Interim Technology Performance Report
June 2014

Pecan Street Smart Grid Demonstration Program

Award Number: DE-OE-0000219

Project Type: Regional Demonstration

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Acronym List

Acronym	Definition
AMI	Automated meter infrastructure
AMR	automated meter read
ARRA	American Recovery and Reinvestment Act
ATI	Austin Technology Incubator
DOE	Department of Energy
EDF	Environmental Defense Fund
FTE	full time equivalent
HAN	home
HEMS	home energy management system
kV	kilovolt
kW	kilowatt
kWh	kilowatt hour
NIST	National Institute of Standards and Technology
PV	photovoltaic
ROI	return on investment
SGDP	smart grid demonstration project
SIR	savings to investment ratio
SOC	state of charge
TPR	technical project report
UT	University of Texas

Pecan Street Inc.

I. Introduction

This document represents an interim Regional Demonstration Project Technical Project Report (TPR) for Pecan Street Inc.'s (Pecan Street) Smart Grid Demonstration Program, DE-OE-0000219. Please note that comments were received on the September 2013 TPR on June 23, 2014, which will be incorporated into the final TPR. Pecan Street is a 501(c)(3) smart grid/clean energy research and development organization headquartered at The University of Texas at Austin (UT).

Pecan Street is working with Austin Energy, UT, Environmental Defense Fund (EDF), the City of Austin, the Austin Chamber of Commerce and selected consultants, contractors and vendors to take a more detailed look at the energy load of residential and commercial meters while the power industry is undergoing modernization. Never before has a program been able to record, down to the circuit level at 1-minute intervals, detailed information about what drives peak electricity demand.

The Pecan Street Smart Grid Demonstration Program signed-up over 1,000 participants who are sharing their green button, smart meter, and/or HEMS data with the project, and Pecan Street completed the installation of Home Energy Management Systems (HEMS) in 750 homes and 25 commercial properties. The program provided incentives to increase the installed base of roof-top solar photovoltaics (PV) systems, plug-in electric vehicles with Level 2 charging, and residential energy storage.

Over 200 participants in the Mueller took advantage of Austin Energy and Pecan Street's joint PV incentive program and installed roof-top PV. Of these homes, 69 purchased or leased an electric vehicle and received a Level 2 charger from Pecan Street. Pecan Street is studying the impact of a variety of consumer behavior interventions, including pricing models, real-time feedback on energy use, incentive programs, communications on peak demand days, as well as the corresponding impacts on Austin Energy's distribution assets.

The primary demonstration site is the Mueller community in Austin, Texas. The Mueller development, located less than three miles from the Texas State Capitol, is a 711-acre LEED Neighborhood Development mixed-use, urban infill redevelopment on the site of Austin's former airport, currently under development through a public-private project between the City of Austin and Catellus Austin LLC. Currently, Mueller is less than 50% complete and more than 3,500 people live or work at Mueller. At full build-out, the project will include more than 3 million square feet of commercial and institutional space, more than 13,000 residents from approximately 5,700 single-family and multi-family dwelling units.

Figure 1 shows a Google Map image of the Mueller community, zoomed in on the residential streets participating in the Program.

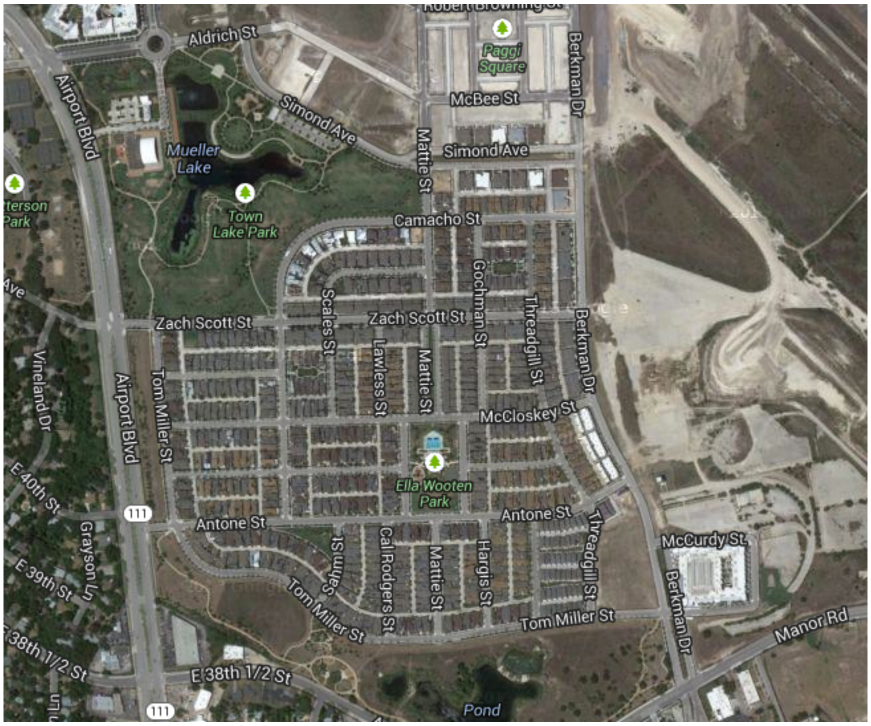


Figure 1. The Mueller community

II. TPR Structure and Content

II.1 Scope

Project Abstract

Pecan Street's goal is to develop and implement an open platform Energy Internet Demonstration in Austin, Texas. The Mueller community possesses utility interconnection, storage, distributed energy sources, critical loads, and conventional loads found in neighborhoods across the country. Every new building is green built, either certified through LEED or Austin Energy's nationally recognized Green Building program. The development is urban in-fill redevelopment, built on the site of Austin's former municipal airport. It is a prototypical development model, similar to hundreds like it across the United States.

This context provides a dynamic platform on which to research, develop and demonstrate advances in home area networks, distributed energy generation and energy management techniques.

As part of the Smart Grid Demonstration, Pecan Street constructed and operates the Pike Powers Lab & Center for Commercialization located in the Mueller community. This lab opened its doors in June 2013 and serves two critical functions:

1. A testing laboratory for key technologies and systems that the Project Team determines should first be tested in a carefully controlled setting on the distribution feeder serving Mueller prior to deploying in customer premises, and
2. A research facility for university faculty, graduate students and industry partners conducting research to improve understanding and develop impactful solutions in the areas of utility system operations, climate change, integration of distributed energy and storage, and customer needs and preferences

The project is collecting and evaluating data in the areas of electricity generation, distribution, and consumption to determine the effects of integrating new technologies and controls in customer homes and the resulting impacts on distribution systems. Pecan Street will produce a comprehensive and up-to-date analysis of residential energy use including the impact of introducing disruptive technologies and consumer behavior interventions on the residential demand for energy.

The dynamic impact of commercial energy management is also being studied. Researchers are using data from commercial buildings to examine changes in the electric system's performance with regard to reliability and power quality, environmental impact through reduced emissions and water use, and customers' experiences and preferences on the technology. Omnibus data on the participants is also collected for analysis through detailed online surveys.

Smart grid systems utilized in this project include automated meter information, AMR and AMI smart meters, energy routers, advanced billing platforms and HEMS. These technologies integrate with plug-in electric vehicles, smart appliances and solar PV in select homes. Approximately 200 of the residential volunteers have rooftop solar PV, including a number that will have both south- and west-facing PV. The project also integrated smart water and natural gas technologies in a subset of participating homes. The Project Team is testing system integration requirements for energy storage.

Recipient Team Overview

The Project Team is broken down into program teams, each of which is managed by a project executive. The teams are as follows, with the following staff and team member leads:

- Utility-side of the meter systems: Pecan Street executive lead is the Lab Director. Team co-leads are with UT and Austin Energy.

- Customer-side of the meter systems: Pecan Street executive lead is the Project Manager. Team co-leads are with Austin Technology Incubator (ATI) and UT.
- Data Team: Pecan Street executive lead is the Data Group Director. Team co-leads are with Austin Energy, EDF and UT.
- Pricing and Commercialization: Pecan Street executive lead is the Chief Executive Officer. Team co-leads are ATI and Austin Energy.
- Interoperability and Cybersecurity: Pecan Street executive lead is the Chief Technology Officer.

Project Overview

The Pecan Street Smart Grid Demonstration Program at Austin's Mueller community is a collaborative effort of Pecan Street, private sector firms and the Project Team. Pecan Street leads the demonstration project.

The Project Team has chosen to base system designs and implementation on open platform principles. With the breadth of technologies and functions involved in integrating customer-premise technologies and systems with the traditional utility-side of the meter systems, maintaining interoperability not only within the demonstration project itself but with evolving standards and specifications in the broader smart grid community is paramount.

As with the internet and the subsequent convergence of the telecom and information technology sectors, creating a distributed networked electricity system with open protocols has the potential to catalyze significant economic opportunities. Such a system also faces significant security and privacy challenges. Cyber security for such a system must ensure confidentiality, availability and integrity of information and systems for newly developed technologies and innovative methods for managing smart grid functions. The cyber security approach must also address the challenges of customer-premise hardware integration with the distribution management system. Demonstrating that systems operating on an open platform can be effective, interoperable and secure is a major criterion for project success.

Working with volunteer participants, the Project Team will demonstrate and optimize integration of customer-side of the meter systems along with deployment of utility-side of the meter energy monitoring systems. The project has also deployed and is comparing different consumer behavior interventions, including dynamic pricing.

Project Objectives

1. Create an interoperable, standards-based technical approach that can be integrated into other systems with minimal additional engineering and design.

2. Establish a cyber security protocol that allows for interoperability of systems without risking the security and privacy of participants.
3. Demonstrate and optimize integration of customer-side smart grid systems along with deployment of utility-side of the meter energy monitoring technologies on the distribution feeders serving Mueller.
4. Deploy and compare different consumer behavior interventions, including pricing models and features, to identify a menu of options that incentivize investments in smart grid systems without jeopardizing utilities' revenue stream.
5. Construct and operate a lab located in the Mueller community that will serve as a testing laboratory, public education and research facility. The lab will enable the Project Team to test key technologies and systems in a carefully controlled setting on the distribution feeder serving Mueller prior to deploying in customer premises.

Table 1 shows the project milestones identified in this program's Project Management Plan, including a generalized schedule for when the milestones are expected to be met and the actual completion date, as applicable.

Table 1. Project Milestones

Title	Planned Completion	Actual Completion
Complete Updated Project Management Plan	12/04/2010	12/07/2010
Complete Metrics & Benefits Plan	02/04/2010	06/22/2011
Sign up 1,000 homes and 25 commercial properties to participate in demonstration	12/01/2011	08/31/2012
Acquire leases/access rights to commercial space for PV installation	03/01/2011	11/9/2012
Select solutions and technologies for deployment in demonstration project	05/01/2011	09/30/2011
Design pricing models	08/31/2011	08/31/2011
Acquire plug-in electric vehicles for deployment in participant homes	09/01/2011	09/30/2012
Open Lab to the public	01/01/2012	06/11/2013
Complete baseline data collection	02/01/2012	02/1/2012
Deploy selected solutions	02/01/2012	Constant iteration and replication continues

Title	Planned Completion	Actual Completion
Complete data collection from demonstration	11/02/2014	
Dismantle demonstration systems	02/05/2015	

Technologies and Systems to be Demonstrated

Pecan Street will utilize in-home consumer systems, HEMS, distributed energy resources, and other energy and water technologies to deploy a fully integrated home smart grid infrastructure. Through this demonstration, Pecan Street will implement and collect data from the following smart grid technologies:

Home Energy Management Systems

HEMS (either with in-home displays, online portals, and/or smart phone/tablet apps) provide real-time feedback to customers regarding their energy use, the cost equivalent of kilowatt-hours used and estimated bills. They also are likely the enabling technology for a new generation of in-home consumer products and services. The system will provide data on individually metered equipment, including water consumption, gas consumption, and electricity generation. Providing this data in real time may result in significant and measurable peak energy use reductions as well as enable a new wave of consumer applications in appliances, electronics, healthcare and home improvement.

Smart Meters

Smart meters record electricity consumption and communicate that information to the utility for monitoring and billing purposes. Smart meters enable two-way communication between the meter and the central utility, and between the meter and a home energy management system. Most smart meters involve real-time or near real-time sensors, power outage notification and power quality monitoring.

Smart Grid Water Systems

Smart grid water systems enable the development of a water monitoring network. The installation of these meters can result in time-of-use billing, convey end-use information to consumers and the utility and provide the possibility of remotely operated controls for water-intensive activities, such as automatic shut-off when a leak is detected between the home and the meter. Providing real time use information to consumers may lead to water conservation of 5-15 percent, resulting in related energy savings for water distribution and in-home hot water uses. Providing real-time use information could also help consumers detect costly but invisible water leaks. Reducing peak water demand may also lead to improved electrical system reliability and peak electric demand reduction.

Solar PV

Solar PV produces distributed energy that can potentially offset peak demand. Solar PV has been installed at homes and includes a comparison between west-facing and south-facing panels to determine the optimal installation configuration that maximizes utility and customer benefit. The electricity produced by the panels has been monitored and compared to the peak demand curve to analyze potential benefits.

Plug-In Electric Vehicles

Plug-in electric vehicles are gaining popularity in the marketplace and, depending on when electric vehicles are charged, could have a significant impact on the electric grid. Electric vehicle adoption is following a standard technology adoption curve and it is anticipated that over the next few years electric vehicles will become a more common household purchase. Through study of electric vehicle adoption in major markets, it is apparent that the adoption trend will result in dense networks of electric vehicles focused within specific neighborhoods. The impacts of electric vehicle charging is therefore anticipated to be most pronounced on transformers and distributions feeders. Electric vehicle driver behavior and preferences are being studied to analyze the effects on the grid of greater electric vehicle adoption and effective mechanisms to reduce electric vehicle charging during peak demand times.

Pricing Models

The Project Team is demonstrating multiple pricing models and consumer behavior interventions to determine the most effective strategies utilities can employ to reduce peak demand and promote energy conservation behavior.

Battery Storage

Battery storage could be the link allowing the use of renewable energy during any time of day, not just when the sun is shining or the wind is blowing, and stabilizing grid demand throughout the day A battery system would be charged by solar or wind, and used either for a specific purpose, such as charging an EV, or shaving peak demand. Pecan Street has installed and tested a battery system connected to the solar system at the Pike Powers Lab.

Table 2. Energy Storage Applications and DOE Smart Grid Functions by Project

Application	Applicability to Project
Energy Storage Applications	
Electric Energy Time Shift	No
Electric Supply Capacity	No
Load Following	No
Area Regulation	No
Electric Supply Reserve Capacity	No
Voltage Support	No
Transmission Support	No
T&D Upgrade Deferral	No
Substation Onsite Power	No
Time-of-Use Energy Cost Management	Yes
Demand Charge Management	Yes
Electric Service Reliability	No
Electric Service Power Quality	No
Renewables Energy Time Shift	No
Renewables Capacity Firming	No
Wind Generation Grid Integration, Short Duration	No
Wind Generation Grid Integration, Long Duration	No
DOE smart grid function	
Fault Current Limiting	No
Wide Area Monitoring, Visualization, and Control	No
Dynamic Capability Rating	No
Power Flow Control	No

Adaptive Protection	No
Automated Feeder Switching	No
Automated Islanding & Reconnection	No
Automated Voltage and VAR Control	No
Diagnosis & Notification of Equipment Condition	No
Enhanced Fault Protection	No
Real-time Load Measurement & Management	No
Real-time Load Transfer	No
Customer Electricity Use Optimization	No

Technical Approach

To ensure that all deployed systems are interoperable, Pecan Street is selecting, testing, deploying, re-testing, operating and collecting data from multiple applications. Interoperability requirements are being created based on available standards that apply to all devices, systems and technologies that are deployed. Pecan Street will specify an open platform standard that supports the National Institute of Technology and Standards (NIST) emerging smart grid framework.

