Pacific Gas and Electric Company

EPIC Final Report

Program	**Electric Program Investment Charge (EPIC)**
Project	**EPIC 1 Project 18 – Demonstrate SmartMeter™-Enabled Data Analytics to Provide Customers With Appliance-Level Energy Use Information**
Department	*Customer Care*
Business Lead	Anh Dong
Project Sponsor	Maril Wright
Contact	EPIC_info@pge.com
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Executive Summary

SmartMeter™ data could potentially enable a valuable opportunity to provide insight and actionable recommendations to customers to help better manage their energy bills. By providing customers with an energy management tool that allows them insight into how they use energy, including operating cost information for their major appliances, they can proactively manage their bill and save money. This type of information could help customers understand appliance usage or inspire them to upgrade to more efficient technologies. In addition, if these consumers were on a time-of-use rate plan, understanding the energy usage of their appliances could provide a basis by which they could decide to implement some time-shifting usage. Pacific Gas and Electric Company's (PG&E's) SmartMeter™ platform provided the foundation for this project, which was funded by PG&E's Electric Program Investment Charge (EPIC). Regulators and energy suppliers perceive this information as an opportunity to help consumers understand and manage their energy consumption behavior or even diagnose inefficiencies or equipment failures.

Project Objectives

In order to assist with this information gap noted above, this project set out to achieve the following objectives:

1. Demonstrate appliance-level itemization of monthly bill charges for residential customers;
2. Assess and compare the current analytical capability and accuracy of energy disaggregation software; and
3. Understand customer perception of the end-use cost presentations and the value of the disaggregated data.

Project Methods

For a period of six months, the SmartMeter™ was reconfigured on approximately 500 sample homes to provide energy demand data in one-minute intervals, instead of the one-hour interval data PG&E typically collects for residential customers. PG&E selected three disaggregation software vendors for the study and provided them access to the anonymized one-minute interval data from the SmartMeter™ platform. The project consisted of two tests. The first test gauged customer receptivity and the second tested vendor accuracy. For the first test, each vendor provided the participating customers with a dashboard of the disaggregated results for their home. The second test was done by installing power-monitoring equipment within the home and comparing the vendors' modeled results to the known appliances as identified by the power monitoring data. A third party evaluated the three vendors' disaggregation results. A subset of the sample was used as a control group to validate the quality of vendor disaggregation results by the third party evaluator.

To evaluate customer perception of the information and reporting formats, as well as the presentation of the information and the usefulness of the information in influencing individual behavior, PG&E surveyed project participants in three ways:

1. An initial online survey of participants conducted shortly after the initiation of the customer acquisition;
2. A qualitative evaluation of participants' mid-project attitudes and experiences conducted through a series of online focus groups; and

3. A final survey of participants conducted at the conclusion of the project.

Key Results

The key results of the assessment of the vendors' accuracy are:

- The vendors' algorithms had trouble distinguishing between the signals of some similar devices, such as washers and dishwashers.
- Not all end uses, particularly smaller energy using appliances, can be accurately monitored and measured.
- Even with detailed end-use information, disaggregation algorithms had difficulty accurately estimating energy use.
- Although project findings suggest disaggregation algorithms could not reliably estimate end-use energy, there were demonstrated strengths, which varied by vendor, that could be leveraged to better focus near-term efforts to potentially realize energy savings.

The overall surveys and customer evaluations indicated the following:

- Participants valued clear, easy-to-find, real-time, and accurate electricity usage costs for all major appliances and systems, which would be ideally broken out by the hour and refreshed daily, if not more often.
- Participants had a general lack of enthusiasm for both vendors' disaggregation reporting services. These reactions were driven by perceived failure of the technology to either accurately detect appliances or provide granular, near real-time data.
- Consumers did not modify their usage over the course of this study, but the study period was very brief (six months), and their perceptions remained consistent that appliance-level disaggregation would be useful in order to better understand their energy usage patterns to ultimately change their behavior and save energy and money.
- Feedback indicated consumers were not satisfied with the accuracy and detail of disaggregation, the timeliness of the disaggregated reporting,[1] and how the information was presented. For example, customers expected to view usage costs for both major and plug-load appliances;[2] however, this type of data for plug-level appliances is extremely difficult for current algorithms to recognize and differentiate. For the most part, the costs of running these appliances are low, and most vendors concentrate their solutions on higher cost appliances that consumers show propensity for reduction or usage shifting.

Lessons Learned and Conclusions

In the end, no vendor platform was able to accurately identify all of the appliance level categories in the study or meet the customers' expectations for real-time visibility into their appliance use. Each

[1] During this project, vendors only updated data once per day.

[2] Plug-load appliances are smaller, miscellaneous equipment that is usually plugged into an outlet and is not related to general lighting, heating, ventilation, cooling, and water heating. Plug loads include products like computers, printers, microwaves, blenders, etc.

disaggregation vendor had individual strengths that offer a range of opportunities based on specific end uses, which could ultimately set the stage for the development of a repository of end use signals for specific devices that could be recognized by various disaggregation algorithms.

While the identified learnings of this project will help advance industry knowledge of customer expectations for real-time visibility into their appliance use, the project's findings demonstrated that the load disaggregation technology that is currently available in the market is in need of further refinement. The end use device dataset that was built in this project can potentially be used in the future to assess the anticipated improvements to load disaggregation software. As utilities continue to pursue ways to help customers reduce their energy bills, this data can be used to assess future improvements to disaggregation technology.

1. EPIC Program Introduction

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this project. The CPUC initially issued D. 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level,*[3] which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued D. 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020,*[4] which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. D. 12-05-037 defined TD&D as "the installation and operation of pre-commercial technologies or strategies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments to enable appraisal of the operational and performance characteristics and the financial risks associated with a given technology."[5] D. 12-05-037 also required the EPIC Program administrators (PG&E, SCE, SDG&E, and the CEC) to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. In November 2015, D.13-11-025[6] approved PG&E's initial EPIC triennial investment plan application, A.12-11-003,[7] wherein PG&E proposed 26 EPIC projects for the first Triennial Investment Period. One of the 26 approved EPIC 1 projects was Project #1.18, Demonstrate SmartMeter™-Enabled Data Analytics to Provide Customers with Appliance-Level Energy Use Information, also referred to as "Residential Appliance-Level Load Disaggregation."

On November 1, 2012, in A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application at the CPUC, requesting $49,328,000 for 26 Technology Demonstration and Deployment Projects. On November 14, 2013, in D.13-11-025, the CPUC approved PG&E's EPIC plan and its request of $49,328,000 for this program category. Pursuant to PG&E's approved EPIC triennial plan, PG&E initiated, planned, and implemented the following project: Demonstrate SmartMeter™-Enabled Data Analytics to Provide Customers with Appliance-Level Energy Use Information. Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project. The following is PG&E's final report on this project.

