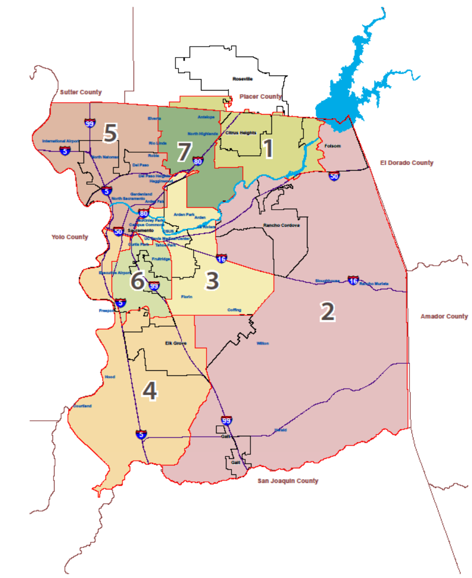

Figure 10. SMUD Service Territory Map

SMUD's SGIG project has a total budget of almost $308 million, including DOE funding of almost $128 million. The project includes deployment of advanced metering infrastructure, communications networks, and systems for meter data management; 617,000 smart meters; customer systems such as in-home displays, programmable communicating thermostats, direct load control devices, and time-based rate programs; distribution automation equipment for more than 170 feeders such as automated switches and capacitors; and 80 electric vehicle charging stations.

Time-Of-Use Rate and Charging Station Evaluations: SMUD conducted a Residential Electric Vehicle Pilot Program with roughly 200 vehicle participants to better understand off-peak charging potential with time-of-use rates and dynamic rate options. SMUD tested two different time-of-use pricing plans to determine driver satisfaction: a Whole House Time-of-Use pricing plan and a Dedicated Meter Pricing Plan that was sub-metered. The latter rate included up to 12 Conservation Days when customers were signaled to reduce load during peak hours. Both pricing plans experienced high customer satisfaction. Table 3 summarizes the three residential treatment groups evaluated by SMUD.

Table 3. Summary of SMUD Electric Vehicle Charging Options	
Treatment Groups	**Descriptions**
Whole House Time-of-Use Plan	• Level 1 charging only (120V); 39 participants • Single smart meter monitors combined house and electric vehicle usage • Wave 1: No initial incentive; Wave 2: Convenience cord-set valued at $595 • No Conservation Day participation
Dedicated Meter Time-of-Use Plan (Self-Managed during Conservation Day events)	• Level 1 and 2 charging (120V and 240V); 98 participants • AMI time-of-use sub-meter on dedicated circuit monitors electric vehicle usage • Wave 1: Installation of Meter Socket Box valued at ~$600; Wave 2: If already has sub-meter, received $599 rebate • No utility control. Participant was responsible for reducing load during Conservation Days, or they would incur a demand charge of $3.50/kW in addition to the time-of-use peak energy charge of $0.42/kWh.
Dedicated Meter Time-of-Use Plan (SMUD Managed during Conservation Day events)	• Level 2 charging (240V); 60 participants • AMI time-of-use sub-meter on dedicated circuit monitors electric vehicle usage • Installation of Dedicated Circuit, Meter Socket Box, and smart charging station with ZigBee radio to receive load reduction signals from SMUD. Total value: ~$3,600. • On Conservation Days, SMUD would send a signal to the SMUD-controlled charging station, signaling the connected electric vehicle to reduce load to 1.4kW during the peak hours from 2 pm to midnight.

3. Project Results and Lessons Learned

While electric vehicle markets are in early development and adopters are just beginning to establish regular charging schedules, the projects delivered valuable data that utilities continue to analyze. Evaluation of charging station usage and behavior provides key insight that can inform utility decisions as plug-in electric vehicle adoption rises.

The utilities identified several common technical and market needs that must be met before electric vehicle charging stations can be adopted more widely:

1. Improve significantly the reliability of communications and ease of integration between smart meters and charging stations.
2. Achieve better coordination with equipment vendors to ensure that performance specifications are understood and properly implemented.
3. Reduce the costs for equipment and maintenance for public charging stations.
4. Make Level 2 chargers available to residential customers in a convenient and cost-effective manner.
5. Develop pricing strategies for public stations that encourage consumers to use them, don't exacerbate peak demands, and enable profitable business models for ownership and operation.