To determine which technologies to deploy, an open request for proposals/request for information invited the private sector to participate in the program, either by deploying, operating or collecting and evaluating the data. The project interoperability requirements were defined to ensure that every deployed application is configured so that the Project Team could integrate multiple applications into a single functioning system, inventory the monitoring, measure and evaluate the performance, provide remote software upgrades, detect and correct faults, and document user interface and ease-of-use issues.

The Pecan Street Smart Grid Demonstration Program is largely a "Customer-Side" research project in which the existing Home Area Network (HAN), the residential Internet gateway and the Internet provides the foundation for the systems that we will deploy.

The program did not install systems that interface with the utility's private network. The cybersecurity plan provides an appropriate level of security for systems that interface with the HAN.

The Project Team conducts annual cyber security audits to ensure the systems deployed and data management processes adhere to the Department of Energy-approved Cybersecurity Plan. These audits are conducted under the supervision of Pecan Street's Chief Technology Officer.

The audits include, but are not limited to, the following actions:

1. A review of all Home Energy Management System architectures deployed in the project to establish;
    a. that the systems are not passing control signals to utility assets nor providing a logical path to utility databases,
    b. that the systems are adhering to the encryption requirements for all residential data streams moving over the HAN or Internet.
        i. Binary obfuscation (or better) encryption for resource use data telemetry
        ii. AES-128 (or better) encryption for energy management control signals
2. A review and verification that the policy of de-coupling residential identity information from the individual data streams and the aggregated database by the following means:
    a. All data packets are identified by a unique MAC address and/or unique project ID number but contain no personal information that reveals the source of the data such as an address, phone number, name, credit card number, social security number or identifier that is associated with an online account.
    b. The file that links personal identification to the unique project ID number or MAC address is maintained on the secured server and that access to that file is limited by secure username and password to a limited set of Pecan Street staff on a need to know basis.

Interaction with Project Stakeholders

Pecan Street – The board of directors and staff meet monthly to communicate all project issues, review designs, approve budgets, disseminate Project documents, review press releases and make sure staff is aligned with DOE and external stakeholder expectations.

DOE Project Team – Pecan Street staff meets regularly with the DOE Project Team in order to disseminate information from the board of directors, as well as to discuss project management items related to the four project programs. Additionally, staff from each of the four programs report on the progress of their teams and issue project documents for review.

Executive Committee – Pecan Street staff and DOE Project Team met regularly with the Executive Committee, which included two residents from the community, in order to disseminate information about the project and gather information about key community issues during the project planning and deployment phases.

Utility Side Team – DOE Project Team Council and Pecan Street staff meet regularly with the Utility Side Team in order to communicate project management issues related to the utility-side deployment and the data it will generate.

Customer-Premises Team – DOE Project Team Council and Pecan Street staff meet regularly with the Customer-Premises Team in order to communicate project management issues related to the customer-side deployment and the data it will generate.

Data Team – DOE Project Team Council and Pecan Street staff meet regularly with the Data Team in order to communicate project management issues associated with data collection, survey gathering and modeling of such data.

Pricing and Commercialization Team – DOE Project Team Council and Pecan Street staff meet regularly to communicate issues associated with the development and testing of pricing models.

Lab – The Lab Design Team and Pecan Street staff met regularly with the Lab sub-team to communicate expectations, review designs and develop scientific and educational programming for the lab during building design and construction.

DOE - Pecan Street staff meet regularly with DOE and their project management team in order to communicate changes in scope and project management issues associated with project milestones. Monthly progress reports also communicate changes in scope, budget and schedule. Additional governmental review may be augmented as needed to ensure that the project meets American Recovery and Reinvestment Act (ARRA) and DOE goals and requirements.

Resident Communication - The executive board for the Smart Grid Demonstration Program has two residents from Mueller to ensure two-way communication between the volunteers and Pecan Street. A Resident's Council that includes 12 members of the community was also formed by Pecan Street in 2011 to broaden resident engagement in the project planning. The Council met regularly during planning and design of the study and the members served as a distribution network for information about the program.

Industry Community - In 2010, Pecan Street established an Industry Advisory Council comprised of technology companies and utilities leading the smart grid industry. Through access to Pecan Street's research assets, these companies collaborate on pre-competitive research in the areas of smart grid, clean energy, consumer preferences and electric grid reliability. Member companies also support Pecan Street's Research Consortium through mentorship and by curating research topics answerable using Pecan Street data that address questions of interest to industry.

II.2. Technical Approach

A reinvented electricity system can and must achieve transformative environmental improvements. That means any system or component should be developed and implemented in such a way as to independently achieve – or align with approaches that achieve – transformative environmental advances. This includes innovations that provide customers the tools to reduce or eliminate their carbon pollution impact. Clearly, there is a broad array of electricity related environmental issues, from local air quality to water quality and availability. Above all these issues, however, is the importance of dramatically reducing the carbon impact of electricity use.

The enormous national investment in utility smart grid infrastructure should aspire to achieve more than incremental improvements to utility operations. The benefits of deploying significant information technology onto a grid can be leveraged for more than improved billing efficiency and outage detection. These deployments can also create the information technology platform that makes possible a wide range of new products and services that provide customer value.

The project metrics include analysis of how the deployed smart grid technologies influence the customer's environmental impact, affect the customer's electric bill, promote private sector interest offering new products and services, impact the load curve of customers and microgrids, and impact utility revenues.

A customer-side, year-long, 100 resident baseline data collection has produced data for comparison as the Project Team integrates smart home devices, solar PV, electric vehicles, and energy storage.

Pecan Street's Data Team is collecting 24 months of operational data with these technologies deployed. The data collected includes cost, utility consumption, socio-demographic, customer satisfaction, environmental impact, and performance of the systems tested. For the systems tested inside of volunteer customer premises, electric use data will be collected at the device level for major building systems, such as HVAC, electric vehicle charging, major appliances, solar panel generation, heating, water heating, and irrigation systems. The baseline data will be compared with the demonstration period data to analyze the impact of deployed systems on household consumption.

Using financial incentives, Pecan Street has facilitated the installation of rooftop solar PV on over 263 participating homes. An additional 48 homes in participating homes in Mueller installed roof-top PV systems, bringing the total to 211 homes participating in the demonstration project that together installed over 1MW of distributed generation. The installations will be split between east and west-facing panels to provide more data on the potential for electricity load alignment with solar.

Pecan Street will also initiate electric vehicle behavioral research within and surrounding Mueller.

Energy storage equipment has also be purchased for testing and system integration specifications development at the lab.

Pecan Street's Data Team will evaluate the data collected to test against hypotheses and to determine how various systems and pricing models performed and interacted with each other. The results of this evaluation will form the basis for the final report and quantify how the demonstration project is achieving the project objectives.

Upon conclusion of the demonstration project, Pecan Street will dismantle those portions of the demonstration project (such as sensors deployed to collect data) no longer needed to carry out the utility systems functions at Mueller.

II.2.1 Project Plan

Design and Development

Pecan Street has created participant legal agreements to establish the terms for residents' participation as volunteers and the terms for locating smart grid equipment on residential and commercial properties in and around Mueller.

Pecan Street's Data Team has installed sensors and monitoring equipment on the premises of over 600 of the residential properties participating in the demonstration project. For 12 months, the Data Team collected information on energy use, down to the major device level in 200 homes prior to those homes receiving access to their energy use data to develop a 12-month hourly load profile. This information serves as the baseline information to measure the impact of systems deployed in all 1,000 residential properties and at least 25 commercial properties.

Pecan Street has recruited 1,000 residential participants and 33 commercial properties to participate in the demonstration.

Pecan Street's Utility Side Team is integrated production data from distributed solar PV on individual homes tied to the grid serving the Mueller community and the energy consumption data from these homes into a distribution model for Austin Energy's infrastructure in the Mueller community.

Pecan Street's Customer-Side Team has been working with the private sector to identify the next generation systems to be deployed in the premises of the volunteer residential and commercial project participants. The systems deployed may include mixes of smart appliances, smart irrigation, smart water, home energy gateways, rooftop solar, building efficiency, natural gas systems, and electric vehicles and EV charge controls.

Pecan Street's Customer-Side Team has incentivized the deployment of plug-in electric vehicles in 72 participating homes, 69 of which are in the Mueller community. Participants will use these vehicles for at least two years.

Pecan Street installed 8 Valence Technology lithium iron magnesium phosphate batteries at its lab, resulting in 30 kWh of energy storage. The batteries were donated by the Center for Commercialization of Electric Technologies (CCET). The energy storage system is paired with a 3 kW crystalline silicon solar array that is south-facing and 2.8 kW of CIGS thin film solar that is west-facing, totaling 5.8 kW of solar production capacity.

Pecan Street is conducting an electricity pricing trial, the purpose is to determine the degree to which electric customers are willing to alter their pattern of electricity use in response to prices that vary with the time of day, lessening the burden to utilities. Over the course of this 20-month experiment (March 2013 – October 2014), participants continue to receive and pay their Austin Energy electric bills, which will reflect the normal Austin Energy electric rates. To provide a monetary incentive for participants, Pecan Street has established a credit account with a baseline of $200 for each participant, which reflects their response to specific pricing signals.

The study consists of two total groups of homes:

- Approximately 60 homes exposed to the Experimental wind and critical peak pricing (CPP, explained in detail below)
- Approximately 60 homes in the control group. These homes do not receive the special pricing.

The experimental electric rate contains two features that differ from the current Austin Energy rate:

- A peak price feature that applies only during designated days of the summer months (June – September), and
- A very low nighttime rate that applies during the five windiest months (March – May, November – December)

During the remaining three months (January, February and October), the experimental rate will be the same as the standard Austin Energy rate.

Experimental bills always include three components:

- Customer charge (the same as Austin Energy's charge), a flat rate of $10
- Baseline price, (the same as Austin Energy's charge), applied only to consumption during non-wind hours or non-peak hours

- Surcharge or discount, a single price based on total monthly consumption applied during non-wind hours or non-peak hours, respectively

During the five windiest months and designated days of summer months, the bill will also factor in a fourth component:

- An "experimental wind" price applied to consumption during wind hours (10 p.m. – 6 a.m.), $0.0265 per kilowatt hour
- A "critical peak" price applied to consumption during critical peak hours (4 p.m. – 7 p.m.), $0.64 per kilowatt hour

Pecan Street's Pricing and Commercialization Team is and will be promoting the commercialization of smart grid technologies through the co-hosting of an annual Clean Energy Venture Summit. They are also providing consulting services to emerging technology firms with relevant technologies, providing the opportunity for emerging technology firms to beta test their systems in a carefully controlled, highly integrated real world setting on the distribution grid serving the Mueller community, and held two smart grid commercialization short courses that were open to the community.

During the project performance period, Pecan Street acquired a site within Mueller and built a lab to serve as an educational and testing site for the technologies and systems being deployed, in addition to technologies and systems of interest to researchers, utilities, and companies that are affiliated with Pecan Street. Located just three miles from the Texas Capitol, it also serves as an educational resource for the Texas Public Utility Commission.

Pecan Street is using the lab to educate the public, policymakers, educators, and the private sector on the benefits of smart grid and the new opportunities for consumers and businesses that are created by the systems the project is testing. Pecan Street is carrying out its education efforts through lab operations and exhibits, technical conferences with industry and academic publications, social media, media outreach, presentations at community events and technical conferences, presentations to policymakers and other means. Every summer Pecan Street hosts teachers participating in its Smart Grid for Schools program at the lab for a 2-day workshop on how to use the data collected through this demonstration project for innovative STEM programs. Pecan Street will continue to use the lab beyond the Period of Performance, without obligation, to achieve the objectives for which Pecan Street was awarded FOA36 funds.

Information Exchange Interfaces for Communicating Devices

Figure 2 depicts the conceptual system architecture of the applications to be deployed. For these applications, key information exchange interfaces will be:

- The meter

- In-home display
- In-home appliances
- Gateway – both in the meter and in the premises
- Inter-gateway – between the meter and the premises gateway(s)
- The distribution system communication network

The customer-premises equipment communications medium will be either wired (one of the power line carrier standards such as HomePlug or IEEE 1901) or wireless (one of the wireless standards such as wi-fi or 802.15.4g).

The project's preferred approach is for the gateway to reside in the customer premises as a separate device from the meter. For deployments in this configuration, the meter will require only two interfaces – one to the distribution system and one to the gateway. In that architecture, the gateway will need to support multiple home networking connectivity approaches. This leads the project to favor modular designs not only for the gateways but also the appliances and in-home displays. Modular designs also make hardware upgrades more efficient.

If the gateway is integrated with the meter, the meter will have interfaces into the appliances in the home and the in-home display, and possibly a different interface to the distribution system. In this case there may need to be multiple interfaces in the customer-premises equipment to support multiple home networking standards. This approach increases complexity and system vulnerability, both for the customer as well as the grid operator.

Pecan Street will employ standardized and openly available interface specifications for systems deployed as part of the demonstration project. Much as wireless Internet home systems integrate openly available communications standards (e.g., Wi-Fi, Bluetooth or cellular networks) into proprietary technologies through hardware or firmware (e.g., computers, video game systems, smart phones) or software, Pecan Street's project interoperability standard will define open platform standards by which technologies from multiple suppliers will communicate and interact. Pecan Street's Cyber Security Plan ensures the data is protected from unwanted intrusions. Mueller is a relatively new development that is approximately half built. Austin Energy's legacy system in place at the demonstration site already has smart grid functionality with Automated Meter Reading (AMR). This legacy smart grid system will be used as a baseline in parallel with other systems deployed for the demonstration, as depicted in Figure 2.

Austin Energy is using the Pecan Street backhaul to test their over the air upgrade from AMR to Advanced Metering Infrastructure (AMI). Since a real-world test was needed for process verification, the Pecan Street backhaul provided the testbed for this rollout without risk to the utility. The meter firmware is being upgraded over the air and the billing meters aren't affected.

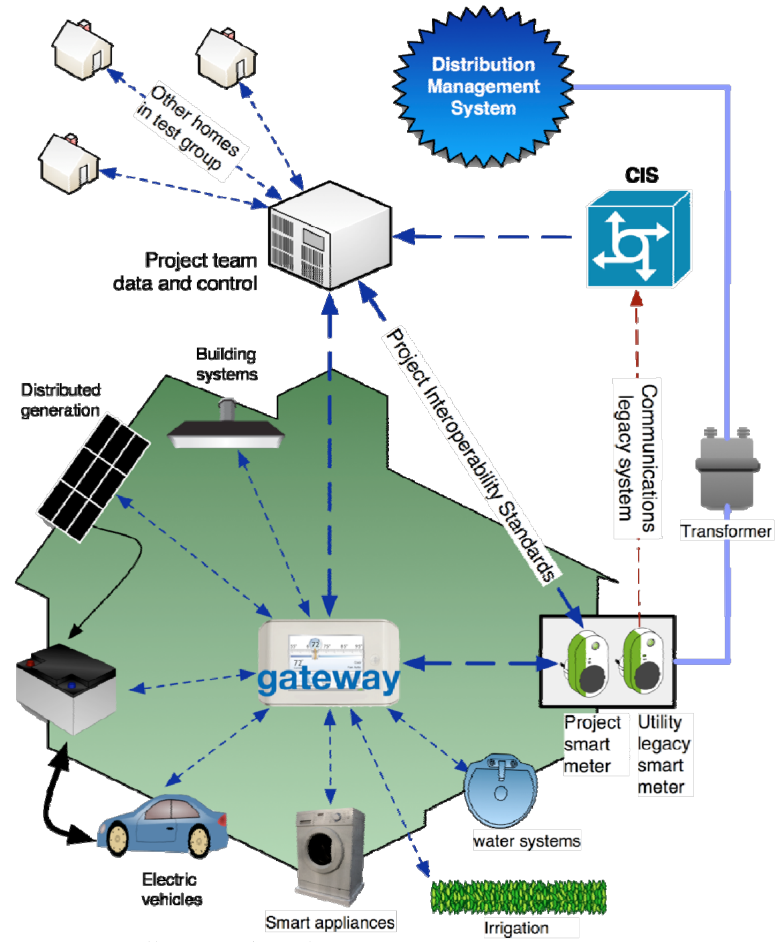


Figure 2. Overall network architecture

Because interfaces will be certified industry standard as noted above, the potential exists to integrate legacy devices into the system by virtue of the backward compatibility nature of the certification programs.