2. Project Background

2.1 Issue/Problem Statement

PG&E has conducted numerous research projects with residential, Small and Medium Business (SMB), and agricultural customers to learn how best to engage customers with rate plans and energy management strategies. One such study, conducted in 2012, indicated that customers highly valued energy management tools that provided insight to customers about their energy usage of individual

[3] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF
[4] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF
[5] Decision 12-05-037 pg. 37
[6] http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M081/K773/81773445.PDF
[7] http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M031/K735/31735305.PDF

devices or appliances. Seventy-one percent of surveyed residential customers and fifty-five percent of surveyed SMB customers rated itemized billing as the highest value tool.[8]

In order to provide itemized billing, the utility must be able to identify or disaggregate the energy usage of appliances and other energy demands from the total energy bill. SmartMeters™ are believed to be capable of providing the data needed for appliance-level disaggregation if the usage is reported as output in short enough time intervals. Several disaggregation vendors claim they have proprietary software to accomplish this level of disaggregation into individual end uses without the need for an energy audit. If true, this would allow PG&E to provide customers with actionable insights into their energy use patterns in place of time-intensive energy audits. Ultimately, itemized billing, paired with targeted education campaigns, could help customers better understand and manage their specific energy use.

2.1.1 Project Overview and Objectives

This project was designed to evaluate the ability of commercial vendors to use PG&E SmartMeter™ data to accurately disaggregate energy usage for residential customers and to explore how to provide that information to customers meaningfully.

The three primary objectives for this project were to:

- Demonstrate commercial analytic capabilities to achieve end use load disaggregation using one-minute interval data captured by PG&E's SmartMeter™ platform;
- Evaluate the accuracy of the commercial disaggregation software and compare vendors' abilities to demonstrate appliance-level itemization of monthly bill charges using SmartMeter™ data as the inputs; and
- Gather insights from customers regarding individualized end-use cost presentations and the value of the disaggregated data. These insights will be used to develop a strategy for further deployment of appliance-level billing.

2.2 Project Scope

The project had two phases that were conducted concurrently. Phase 1 was a proof of concept test to assess and validate disaggregation technology using SmartMeter™-enabled data. Phase 2 was a customer evaluation of the effectiveness of the disaggregation reporting. Three vendors were selected by PG&E to participate in Phase 1, and two of the three vendors' reporting interfaces for consumers were included in Phase 2.[9]

Both phases involved the use of one-minute interval data collected by the PG&E SmartMeter™ platform. The project team collected electric energy data from a sample of approximately 500 PG&E SmartMeter™-enabled homes. The data collected was made available to three vendors who used proprietary end use disaggregation software to provide estimates of energy use by appliance type. The

[8] Itemized billing is the presentation of the bill by energy using appliances instead of just by energy consumption (kWh).
[9] One of the three vendors did not have web-based reporting and was not included in the customer project.

vendors were selected based on the presumed quality of their disaggregation tools. Each vendor analyzed the one-minute interval data provided to identify a set of end use appliances[10] and to estimate appliance-level energy consumption in each home on an hourly basis for a period of six months (November 2014 Test Period through April 2015 Final Reporting).

This project specifically required one-minute interval electric usage data. Because one-minute interval data is not currently available via PG&E's SmartMeter™ platform, the configuration of each SmartMeter™ in the sample was modified to collect the necessary interval data.

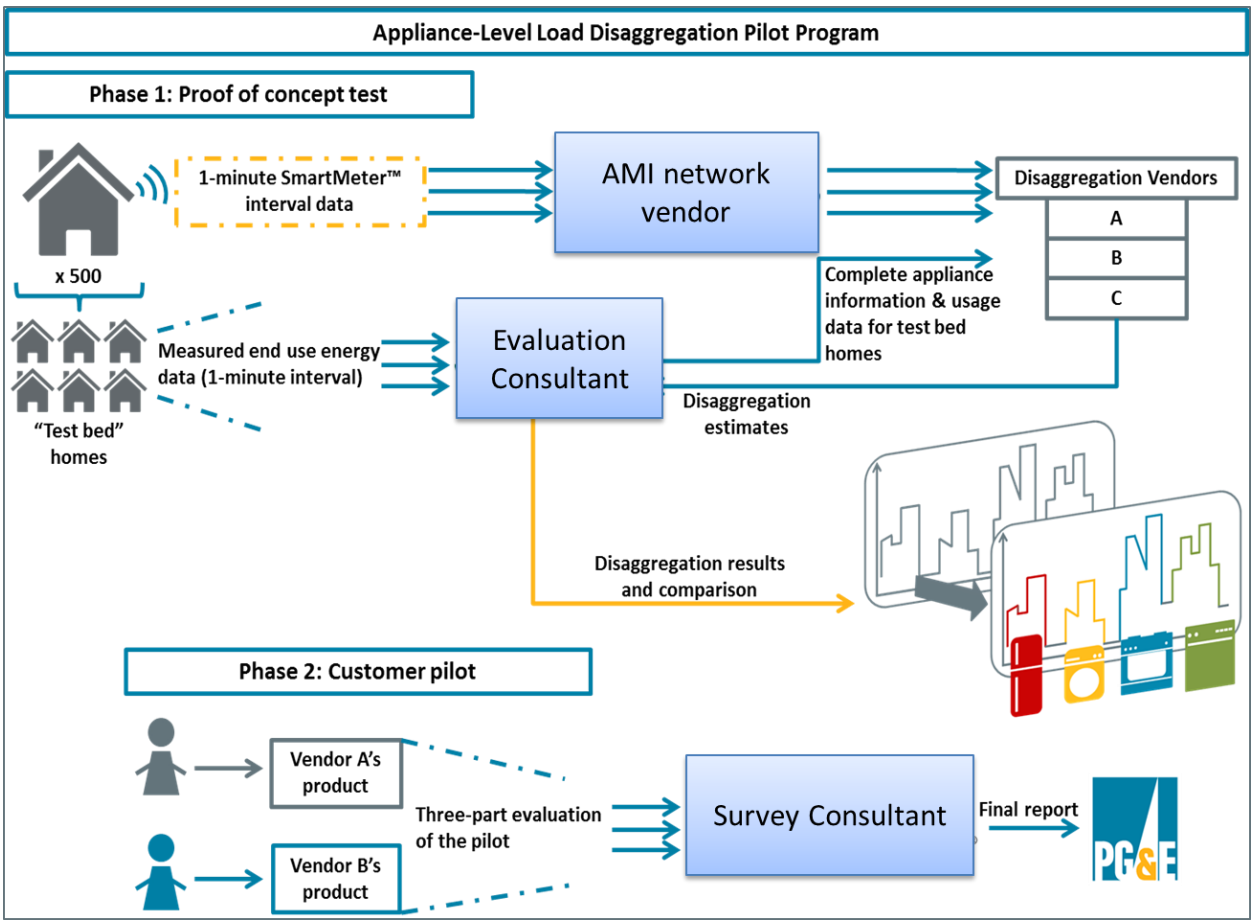
Embedded within the sample of approximately 500 homes were six "test bed" homes. PG&E's vendor installed extensive monitoring equipment (e.g., plug load energy monitors, wireless data collection, and transmission devices) in the six "test bed" homes to measure actual electric use data at one-minute intervals. For each of the six test bed homes, the monitoring equipment provided appliance-level usage for PG&E's defined end uses. This test bed data was collected and maintained by an external evaluation consultant. The evaluation consultant compared the usage data with the disaggregation results from each vendor to verify the accuracy of each vendor's disaggregation algorithms.