3.1 Charging Behaviors

Charging behaviors differ depending on whether the customer is charging at home or at a public station, and what type of vehicle they have—either an all-electric vehicle or a plug-in hybrid. IPL found that approximately 76% of the electricity used for charging occurred during off-peak periods, an additional 4% occurred during mid-peak, and the remaining 20% occurred during peak periods. Figure 11 from Progress Energy shows differences in charging patterns with and without time-based rates.

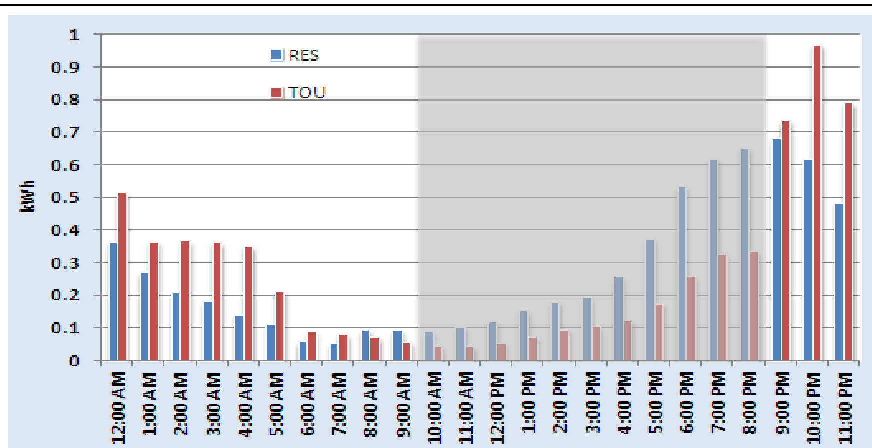

Figure 11. Charging Patterns with (TOU) and without (RES) Whole House Time-of-Use Rate during Summer Weekdays at Progress Energy (Peak period is in gray)

Customers took advantage of time-based rates to save on overnight residential charging. Participants generally prefer charging their cars overnight at home. Time-based rates encouraged off-peak charging and provided savings for overnight chargers. The rates were especially convenient when customers could pre-program charging sessions to start when off-peak rates came into effect.

Plug-in hybrid owners with quicker charging times "top off" at public charging stations more frequently than all-electric owners. MGE learned that plug-in hybrid electric drivers often use public charging stations—especially where free public charging was available—before returning home. All-electric drivers more often chose to wait and charge their depleted batteries at home, in large part because of the longer times required to charge the all-electric vehicle batteries. Duke Energy reported over 84% of charging sessions at public retail locations lasted less than 2 hours, while only 45% of sessions at office and municipal locations lasted under two hours. This highlights the different utilization and charge profiles that may be expected in different locations.

Burbank similarly reported that most charging sessions at its public stations lasted 1-2 hours, though there were sessions that lasted 8 hours and longer. As shown in Figure 12, Burbank found that 52% of sessions were 2 hours or less and that only 6% of sessions exceeded 4 hours.