Pecan Street's interoperability requirements ensure that every deployed application is configured so that the Project Team can carry out critical project functions such as integrating multiple applications into a single functioning system, inventory monitoring of deployed applications and evaluating the performance of those applications, remote software updates and detecting and correcting faults. The team will also be able to document user interface and ease-of-use issues.

While the project architecture avoids introducing a critical point of failure for other stakeholders (utility and residential customers), it does create data that is sensitive to all parties. Data regarding resource use, the comparative accuracy of utility meters and submeters, and consumer preferences with various pricing models are all points of sensitivity to the utility. The residential customer may consider information about personal energy use, pricing preferences and smart appliance inventory to be very sensitive as well. Pecan Street also considers the body of data to be an intellectual property resource on which it can generate significant value, provided the integrity and quality of the data can be maintained. Thus, the data collected in this project should be viewed as highly sensitive.

Data from Pecan Street's research projects constitutes the nation's largest database of consumer energy use data that can be shared with researchers. The Pecan Street database contains over 40 billion records and is currently growing at a rate of 12 million records per day.

The Research Team prioritized cyber security and protection of participants' privacy in data integration and storage. The main security principle applied was protection of project participants' identity and privacy pursuant to the Internal Review Board procedures to protect confidentiality of all participants. The database adheres to Pecan Street's Department of Energy-approved Cyber Security Plan, which protects the identity of all research participants and organizes the data so that it is accessible only to approved researchers. The plan requires that any personal identifier, including internally used customer IDs, must be kept in a separate database from all other data from the participating premise and linked by a master database accessible only to Pecan Street staff via a 2-factor authentication process.

Access to data is limited to Pecan Street and university researchers directly involved with managing and integrating data, research staff who use the data for their projects, and approved utility companies and firms who use the data to develop smart grid products. When setting up the database, Pecan Street determined that researchers would have the need to ask ad-hoc questions or queries that would span across multiple data sets. In response to this need, a data warehousing strategy was developed that integrates the data sets into common schema or systems, that emphasize commonalities in the data such as participant, measurement type and timestamp.

Potential cyber security considerations were focused mainly on the identification and mitigation of cyber threats. Natural threats possible in the Mueller community where the HEMS systems are being employed include fire, flooding, tornadoes and electrical storms. Environmental threats include long-term power failure, extended Internet outages and environmental degradation of system electronics. Human threats are more likely and dangerous since they are conducted with intelligence and motivation. The table of human threats in Table 3 was extracted from NIST 800-30.

Table 3. Human Threats: Threat-Source, Motivation, and Threat Actions

(from NIST 800-30)

Threat Source	Motivation	Threat Actions
Hacker, cracker	Challenge Ego Rebellion	Hacking Social engineering System intrusion, break-ins Unauthorized system access
Computer criminal	Destruction of information Illegal information disclosure Monetary gain Unauthorized data alteration	Computer crime (e.g., cyber stalking) Fraudulent act (e.g., replay, impersonation, interception) Information bribery Spoofing System intrusion
Terrorist	Blackmail Destruction Exploitation Revenge	Economic exploitation Information theft Intrusion on personal privacy Social engineering System penetration Unauthorized system access (access to classified, proprietary, and/or technology-related information)
Industrial espionage (companies, foreign governments, other government interests)	Competitive advantage Economic espionage	Economic exploitation Information theft Intrusion on personal privacy Social engineering System penetration Unauthorized system access (access to classified, proprietary, and/or technology-related information)

Threat Source	Motivation	Threat Actions
Insiders (poorly trained, disgruntled, malicious, negligent, dishonest, or terminated employees)	Curiosity Ego Intelligence Monetary gain Revenge Unintentional errors and omissions (e.g., data entry error, programming error)	Assault on an employee Blackmail Browsing of proprietary information Computer abuse Fraud and theft Information bribery Input of falsified, corrupted data Interception Malicious code (e.g., virus, logic bomb, Trojan horse) Sale of personal information System bugs System intrusion System sabotage Unauthorized system access

The vulnerability of the deployed HEMS systems to human threats is summarized in Table 4. The table in the figure below is a checklist for identifying our system vulnerabilities.

Table 4. Vulnerability of Pecan Street HEMS systems to Human Threats

Vulnerability	Threat Source	Threat Action
Customer HAN is "Open"	Proximate hacker, thief, or malcontent	Connecting to the HAN with a WiFi enabled client and accessing residential HEMS systems (and other systems)
Residential internet gateway firewall is not activated	Remote hacker, thief or malcontent	Accessing the HAN and ALL connected devices over the internet through the broadband gateway (usually a cable modem in our project)

Vulnerability	Threat Source	Threat Action
Internet traffic is monitored	Remote hacker, thief or malcontent	Accessing the stream of project data on the internet as it moves between the residence and the project servers
Insufficient security policy implemented on Project Servers.	Remote hacker, thief or malcontent. Disgruntled project staff or researchers	Project data is destroyed or compromised. Sensitive data is accessed and misused.

Test Plan

Each team develops test plans as the next steps are encountered with each separate technology and test. During the next phases of the Program, our technologies and solutions will be refined.

II.2.2 Data Collection and Benefits Analysis

The Project Team collected one year of baseline data and at is concluding 12 months of operational data. The data collected includes cost, environmental impact and performance of the systems tested. For the systems tested inside of volunteer customer premises, data is collected at the device level for major building systems (such as HVAC, plug-in electric vehicle, major appliances, solar panels, heating, water heater and irrigation systems).

Data is collected through a variety of sensors, meters and intelligent appliances. This data is stored on the device itself and reported over the residential Internet gateway and the utility networks, where practical. A key feature of the data communication and management strategy is that it does not rely on the utility network for data collection. All project data is transmitted, with minimal but variable latency, to secure servers at the Pike Power's Laboratory and Center for Commercialization. Pecan Street personnel concatenate and synchronize data flows from various sources and link all data from individual residences to a unique project identifier. Pecan Street personnel, through use of database processing techniques, create custom data sets in various formats for research teams, available on wiki-energy.org. In general, resource consumption data is gathered at a 15-minute intervals and, where possible, 1-minute.

Pecan Street's Data Team will evaluate the data collected to test against hypotheses and to determine how various systems and consumer behavior trials performed and interacted with each other. The results of this evaluation will form the basis for the final report.

Build and Impact Metrics

This section contains each of the Build and Impact Metrics that Pecan Street will report. The metrics apply to the total project supported by the DOE and Pecan Street cost shared funds. Included in the Build and Impact Metrics are explanations of the data collection methods, frequency, and aggregation and analytical methods that will be used to determine the metrics and the associated benefits achieved by Pecan Street at the conclusion of the Program.

Monetary Investments

Pecan Street reports on funds that have been expended for the deployment of the Smart Grid Demonstration Program. The report includes the DOE grants award and the cost share of all recipients. Pecan Street will report investments related to the 'installed cost of equipment' once the assets are deployed and considered utility assets.

Financial analysts will utilize the Pecan Street Financials System to determine or estimate the monetary investments related to the installation of equipment. Pecan Street expects to develop some estimates, based on vendor contracts and internal labor rates for equipment installation, testing and commissioning and apply those costs as assets are installed.

Jobs Reporting

Pecan Street tracks and reports the number and types of jobs by labor category and smart grid demonstration project/research data storage infrastructure classification, quarterly. In coordination with the DOE, jobs created and retained are reported using the appropriate DOE full time equivalents (FTEs) calculation, resulting from both ARRA funding as well as Pecan Street's funds.

Equipment Asset Build Metrics

Pecan Street reports on the equipment asset build metrics as either project or system metrics throughout the plan and reporting process. Pecan Street reports on project metrics for the assets and programs funded by the ARRA and cost share. Pecan Street reports on the system metrics for the applicable Smart Grid assets and programs that are already in place or will be deployed using only Pecan Street funding during the reporting period. The system metrics are listed as a cumulative amount including the project representing the total assets deployed on the Transmission and Distribution Systems.

AMI Assets

Pecan Street will use DOE funds to purchase customer systems only. Advanced metering infrastructure (AMI) assets for the project will be purchased by Austin Energy, if needed, as part of the Pecan Street cost share.

Customer Systems Assets

Pecan Street has acquired and deployed energy data routers from various providers in 618 homes. These HEMS communicate over the HAN and, where external communication is needed, over the Internet via the residential broadband gateway. In some cases these HEMS also communicate with pre-existing utility AMI meters.

The HEMS selected for deployment are capable of communicating with smart appliances, distributed energy devices, electric vehicle charging and utility meters, and provide home energy management capability to the home owner though a web interface or a custom in-home display. These HEMS enable the customer to interact with a variety of experimental pricing plans.

Distributed Energy Resources

Pecan Street incentivized the purchase and installation of plug-in electric vehicles, electric vehicle charging, distributed storage and distributed PV systems in 70 homes in the Mueller community. The Pike Powers Lab demonstrated the integration of solar PV storage with electric vehicle charging, allowing stored renewable energy to power the plug-in electric vehicle.

Behavioral Research Trials

The Project Team has specially configured multiple consumer behavior trials, including pricing models, using this system and is testing these multiple pricing models and pricing features – in parallel – with volunteer participants.

Pricing models being tested fall within a range of purely volumetric pricing (i.e., the prevailing paradigm) to non-volumetric (i.e., flat fee, similar to a mobile phone plan with unlimited minutes).

The project is also testing various pricing features across the pricing models. Pricing features are essentially "plug-ins" – i.e., they can be added to any of the pricing models and are not inconsistent with any of the models. Pricing features being tested include types of real time information, carbon information and peer (comparison to similar customer premises) information. The project's Pricing Team, in collaboration with members of Pecan Street's Industry Advisory Council, defined the pricing models and features, as well as the experiment structure for the pricing trials. This definition work took place over the first half of 2011.

The demonstration project's pricing program creates implications for interoperability and cyber security. Examples of interoperability needs include:

- For customer-premise systems or individual applications to alter their use based on price signals, particularly electric vehicles and HVAC systems, they will need to have communications protocols that are interoperable with gateways, smart meters and potentially with wide area networks through which the grid operator or a private sector aggregator sends pricing signals

- Net metering for rooftop PV (the Austin Energy pricing model used during the initial year of the project) may depend on either a dynamic inverter or a home gateway receiving pricing signals from the grid operator or a third party aggregator, which has received the pricing signals from the grid operator, that then automatically alters the allocation of electricity coming from the rooftop PV system
- Real time information on electric bills that a consumer can access through a gateway interface potentially requires communications interoperability between the gateway and the entity controlling pricing. This is particularly the case when real-time information is provided down to the major application level in a time of use pricing model

Impact Metrics

Pecan Street will assess its impact primarily in the area of customer systems. Any modifications made by Austin Energy to the local distribution system in response to the systems deployed on the customer-side will also be documented and analyzed for applicable lessons learned in other residential distribution systems throughout the nation.

Project and System Metrics

Pecan Street reports on project metrics for impacts observed from project and system metrics relative to the systems deployed including HEMS, residential PV, residential storage, electric vehicle and electric vehicle charging.

Customer Systems

Pecan Street combines detailed appliance-level and distributed energy system-level data garnered from the installed HEMS with data collected by the utility meter to report the impacts of the project on key metrics.

Electric Distribution Systems

Austin Energy will provide Pecan Street with project and system impact metrics that compare baseline system performance with the system performance after the installation of distributed energy technologies and HEMS. These metrics will be used to assess the effectiveness of pricing programs on the management of peak load, as well as the ability of residences to conveniently manage their power use.

Electric Transmission Systems

Pecan Street does not address transmission system metrics in its research program.

Baseline Data

Pecan Street conducted a 12-month baseline study on 200 homes - 100 new, green-build homes and 100 older homes - gathering granular power use data for all major appliances and for the whole home. The baseline data is being compared to the data for the same and additional homes that have fully interactive HEMS systems and distributed energy technologies to gauge the impact of technologies and consumer behavior interventions on peak demand, customer satisfaction and the environmental impact metrics. The baseline data collection began on February 1, 2011, and concluded in February of 2012. The baseline data included the results of advanced energy audits, sub-circuit monitoring and whole-home circuit monitoring. Approximately 20 different types of devices were being monitored on sub-circuits, including sixteen homes with photovoltaic systems. Results of the baseline study will be included in the Final TPR.

Pecan Street requested that Austin Energy supply the utility-side aggregated load data for the Mueller community for the time period of the baseline study. UT researchers developed a load aggregation model for the feeders that service Mueller, using data provided by Pecan Street and Austin Energy. Austin Energy provided distribution data for the Mueller community and Pecan Street provided in residential consumption data collected through its customer-side systems. The model can be utilized to produce critical metrics that include:

- Baseline power use by major appliances
- Aggregated peak load components on distribution feeder by major appliance type
- Impact of electric vehicle charging, rooftop PV and residential storage on aggregate load profiles for the feeder
- Other important metrics that may emerge through sensitivity analyses conducted on the model

II.3 Results

II.3.1 Operation of Smart Grid Technologies and System

A summary of the operating performance and associated costs of Smart Grid technologies and systems demonstrated to date is included in the Table 5.

Table 5. Operating and Performance Costs

Task	Estimate to Completion	Budget at Completion
The Pecan Street Smart Grid Demonstration Program	$3,313,618	$24,657,078
Establish Guidelines	$-	$169,452
Develop Operating Guidelines	$-	$169,452
Design and Construction	$165,680	$19,520,709
Energy Internet Demonstration planning and preparation	$-	$9,757,476
Collect Baseline Data	$-	$245,492
Construct Lab	$-	$1,218,540
Operate Lab	$-	$114,191
Create and Deploy Pricing Models	$-	$4,234,375
Select and Deploy Utility Side Systems	$-	$761,952
Select and Deploy Customer Side Smart Grid Systems	$-	$1,782,664
Deploy Electric Vehicles	$-	$619,452
Promote Commercialization of Smart Grid Technologies	$165,680	$786,567
Operation	$3,147,937	$4,966,917
Issue Project Reports, Share Findings and Conduct Education	$497,042	$893,844
Collect and Evaluate Data	$2,611,077	$4,033,255
Dismantle Project	$39,817	$39,817

Interoperability and Cyber Security Plan

The Research Team prioritized cyber security and protection of participants' privacy in data integration and storage. The main security principle applied was protection of the project participant's identity and privacy pursuant to the Internal Review Board procedures to protect confidentiality of all participants. The Pecan Street's Customer Energy Use Database adheres to Pecan Street's Department of Energy-approved Cyber Security Plan, which protects the identity of all research participants and organizes the data so that it is accessible to approved researchers. The plan requires that any personal identifier, including internally used customer IDs, must be kept in a separate database from all other data on the home and linked by a master database accessible only to Pecan Street staff via a two-factor authentication process. During the course of the Program, the plan will be audited to continually ensure security and interoperability.