In Phase 2, PG&E asked a portion of the approximately 500 program participants to evaluate and provide feedback on disaggregation reporting and the usefulness of the data. A majority of the participants also have access to their billing and usage data through PG&E's "My Account" web portal. These My Account participants were also asked to provide feedback comparing the PG&E My Account web portal to their vendor's presentation of the data. The customers' experiences were evaluated through two online surveys, one at the beginning of the project and one at the end, in addition to a mid-point deeper insights focus-group discussion online.

Figure 1 illustrates the high-level activities that were undertaken in the process of the Appliance-Level Load Disaggregation program.

[10] The project team defined a list of 14 end uses for the vendors to identify (see Table 1).

Figure 1: Diagram of Appliance-Level Load Disaggregation Key Program Activities



2.3 Project Tasks, Milestones and Deliverables

There were five major tasks associated with this project:

1. **Establish test bed homes:** This task established six test bed homes that had monitoring systems installed to measure actual one-minute interval use data at the end use devices. The identities of the test bed homes were unknown to the vendors, and their one-minute data was embedded in the regular feeds of total electric usage from the approximately 500 sample homes. This created a blind test to avoid human intervention or evaluation of appliance usage patterns without the need for an algorithm. The actual monitoring data collected from the six test bed homes by the Evaluation Consultant were compared to the vendors' disaggregation results.
2. **Provide one-minute interval data to vendors:** This task required reconfiguring the SmartMeters™ of the project homes and configuring backend processes to collect and store one-minute interval electric data to be transferred to the three vendors.
3. **Disaggregate data using commercially available software:** For a subset of the homes, this task tested the abilities of three vendors to successfully disaggregate electric use data for each of the sample homes into the PG&E categorized end uses. This disaggregated information was submitted to the Evaluation Consultant via an Application Program Interface (API).

4. **Evaluate the accuracy of the disaggregation results:** For this task, the Evaluation Consultant compared the vendor's disaggregation estimates (calculated using the one-minute interval data from the SmartMeter™ platform) to the actual measured data collected by the end use monitors in the six test bed homes. The vendors' accuracy was evaluated using a number of comparison and assessment metrics.
5. **Gather and evaluate feedback from project participants:** A subset of the sample homes was provided access to the vendors' websites and encouraged to review the disaggregation estimates for their homes. This group was offered the opportunity to participate in a series of two online surveys and an online focus group to provide feedback about the vendors' reporting services and the overall usefulness of the disaggregation data.

The project had four major milestones:

1. **Collection of data from test bed homes:** This milestone included the selection of the test bed homes, the installation of the end use monitoring system, the collection and transmission of monitoring data from the homes to a reporting format accessible to the Evaluation Consultant , and the provision of the one-minute interval data to the Evaluation Consultant. The Evaluation Consultant compared the meter data for the six test bed homes to the monitoring data they collected for verification purposes. The collected meter data was provided in the Evaluation Consultant's report titled, "PG&E's End Use Monitoring Test Bed," dated May 21, 2015. A copy of this report is in Appendix A.
2. **Disaggregation of data using commercial software:** The deliverables for this milestone included the monthly disaggregation results for approximately 500 homes. The results were provided to the Evaluation Consultant and customers via the online reporting platforms offered by the two disaggregation vendors.
3. **Evaluation of disaggregation results against test bed homes:** This milestone included the completion of monthly comparisons of the test bed end use energy data with the vendors' disaggregated results. This was delivered in the Evaluation Consultant's report titled, "PG&E's End Use Monitoring Test Bed," dated May 21, 2015 (see Appendix A).
4. **Evaluation of feedback from customer project participants[11]:** This milestone included the completion of two online surveys and a series of online focus groups to gather feedback on the participants' experiences with the vendors' disaggregation reporting tools, including the value of the usage information provided. The deliverables were three reports provided by an external surveying vendor: (1) "EPIC Appliance Disaggregation Demonstration Phase 2, Report on the Initial Survey", dated January 26, 2015 (Appendix B); (2) "EPIC Appliance Disaggregation Demonstration Phase 2, Report on the Qualitative Research", dated February 19, 2015 (Appendix C); and (3) "EPIC Appliance Disaggregation Demonstration Phase 2, Report on the Final Survey", dated June 10, 2015 (Appendix D).

[11] Because the project was small and the program only ran for a brief period, it was not possible to conduct a formal, robust evaluation of the behavior change and energy reduction that potentially could have been realized.

3. Project Results and Key Findings

3.1 Technical Findings

3.1.1 Development of End Use Categories

During the project timeline, no industry standards defining end uses existed; each of the three disaggregation vendors had their own end use definitions. For the first phase of the project, PG&E and the Evaluation Consultant developed their own standard to categorize end uses and required the vendors to estimate usage against this standard. Table 1 shows the 14 disaggregation end uses defined for this project.

Table 1: Disaggregation and Detailed End Uses Defined by PG&E[12]

Category #	Category Name
1	**Space heater** *Room space heater* *Central space heater*
2	**Air conditioner** *Room air conditioner* *Central air conditioner*
3	**Domestic water heater**
4	**Pool / spa heater**
5	**Light**
6	**Refrigerator / Freezer**
7	**Cooker**
8	**Clothes dryer**
9	**Clothes washer**
10	**Dish washer**
11	**Electric vehicle**
12	**Spa / pool pump**
13	**Other pump**
14	**Other** *Audio / visual system* *Television* *Set-top box / DVR* *Game console* *Computer / accessory* *Other*

[12] Detailed end uses under a specific category are presented in *italics*.

3.1.2 Definition of the Data Collection Protocol

The project was designed to meet the three objectives (see Section 2.1.1), which required a high degree of confidence in the quality of the data collected. The data was collected from PG&E's existing SmartMeter™ platform by PG&E's AMI network provider between November 1, 2014 and April 15, 2015 and made available to the three vendors via an API.

3.1.3 Selection of Test Bed Homes

The Evaluation Consultant assisted PG&E in the selection of six test bed homes. These six test bed homes were selected from a group of 37 recruited homes[13] that had PG&E electric and gas service. A number of the test bed candidate homes were initially rejected because they had safety, monitoring, or other issues impacting eligibility, such as:

- Installed solar photovoltaic (PV);
- Combined space and water heating; and
- Home remodeling plans.

After the initial screening, nine finalists were asked to send in photos of their homes' electric panels and other information. The Evaluation Consultant and its sub-contractors completed device/circuit inventories for the nine homes, selecting the final six test-bed homes based on a variety of technical and cost factors. The selection of the final test bed homes emphasized including as many different and duplicated appliances (e.g., multiple refrigerators) in the test bed as possible.

