California Energy Commission

CONSULTANT REPORT

Phase 2 Evaluation, Measurement and Verification Framework

Lead Locally, EPIC Grant EPC-17-041

Prepared for: **California Energy Commission**
Prepared by: **Sonoma Clean Power Authority**

Sonoma Clean Power

California Energy Commission

Edmund G. Brown Jr., Governor

STATE OF CALIFORNIA ENERGY COMMISSION

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PREFACE

Project Overview

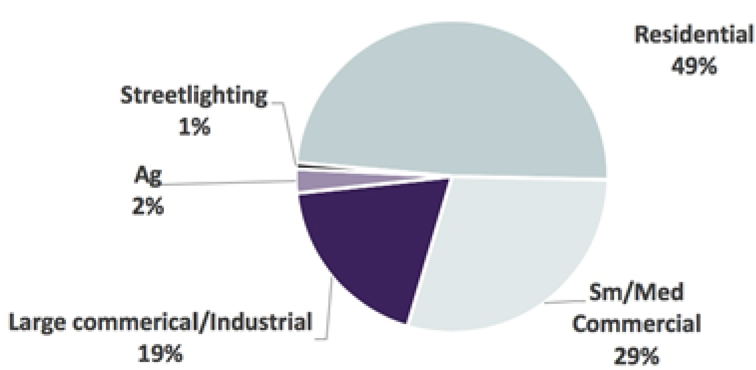
Sonoma Clean Power's (SCP) "Lead Locally" project (Project), funded through the California Energy Commission's (CEC) GFO-17-304, aims to identify strategies and technologies that can assist with the State's goals of doubling the efficiency of existing buildings by 2030. The Project will include applied research and technology deployment activities, each of which will propose innovations that could stimulate the energy efficiency market. With the applied research work, the team will investigate a series of innovative technologies that have the potential to be integrated into existing program models. Lessons learned from the applied research projects will be funneled directly to consumers, contractors, real estate professionals, and building officials through SCP and its local partner organizations. The technology deployment work will be driven in part through the SCP "Energy Marketplace", a physical storefront where consumers can directly procure energy efficient products and services. The Energy Marketplace has the potential to increase the deployment speed of energy efficiency products, make energy efficiency programs more accessible to all customers, and increase customer knowledge of energy efficiency and energy code requirements.

About Sonoma Clean Power and its Customers

SCP is a public power provider operating as a Community Choice Aggregator (CCA), and the default electricity provider for Sonoma and Mendocino Counties. SCP exists to provide broad public benefits relating to affordability, reliability, climate change and sustainability, coordination with local agencies, customer programs, and to support the local economy. The default service for SCP customers is CleanStart, which provided customers in 2017 with 45% renewable power and 87% carbon free power. SCP customers also have the option to select EverGreen service, which is 100% renewable power produced entirely within the SCP service area.

SCP serves just over 220,000 accounts, of which 86% are residential accounts. On an annual basis, SCP's load is comprised of about 50% residential energy use as shown in Figure P-1.

Fig P-1. SCP Customer Load for 2017



SCP, its employees, agents, contractors, and affiliates shall maintain the confidentiality of individual customers' names, service addresses, billing addresses, telephone numbers, email addresses, account numbers, and electricity consumption, except where reasonably necessary to conduct SCP's business or to provide services to customers as required by the California Public Utilities Commission (CPUC). SCP shall not, under any circumstance, disclose customer information for third-party telemarketing, e-mail, or direct mail solicitation. Aggregated data that cannot be traced to specific customers may be released at SCP's discretion.

Any questions or concerns regarding the collection, storage, use, or distribution of customer information, or who wish to view, inquire about, or dispute any customer information held by SCP or limit the collection, use, or disclosure of such information, may contact Erica Torgerson, Director of Customer Service, via email at etorgerson@sonomacleanpower.org.

Project Team, Roles and Responsibilities

The applied research team is comprised of the following parties, with roles and responsibilities outlined below.

Sonoma Clean Power serves as the prime coordinator with the CEC, and will be responsible for identifying project sites, initial outreach to customers, and reporting Project progress to the CEC.

Frontier Energy's lead roles are management of the applied research activities and associated subcontractors, execution of laboratory testing, installation of instrumentation at test sites, analysis of monitored data, energy modeling, and technical reporting.