Selection of Data Collection Equipment and HEMS

Pecan Street's Customer-Side Team released an Request for Information in 2010 to private industry to test and deploy energy data collection technology for the baseline study. While 25 companies submitted proposals, only six of these were considered for the Smart Grid Demonstration Program. It was important that the device had a built-in web server, on-board storage and remotely reconfigurable software.

Ultimately, one HEMS was selected for the baseline period based on its ability to monitor both whole-home and sub-circuit energy use data at 1-minutes intervals. A total of eight circuits were monitored in each home during the baseline, including two circuits that captured whole-home measurements. Circuits were prioritized based on a list of circuit types that typically have high power draws, and then narrowed down for each home depending on which circuits have a dedicated power draw and could therefore be disaggregated from other uses.

The data collected were sent to Pecan Street's Energy Use Database where they were securely stored and made available to the Project Team for analysis. With data obtained over the course of the study, the Project Team is able to perform advanced analyses such as average power draw and energy consumption across different time periods, load profiles showing the relative loads of different devices in the home, regression analysis to determine the impact of various home energy retrofits, and Savings to Investment Ratio (SIR) calculations looking at the cost and benefit of carrying out these retrofits. Home energy consumption data were collected for all participants and energy generation data were collected for participants with a PV system. In addition, time-stamped weather data were collected for the study period in order to correlate home energy use with external temperature and cloud conditions.

After the year-long baseline data collection period from February 2011 to February 2012, the Data Collection Team moved the data from the Texas Advanced Computing Center to Pecan Street's data center at The University of Texas's West Pickle Research Campus to analyze the data's quality. Inaccurate data readings were sometimes present due to internet connection loss. These readings could be either too high or too low to be considered reasonable, or could be a series of numerous duplicate readingsThe inaccurate data points were filtered out by using standard deviation and tests for numerous consecutive duplicate readings.

A second HEMS system was then deployed in a number of test homes to ascertain the quality of data that it could collect. This system delivered more consistent data and included a web portal for participants to view their information, but the device was susceptible to outages and required a monthly service charge.

A third system that was common in PV systems installed in participants' homes was selected for wide-scale deployment. This system most closely met team's criteria, which included: -

- a built-in web server that provided immediate customer and researcher access to data
- local data caching for up to a year's worth of data
- ability to retrieve all data even if the team's backhaul is down for an extended period
- remote reconfigurability through firmware downloads
- no cloud service fees

The selected system also provides a user-friendly web portal interface that delivers real-time data to the participant. Figure 3 is an example screenshot from the web portal.

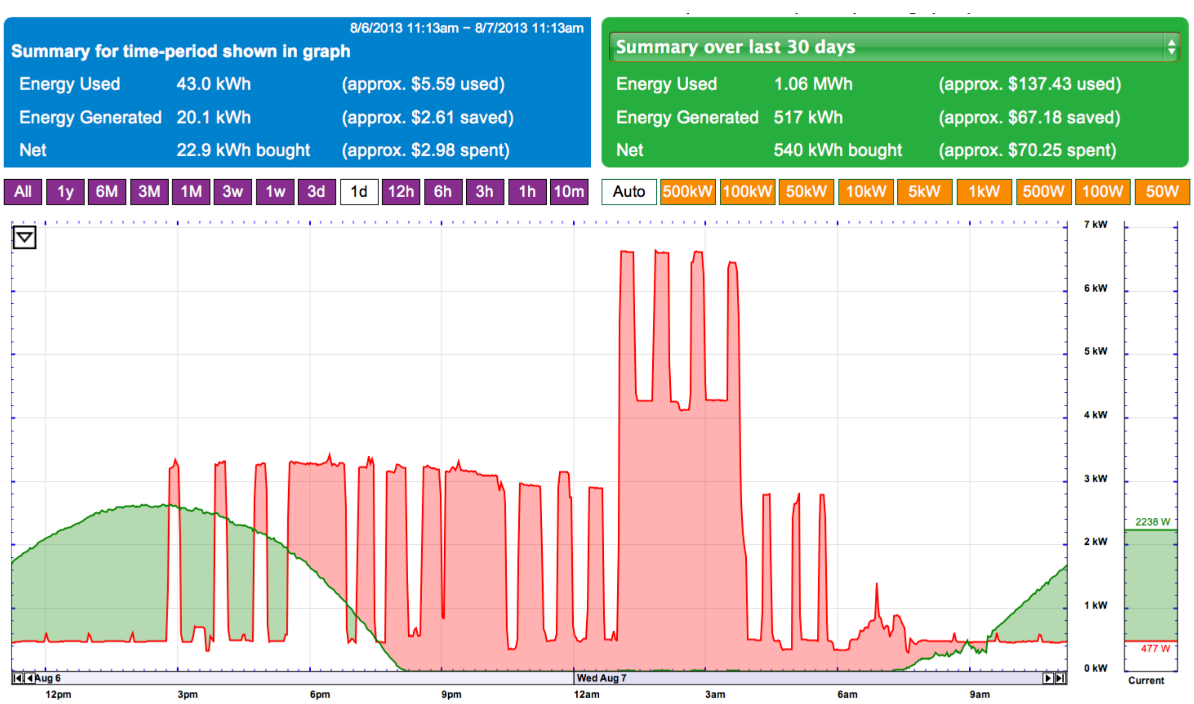


Figure 3. HEMS web portal screenshot

Smart Meters

To mimic the utility-side smart meters, Pecan Street has provisioned 422 AMI smart meters and Austin Energy deployed a majority of the units within Mueller on a dual socket configuration. These meters are industry standard and act as a HAN gateway. Data is collected in 15-minute whole-home readings. A map of the deployed meters is shown in Figure 4.

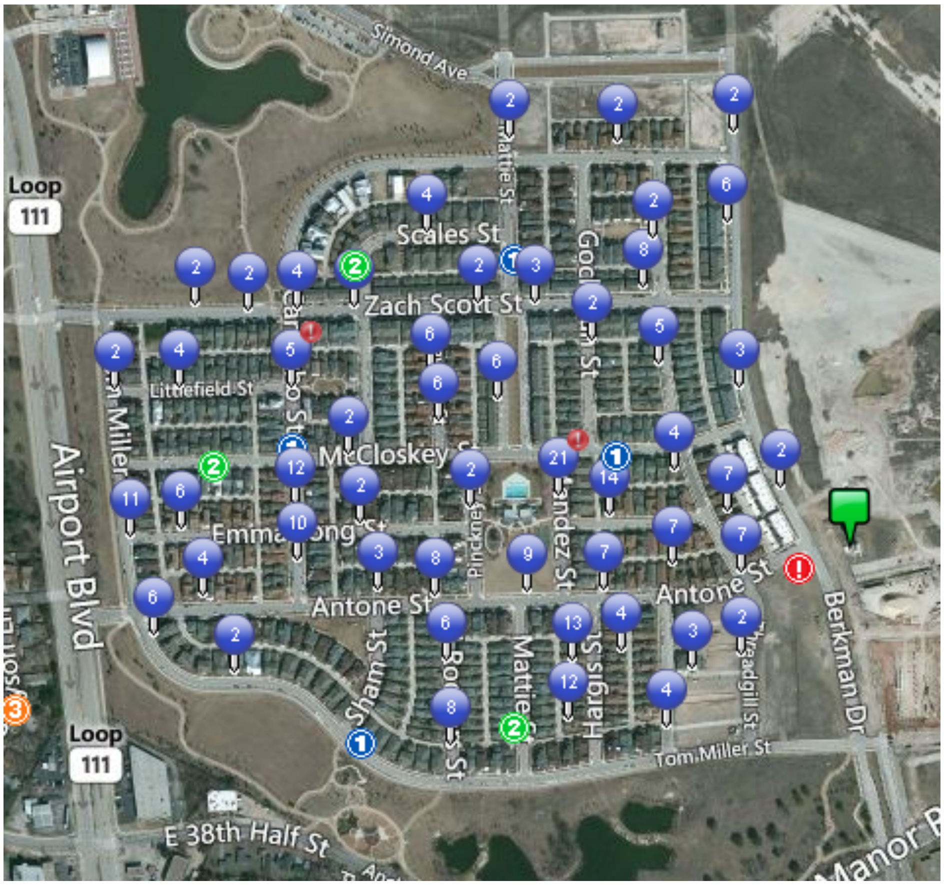


Figure 4. Distribution of AMI meters in Mueller.

The deployment of these meters was a success. Software provided by Industry Advisory Council member Landis+Gyr provides a user-friendly interface that enables Pecan Street to control all of the meters. Because the meters were deployed on a dual socket, Pecan Street's research activities over this meter network does not interfere with Austin Energy's billing meters.

WikiEnergy

WikiEnergy is a suite of online research tools that includes Pecan Street's research database of customer energy, gas, and water use.

WikiEnergy (www.wiki-energy.org) access is available for free to university and 501(c)3 not-for-profit researchers conducting scientific and public interest research and to teachers for STEM curriculum development. WikiEnergy's mission is to advance global university-based research and training on data science, energy, engineering, the environment and human behavior. The service will also provide a free set of tools for high school and post-secondary instructors for curriculum development in science, technology, engineering and math (STEM) fields.

WikiEnergy members help validate data which is then quality checked and certified for inclusion by Pecan Street's trained staff in a validated data table that other members are able to access. Member researchers also identify and prioritize needed survey, energy audit and other types of static data, provide guidance on database formatting upgrades, and recommend solutions for any persistent data quality issues.

WikiEnergy is operated by Pecan Street, with oversight and guidance from a board of advisors made up of five university faculty from four-year postsecondary educational institutions: MIT, Stanford, Carnegie Mellon University and UT. Pecan Street staff are responsible for operating computing systems, database systems, data protection, research participant recruitment, and identity anonymizing protocols.

WikiEnergy launched on March 6, 2014. To date, WikiEnergy has 142 active members from around the world, with particular concentrations from MIT, Carnegie Mellon University, University of Texas at Austin, Cal Berkeley, and Stanford University.

Solar PV

To encourage the adoption of solar among research participants, Pecan Street offered additional rebates in partnership with Austin Energy's rebates for installation of residential PV. Prior to Pecan Street's enhanced solar rebate offering, 11 homes in Mueller had installed PV systems. At the end of September 2011, when Pecan Street's solar rebate expired, over 200 homes in Mueller had installed roof-top PV systems.

To determine if solar is cost-effective for homeowners, the Savings to Investment Ratio (SIR) and Return on Investment (ROI) were calculated for participants in Pecan Street's study in 2013. The analysis used PV cost data from the time period of the installations, most of which occurred in 2012. PV component prices have fallen since that time so the project team expects that the SIR and ROI of distributed solar systems in Austin will improve over time if utility rebates remain constant or decrease commensurate with the decrease in PV system costs.

SIR equals total energy savings over the lifetime of an improvement in Net Present Value. A SIR value of greater than 1 means the system will pay for itself over its lifetime. Higher SIR scores indicate greater cost effectiveness and a shorter payback period. SIR value is calculated as:

*SIR = (Annual Energy Delivered * Cost of Electricity * Present Worth Factor) / System Cost*

The analysis drew upon the following data:

- Regression analysis of retrofit measures and energy savings
- Retrofit cost data obtained from Austin Energy
- Austin Energy's rate structure
- Solar PV attribute and cost data from Pecan Street
- PV Watts online solar generation calculator

Estimated saved kilowatt hours (kWh) per day from the regression were analyzed with Austin Energy's rate structure. Figure 5 shows average monthly power and it reveals that for the entire study period, the marginal power for the average home in the study fell between 501 and 2,500 kWh, an interval equivalent to tiers 2 and 4 of Austin Energy's rate structure. In the calculation, it was assumed that the energy savings would be spread throughout the year. Therefore summer rates as well as non-summer rates were applied for the correct number of days respectively.

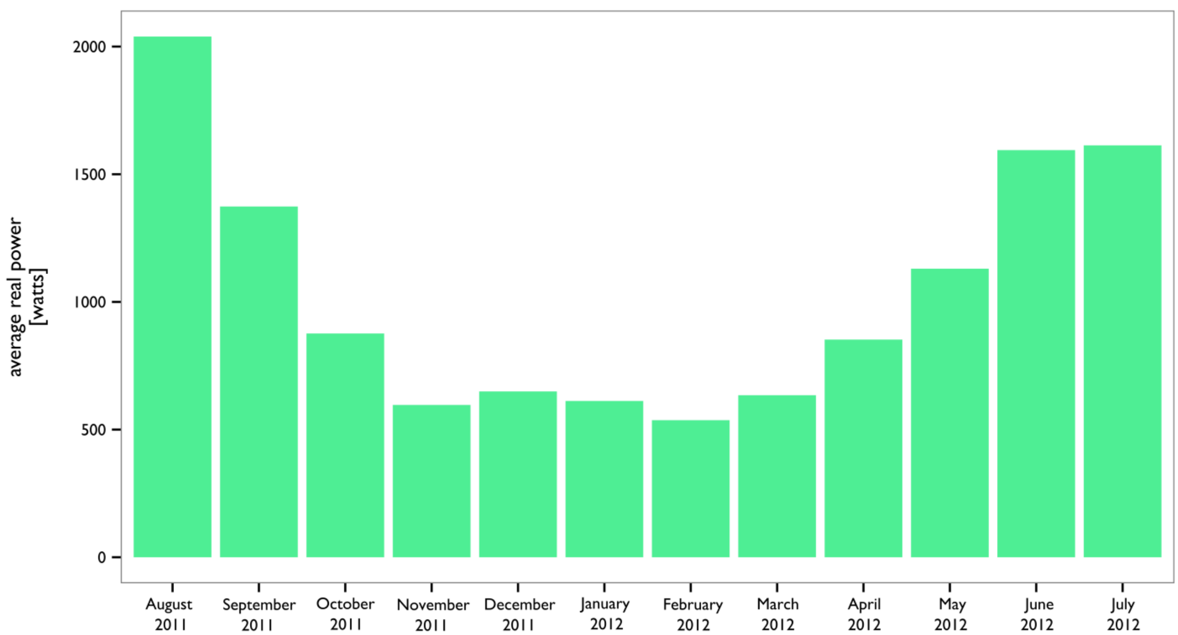


Figure 5. Average monthly whole home power, all participants

To calculate savings from solar, PV systems were analyzed based on three different orientation options:

- PV system with both south- and west-facing panels
- PV system with only south-facing panels
- PV system with only west-facing panels

For this analysis, total system size was held constant as the average system size from the study (5.52 kW). Values for tilt and azimuth were based on averages for each orientation. For systems with both south- and west-facing panels, a two-part analysis was conducted for both orientations. All values were entered into PV Watts, a program that can estimate energy generated by PV systems for a typical meteorological year based on the system's location and attributes. PV Watts delivered figures for annual AC energy generated, which were converted to daily values.

Cost data for PV systems was provided by the solar installers as part of the requirement to receive Pecan Street's rebate. Average cost per watt for each orientation as well as average rebate per watt were calculated separately for each orientation. Cost per watt values were adjusted to the normalized system size of 5.52 kW to estimate costs for each system.

Another value that is required for the analysis is the lifetime of the system. The figure used for solar PV systems was 25 years, equivalent to the time that the typical system is under warranty.

Currently, homeowners in Austin Energy territory investigating the possibility of installing solar panels must receive an inspection from an approved solar installer to determine whether the home qualifies for an Austin Energy rebate. Pecan Street's analysis of SRI and ROI found that PV is a cost-effective option for homeowners seeking energy improvements and it is one that is scalable to the size of the home.

The Pecan Street Data Team analyzed the data collected from south and west facing PV, compared to whole-house consumption. Figure 6 illustrates that while south-facing panels may produce more overall energy, the west-facing panels actually match more directly with peak demand.