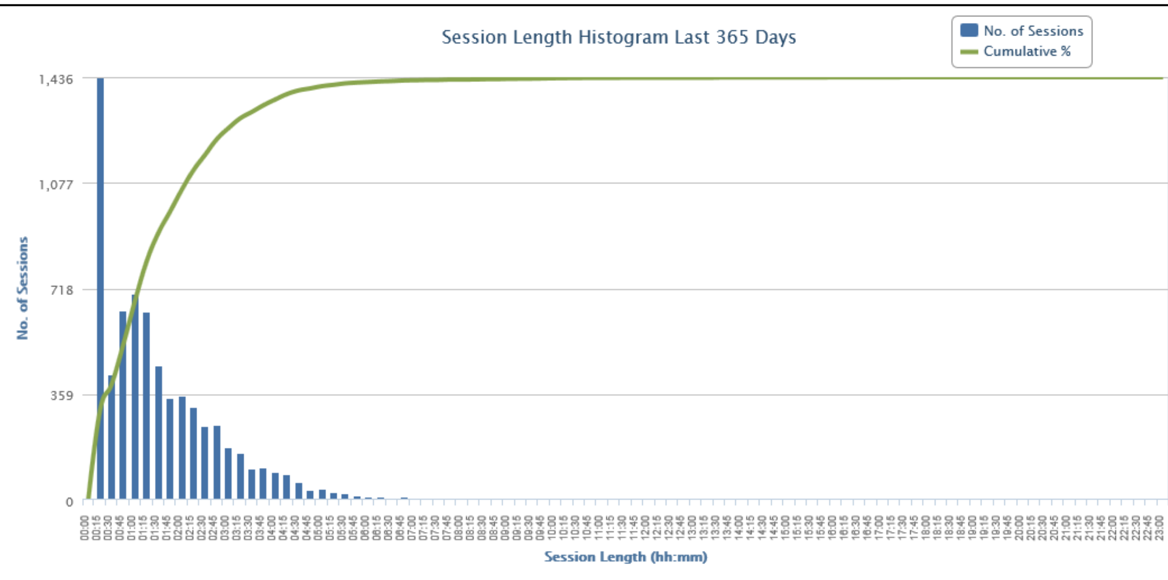

Figure 12. Data on the Length of Charging Session from Burbank

Public charging stations were used primarily during the day and increased potential overlap with peak periods. Commercial and public stations were used mostly during business hours, and as such, there was a higher likelihood for overlap with typical peak time periods for utilities. While this is usually the late afternoon in the summertime, exact peak times will vary based on the utility. Figure 13 shows data from Progress Energy on public charging patterns, with the vast majority of charging sessions occurring between 9:00 a.m. and 7:00 p.m. Public charging stations were used infrequently compared to residential units.

Low electric vehicle adoption resulted in limited use of public charging stations. The utilities generally did not observe public stations causing demand impacts; therefore the analysis focused on customer acceptance and use, and several utilities offered promotional rates to encourage access. For example, IPL offered customers a $2.50 flat rate with unlimited duration and still observed low levels of use. Several offered free charging, though customer use was still low despite the clear incentive. With time and sales growth the utilities expect use of public stations to grow. MGE, for example, saw driver enrollments grow from 8 to 123 over a one-year period.

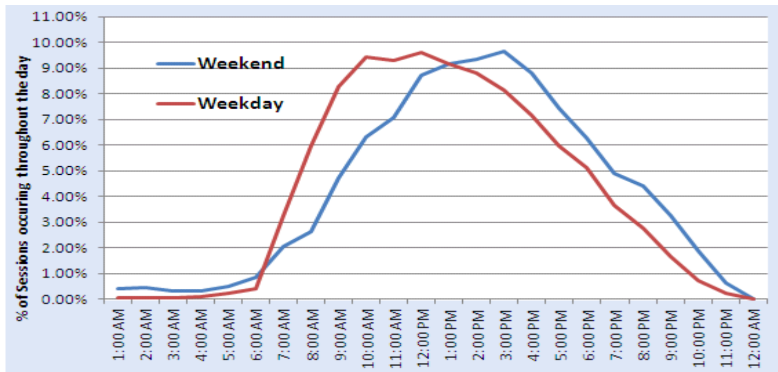

Figure 13. Percentage of Charging Sessions by Time-of-Day for Commercial Charging Stations at Progress Energy

Extended duration charging sessions at public stations—longer than necessary to complete charging—reduces the number of chargers available for other drivers. MGE found public station users occupied the stations about 45 minutes longer on average than was needed to charge the batteries. This caused problems as the station was unavailable during these periods for other drivers to use.

3.2 Grid Impacts

Project results indicate that as the numbers of electric vehicles on the road increases, utilities may need to upgrade existing infrastructure or build new capacity to handle growth in electricity demand. These actions can be mitigated if electric vehicles charge when air conditioning use begins to decrease.

Current electric vehicles have chargers rated at from about 3 kilowatts to 20 kilowatts, whereas the grid-connected chargers are Level 1 AC at 120 volts, Level 2 AC at 240 volts, and DC fast chargers at usually 480 volts. Charger demand capacity is independent from the size of the car battery pack. For example, MGE found that the most common all-electric vehicle in the MGE program averaged 3.7 kilowatts and the most common hybrid-electric vehicle in the MGE program averaged 3.2 kilowatts during home charging sessions with the Level 2 240-volt units.

Plug-in hybrid electric vehicles have battery sizes that range from 7 kilowatt-hours to 17 kilowatt-hours, and battery-only electric vehicles have battery sizes that range from about 20 kilowatt-hours to 50 kilowatt-hours, or greater. Charger size determines how fast the battery draws energy from the grid; battery size relates to the amount of energy stored.

For example, Progress Energy reported that energy use at commercial charging stations averaged about 6.9 kilowatt-hours per day, but the standard deviation was 4.8 kilowatt-hours, indicating high variability (see Figure 14). Average daily energy use for residences was about the same—7.1 kilowatt-hours—but had less variability. This amount of energy use is the equivalent of driving about 24 miles per day (assuming 3.3 miles per kilowatt-hour). **Daily charging sessions used on average 7.1 kilowatt-hours, which would add about 2,500 kilowatt-hours per year to a customer's energy bill.** Utilities also monitored the amount of energy used for charging sessions.