DNV GL will provide independent Evaluation, Measurement, and Verification (EM&V) for the Project, specify required measurement points and accuracy levels for the instrumentation package, and evaluate performance relative to the metrics for success.

California Lighting Technology Center will manage the commercial daylighting project, select and evaluate daylighting technologies in both laboratory and field test settings, and assist in extrapolating field performance to estimate energy savings and peak electricity demand reduction for other space types and locations across California.

Winwerks will serve as the vendor for phase change materials and provide informal design guidance and field test support throughout the project.

PLT Multipoint and **Huvco** will serve as vendors for daylight harvesting sensors and daylight enhancement technologies, respectively, and provide informal design guidance and field test support throughout the project.

ABSTRACT

The purpose of this Phase 2 Evaluation Measurement and Verification (EM&V) Framework is to document the methodology that will be used by the Lead Locally project team to evaluate specific retrofit measures involving innovative building technologies or applications that present some level of performance or economic risk to building owners and occupants. This Framework addresses the Phase 2 technologies: grid-interactive heat pump water heaters for residential applications and phase change materials for residential building applications.

This Framework will present general strategies for conducting the EM&V for the applied research phase for Lead Locally, which will be relevant for both Phase 1 technologies as well as the Phase 2 technologies (phase change materials and optimized grid-interactive heat pump water heaters). We will also discuss proposed steps tailored to the specific technology and retrofit application to be used if the applied research determines the technology is a suitable candidate for large-scale deployment in Sonoma and Mendocino Counties, or elsewhere in California.

During the applied research stage of the project, the research team will not be estimating the large-scale energy saving benefits of the interventions, but rather will carry out retrofit isolation to quantify savings in the context of a specific application and geographic location. The EM&V Framework sets up approaches to quantify and extrapolate energy savings and other benefits to determine future statewide impacts and cost-effectiveness.

Keywords: California Energy Commission, energy, phase change materials, buildings, research, measurement, verification, EM&V, heat pump water heaters, energy efficiency, lighting, daylighting

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The purpose of the Phase 2 Evaluation Measurement and Verification (EM&V) Framework is to document the methodology that will be used by the Lead Locally project team to evaluate the energy savings potential for grid-interactive heat pump water heaters for residential applications and attic-mounted phase change materials for residential buildings, and to supplement the Phase 2 Research, Instrumentation, and Monitoring Plan.

It is anticipated that the research projects will include International Performance Measurement and Verification Protocol (IPMVP) Options B where direct end use metering isolates the measure impacts. In the technology demonstration and deployment, IPMVP Option A may be applicable as some input parameters can be assumed and measurement limited. For envelope measures, the HVAC system(s) are monitored through data loggers or direct data from the installed equipment (may go through the manufacturer). The analyses will include whole building analysis under IPMVP Option C to determine, at a minimum, if the end-use effects can be detected in whole building advanced metering infrastructure (AMI) metering. Calibrated simulation under IPMVP Option D may be used for multi-measure retrofit savings analysis and in secondary analyses to extrapolate measured equipment performance to other situations.

Specific approaches to EM&V, including baselines, timelines, and methods for quantifying energy savings, are detailed in Chapters 3 and 4.

CHAPTER 1: Introduction

The Lead Locally Project is an innovative programmatic approach to existing buildings research, development, and demonstration that includes a range of innovative technologies, program features, and market strategies to engage new customers in energy efficiency upgrades and deliver benefits to California's electric ratepayers. The Project is led by Sonoma Clean Power (SCP) under funding by the California Energy Commission (CEC) through the Electric Program Investment Charge (EPIC) program. This robust existing building initiative will also serve to complement current fire recovery efforts in Sonoma and Mendocino Counties, enabling SCP programs to have impact far and beyond the scope of this project.

The applied research portion of the Project focuses on several innovative technologies that will be evaluated through laboratory and field testing with the objective of expanding SCP's and other energy efficiency program administrator's portfolio of cost-effective retrofit options. These applied research projects are designed to remove uncertainty around the installed performance and cost of the technology, especially in combination with other retrofit measures, prior to broad deployment of the technology through the Lead Locally Energy Marketplace. The Project will not develop new technologies but will instead focus on increasing awareness of new and innovative commercially available technologies, providing building owners and contractors with the knowledge and tools they need to select the right applications, and installing the technologies in a manner that yields the expected energy savings. If at any point specific technologies prove nonviable for near-term application in California, the remaining funding will be applied to more promising technology demonstration projects or technologies identified through the Energy Marketplace.