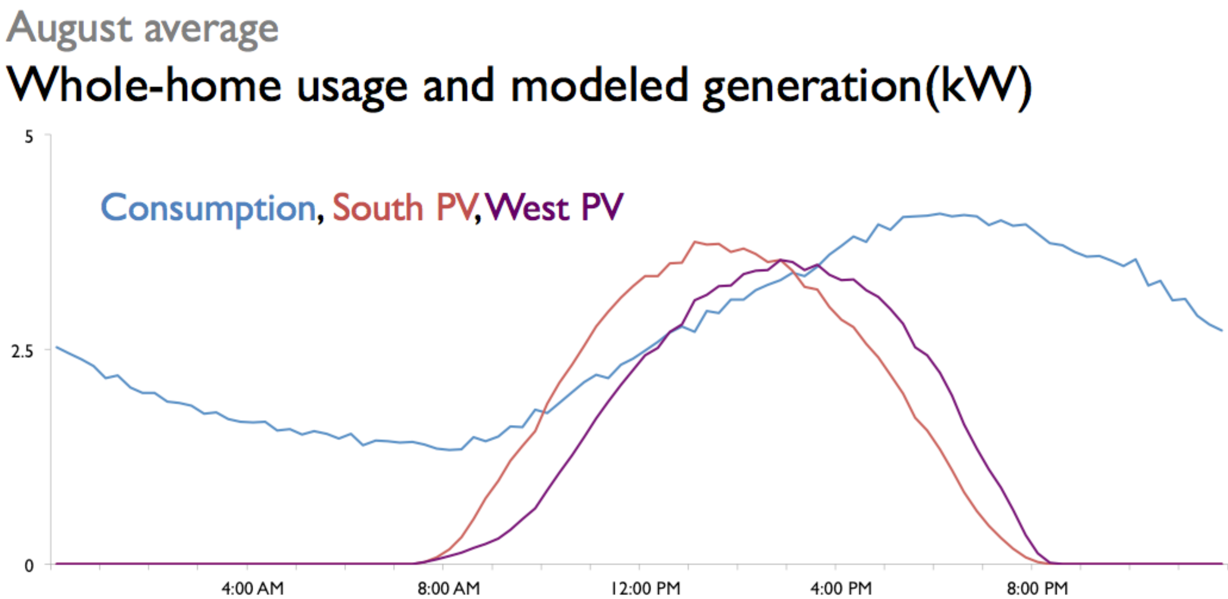


Figure 6. Comparison of whole home consumption to south and west facing PV, August 2013 daily average

The whole-home net electricity use was also calculated from the data collected during the solar PV study, and those results are shown in Figure 7.

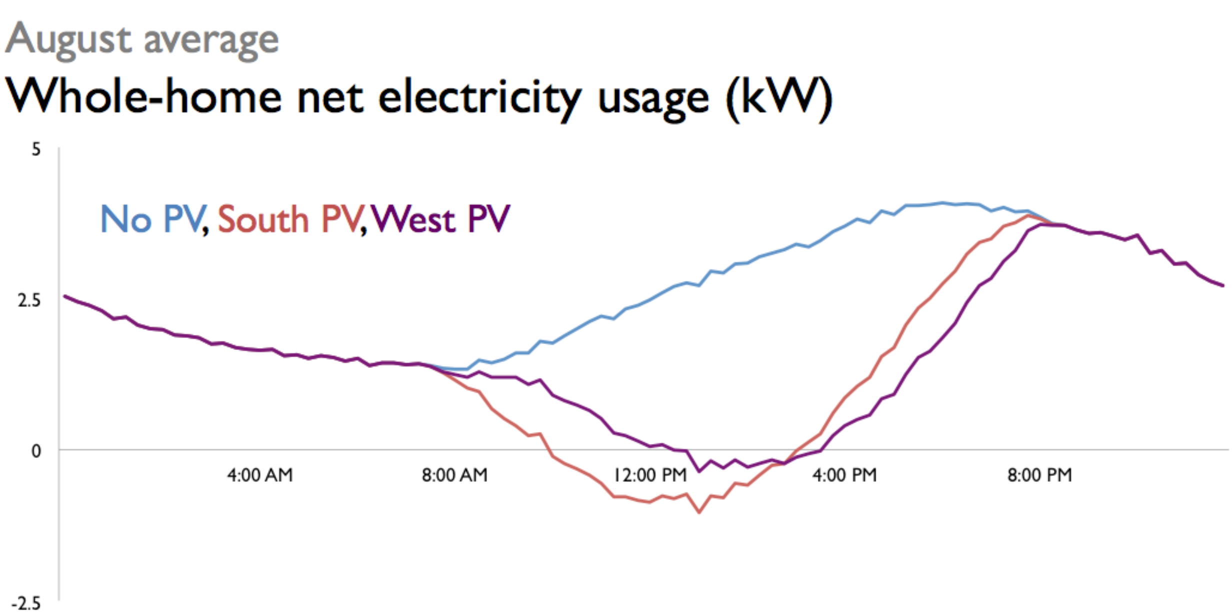


Figure 7. Comparison of whole home net electricity use, August 2013 daily average

Since the whole-home net electricity use is reduced with solar PV, this will have an effect of reducing a customer bill. Figure 8 shows the price implications of solar compared to those of homes with no PV, south-facing PV and west-facing PV.

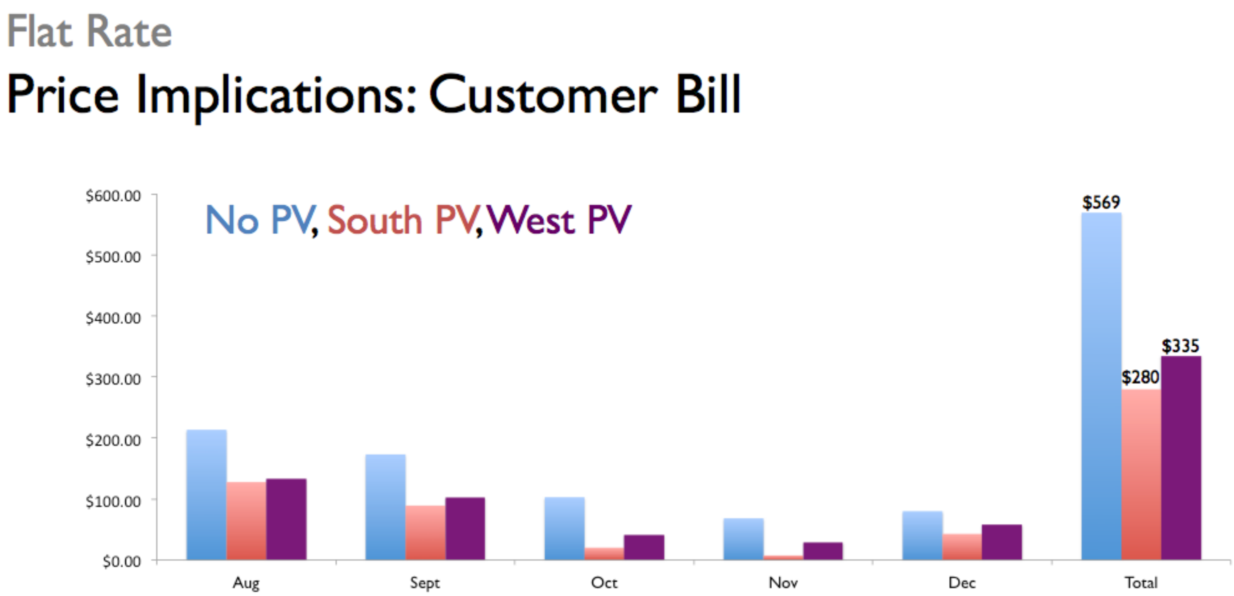


Figure 8. The price implications of a customer bill with solar

Table 6 shows detailed utility bill savings and the annual savings that are expected with varying solar panel orientations. Table 7 calculates the SIR for varying solar PV system orientations.

Table 6. Utility Bill Savings

Retrofit	Saved kWh per day	Annual savings	Lifetime (years)
PV system with only south-facing panels	20.57	$961	25
PV system with south- and west-facing panels	19.33	$903	25
PV system with only west-facing panels	18.14	$847	25

Table 7. Savings to Investment Ratio Analysis

Retrofit	Lifetime savings	Cost before rebates	Cost after rebates	SIR with Rebate	SIR no rebate
PV system with only west-facing panels	$16,543	$24,196	$3,234	5.12	0.68
PV system with south and west-facing panels	$17,635	$24,983	$3,878	4.55	0.71
PV system with only south-facing panels	$18,765	$24,741	$4,479	4.19	0.76

Installing solar PV also has a positive effect on the profitability of the utility. During the hottest times of the year, most often in August, the price per kWh is so high that the utility loses money during peak demand; however, with solar PV installed, facing either south or west, the utility is able to remain profitable with a flat rate (see Figure 9).

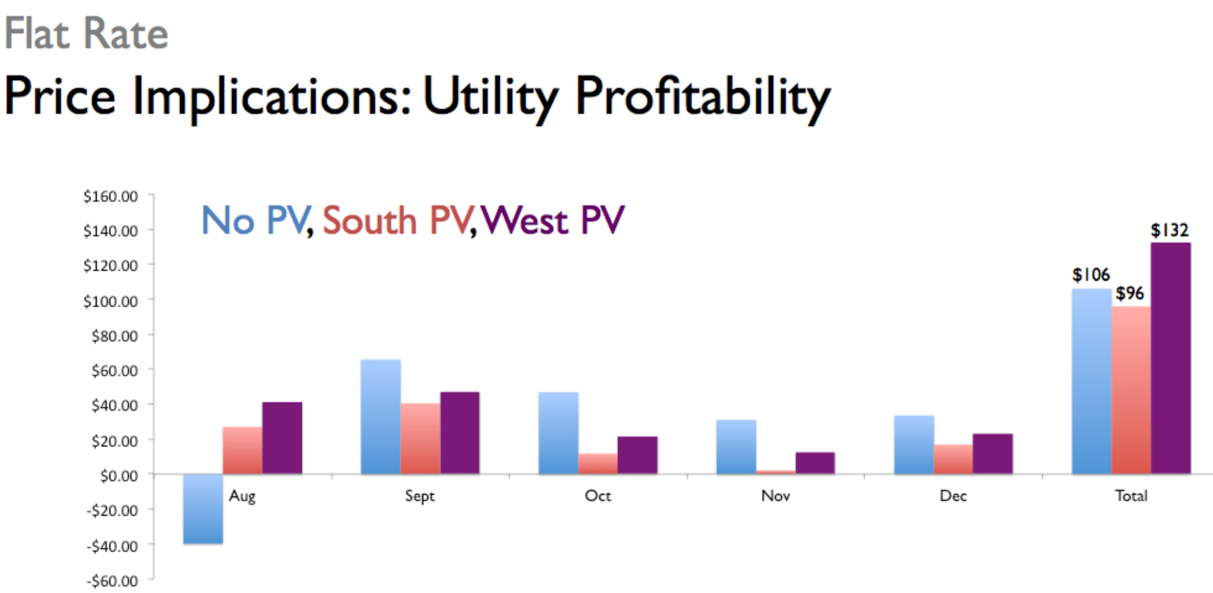


Figure 9. The price implications for utility profitability

While it was once thought that south-facing panels was the best scenario for solar panel installation to generate as much electricity as possible, the Project Team found that to combat peak electricity demand, the key is west-facing solar panels, which more directly align with peak demand.

Natural Gas and Water Metering

In partnership with Texas Gas Service and Austin Water Utility, Pecan Street installed smart gas and water meters along with a third-party ERT reader that transmits data over the participant's wireless network in 50 participating homes. These homes also have HEMS installed that enable the project team to disaggregate gas and water use within the home. Pecan Street is currently undertaking this analysis and will report on the results in the final TPR.

Plug-In Electric Vehicles

Plug-in electric vehicles represent the most significant new electric load to appear in homes in half a century. Uncertainty surrounds the rate and extent of customer adoption. However, the experience of hybrid vehicles — where adoption has clustered in handfuls of urban neighborhoods — suggests the possibility that clusters of electric vehicles in percentages exceeding 15 percent could begin to appear in a number of urban distribution feeders in the coming years. The Mueller community has experienced elevated levels of electric vehicle adoption, which occurred in tandem with a significantly higher adoption rate of solar PV than the population at large.

These observed conditions raised important research questions:

- In a neighborhood where electric vehicle clustering does occur, what is the charging behavior pattern?
- How does the presence of rooftop solar PV impact electric vehicle owners' peak load and distribution system impact?

To date, Pecan Street has incentivized the purchase or lease of 69 electric vehicles all with Level 2 charging stations located in and near the Mueller community. Over 4,000 charging events were measured between June 1, 2012 to January 15, 2013. As shown in Figure 10, the distribution of charge duration in minutes by the number of charges that occur for the seven-month time frame indicates that the majority of charges last between 41 and 80 minutes.

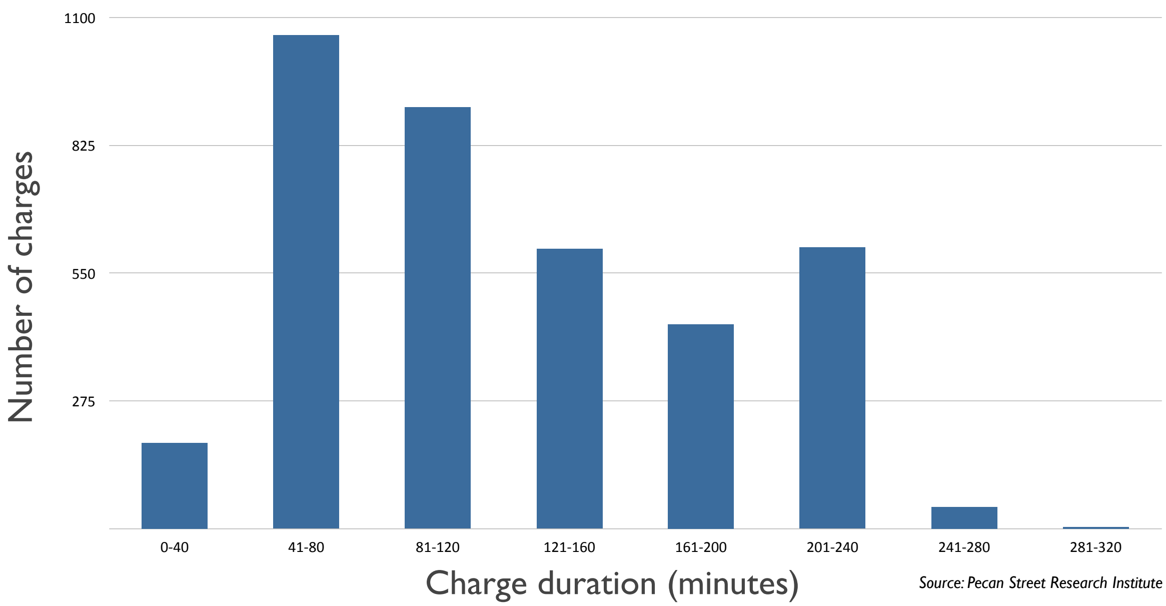


Figure 10. Electric vehicle charge duration in minutes, from June 1, 2012 to January 15, 2013

Preliminary analysis of electric vehicle start times suggests that 12% more charging occurs on a workday versus on a weekend and that 35% of charging start between 4:00 pm and 8:00 pm. The analysis also suggests very few participants have their vehicles set for delayed charging, which is a common EV feature, but requires a degree of user intervention. Figure 11 shows electric vehicle charge start times for weekdays.