Upon selecting the final six test bed homes, the Evaluation Consultant and its sub-contractors installed monitoring systems in each home. The monitoring system collected: (1) total energy use at one-minute intervals and (2) one-minute interval electricity use for each of the individual electric devices and appliances needed to disaggregate electric end uses (Table 1) and (Table 3) gas end use at one-minute intervals.[14] The overall system consisted of:

- The installation of an additional electrical box adjacent to the circuit/fuse box in which the overall monitoring equipment was installed. This included installations of current transformers (CTs) on the mains in the primary breaker panel (to collect total energy usage at one-minute intervals);
- Power monitoring of each circuit in the primary breaker panel (including feeds into subpanels, as needed) and installations of plug load energy monitors on individual electric devices, as needed (to collect electric end use at one-minute intervals); and

[13] These 37 homes were not part of the initial approximately 500 volunteer homes. Instead, they were separately recruited and then added to the group of electric meter data access participants when the test launched.

[14] The Evaluation Consultant and their sub-contractors collected gas usage data for the six test bed homes; however, there were no vendors offering disaggregation products for gas usage at the time of the study. To reiterate, the collection and use of gas data was not funded by EPIC.

- Installation of gas meters on individual appliances (to collect gas end use at one-minute intervals).

The monitoring systems collected approximately 100 separate installation measurements for each test bed home. The Evaluation Consultant used wireless networks connected to multi-protocol controllers to upload data to a web portal every minute via a cellular connection. The data was then transferred to a permanent data storage system every day. All of the end use data was collected for a full year from the period of November 1, 2014 through October 31, 2015. After that, four of the homeowners took the option to take possession of the monitoring equipment. The Evaluation Consultant removed the equipment in the other two homes. The year's collection of gas and electric monitoring data will be available for use in other potential applications or to help disaggregation vendors further develop and refine their algorithms.

3.1.4 Verification of the Data Collected

To meet the objectives of the project, it was necessary to obtain energy usage data from the SmartMeter™ platform in one-minute intervals. To achieve this, PG&E's AMI Network provider reconfigured the SmartMeters™ for approximately 500 sample homes. The sample homes included:

- 370 randomly selected high usage homes throughout PG&E's service territory;
- 131 homes recruited through PG&E's network of employees, vendors, and contractors, representing a variety of home sizes, energy usage profiles, and appliance types; and
- Six test bed homes that were monitored to measure actual minute-level energy usage of the PG&E categorized end uses within the home.

The 131 homes (recruited through PG&E's network of employees, vendors, and contractors) were assigned to websites hosted by two vendors so that participants could track their appliance level costs and usage. The third vendor did not participate in the website portion of the project because it did not have a web-based application at the time of the project.

The Evaluation Consultant also performed regular verification testing for abnormally high values, missing values, repeated values, and check-sums. Any verification problems identified were resolved by contacting PG&E's AMI network provider. The Evaluation Consultant compared the sum of measured hourly end use (kWh) to the provided meter total. Any measured hourly values with a variance greater than 10% from the available meter data were not included in the accuracy comparisons for that month's reporting period. Sixty-nine percent of the measured end use data fell within the threshold of allowing reliable comparisons of disaggregation estimates.

3.1.5 Evaluation of Vendor Accuracy

Each vendor used the one-minute interval data and its proprietary disaggregation algorithm to identify end uses in each home and the energy consumed by each end use device on an hourly basis. First, vendors were given a month long calibration period in November 2014 to test and improve their algorithms. Concurrently, the vendors, PG&E's AMI Network vendor, and the Evaluation Consultant also tested their processes for data collection and submission.

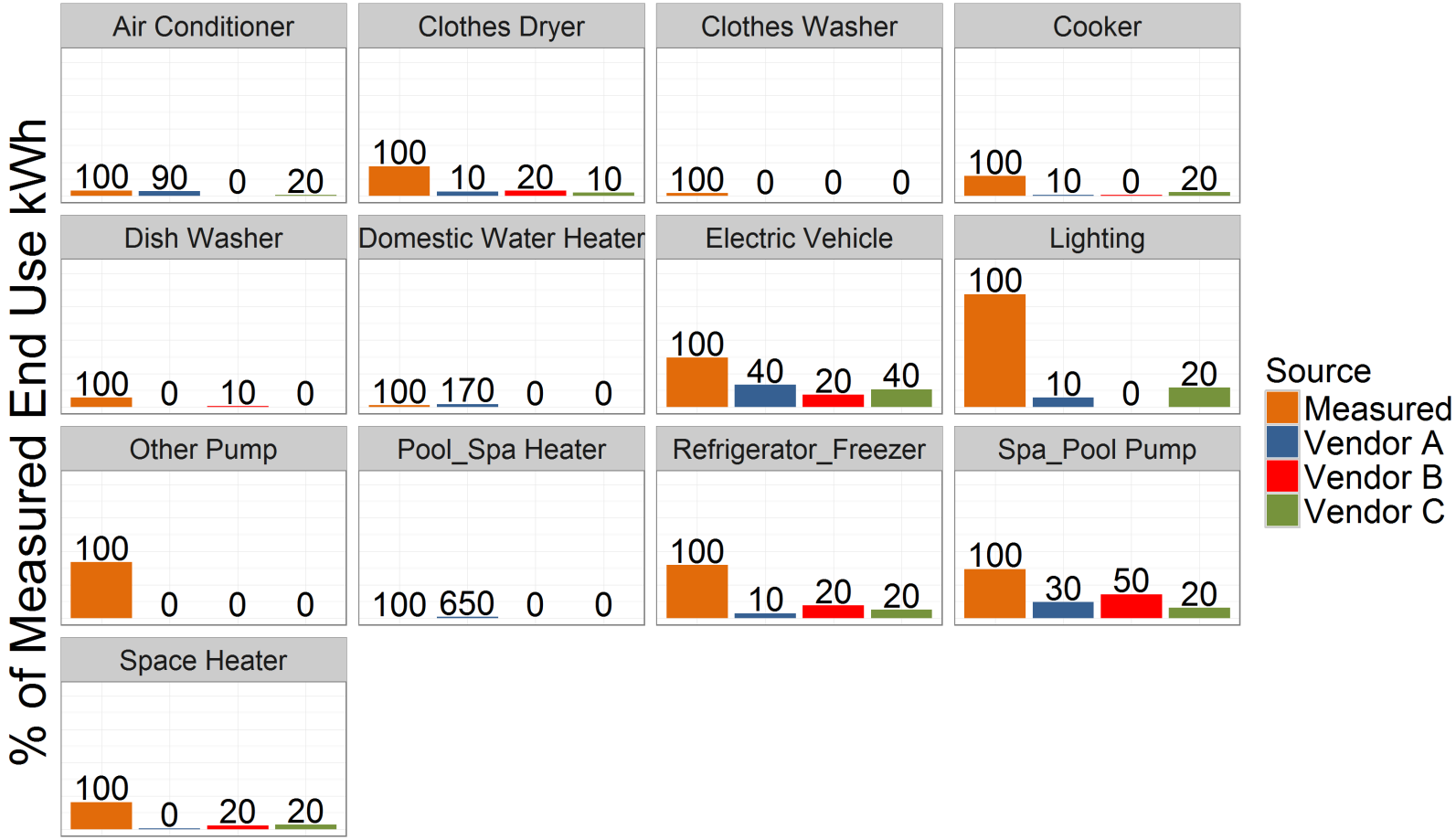
The disaggregation vendor evaluation started in December 2014. At the end of each month in the test period (December 1, 2014–April 15, 2015), each vendor submitted estimates of hourly usage for all end use categories for each home in the sample. The Evaluation Consultant processed the vendor's estimates for the six unidentified test bed homes within the sample and compiled a comparison report that was reviewed by the PG&E project management team. Because of the learning period described above, the November disaggregation results were not used for the evaluation. The disaggregation vendors were subject to this blind test for a period of six months.