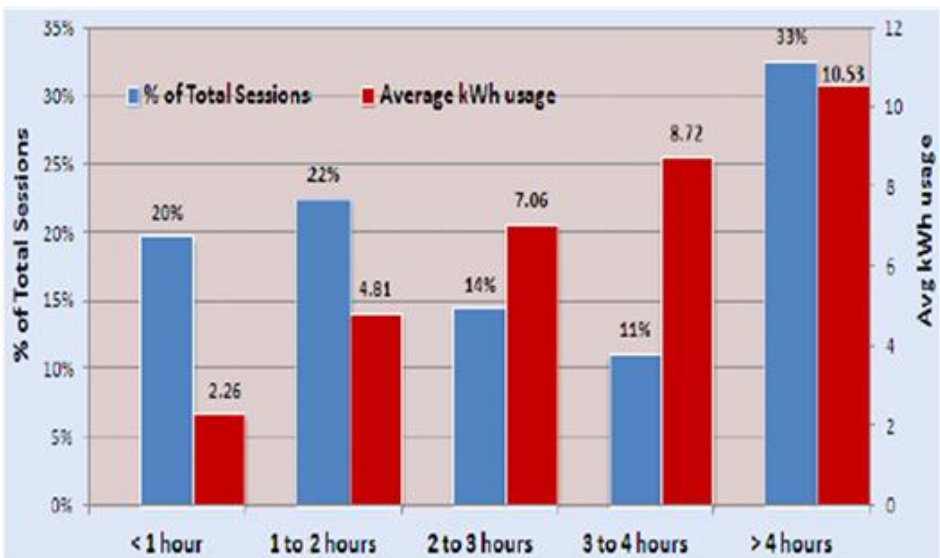

Figure 14. Energy Use at Commercial Stations by the Duration of Charging Sessions at Progress Energy. (Note: Time is connected time and not just charging time.)

Figure 15 shows how energy use varies by the time of day and the length of residential charging sessions at Progress Energy.

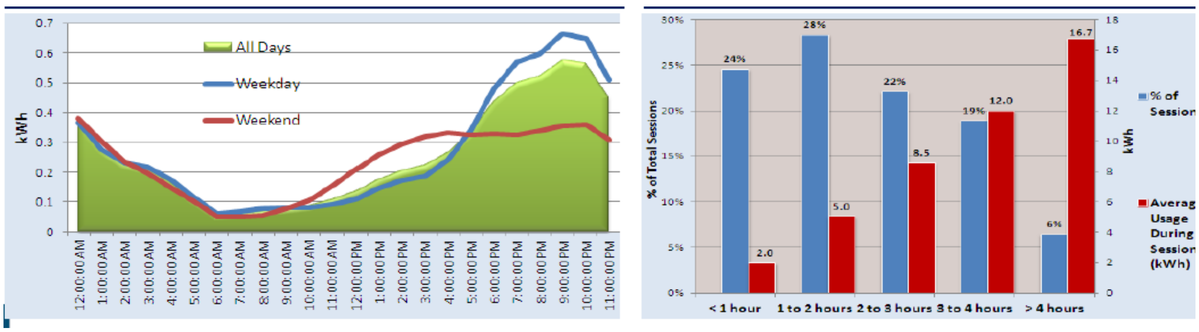

Figure 15. Residential Energy Use by Time-of-Day and the Duration of Charging Sessions. (Note: Time is active charging time only.)

Key potential adverse impacts on the grid include overloading circuits by excessive demand on any particular circuit, at any particular time. This can be mitigated by tracking the number and location of Level 2 AC chargers on residential customers. Smart grid technologies enable utilities to more easily monitor this potential overload problem. In addition, deployment of DC fast chargers could easily overload most residential neighborhood circuits, so their installations should be and commonly are managed by utilities. Properly designed and installed chargers of any size can be safely installed in suitable locations on the grid.

Secondly, **with increased volumes of car charging, there is a cost and reliability impact if an excessive number of charging sessions occur during the peak hours of the day**. Time-of-use rates may be used to encourage customers to charge their vehicles during off-peak periods.