Purpose

The purpose of this Phase 2 Evaluation Measurement and Verification (EM&V) Framework is to document the methodology that will be used by the project team to evaluate specific retrofit measures involving innovative building technologies or applications that present some level of performance or economic risk to building owners and occupants.

Scope

This Framework addresses two Phase 2 technology categories:

1. Efficiency optimizing control strategies for grid-interactive heat pump water heaters
2. Phase change materials for residential attics

We provide a detailed description of the EM&V approach to commercial daylighting retrofits in Chapter 4 of the *Phase 1 Evaluation, Measurement and Verification Framework*. For a high-level overview of the research approach to commercial daylighting retrofits, please see Chapter 4 of the *Phase 1 Research, Instrumentation, and Monitoring Plan*. For a detailed description of the research strategy that will be employed to evaluate daylighting measures for Lead Locally, please see Chapter 5 of the *Phase 2 Research, Instrumentation, and Monitoring Plan*.

In the chapters that follow, we present general strategies for conducting the EM&V for the applied research phase for the Project, which are relevant for both Phase 1 technologies as well as the Phase 2 technologies. We will also discuss proposed steps tailored to the specific technology and retrofit application to be used, if the applied research determines the technology is a suitable candidate for large-scale deployment in Sonoma and Mendocino Counties, or elsewhere in California.

Research and EM&V Coordination

SCP is working with its partners Frontier Energy and DNV GL to deliver a collaborative process for Applied Research and Evaluation, Measurement and Verification (EM&V) methods, baselining methodology, certainty of reported results, data management protocols and application of updates. These methodologies are documented in the Phase 2 Research, Instrumentation, and Monitoring Plan (Plan) and this Phase 2 EM&V Framework (Framework), which is a corollary to the Plan.

As described in the Phase 2 Research, Instrumentation, and Monitoring Plan, in most cases, applied research projects will include the following components:

1. Literature review to understand past research and identify unresolved questions
2. Laboratory testing under controlled conditions
3. Field testing of electricity savings and cost-effectiveness in occupied buildings
4. Building energy simulation to evaluate technologies in other climates and building types
5. Evaluation against success factors for inclusion in future technology demonstration projects, the Energy Marketplace, and/or state-wide energy efficiency programs

During the applied research stage of the project, the research team will not be estimating the large-scale energy saving benefits of the interventions, but rather we will carry out retrofit isolation to quantify savings in the context of a specific application and location. The EM&V Framework sets up approaches to quantify and extrapolate energy savings and other benefits to determine future impacts and cost-effectiveness.

This EM&V Framework addresses the following:

- A detailed summary on independent project monitoring and verification, using Investor Owned Utility accepted protocols and the CPUC's California Energy Efficiency Evaluation Protocols
- A detailed timeline of the evaluation period pre- and post-installation
- A description of data assumptions and inputs to be used for building simulation models
- A description of data extrapolation strategies
- A description of on-going monitoring and verification to evaluate persistence and sustainability of savings, post-EPIC funding

Table 1 details the general roles of Frontier, the Applied Research team, and DNV GL, the EM&V team, in relation to EM&V during the Applied Research Stage:

Table 1: Applied Research Stage EM&V Roles.

Applied Research Team - Frontier Energy	EM&V Team – DNV GL
Write Research, Instrumentation, and Monitoring Plan consistent with the EM&V framework, including minimum data sets and collection methods specified by EM&V team.	Write EM&V Framework for applied research projects consistent with the project vision articulated in the proposal and the Research, Instrumentation, and Monitoring Plan.
Determine characteristics of target test houses for each technology.	Advise applied research team if additional test houses, operating scenarios, or control samples will be needed to obtain reliable energy savings estimates.
Identify and purchase appropriate monitoring equipment and instrumentation.	Verify that all sources of uncertainty are monitored or addressed.
Install pre-retrofit instrumentation in test houses, install additional sensors if needed following retrofit, and remove instrumentation after one year of post-retrofit monitoring.	Perform quality assurance on monitored data, and inform Frontier when problems are observed.
Provide EM&V team with access to monitored data.	Obtain and store utility billing data for test houses.
Characterize the performance of each technology in terms of energy savings and comfort relative to expectations.	Extrapolate energy savings to the rest of California using market diffusion modeling and Frontier's energy savings, cost, and target market data.
Analyze the expected cost-effectiveness of the technology in alternative building types, applications and California climate zones based on test results and cost data.	Recommend whether to abandon the technology, proceed with a Technology Demonstration, or begin deployment.