The Evaluation Consultant's monthly summary report contained each vendor's performance against the accuracy metrics and its performance compared to the remaining two vendors. Figure 2 shows a comparison of the average measured electricity usage for each end use in the six test bed homes versus the average estimates from each vendor's disaggregation software over the entire test period.

Overall, none of the vendors were able to identify all 14 PG&E end use categories, though each demonstrated different identification capabilities and strengths. Other notable results from the proof of concept test shown in Figure 2 are the following:

- All vendors were able to correctly identify the presence of the refrigerator/freezer end use. However Vendor C's estimates were most consistently accurate, relative to the actual measured usage.
- Vendor A incorrectly identified the presence of both a water heater and pool/spa heater at five of the six test bed homes. If it correctly identified their presence, the estimated usage was much larger than the measured value.
- None of the vendors identified the presence of the "other pump" that was present at one of the six test bed homes;
- Only Vendor A correctly identified the presence of the dishwasher in all of the homes. However, the estimated usage was much smaller than the actual measured usage for four of the six homes.
- Vendor B was unable to identify lighting end uses at any of the test bed homes.
- Vendor C's estimates most closely matched the actual measured usage at all of the test bed homes.
- Vendor A was the only vendor to correctly identify all three instances of an electric vehicle (Vendors B and C were able to identify one of the three), and its usage estimates were close to the actual measured usage, except for one home where Vendors B and C estimated usage more accurately.
- Vendor A correctly identified the three instances of air conditioning. However, two of the three estimates were much lower than actual measured usage, and it misidentified air conditioning signals at the other three homes.
- Vendor B correctly identified two of the three instances of air conditioning, but its estimates were the most accurate relative to actual measured usage. Vendor C correctly identified one instance of air conditioning usage, but its estimate was much larger than the actual measured usage while it misidentified air conditioning signals at two additional homes.

Figure 2: Measured vs. Disaggregation Estimate Results by Site for December 1, 2014 – April 15, 2015



The three vendors were evaluated based on their ability to estimate energy consumption across the 14 end uses defined by PG&E (Table 1). The vendors were initially evaluated on the following metrics:

1. Number of best accuracy rankings (i.e., the number of end uses in which the vendor had the highest accuracy rating);
2. Number of measured uses that were not reported for any site (i.e., the number of end uses the vendor's algorithm failed to report); and
3. Number of site usage reported when no measured usage (i.e., the number of false readings generated or false positives).[15]

Table 2 summarizes the average scores of each vendor over the test period prior to the vendors' knowledge of any information from the six test bed homes.

Table 2: Energy Disaggregation Vendor Scores from December 1, 2014 to March 2015

	1. Number of best accuracy rankings – score out of 14	2. Number of measured uses that were not reported for any site (of 14 – lower # is better)	3. Number of site usage reported when no measured usage (max 84 – lower # is better)
Vendor A	3	1	17
Vendor B	6	0	1
Vendor C	5	5	3

Key:
Best Performance
Worst Performance

Overall, none of the vendors were able to identify all 14 PG&E end use categories, though each demonstrated different identification capabilities and strengths. Vendor A achieved fewer best accuracy rankings and generated the most false positives. Vendor B neither missed any end uses nor falsely identified any end uses that were not present. Vendor C achieved the best accuracy ranking for the most number of end uses (6 out of 14) it identified, but failed to identify the most end uses that were actually present in the household (5 out of 14).

After data collection in March was complete, the vendors were given the identities of the six test bed homes and access to the appliance surveys completed by the Evaluation Consultant. The detailed data included a list of all end use appliances being monitored in that particular house. The vendors used the data to re-calibrate their usage estimates for the month. Table 3 shows how each vendor scored against the four initial metrics after recalculating usage estimates using information from the six test bed homes.

[15] E.g., a vendor that reported five additional end uses that weren't actually in the house would receive a score of 5 for this category

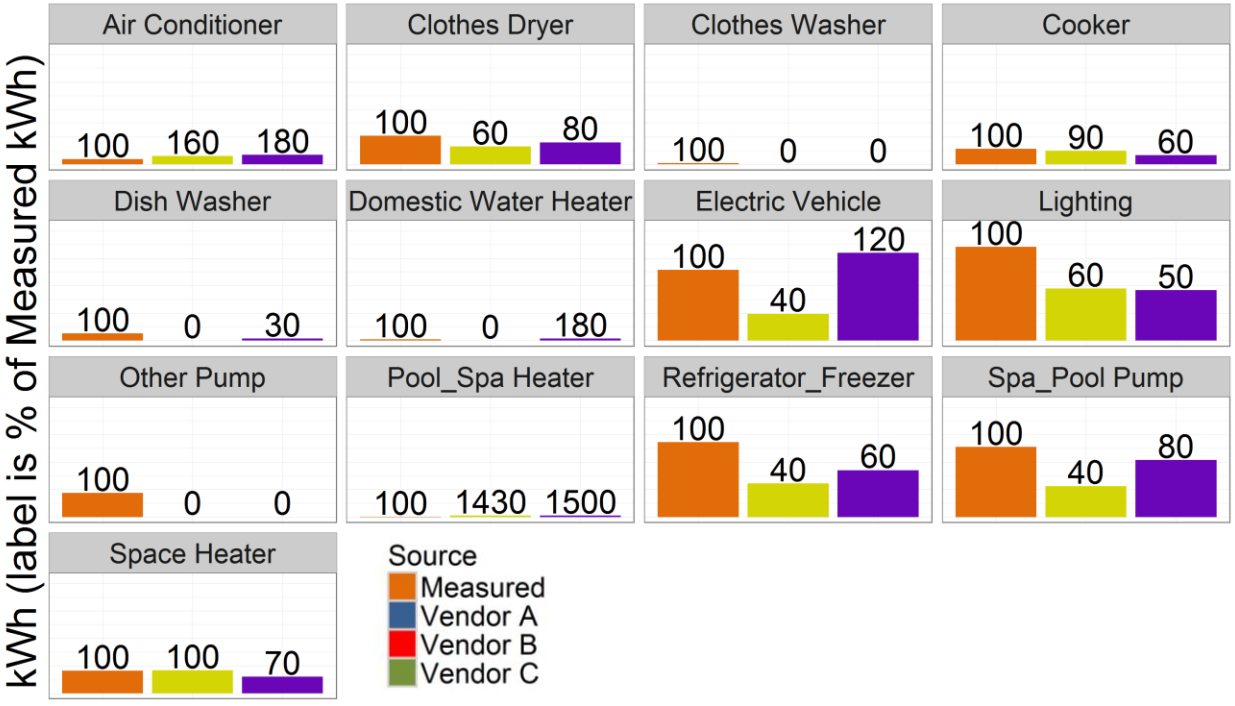
Table 3: Energy Disaggregation Scores for March 2015—Post Data Release

	1. Number of best accuracy rankings – score out of 14	2. Number of measured uses that were not reported for any site (of 14 – lower # is better)	3. Number of site usage reported when no measured usage (max 84 – lower # is better)
Vendor A	3	2	17
Vendor B	5	4	1
Vendor C	4	6	3

Key:
Best performance
Worst Performance

Figure 3 visualizes the results after the March re-run, when the vendors were provided the appliance and residential profiles of the test-bed homes.