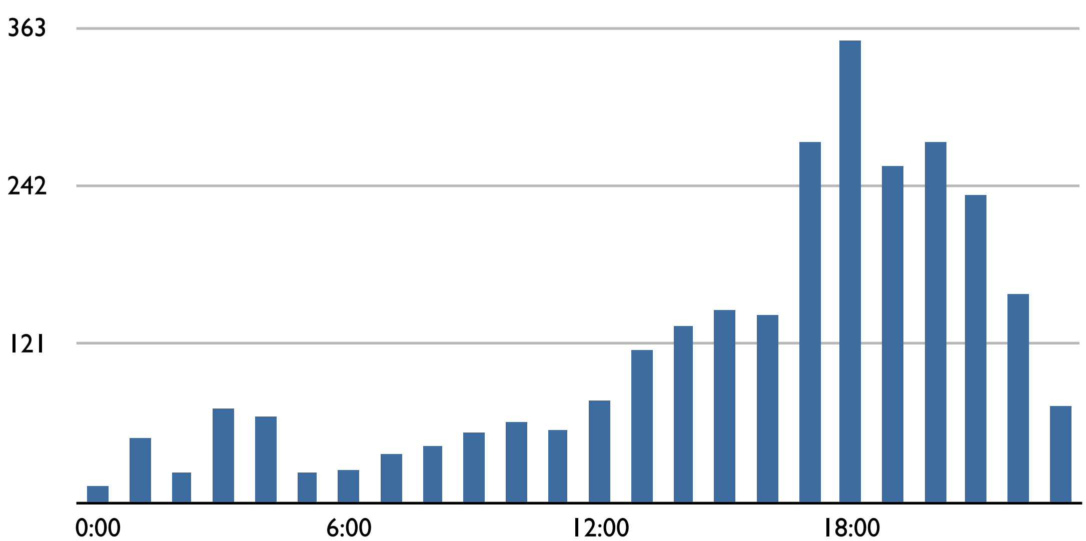


Figure 11. Electric vehicle charging start times from June 1, 2012 to January 15, 2013 (Y axis is number of recorded instances; X axis is the start time of a charge event.)

As shown in the Figure 12, peak PV generation does not correspond with customer electricity use or peak electricity demand. Effective PV energy storage solutions may help offset peak demand. PV generation provides more than enough energy to fully offset electric vehicle charging demands; average additional peak load due to electric vehicle charging is 600-1,000 watts.

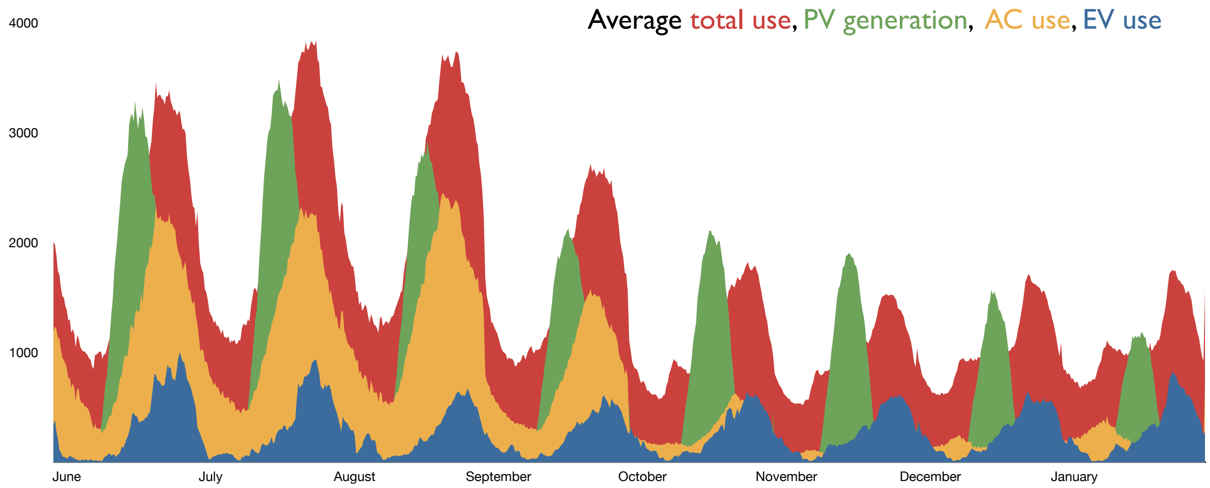


Figure 12. Average energy use over time (in watts)

Pricing Models & Commercialization

In addition to using technology-based tools to address load management challenges, utilities and regulators are increasingly examining the viability of methods that produce changes in customer behavior and consumption. Metrics that utilities frequently apply to customer behavior-based load management include:

- Predictability: i.e., does the method produce a change in customer electricity use that is sufficiently predictable that it can be incorporated into system planning?
- Cost — both to customers and to utilities
- Complexity — for both customers and utilities
- Customer satisfaction
- Impacts on specific customer groups, such as older customers and low income customers

A key issue for electricity providers is peak demand: when demand for electricity rises, it stresses the utility grid – and too much stress can lead to major losses for utility providers and rolling blackouts for the communities they serve.

The purpose of Pecan Street's electricity pricing trial is to determine the degree to which electric customers are willing to alter their pattern of electricity use in response to prices that vary with the time of day, lessening the burden to utilities.

Homes that participate in the pricing trial are engaged in different ways throughout the trial, and participants were separated into groups. Some of the homes receive a generic text-based notification asking them to conserve power during an event. Another group of homes received an actionable text-based notification asking them to perform something during an event. For example, "Please turn off your oven from 4 to 7 pm." A third group of homes receive access to a pricing web portal to see what the difference in their energy bill would be if they were involved in a pricing program. A final group of homes received a learning thermostat.

As the pricing trial comes to an end, data will be analyzed and presented in the final TPR.

Corrective actions to date

Pecan Street's initial research challenge lied in the reliability of continuous data reporting from HEMS deployed in the field. To solve this problem, the Project Team developed two methods to protect against data loss. First, the team found a data collection device that locally caches data for up to one year. If data is not transmitted correctly at a given time, the database is able to fill data gaps with this feature. Figure 13 illustrates how the data self-heals in this way. Second, Pecan Street uses an offsite web-based backup system as well as long-term archival storage for raw data to prevent data losses.

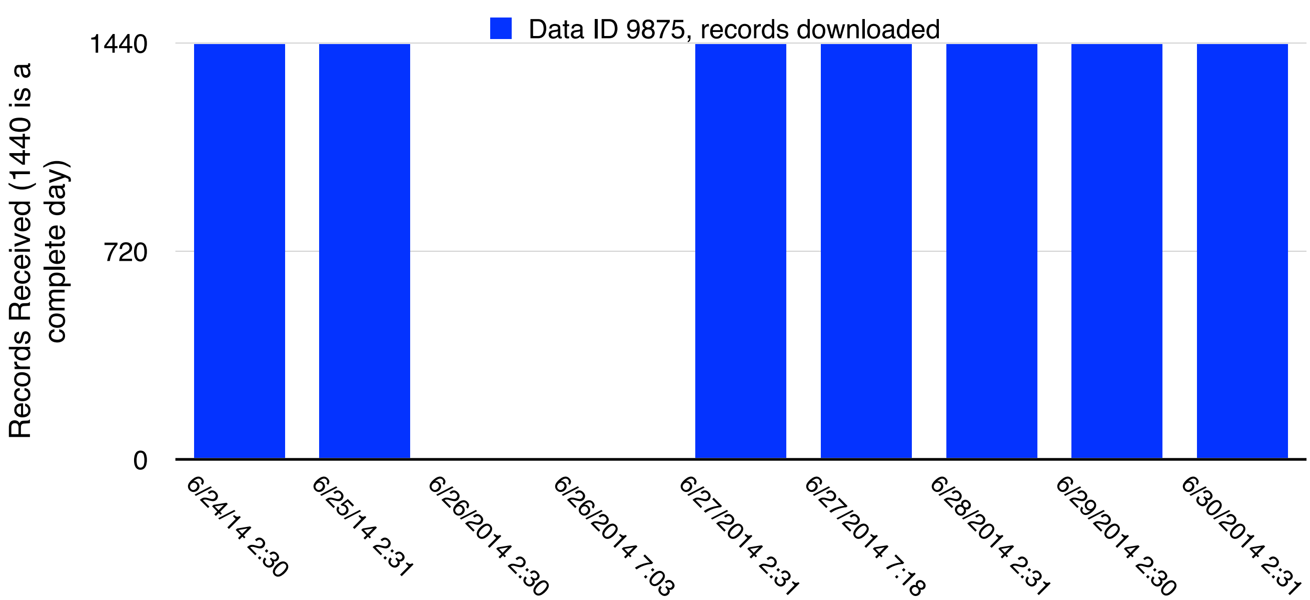


Figure 13. Self-healing algorithm results, Data ID 9875

II.3.2 Energy Storage System Performance Parameters

Pecan Street's energy storage research, included as part of the Smart Grid Demonstration Program, is focused on evaluating the impacts of energy storage solutions implemented alongside a single transformer, known as "community energy storage," and designing systems integration specifications for multi-fuel, islandable pico- and micro-grids.

The impacts of potential energy storage solutions were hypothesized in the Mueller Community in Austin, TX through a theoretical and mathematical model developed by Dr. Fabian Uriarte from the University of Texas's Center for Electromechanics. The entire community is fed from a single three phase lateral where each phase inside the community serves 20 to 40 transformers. For the model, the PV generated energy storage unit would be installed on only one transformer.

An overview of the Mueller Community's distribution network is illustrated below:

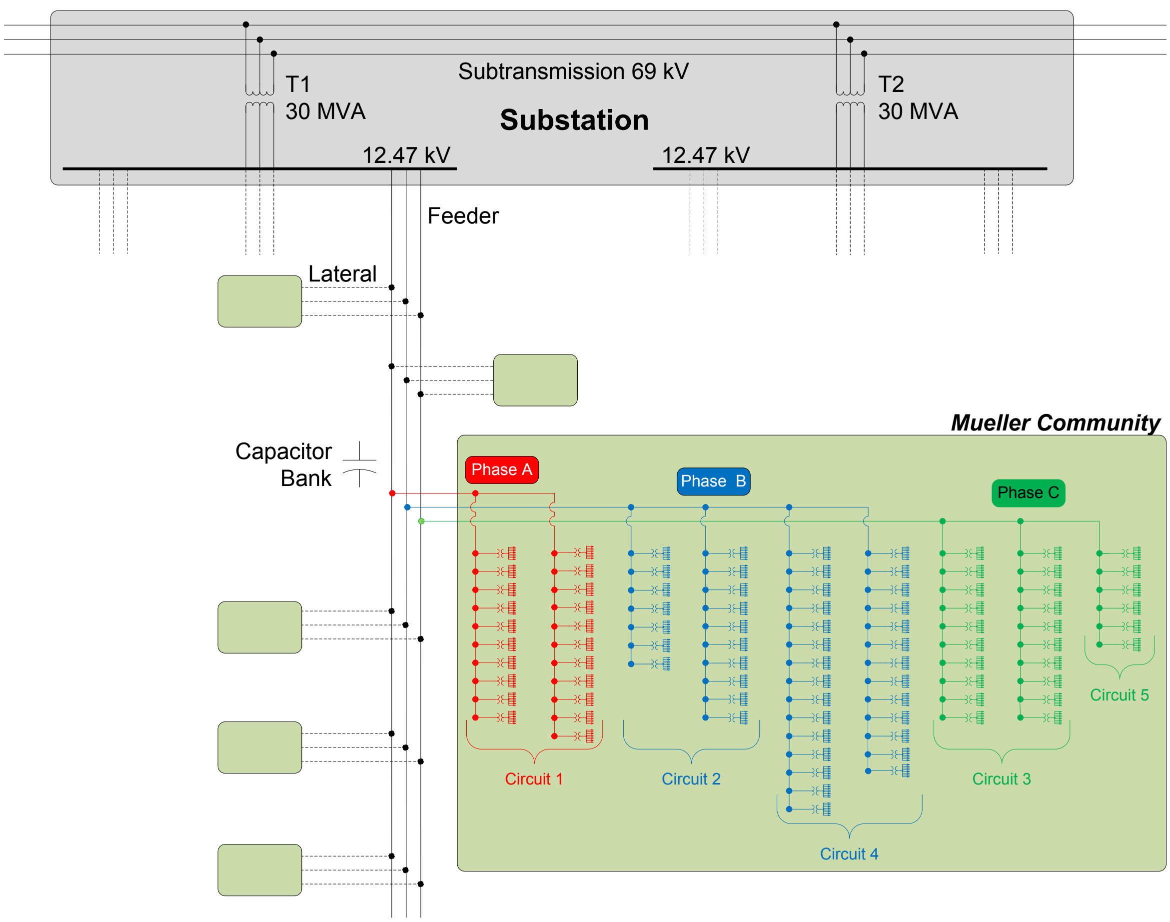


Figure 14. Mueller distribution network [1]

[1] Dr. Fabian Uriarte et. al. Community Energy Storage: 7-Day Forecast. Presentation at June 2012 Pecan Street Inc. Industry Advisory Council Quarterly Workshop.

Charging of the energy storage batteries is set to occur in this model under the following conditions:

a. When transformer load is low (< 30 kW)

b. When sun is out (PV > 5 kW)

c. When state of charge (SOC) < 90 %

Charge logic: (a OR b) AND c

Discharge of the energy storage units is set to occur under the following conditions:

a. When PV output fluctuates

b. When transformer load is high (≥ 30 kW)

c. When SOC > 10 %

Discharge logic: (a OR b) AND c

The community energy storage unit consists of a single-phase transformer stepping down from 7.2 kilovolts (kV) to 240 volt (V) split phase. The unit includes a disconnect switch at the community energy storage that permits entering island mode. Inside the storage unit, there is a connection from a 25 kW PV and a 25 kWh, 25 kW battery unit. The PV and the battery are interconnected to an internal 240 V AC Bus. The residential loads, including solar panels and electric vehicles, are connected from this internal AC Bus as shown.

A diagram of the unit is illustrated in the figure below:

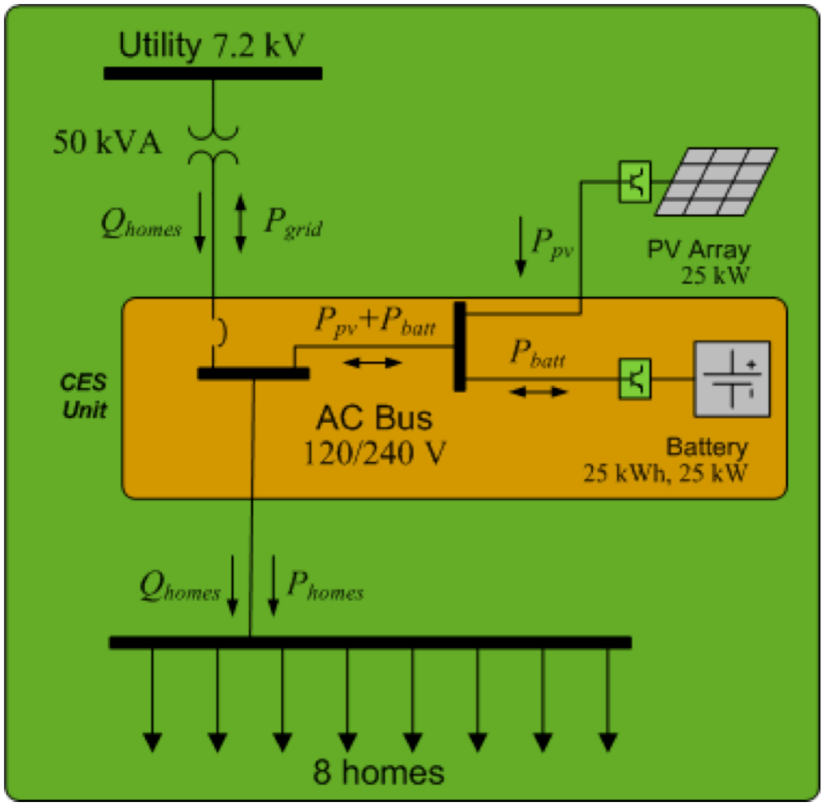


Figure 15. Community energy storage diagram[1]

Three hypothetical case studies were considered as part of this research. The first case study focused on charging and discharging the battery when the state-of-charge reaches its threshold. This scenario demonstrates how long the battery can support the residential load of 10 homes.