The research team will maintain accurate, up-to-date, and secure records for individual project sites and overall grant/project data over the course of the grant (minimum: 3½ years). Reporting on customer sites will continue for up to 3 years of activity, potentially across multiple technologies and multiple phases of the project.

Baseline monitoring will be used to determine the conditions prior to the energy efficiency technology being installed. In all cases, we will attempt to capture representative operating modes of the building (system) or the equipment during a normal operating cycle; the period will include a full operating cycle from maximum energy consumption and demand to minimum.

The reporting activities for each energy measure will include the following:

- The measurement period start and end points in time
- Observed data of the reporting period
- The values of independent variables
- Description/justification for any corrections made to the recorded data
- Any estimated values used in the calculations
- Energy prices used
- Details of any non-routine adjustments performed on the baseline
- Explanation of the change in conditions since the baseline period
- All observed facts and assumptions, including equipment costs and contractor labor time
- Engineering calculations leading to the adjustment
- Computed savings for energy, demand and cost

The project will roll-out to additional sites to get to 300,000 square feet of building space achieving an average minimum site electric savings of 10% for residential sites and 20% for commercial sites. This will likely be approximately 100-150 sites across all technologies, which may or may not include “Sites with Monitoring”.

CHAPTER 2: Lead Locally EM&V Approach

Evaluation, Measurement and Verification (EM&V) is the collection of methods and processes used to assess the performance of energy efficiency activities so that planned results can be achieved with greater certainty and future activities can be more effective.

The main objectives of an EM&V process are to assess the performance of an energy efficiency program or project, measure the energy or demand savings, and verify if the program is generating the expected level of savings. EM&V data can inform recommendations for improvements in program performance. Having a clear understanding and description of how the program is expected to deliver results is critical to an effective EM&V process.

The EM&V process is analogous to the evaluation of business or employee performance. For example, did the company meet its profit or growth objective? What can be done to improve performance? In the energy efficiency market, the EM&V process answers the question of whether the investments in energy efficiency achieved the expected or required objectives.

DNV GL's EM&V Framework is designed to align with California Protocols and IPMVP. The energy savings calculations will include both end-use measurement and whole building approaches to ensure state goals and ratepayer-funded program requirements are met. The projects range across residential and commercial building types and primarily impact the heating, cooling, ventilation, water heating, lighting, and cooking end uses. We anticipate most applied research projects will include IPMVP Options B where direct end use metering isolates the measure impacts. In the technology demonstration and deployment IPMVP Option A may be applicable as some input parameters can be assumed and measurement limited. For envelope measures, the HVAC system(s) are monitored through data loggers or direct data from the installed equipment (may go through the manufacturer). The analyses will include whole building analysis under IPMVP Option C to determine, at a minimum, if the end-use effects can be detected in whole building advanced metering infrastructure (AMI) metering. Calibrated simulation under IPMVP Option D may be used for multi-measure retrofit savings analysis and in secondary analyses to extrapolate measured equipment performance to other situations. Table 2 below summarizes the four IPMVP M&V options along with how savings are calculated for these option and typical applications of these options.

Table 2: IPMVP M&V Options.

IPMVP M&V Option	Descriptions	How Savings are Quantified	Typical Applications
A. Partial Retrofit Isolation	Savings are determined by partial field measurement of energy use of the affected system. Engineering estimation using short-term/ continuous post measurements and stipulations.	Engineering calculation of baseline and reporting period energy from: 1. short-term or continuous measurements of key operating parameter(s); and 2. estimated values. Routine and nonroutine adjustments as required.	A lighting retrofit where power draw is the key performance parameter that is measured periodically. Estimate operating hours of the lights based on facility schedules and occupant behavior.
B. Retrofit Isolation	Savings are determined by field measurement of the energy use of the ECM-affected system. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period.	Short-term or continuous measurements of baseline and reporting period energy, and/or engineering computations using measurements of proxies of energy use.	Application of a variable speed drive and controls to a motor to adjust pump flow. Measure electric power with a kW meter installed on the electrical supply to the motor, which reads the power every minute.
C. Whole Facility	Savings are determined by measuring energy use at the whole facility or sub-facility level.	Analysis of whole facility baseline and reporting period (utility) meter data.	Multifaceted energy management program affecting many systems in a facility.
D. Calibrated Simulation	Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility.	Energy use simulation calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.	Multifaceted energy management program affecting many systems in a facility but where no meter existed in the baseline period.