Figure 3: March 2015 Post-Data Release of Disaggregation Results with Appliance Survey Data



Having the complete information on the appliances and residential profiles of each of the six test bed homes did not enable any of the vendors to identify all 14 end uses of interest. However, Vendors A and C made improvements from their initial estimates for March. Vendor A generated one less false positive (score of 16 from 17 after the data release) and achieved best accuracy in one additional end use category. Vendor C also improved regarding false positives and generated none after the data release. Vendor B added more appliances to its disaggregation algorithm, resulting in Vendor B identifying more

appliances than it did previously. Despite the inclusion of actual appliance and residential profile information, the estimates were still inaccurate.

In addition to assessing overall disaggregation performance across all 14 end uses, each vendor's accuracy for the top five defined energy end uses[16] was evaluated (from largest to smallest). The top five end use categories represent just over 50% of all measured electricity use for the test period.

Additionally, the vendors' disaggregation estimates were compared by site (i.e., by test bed home). Vendor performance was assessed by comparing the percent difference between the vendor's estimate of end use (kWh) and the measured kWh. Table 4 shows the results of this percent difference comparison for all end uses of interest by site.[17]

Table 4: Percent (%) difference of vendor estimated kWh and measured kWh by site

Site	Vendor A	Vendor B	Vendor C
13	-34%	14%	-365%
21	1%	-219%	-110%
27	-1%	-25%	-79%
32	15%	-34%	-50%
40	-1957%	-4080%	-12861%
45	-626%	-381%	-298%
Average of Rankings	**1.5**	**2.0**	**2.5**

3.1.6 Evaluation of Participant Feedback on Disaggregation Reporting

Phase II of the project sought to evaluate the customer experience with the disaggregation products and reporting services:

- **What customers experienced:** Perceptions regarding disaggregated consumption data, what it was like for them
- **What customers did:** Accessing online data displays via the vendor's website, actions taken in response to that, including the disaggregated cost and usage data
- **What customers thought and felt about the project:** Satisfaction with the technology, software, data, and overall program

The 131 residential participants in this phase were assigned to one of the two vendors with a reporting website. Of the 131 customers recruited, 50 participated in the survey. The survey was completed by 29 participants assigned to Vendor A and 21 participants assigned to Vendor B. Participants also assessed

[16] The largest end use category (by magnitude) was "Other", which encompasses any energy end use not otherwise defined. "Other" accounted for approximately 37% of total energy consumption, but was highly varied across the test bed homes and was therefore not viable to assess across the three vendors. Therefore, the top five end uses that were evaluated included: lighting, refrigerator/freezer, electric vehicle, spa/pool, pump, and clothes dryer

[17] The percent differences for all end uses calculated by a vendor were averaged together to give an approximate measure of accuracy by site.

their preference for the PG&E My Account web portal relative to their assigned vendor. An external vendor was contracted to conduct a three-part customer evaluation, which included:

- **Part 1:** An initial online survey of participants conducted shortly after the initiation of the customer acquisition to assess the ease of enrollment;
- **Part 2:** A qualitative evaluation[18] of participants' mid-project attitudes and experiences conducted through a series of online focus groups; and
- **Part 3:** A final survey of participants conducted at the conclusion of Phase 2 (Spring 2015) to assess customer receptivity of the disaggregation results.

The two vendors who had web-based applications did not make any changes to their normal websites. This means that the appliances requested for the disaggregation reporting in the Proof of Concept test did not match the appliances reported on the two vendors' websites and there were fewer appliances presented through the vendors' current web offerings. Customers preferred to view costs for more appliances.

The surveys focused on testing customers' responses to the concept of reporting services at an end use level. The surveys did not focus on testing user interface of reporting websites.

Initial Online Survey Results

The initial online survey found that customers had an overall positive experience with both vendors' disaggregation reporting tools. Vendor A was rated more favorably on all evaluated attributes (e.g., visual appeal, ease of understanding energy usage, etc.). A list of the attributes evaluated by the external vendor can be found in Appendix B. Additional results from the initial online survey includes the following:

- 65% of participants logged on less than once per week since joining the program;
- Four out of ten project participants (39%) rated the disaggregated energy use detection as accurate and three quarters of participants (78%) believed that usage of some devices were not being accurately detected;[19]
- During their last log-in, the majority of participants spent 1-5 minutes on their disaggregation websites;
- Overall, project participants would prefer to be provided with both energy usage and energy cost data for appliances being detected by the disaggregation technology;

[18] Because there were only 50 participants in the project and the program only ran for a brief period, it was not possible to conduct a formal, robust evaluation of the behavior change and energy reduction that could have been realized.

[19] Most commonly, participants cited their pool/spa pump, clothes washer, 2nd refrigerator/freezer, and/or microwave as being inaccurately reported.

- At this early stage in the project, virtually none have changed their household's energy usage; and
- The majority of project participants were also enrolled in PG&E's My Account. Participants were approximately evenly split in their preference for MyAccount versus their disaggregation website (53% to 47%).

Qualitative Evaluation (Focus Group) Results

In the second part of the customer project evaluation, four online focus groups were conducted using the vendor's proprietary $(IQ)^2$ platform (Appendix C). There were a total of eight participants from the Vendor A group and nine participants from the Vendor B group.[20] The qualitative evaluation showed that participants preferred Vendor A's interface due to its uncluttered and more sophisticated design. Overall, both vendors' websites had minimal impact on participants' energy usage and behavior up to the date of the focus groups. Similar to the initial survey respondents, focus group participants were disappointed with the quality of appliance disaggregation by both vendors due to the following reasons:

- Poor disaggregation by appliance to date (e.g., too much of a participant's cost/usage remaining in the "Always On" and/or "Learning" statuses);
- Questionable accuracy of usage detected by appliance or within end use categories; lack of real-time or close to real-time data; questionable validity of comparative usage and efficiency data (e.g., for similar homes or by zip code); and/or
- Lack of behavioral tips perceived to be insightful, valuable, or useful (e.g., participants expected to see how their appliance usage compares to those with similar appliances).

Additional results from the four-part focus group evaluation include the following:

- Curiosity regarding the technology/relative cost or usage of appliances and/or desire to reduce electric bills were the primary reasons why participants joined the project;
- Group participants' initial expectations for what their portal would offer included accurate disaggregation (at least into 5 or more separate "buckets" containing appliances with the highest draw), real time data, and energy saving tips;
- While billing cycle or monthly data was most useful to detect and track overall trends, participants also wanted daily, hourly, or even more granular usage data; and
- Most participants only occasionally visited their vendor's website to check usage or costs. Others who checked the site more frequently did so to see either if it was working better (e.g., "learning") or when they have specific concerns about energy usage.