3.3 Technology and Cost Issues

Customers strongly prefer shorter charging sessions, but this requires higher-voltage charging stations that can add from $600 to $3,600 per residential installation. Reducing installation costs is a top-priority issue for the electric vehicle industry. Table 4, from MGE, provides information about typical charging times for plug-in hybrid and all-electric vehicles. The table shows that times can be greatly shortened with higher power charging units.

Table 4. Typical Charging Times by Power Level and Electric Vehicle

Charger Voltage/Amperage	Demand Impact	Plug-in Hybrids	All-Electrics
120 volts/<20 amps	1.4-2.0 kilowatts	6-9 hours	12-14 hours
240 volts/<80 amps	<19 kilowatts	2-3 hours	3-4 hours
250-450 volts-dc/<200 amps	<90 kilowatts	NA	80% in 30 minutes

While customers strongly prefer shorter sessions, the incremental cost involved has a longer payback. The 120-volt charging units use standard wall outlets, typically requiring no installation costs. Installation of faster charging 240-volt units typically requires a licensed electrician to install a dedicated circuit, and in some cases a sub-meter, which SMUD found may cost from $600 to $3,600 (including smart, electric vehicle supply equipment, or EVSE) depending on how much work is needed. The cost of "fast charging" units that use 480 volts DC is much higher and therefore suitable for public charging stations only.

High costs of public charging stations combined with low current use led utilities to adopt a "wait and see" approach before installing additional stations. Several speculate that third-party providers may have greater success. Equipment and installation costs for public charging stations vary considerably based on the distance from the charger to the nearest electric distribution system transformer, host site requirements for underground wiring, and Americans with Disabilities Act compliance. All of the utilities found that costs for public stations, coupled with their relatively low level of current use, made it difficult to develop a financially attractive business case for public charging stations *now*. A BWP analysis showed that with growth in usage of 25% per year, utility investments in public charging stations could have a seven-year payback, which may be financially attractive enough to invest. This will require many more electric vehicles on the road and increased demand for public charging.

Additional costs for public charging stations involve coordination with host entities and sometimes with local officials to identify suitable sites and work out operating schedules and availability. The utilities found a need for education to raise awareness about operating procedures and safety requirements. As a result of total cost issues, most of the utilities do not currently plan to build and own additional public stations until regional electric vehicle adoption increases.

Charging station technology is not mature and some experienced meter interoperability issues. Utilities found they need additional coordination with equipment vendors to ensure products satisfied utility requirements. SMUD found that available products with ZigBee radios were not mature enough for its needs, and has partnered with equipment developers to improve performance, particularly communications interoperability between the ZigBee radio in the charging station and the SMUD meter. SMUD found charging equipment communication modules successfully connected to SMUD meters about 50% of the time for several reasons, including poor ZigBee radio signal quality (often range related), problems with power supply circuits in the EVSE communications module packet loss recovery, and environmental interference.

3.4 Lessons Learned

The lessons learned involved specific business process improvements and general needs for outreach and education. The low saturation of electric vehicles resulted in no measurable grid impacts. Table 5 is a summary of major lessons learned.

Table 5. Summary of Lessons Learned	
Category	**Lesson Learned**
Planning and Management	• Initially install a small number of chargers as demonstrations, and evaluate their use to justify larger deployments. • Plan for sufficient resources to support customer issues throughout the project. A high level of customer support to address technical issues was typically required. • Conduct smaller, in-house process and field tests prior to full field implementation, perhaps using employees. • Develop detailed process maps to streamline operating procedures; guide vendors, installers, and service technicians; and provide higher quality customer services and issues resolution.
Market Development	• Consider the needs of the different target markets, such as single families, multi-family housing units, fleets, employers, dealerships, and public access. Evaluate use cases for each that examines the charging patterns of the users in those segments.
Implementation	• Site and installation scheduling requires hands-on attention which vendors can provide to help ensure customer satisfaction. • Locate chargers where it is convenient for the consumers, not necessarily for utilities. This will optimize utilization and shorten capital cost recovery.

In addition, all of the utilities agreed that outreach and education is important. While all of the projects were limited in scope, and focused on studies and evaluations, not program roll-outs, the activities involved many players and moving parts. The utilities found it valuable to educate customers, auto dealerships, vendors, host sites, local officials, installation contractors, and others on the program and technology prior to implementation. Public sites particularly required coordination and negotiation with site hosts for use of space and equipment installation. The utilities generally found outreach and coordination with outside groups to be necessary ingredients in electric vehicle charging programs.