EM&V Process

There are five (5) major steps in implementing EM&V:

1. Define evaluation objective: The first step of an EM&V project is to establish evaluation objectives. The objectives of the evaluation are energy savings, risk management and program improvement. The other benefit may include calculation of co-benefits such as greenhouse gas (GHG) emission and other non-energy benefits.
2. Select an evaluation savings determination approach: Determining appropriate methodology of savings estimation is critical part of the M&V process. The selection of M&V method depends on the following:

    - Complexities of measure
    - Number of interrelated measures at a facility
    - Risk of the savings
    - Project cost and expected savings
    - Availability of M&V data

    Simpler project may require simple methods whereas more complex projects may require more complex methods to determine savings. For example, it will be easier to assess the energy savings of a one to one lighting replacement project where the T8 fixtures are simply replaced by LED fixtures and operating hours of the lighting system remain unchanged from pre-existing condition to the retrofit conditions. In this case, IPMVP A could be used to quantify the savings where the key performance parameter, such as lighting pre- and post-retrofit installed wattage, are known and the operating hours based on facility-wide schedule need measurement. On the other hand, a complicated chiller measure may not be difficult to assess, if there are energy sub-meters and monitoring systems dedicated to the chiller system. Thus, while defining the appropriate M&V requirements for a given project, it is important to consider the following categories of the measures to assign M&V methods.

    - Constant load, constant operating hours
    - Constant load and variable operating hours
    - Variable load and variable operating hours

    If the measure is in first category, IPMVP Option A is more suitable because one key performance parameter, such as kW, could be measured and the operating hours could be stipulated. But, for the two other categories, it is advisable to utilize IPMVP Option B to capture all the variability of the measure to quantify the savings.

    If multiple measures are installed in a single building, the savings of each measure may be related to the savings of the other measures. For example: interactive effects between lighting and HVAC measures or envelop measures. In this scenario, it may not be possible to isolate and measure one system to estimate savings. Therefore, for multiple interactive measures, whole facility IPMVP Option C or D may be most appropriate.

3. Verify installation and conduct data collection and analysis: Key aspects of EM&V are data collection and measurement and equipment installation verification. Verification activities will include physical verification of installation of the new equipment and ensure that they are operating as intended. Measurement activities include the data collection, monitoring, and analysis necessary to document the energy and demand savings and expected costs of the energy efficiency project. Measurement activities involve recording or estimating:
    - Equipment specifications for both existing equipment (the baseline) and the new energy efficient equipment installed
    - Actual energy usage of the baseline equipment and the installed energy efficient measure(s)
    - Total cost of the new equipment being installed, including material, labor, shipping and taxes and any other costs incurred
    - Additional data that may also be needed to document the utilization of the equipment in order to reasonably estimate savings
    - Other factors affecting the measure's energy usage such as weather for temperature sensitive uses
4. Calculate energy and demand savings; energy savings reflect the difference in energy usage (gas or electric) between the existing equipment and the energy efficient technology installed in its place, adjusting for any significant changes that would impact the savings estimate.

    For example, to replace a major HVAC system perform M&V that includes direct metering of the existing HVAC unit during the cooling period, and subsequent metering of its replacement in the next year. The direct metering of the old and new unit provides excellent data, but without taking into consideration changes in weather between the two years, the savings estimate will be biased. If the weather in the year the new unit was installed was warmer than the year before, without adjusting for weather the savings estimate would be understated. If, in addition to replacing the HVAC system, the structure was enlarged, and the HVAC size remained the same, one would also have to compensate for the increase in building size to get a more accurate estimate of energy savings attributable to the more efficient HVAC system.
5. Calculate Co-benefits: Co-benefits may include avoided greenhouse gas emissions and other environmental benefits, energy price effects, economic impacts such as job creation and increases in income, non-energy benefits to program participants (e.g., health, comfort, reduced maintenance, etc.), and other technical system benefits based on the objectives of the program policy.