The second study charges the battery at midnight, but only discharges it during PV outage. This scenario demonstrates whether the battery can compensate for the 25 kW PV fluctuations that occur when local PV generation is disrupted.

The third case study charges at midnight, and discharges when the residential load is greater than15 kW. This demonstrates whether the storage unit can effectively serve to level the transformer load.

Each case study was analyzed using MATLAB/Simulink to simulate the single transformer with community energy storage. The source, transformer, and main disconnect blocks were taken from the SimPowerSystems library. The residential load, the 25 kW PV and battery storage models were custom subsystems.

Preliminary observations from the research conclude that community transformers appear to be sized appropriately and maintain an average load of 6 kW. The PV installed alongside the storage unit peaks at 20 kW, but can fluctuate intermittently.

Supplemental battery storage can support residential load for up to 2 hours and can compensate for PV fluctuations. Additionally, the battery can level the transformer's load by providing real power. Reactive power support is also possible, but is not part of this study.

Additionally, a financial model was evaluated for battery storage combined with PV. The criteria was if a residential battery could improve power quality, assist with peak shaving, encourage time shifting or allow the customer to go off-grid. Using the installed cost of PV (Figure 16), combined with the battery cost, a model was run to evaluate the projected total installation cost of the community energy storage system.

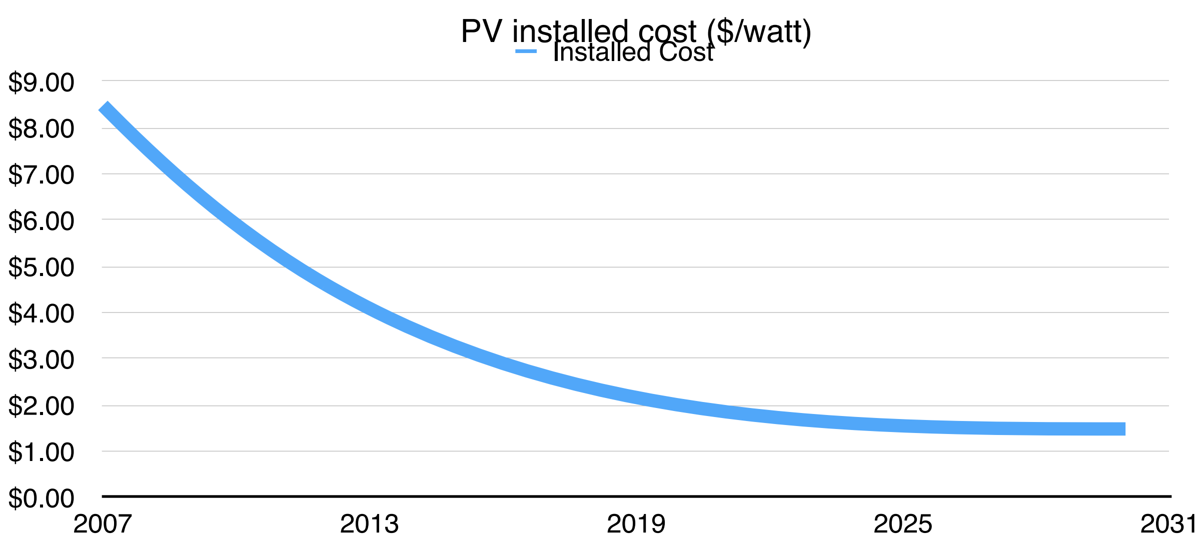
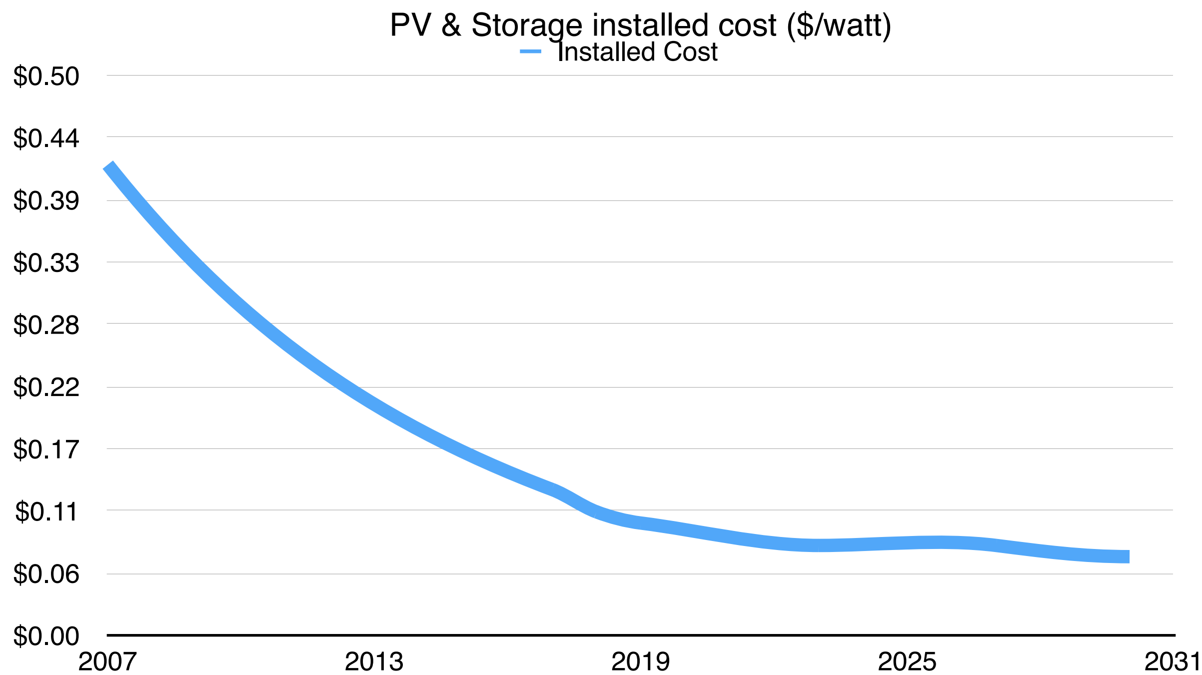


Figure 16. Installed cost of PV over time

A simple cost model for storage for one cycle per day suggests that the cost per kWh discharged is currently cost prohibitive for main-stream residential adoption at $0.48, based on current battery costs.

Figure 17 was generated by converting the previous PV cost curve (Figure 16) to $/kWh for power delivered over the life cycle of the PV, and by converting the cost of kWh of storage to $/kWh for power delivered over the lifecycle of the battery. This curve suggests that an islanded PV power system with storage could produce energy at a cost of $0.25 per kWh by 2020, and $0.12 per kWh by 2030. These costs would be the natural result of a rapid shift to PV as described in the first chart. After 2030 the cost of energy from combined PV-battery systems



will continue to drop.

Figure 17. Cost per kWh for PV and storage

To test the interoperability of battery storage, Pecan Street installed a battery storage system at the Pike Powers Lab. Installation of the batteries demonstrated the system integration requirements for an energy storage system that meets the following specifications:

- Output AC and DC power simultaneously or either one independently
- Integrate distributed generation
- Receive power from the grid or directly from the solar system
- Directly charge an electric vehicle
- Shift loads off the grid during peak
- Directly power individual loads in the building
- Integrate a natural gas generator or other on-site power source

Figure 18 illustrates the integration of the battery storage into the lab's electrical system.

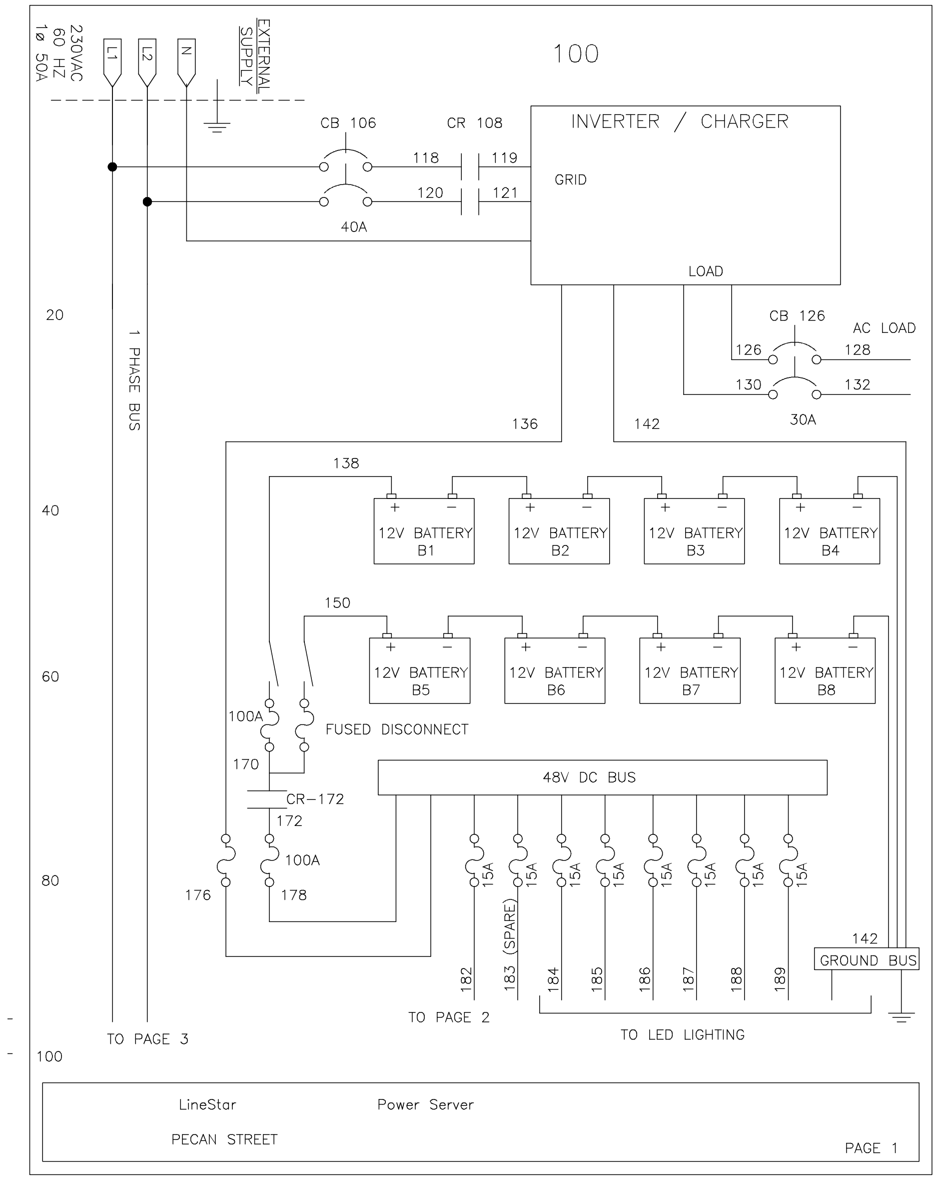


Figure 18. Line drawing showing integration of battery storage at Pike Powers Lab

Currently the energy storage system operates as a pico-grid within the facility because the AC output is not in parallel with the Austin Energy grid. Operating the energy storage as a pico-grid enabled the organization to bypass the jurisdiction's permitting requirements, reducing balance of system costs. Separate circuit beakers were installed in the energy storage system to enable loads under 4500 watts to directly receive power from the batteries.

The most significant system integration challenge involved communications between the battery charger and the batteries. The commonly available battery chargers on the market are designed for lead acid batteries. Pecan Street's lithium iron magnesium batteries required custom software development to enable the battery charger to communicate with the batteries, allowing charge from the grid, the on-site distributed generation, or the on-site natural gas generator.

Over the course of the project duration, the energy storage system has been used to power individual circuits in the building and charge a Volt electric vehicle to full charge, helping to shift significant loads off the grid during peak consumption hours.

II.3.3 Impact Metrics and Benefits Analysis

Pecan Street will evaluate the impact metrics and benefits once the project is nearer to completion.

II.3.4 Stakeholder Feedback

Residential participants in the Pecan Street Smart Grid Demonstration Program are enthusiastic about being a part of this project for varying reasons, from reducing carbon footprints to saving money on energy bills. Many of the participants are happy to be doing their part to address climate change and participating in the Program has helped them reach this feeling of achievement. As one homeowner put it, "adding energy monitoring to my solar panels and electric car has really put me in a place where I can truly feel like I'm helping to save the planet." Many of the participants already consider themselves green, but as one volunteer states, "by being able to monitor my energy use down to the circuit and plug, I can do my part to reduce waste and reduce my overall energy consumption, helping me be more efficient in my electricity use and save even more money." Most homeowners are surprised by the data they receive about their use. One homeowner said "It's been very eye-opening to have access to the small details of our energy use – to be able to put a number on how much energy we save by opening the blinds instead of flipping on a switch, or to understand the cost of one degree of air conditioning, or even just to play around with trying to get our energy use to net zero."

Technology partners agree that Pecan Street is conducting ground-breaking research to shape energy systems. One member says, "Information technology and data management will be crucial to these smarter grids, and we are proud to put technology and expertise toward the goal of ensuring our energy future is efficient and sustainable."

The partnership with a major automaker "provides us with a unique opportunity to observe charging details with many real customers in a concentrated setting. We are moving our lab demonstrations into the real world. This project will help us develop future capabilities of plug-in vehicles."

II.4. Conclusions

II.4.1 Projections of Demonstration and Commercial-Scale System Performance

The initial Smart Grid Demonstration Program design and execution was validated during the first phase of the Program. The Program consistently demonstrates interoperability between hardware needed to collect data and cyber security to protect that data and the privacy of participants.

Given the ongoing iterations of product testing and the significance of summer 2013 and 2014 electricity use data, conclusions informed by data are premature at this time. Based on data analyzed to date, however, the project team has refined and updated its research hypotheses as follows:

1. West-facing rooftop solar PV is more load-aligned than south-facing and therefore may provide greater system benefit and overall higher utility.
2. The lack of load alignment of generation from south-facing solar PV results in higher operational loads and operating temperatures for utility transformers during shoulder months, when PV generation increases but midday residential electricity use is typically low.
3. Electric vehicle residential charging is significantly concentrated during peak demand hours, which coincides with when people arrive home. However, the portion of peak coincident charging does not rise to the level assumed in previous research models by other organizations. This has significant implications on the level of EV adoption that would begin to trigger negative distribution system impacts; i.e., EV adoption can likely rise to higher penetration levels without negative impacts for most distribution systems than has been assumed in many EV impact models.
4. Behavioral modification that relies on manual actions by customers (as opposed to automated, “set and forget” structures) will face significant headwinds in producing predictable customer response. This has implications for the structures of pricing and demand response programs. This situation is analogous to the “blinking VCR clock” syndrome in that significant numbers of customers will not undertake manual actions, even when they receive constant, visible alerts.
5. At one hour intervals, AMI smart meters do not provide sufficient data to enable meaningful algorithmic disaggregation and the consumer services that could be made possible by such disaggregation.
6. Residential air conditioning technology improvements represent the most promising area for achieving high impact in peak demand reduction. Such technology improvement, however, must move beyond technologies that produce greater levels of occupant discomfort and higher temperatures. Instead, innovations should focus

on how to provide current or even greater levels of home cooling through greater system efficiencies. One promising area of air conditioning innovation is in zonal, mini-split systems, which are common in parts of Europe and Asia but rare in the U.S.; such systems empower occupants to cool individual rooms while leaving unoccupied rooms uncooled or set at much higher temperatures.