[20] Given the small sample size and the qualitative nature of the focus groups, results should be used to provide context for general attitudes, but should not be generalized to the wider population.

Final Online Survey Results

For the final survey, all project participants were contacted via email (Appendix D). A total of 42 customers completed the final survey with 23 participants from the Vendor A group and 19 participants from the Vendor B group. Similar to the results from the previous surveys, participants had a general lack of enthusiasm for both vendors' disaggregation reporting services. This was driven by perceived failure of the technology to either accurately detect appliances and/or provide granular, near-real time data. While the number of participants who claimed that their appliances were being detected inaccurately remained about the same, participants in the final survey felt more of their appliances were not being detected accurately. Overall, about 40% of participants were dissatisfied with the information, data, and value provided by their respective disaggregation website. Because this was a proof of concept, usage data was only refreshed once per day. However, customer feedback indicated they were expecting near real-time data on their appliance usage. Additionally, customers were expecting the performance of the disaggregation to improve over time. However, after an initial period, the algorithms no longer "learned," so results remained at the same level of granularity. Other notable results from the final survey include the following:

- There was marginal growth in the proportion of project participants reporting change in behavior based on their website data, but the majority continued to report no behavioral change. This may have been due to the short duration of the project;
- Customer expectations were higher at the end of the project period because they expected the disaggregation algorithms to continue learning in order to report their home energy usage more accurately over time. Therefore, while the number of participants who claim their appliances were being detected inaccurately remains about the same in the mid-survey compared to the final survey, the final survey participants felt like more of their appliances were not being detected accurately;
- The relatively few project participants reporting behavior change reduced usage of at least some electric appliances[21];
- At the end of the project, the perceived inaccuracy and lack of need were the most often cited reasons not to change appliance usage. Participants felt that they did not need to reduce usage or felt that data updates were too infrequent;
- While one out of five users reported that Vendor B added new appliances to their dashboards and one-third of Vendor B participants felt that reporting became more accurate over time, users reported that Vendor A rarely detected and added new appliances or was seen as becoming more accurate;

[21] With only a few exceptions, the same changes were reported in the initial survey, suggesting either a Hawthorne effect (changing behavior because one is observed) or that simply joining the project and getting the dashboard prompted most changes.

- Most participants would be willing to complete a 40 question profile if that would improve accuracy/detection;
- In the final survey, there was significantly more focus on using the disaggregation website to check cost breakdown by appliance rather than checking usage;
- Frequency of visits and time spent on website declined over the course of the project. The vast majority logged on less than once a week at the project's end and there were significantly more participants in the "just glancing at it" category compared to the initial survey responses; and
- More participants prefer the My Account website to a disaggregation portal.

The final survey also indicated that participants remained open to an appliance-level load disaggregation reporting website. Additionally, a survey consultant inferred participants' interests in features such as monthly comparisons, remote-appliance turn-off, and push alerts as being "nice-to-haves" rather than "must-haves". The overall surveys and customer evaluations indicated that participants valued clear, easy-to-find, and accurate electricity usage and cost data for all major appliances and systems (ideally at an hourly level and refreshed daily, if not more often).

4. Key Findings and Recommendations

The results from both phases of the project demonstrate that there are many opportunities for knowledge sharing and further collaboration. This section highlights the key findings and recommendations for future actions.

Key Finding #1: Even with additional appliance and residential profile data, vendors were still unable to accurately identify all end uses of interest.

- **Recommendation:** Do not proceed at full scale until load disaggregation technology is further researched and refined.

Key finding #2: While none of the three vendors tested were able to identify all the end uses defined by PG&E, each demonstrated strengths that could be leveraged under different scenarios and applications.

- **Recommendation:** Work with vendors on their strengths and evaluate possibility of leveraging load disaggregation technologies to target specific PG&E programs. For example, Vendor C correctly identified the refrigerator/freezer end uses at all of the six test bed homes, and estimated their usage most accurately. Vendor C's software is most useful in identifying customers with second refrigerators and potentially valuable to target customers for PG&E's Appliance Recycling program.

Key finding #3: The vendors' algorithms had trouble distinguishing between the signals of some similar devices (e.g., HVAC and central space heater where the HVAC unit included a fan for the heater). Additionally, the vendors' algorithms stopped "learning" after a certain period of time.

- **Recommendation:** Consider opportunities to create a jointly shared platform to enable collaboration among vendors to drive improvements in disaggregation algorithms.

- **Recommendation**: Consider opportunities to create a database of appliance signals and other detailed end use data for specific devices (e.g., set-top boxes and game consoles) and use it to help the three disaggregation vendors improve their algorithms and products.

Key finding #4: Despite the lack of use of the vendors' websites during the customer evaluation, participants remained open to appliance-level disaggregation tools and reporting websites.

- **Recommendation:** Provide feedback to vendors to help them improve the design and usability of their disaggregation algorithms.
- **Recommendation:** Potentially explore opportunities to develop educational and outreach programs to better engage customers.

4.1 Technology-based Lessons Learned

The primary issues this project faced included the monitoring systems installed by the evaluator and the meter configuration requirements to meet PG&E's protocols.

Additionally, there were some technical challenges with collecting one-minute interval data, such as data storage capacity. This report did not assess the impact of collecting one-minute interval data. EPIC Project 14, however, evaluated the available capacity of the current network, confirmed that available capacity currently exists and developed a method for assessing the impact of new use cases. If the project were to go to full deployment, a full impact assessment of the one-minute interval data should be executed, in alignment with the methodology that was developed in Project 14.

The following summarizes the technology-based issues the project faced and the key lessons learned.

4.1.1 Meter Configuration Did Not Meet PG&E's Protocols

Description of the issue: Initial SmartMeter™ configurations provided by AMI meter vendor did not meet PG&E's deployment protocols.

Impact to the project: Because the vendor's SmartMeter™ configurations were neither production ready nor tested by PG&E, additional time and resources were needed to obtain and test the data to ensure the configuration change used by the disaggregation project would not adversely affect other meters that were not participating in the project.

Lessons learned: Determine the pre-existing configuration conditions with the vendor and provide configuration requirements to identify and proactively address any sensitivities and potential barriers or issues to meter configuration set-up.

4.1.2 Not All End Uses Can Be Accurately Monitored and Measured

Description of the issue: Not withstanding plug load monitors, there are still some mixed end uses (e.g., bathroom fans that are also light fixtures) and migratory loads (e.g., space heaters) that are difficult to accurately measure and disaggregate. It is also challenging to trace all loads to each circuit, and some loads are so small that one-minute data is lumpy due to the resolution of sensors.

Impact to the project: This finding not only resulted in the inability to fully measure and disaggregate loads on home circuits with mixed end uses, but also resulted in customer dissatisfaction with the feedback information provided.

Lessons learned:

- It is not currently practical to monitor all end uses, even though consumers would like to know their usage data;
- For small, discretionary loads, utilities may consider making appliance costs available to customers so they can understand their costs relative to their usage, which does not require specific load disaggregation; and
- It is important to establish customer expectations of level of disaggregation that can be provided.