Baselines

To appropriately measure and validate the impacts of certain technologies on household or facility load, one must employ a baseline that correctly controls for all possible exogenous factors other than the deployment of the technology itself. These differences can be related to weather, as well as geospatial, economic, or demographic/firmographic differences. An ideal appropriate counterfactual will account for all external factors aside from the implementation of the technology itself.

The team sees several challenges to estimating an accurate counterfactual or baseline, and thereby providing an accurate measure of technology-related impacts, including:

- Interactive effects of various technology deployments within individual sites and across all sites in the study
- Impacts of programs affecting energy and demand
- Limited number of participant sites with large number of technologies being tested
- Extrapolating results to technical and market potential application for quite a broad customer base
- Non-technology economic effects that may be entangled with the technologies
- Changes to building occupancy and usage over time

Each of these challenges represents an area of concern related to producing counterfactual baselines with respect to evaluation of new technologies. In theory, the most appropriate way to measure a counterfactual in a technology deployment evaluation is to employ a well-randomized control trial for large samples. This experimental design establishes a control group that is statistically indistinguishable from the participant group prior to testing for any technology impacts. With the establishment of a well-randomized control group, a difference-in-difference approach allows for an unbiased estimate of technology-related impacts. In the absence of a control group and the other issues raised above, a fundamental technology specific baseline can be modeled using interval data not impacted by any technology deployment.

Each field test must include a well-established baseline that can be compared to the retrofit case for the purpose of calculating energy savings. The EM&V Framework and process also allows the baseline to change in future year scenarios as we project impacts of moving technologies forward into the market:

- **Pre-retrofit**. The most common baseline case is the site itself prior to the energy retrofit, because the space geometry, operating conditions, internal gains, climatic conditions, and other building attributes are usually identical. Also, recent legislation such as SB 350 and AB 802 ask the Energy Commission and CPUC to create paths forward for bringing existing building up to and above energy code and toward a zero-carbon future. However, year-to-year weather differences must be accounted for, and there must be verification that occupancy levels and usage patterns did not change significantly. In some cases, the retrofit may be part of a remodeling effort that corresponds to a change in occupancy. In those cases, the pre-retrofit case is not a viable control for the field test, except as a hypothetical scenario analyzed using building energy simulation.

- **Similar buildings**. Buildings with similar physical characteristics and occupancy types are sometimes used as the baseline case when pre-retrofit data are unavailable or inappropriate due to a change in occupancy or major remodeling that coincides with the energy retrofits. This approach is more common with new construction in residential neighborhoods with standard home models, and usually requires large sample sizes to achieve reasonable accuracy and overcome variations in occupant behavior. It is unlikely that similar buildings will be used as a control case for applied research or technology demonstration, but this quasi-experimental design may be used for deployment scenarios. Matching may be on the data available to SCP as well as usage patterns.
- **Similar spaces in the same building**. In larger commercial buildings, there may be very similar spaces on different floors or different sections of the buildings. This option can avoid challenges related to year-to-year weather differences, reduce the overall timeline for the field test, and be more efficient from a cost standpoint. However, spaces are never identical, and uncertainty can be introduced by small differences in geometry, layout, and occupant behavior. In some cases, controls improvements can also use this approach where optimization routines or sequences can be bypassed. This is similar to the case of using the same building to synthesize a baseline when a true pre-retrofit is not feasible.
- **Modeled baseline case**. When no physical control case is viable or when current or new energy code should be the baseline, such as new construction or major commercial tenant improvement, building simulation can be used to analyze the theoretical energy use of the test site prior to retrofit. Calibration of the pre-retrofit model is impossible in this scenario, so detailed documentation and spot measurements of the performance of pre-retrofit equipment may be necessary to ensure accuracy. When using a modeled baseline, a calibrated model should also be developed for the retrofit case, using the same modeling assumptions and weather conditions. This approach is sometimes referred to as “Model Enhanced Monitoring”.

The selection of an appropriate baseline depends on the nature of the technology and the characteristics of the test site. Further details on this topic are provided in the specific technology sections of this plan.

Technology Assessment

For each technology assessment, we define specific metrics for technology impacts, customer engagement, and market readiness. We describe this in more detail below.