Pecan Street Inc. demonstrated the system integration requirements to install a zonal air conditioning system at its lab and in a new construction home in Austin, Texas. The organization is currently working with an industry partner to develop sensor control and demand response protocols for the zonal air conditioning system.

7. Moving from electric versions to gas versions of clothes dryers, space heating, water heating and ovens offers an overlooked pathway to reduced carbon emissions, reduced operating costs, peak demand reduction and lower total energy costs.

II.4.2 Lessons Learned and Best Practices

The program is still underway; therefore, lessons learned are being collected and evaluated through the remainder of the project. Based on experiences and data evaluated to date, however, the project team has refined and updated its lessons learned and best practices as follows:

1. Any system that acquires data to provide customer services needs to have on-board data caching. This is due to inevitable intermittencies in even the most robust Internet and cellular networks.
2. Even highly motivated customers quickly lose interest in their home energy data. To achieve any kind of behavioral response, such data needs to be analyzed through software applications to produce useful recommendations to customers that are highly tailored to their specific situations. Recommendations should move beyond "how to save money on your electric bill," which has limited enduring interest for customers. Rather, recommendations should focus on using home energy use to make home highly tailored home maintenance, appliance maintenance and home retrofit recommendations.

II.5 Contacts

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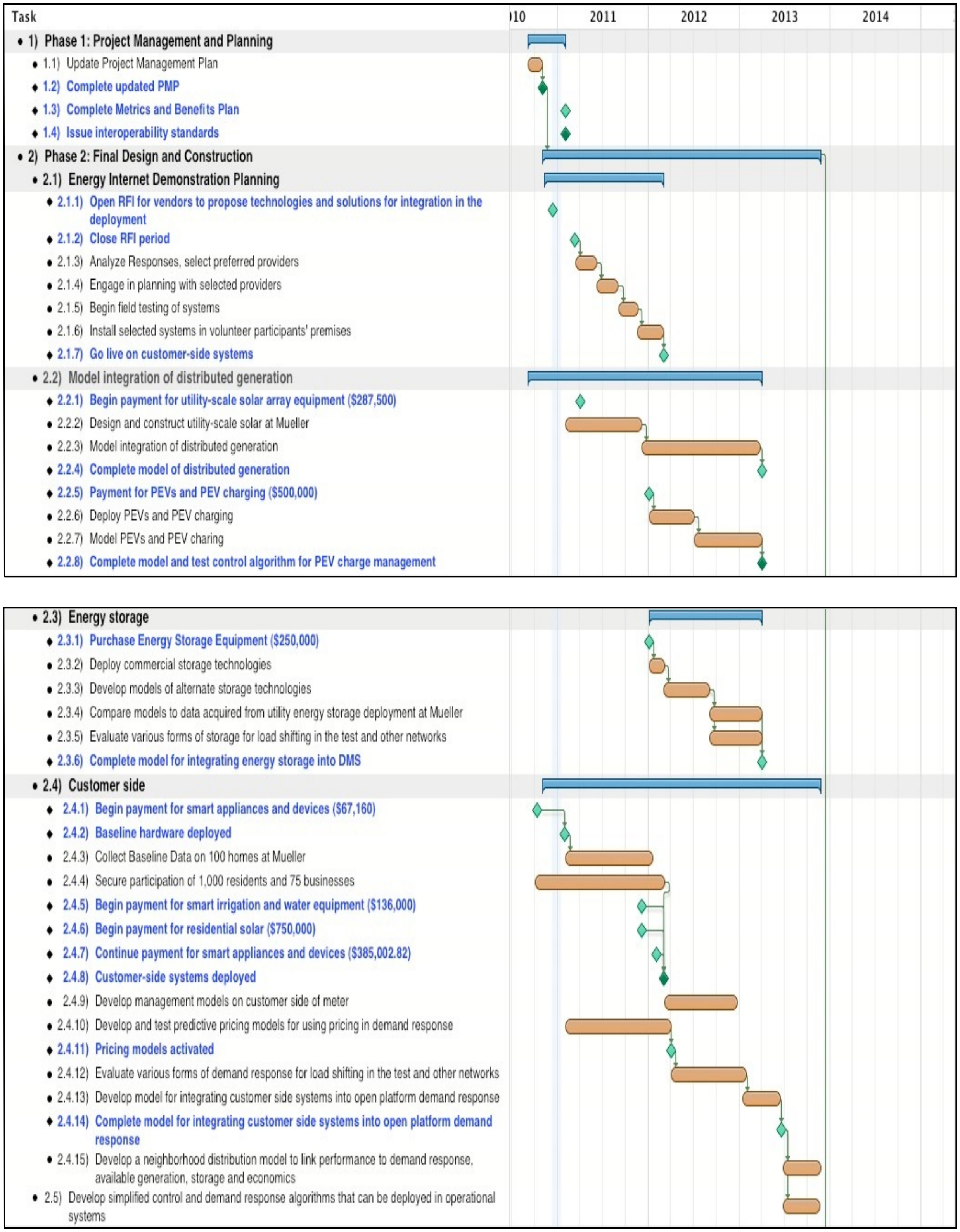
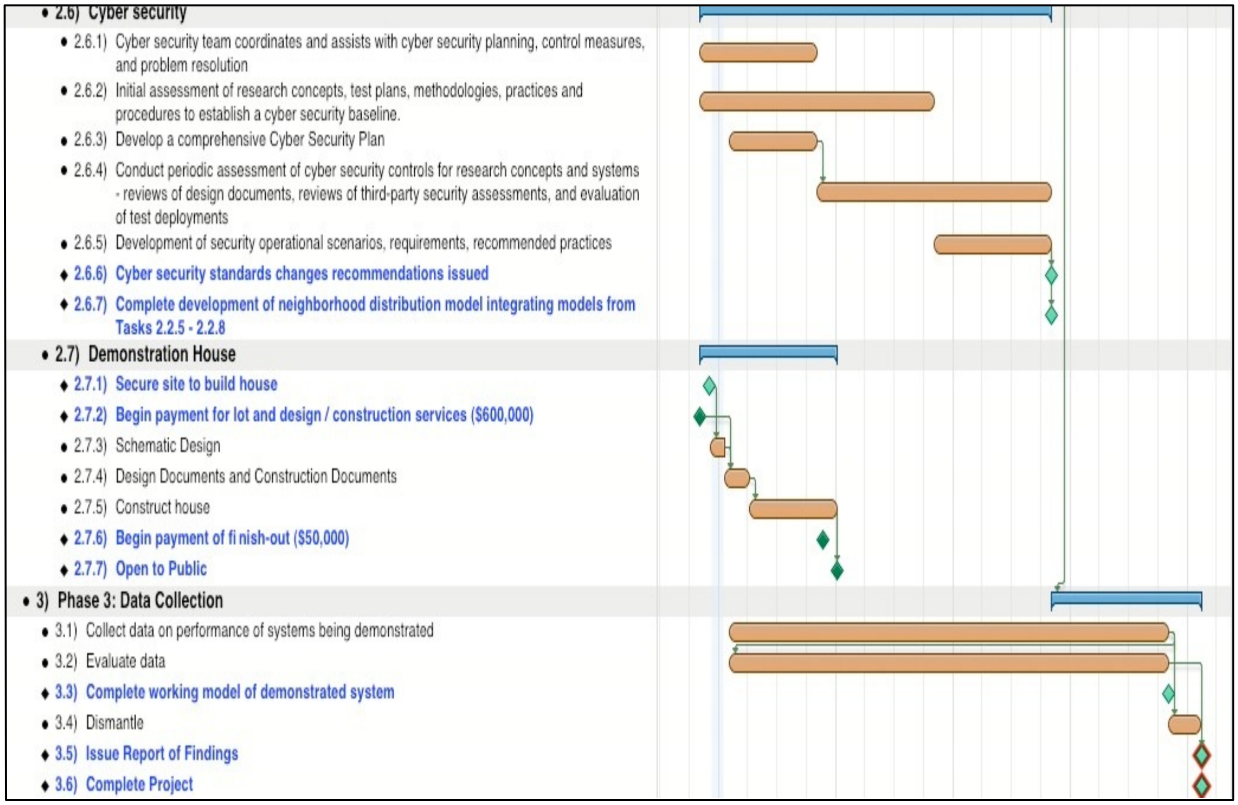
Appendix A: Pecan Street Integrated Schedule




2.6) Cyber security
2.6.1) Cyber security team coordinates and assists with cyber security planning, control measures, and problem resolution
2.6.2) Initial assessment of research concepts, test plans, methodologies, practices and procedures to establish a cyber security baseline.
2.6.3) Develop a comprehensive Cyber Security Plan
2.6.4) Conduct periodic assessment of cyber security controls for research concepts and systems - reviews of design documents, reviews of third-party security assessments, and evaluation of test deployments
2.6.5) Development of security operational scenarios, requirements, recommended practices
2.6.6) Cyber security standards changes recommendations issued
2.6.7) Complete development of neighborhood distribution model integrating models from Tasks 2.2.5 - 2.2.8
2.7) Demonstration House
2.7.1) Secure site to build house
2.7.2) Begin payment for lot and design / construction services ($600,000)
2.7.3) Schematic Design
2.7.4) Design Documents and Construction Documents
2.7.5) Construct house
2.7.6) Begin payment of fi nish-out ($50,000)
2.7.7) Open to Public
3) Phase 3: Data Collection
3.1) Collect data on performance of systems being demonstrated
3.2) Evaluate data
3.3) Complete working model of demonstrated system
3.4) Dismantle
3.5) Issue Report of Findings
3.6) Complete Project

Appendix B1: Metrics Information

Metric	Remarks	Project Value	System Value	Data Collection Method
End-Points (meters)		Yes	Yes	Batch files sent to Pecan St. from Austin Energy
Portion of Customers with AMI				
Residential	100%	Yes	Yes	Verbal confirmation from Austin Energy
Commercial		Yes	Yes	Verbal confirmation from Austin Energy
Industrial	No industrial customers on Mueller distribution feeder.	No	No	
Metering Features				
Interval Reads of 1 Hour or Less		Yes	Yes	Summary reports from Austin Energy
Remote Connection/ Disconnection		Yes	Yes	Summary reports from Austin Energy
Outage Detection/ Reporting		Yes	Yes	Summary reports from Austin Energy
Power Quality Monitoring		Yes	Yes	Summary reports from Austin Energy
Tamper Detection	Austin Energy distribution team will follow-up	Yes	Yes	Summary reports from Austin Energy
Backhaul Communications Network		Yes	Yes	Summary reports from Austin Energy

Metric	Remarks	Project Value	System Value	Data Collection Method
Meter Communications Network		Yes	Yes	Summary reports from Austin Energy
Headend System	Austin Energy distribution team will follow-up.	Yes	Yes	Summary reports from Austin Energy
Meter Data Management System		Yes	Yes	Summary reports from Austin Energy
Meter Data Analysis Systems		Yes	No	Summary reports from Austin Energy
Enterprise Systems Integration				
Billing		Yes	Yes	Middleware interface to Austin Energy back office systems
Customer Information System		Yes	Yes	Middleware interface to Austin Energy back office systems
Outage Management System	Not a new functionality	Yes	Yes	Middleware interface to Austin Energy back office systems
Distribution Management System		Yes	No	Middleware interface to Austin Energy back office systems

Appendix B2: Build Metrics

Build Metrics data on SmartGrid.gov:

https://www.smartgrid.gov/project/pecan_street_project_inc_energy_internet_demonstration/latest_data

Customer Systems Assets

Metric	Remarks	Project Value	System Value	Data Collection Method
Home Area Network	Typically cable modem or digital broadband	YES	YES	Wireless comm. through gateway
In-Home Displays		YES	YES	Survey data
Web Portal		YES	YES	Web analytics
Energy Management Devices/Systems		YES	YES	Wireless comm. through gateway
Direct Load Control Devices		NO	NO	
Programmable Controllable Thermostat		YES	YES	Wireless comm. through gateway
Smart Appliances		YES	YES	Wireless comm. through gateway
Other Customer Devices	Pecan Street will integrate water, electric vehicle, natural gas and possibly storage management functionality into home area networks, in-home displays, web portals, energy management devices and possibly load control devices.	YES	YES	Wireless comm. through gateway Surveys

Pricing Programs

Metric	Remarks	Project Value	System Value	Data Collection Method
Flat		YES	NO	HEMS data collection; syncing with meter data
Flat with Critical Peak Pricing		NO	NO	HEMS data collection; syncing with meter data
Flat with Peak-Time Rebate		YES	NO	
Tier		YES	NO	
Tier with Critical Peak Pricing		YES	NO	
Tier with Peak-Time Rebate		YES	NO	
Time-of-Use		YES	NO	
Variable Peak Pricing		NO	NO	
Time-of-Use with Critical Peak Pricing		YES	NO	
Time-of-Use with Peak-Time Rebate		NO	NO	
Real-Time Pricing		NO	NO	
Real-Time Pricing with Critical Peak Pricing		NO	NO	

Metric	Remarks	Project Value	System Value	Data Collection Method
Real-Time Pricing with Peak Time Rebate		NO	NO	
Pre-Pay Pricing		YES	NO	
Net Metering	Net metering is no longer used at Austin Energy.	NO	YES	
Rate Decoupling	All pricing trials will have rate decoupling.	YES	NO	
Other Programs	Pecan Street: Peer info; possibly an electric vehicle rate; bandwidth--based tier pricing; incentive--based approaches to peak shaving Austin Energy: demand response and energy efficiency rebates.	YES	YES	

Appendix C: Impact Metrics

AMI and Customer Systems

Metrics related primarily to economic benefits

Metric	Remarks	Project Value	System Value	Data Collection Method
Hourly Customer Electricity Use		YES	N/A	AMI systems, gateway, Austin Energy
Monthly Customer Electricity Use		YES	N/A	AMI systems, gateway, Austin Energy
Peak Generation and Mix		YES	YES	Austin Energy will provide this info
Peak Load and Mix		YES	YES	Austin Energy will provide this info
Annual Generation Cost		NO	NO	
Hourly Generation Cost		NO	NO	
Annual Electricity Production		YES	YES	Austin Energy will provide this info
Ancillary Services Cost		NO	NO	
Meter Operations Cost	Functionality already present	NO	N/A	
Truck Rolls Avoided		NO	N/A	

Metrics related primarily to environmental benefits

Metric	Remarks	Project Value	System Value	Data Collection Method
Meter Operations, Vehicle Miles		NO	N/A	
CO2 Emissions		YES	NO	eGRID database, UT and EDF researchers
Pollutant Emissions (SOx, NOx, PM--2.5)		YES	NO	

Metrics related primarily to AMI system performance

Metric	Remarks	Project Value	System Value	Data Collection Method
Meter Data Completeness		NO	N/A	
Meters Reporting Daily by 2AM		NO	N/A	

Customer metrics

Metric	Remarks	Project Value	System Value	Data Collection Method
Reduced Vehicle Miles		YES		Research strategies that will enable rapid adoption of electric vehicle s to accelerate reduction in oil dependence.

Metric	Remarks	Project Value	System Value	Data Collection Method
Deferred Distribution Capacity Investment		YES		Aggregated generation and consumption data from customer side used to demonstrate distribution investment avoidance

Impact Metrics

Metric	Remarks	Project Value	System Value	Data Collection Method
Annual Storage Dispatch	kWh	YES	NO	
Average Energy Storage Efficiency	%	YES	NO	