4.2 Value Proposition

The purpose of EPIC funding is to support investments in technology demonstration and deployment projects that benefit the electricity ratepayers of PG&E, SDG&E, and SCE. The California Public Utilities Commission (CPUC) requires that each EPIC project advance at least one mandatory guiding principle and at least one complementary guiding principle.

4.2.1 Mandatory Guiding Principles of EPIC

The mandatory guiding principle of EPIC is to invest in clean energy technologies and approaches that provide benefits to electricity ratepayers by promoting greater reliability, lower costs, and increased safety. The Residential Appliance-Level Load Disaggregation project advances the principle of lowering costs. Upon the improvement of the load disaggregation capabilities, customers will be able to more effectively manage their usage and ultimately, lower their electricity costs by understanding the underlying drivers of their electricity usage. Additionally, the learnings from disaggregated billing can be used to inform program and product designs for energy efficiency, demand response, and other programs, which may produce lower costs to customers.

4.2.2 Secondary Principles of EPIC

EPIC also has a set of complementary secondary principles that include:

- Societal benefits;
- Greenhouse gas (GHG) emissions reduction and adaptation in the electricity sector at the lowest possible cost;
- The loading order;
- Low-emission vehicles/transmission;
- Economic development; and
- Efficient use of ratepayer funds.

The Residential Appliance-Level Load Disaggregation project advances several of the secondary principles. First, the project produces societal benefits because load disaggregation and itemized billing better engage customers in energy use management. In making energy costs more understandable (e.g., "It takes me $[x] to run my dish washer each month."), customers are more likely to participate in other energy management programs.

Secondly, the project promotes the efficient use of ratepayer funds because the project uses data enabled by PG&E's SmartMeter™ platform to support the ability for customers to lower their energy costs. Additionally, the collection of one-minute SmartMeter™ data from 500 customer homes provides PG&E with a dataset to create a replicable framework to evaluate the improvements made to appliance-level load disaggregation technology in the future. The project also promotes an efficient use of rate payer funds by determining that the load disaggregation technology is not currently viable for full deployment, since none of the disaggregators were able to consistently identify all the end uses.

Finally, the project advances the principle regarding loading order because customers can reduce their energy consumption by using the disaggregation information to better understand and manage their usage.

4.2.3 Technology /Knowledge Transfer Plan

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs within PG&E, across the other IOUs, the CEC, and throughout the broader energy industry. In order to facilitate this knowledge sharing, PG&E will share the results of the Appliance-Level Load Disaggregation project in EPIC workshops with other utilities and industry vendors, in industry forums, such as the American Council for an Energy Efficient Economy (ACEEE), through public reports published on the PG&E website and various internal forums. Specifically, below is a list of the specific information sharing forums where the results and lessons learned from this EPIC project were presented or plan to be presented:

- Non-Intrusive Load Monitoring (NILM) International Workshop
  Vancouver, Canada | May 14-15, 2016
- American Council for an Energy-Efficient Economy (ACEEE) Summer Study
  Asilomar, CA | August 21-26, 2016

Additionally, PG&E will continue to explore potential opportunities to develop and engage in platforms for access to disaggregation information and results from this project.

4.2.4 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

4.2.5 Project Metrics

The following metrics were identified for this project and included in PG&E's EPIC Annual Report.[22] These metrics are forward looking, given the proof of concept nature of this EPIC project. Once the disaggregation vendors improve their algorithms based on feedback from this project, this type of project could potentially benefit customers by helping manage avoided customer energy use and customer bills.

1f – Avoided customer energy use

The availability of disaggregated billing would provide consumers with information to manage energy use in two ways. First, it would provide information about level of use, which in turn could encourage the consumer to reduce its usage.

Secondly, the usage data could provide support for consumers to upgrade their appliances to ones that are more efficient. This would be more apparent if utilities provided typical usage and cost data for end use devices.

1h – Customer bill savings (dollars saved)

Disaggregated billing would provide customers information about actual cost for their appliance usage, which in turn could encourage the consumer to reduce its usage. This information would provide more actionable recommendations if the consumer was on a time-of-use rate.

Additionally, the usage data and associated costs could provide support for consumers to upgrade their appliances to ones that are more efficient and less costly to operate. The benefits of upgrading to efficient appliances would be more evident if average usage and cost data were provided.

5. Conclusion

The project successfully achieved the three primary objectives:

1. Demonstrated commercial analytic capabilities to achieve end use load disaggregation using data captured by PG&E's SmartMeter™ platform;
2. Evaluated the accuracy of commercial disaggregation software and compared vendors' abilities to demonstrate appliance-level itemization of monthly bill charges using SmartMeter™ data as the inputs; and
3. Gathered insights from customers regarding end use bill presentation and the value of disaggregated data. These insights would be used to develop a strategy for deploying appliance-level billing.

[22] http://www.pge.com/includes/docs/pdfs/about/environment/pge/epic/EPIC_2014_Annual_Report_PGE_20150227.pdf

This project demonstrated that PG&E's SmartMeter™ platform could be modified or reconfigured to provide data in one-minute intervals to allow some level of disaggregation of demand data.

The accuracy of three commercial disaggregation software products was also evaluated during the project. While none of the vendors provided disaggregation services for all of the PG&E categorized end uses, each vendor demonstrated strengths in various areas. Since the algorithms are proprietary, the project is unable to determine the level of effort or the ability that would be necessary to improve the results. There may also be a high marginal cost for improving algorithms to accurately detect certain appliances. For example, if an appliance only costs $2 per month to run, it may not be cost effective to improve the algorithm to enable detection. Instead, disaggregation vendors and the broader industry should focus on improving existing strengths of currently available and promising disaggregation software products. The key findings from the project indicate the potential for further research and collaboration in this area to improve the value and cost savings delivered to ratepayers.

The third objective was to obtain insights from customers regarding value of the disaggregated data and the presentation of disaggregated results. The online surveys and focus groups provided a wealth of information on customer experiences and preconceptions about load disaggregation that may be useful for developing of a deployment strategy for appliance-level billing. Overall, project participants remained open to appliance-level disaggregation tools, despite the lack of use of the vendors' reporting websites during the project. This suggests there is ample opportunity to further engage customers to improve the design of disaggregation tools and reporting services to influence behavioral changes.

Ultimately, the project execution was successful, and the learnings helps to advance industry knowledge. The project determined that the load disaggregation technology is not currently viable for full deployment, since none of the load disaggregation vendors were able to consistently identify all the customers' end uses. The project also enabled PG&E and the industry to better understand customer perception of load disaggregation information, evaluate current load disaggregation technologies, and collect end use device usage that can be used for other disaggregation technology studies. Once load disaggregation technology improves, PG&E can better engage with the broader industry to further improve customer service and potentially enable future cost savings for ratepayers.

Appendices

Appendix A: PG&E's End Use Monitoring Test Bed

A_Report_End Use Monitoring Test Bed2

Appendix B: Report on the Initial Survey

Survey 1 Results

Appendix C: Report on the Qualitative Research

Phase II Qualitative Research Results

Appendix D: Report on the Final Survey

Phase 3 Final Survey Results