4. Future Plans

While market projections are uncertain, many of the world's major auto manufacturers are now producing or introducing a variety of electric vehicle models, with the expectation a few million U.S. electric vehicles on the road within the next decade. All six utilities featured in this report will continue to assess the results of their evaluations and consider next steps for electric vehicle charging and related activities.

BWP plans to continue monitoring electric vehicle interest—which it labels as "low but measurable"—in its service territory and will maintain and monitor existing public charging stations. The utility has worked with the City to establish new parking restrictions that improve access and availability of charging stations. It also plans to install more 240-volt charging stations and 480-volt direct current "fast chargers," potentially at the airport and shopping centers. BWP also recently adopted new charger service pricing (in dollars per kilowatt-hour) that are more financially attractive and intended to attract all types of electric vehicles.

Duke Energy (including former **Progress Energy**) is in the process of evaluating its SGIG project results and will determine next steps when those evaluations are complete. Charging stations that were part of the three research projects have conveyed to the host sites as the participants roll off the program. As Duke Energy assesses the next steps for any new charging infrastructure projects, it will continue to work closely with industry and community stakeholders to support education and plug-in electric vehicle readiness. In addition, Duke Energy is also actively involved in developing standards and conducting research to support grid-friendly charging solutions to accommodate future growth of electric vehicles.

IPL continues to monitor and analyze information from its charging stations and refine its strategies for electric vehicle markets in Indianapolis. IPL plans to continue offering time-of-use rates, which have been judged successful in shifting electric vehicle charging to off-peak periods. IPL plans to expand its own fleet of electric vehicles and track their impact on distribution infrastructure and needs for more charging stations. IPL is also working with the City of Indianapolis to support the first all-electric car sharing program in the U.S. If approved by the Indiana Utility Regulatory Commission, up to 1,000 electric vehicle chargers will support a fleet of up to 500 electric vehicles by 2016. See http://www.blue-indy.com/faq for more information.

MGE plans to continue monitoring electric vehicle interest in its service territory and test new technologies and systems for electric vehicle charging as they become commercially available. The utility also plans to continue evaluating alternative pricing strategies for electric vehicle charging to assess customer acceptance and effects on charging behaviors. MGE plans to continue education and outreach activities to inform customers, auto dealers, and charging station hosts about requirements for safe operations and how charging behavior patterns affect peak demand and electricity costs.

SMUD plans to continue evaluating electric vehicle markets in Sacramento, alternative pricing options, and impacts of the alternatives on electric distribution infrastructure. The utility is currently evaluating the results of its SGIG project and will determine next steps when reports are completed.

5. Where to Find Additional Information

To learn more about national efforts to modernize the electric grid, visit the Office of Electricity Delivery and Energy Reliability's **website** and **www.smartgrid.gov**. DOE has published several reports that contain findings on topics related to the six projects featured in this report. Web links to these reports are listed in Table 6.

Table 6. Web Links to Related DOE Reports

SGIG Program, Progress, and Results	i.	Progress Report II, October 2013
	ii.	Progress Report I, October 2012
	iii.	SGIG Case Studies
Recent SGIG Publications	iv.	Smart Meter Investments Yield Positive Results in Maine, February 2014
	v.	Smart Meter Investments Benefit Rural Customers in Three Southern States, March 2014
	vi.	Control Center and Data Management Improvements Modernize Bulk Power Operations in Georgia, August 2014
	vii.	Using Smart Grid Technologies to Modernize Distribution Infrastructure in New York, August 2014
	viii.	Automated Demand Response Benefits California Utilities and Commercial & Industrial Customers, September 2014
	ix.	New Forecasting Tool Enhances Wind Energy Integration in Idaho and Oregon, September 2014
	x.	Automated Demand Response Benefits California Utilities and Commercial & Industrial Customers, September 2014
	xi.	Integrated Smart Grid Provides Wide Range of Benefits in Ohio and the Carolinas, September 2014
	xii.	Municipal Utilities' Investment in Smart Grid Technologies Improves Services and Lowers Costs, October 2014
	xiii.	Smart Grid Investments Improve Grid Reliability, Resilience, and Storm Responses, November 2014
Recent SGDP Publications and Related Websites	i.	AEP-Ohio gridSMART Demonstration Project Final Technical Report, June 2014
	ii.	Pecan Street SGDP – Interim Technology Performance Report, June 2014
	iii.	UCLA Smart Grid Energy Research Center Website
	iv.	UCLA Smart Grid Energy Research Center – Reports and Publications