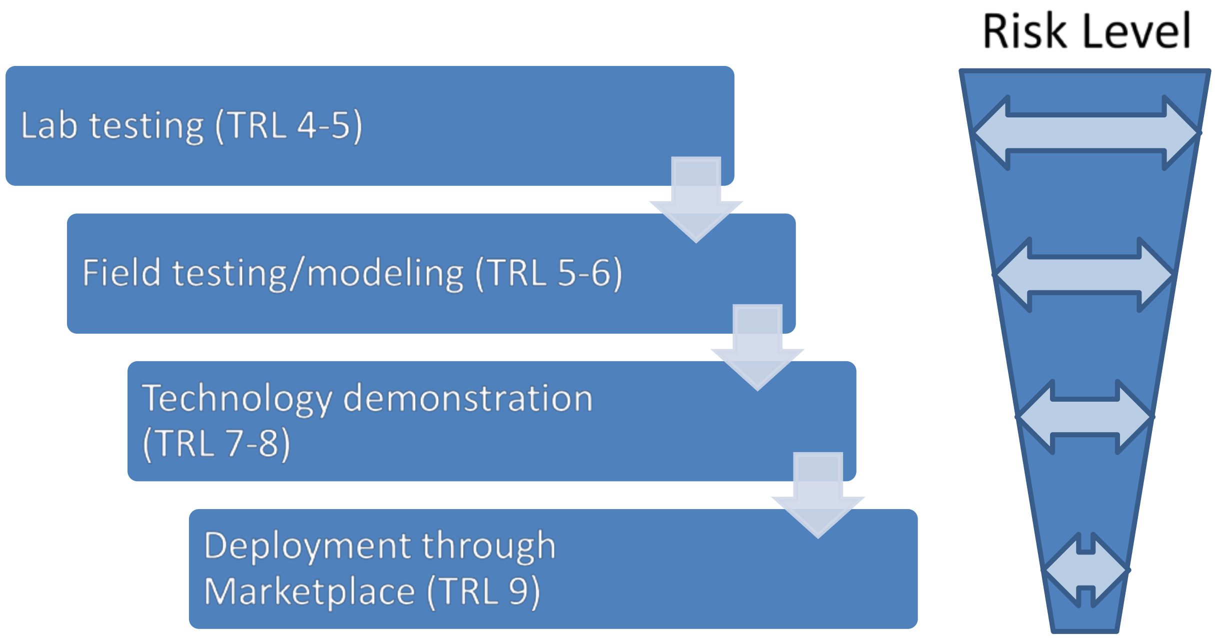
Technology impacts: The Applied research will measure technology performance that can be used to determine technology impacts, especially electric energy and demand savings, for the Lead Locally and future deployment**.** Unit outcomes will be measured via a set of metrics to be determined with SCP and Frontier Energy for each technology study. At a minimum, measured impacts will include energy savings over a baseline technology or time period, demand reductions realized, and greenhouse gas emissions impacts. The algorithm used to estimate greenhouse gas emissions will be determined in conjunction with SCP and Frontier Energy. In addition, the DNV GL will examine the cost-effectiveness of the technology, including installation and equipment costs, and likely economic benefits based on the field test.

Customer engagement is a critical aspect of technology integration into the Energy Marketplace. Therefore, for every technology studied, researchers will develop an approach to measure pre-installation customer awareness, needs, and expectations. SCP will also implement procedures for key participants in the test to maintain a log of their experiences, and conduct a post-test follow up survey or set of interviews. Technologies may work functionally, but it is also important to assess the extent of interaction that end users have with the technology, its ease of use, delivery of expected results, and overall impression given. A debriefing following the end of the test will reveal areas of improvement for the equipment and/or instructions, marketing messaging, etc., that may be required for either a wider pilot test or full-scale implementation.

Market readiness will be studied from the perspectives of technical and market potential as based on secondary data and surveys, integration into current infrastructure, and customer receptivity and willingness to adopt. We propose a methodology for combining these perspectives and indicating our conclusions as to whether a technology is market-ready, not ready, or at what stage of commercialization the technology is, given the research, and what barriers remain for SCP to accelerate adoption.

Technology Readiness Level (TRL) is a good indicator of the level of risk associated with a technology or product. The applied research projects for Lead Locally are considered either TRL 4 (component and/or system validation in laboratory environment) or TRL 5 (laboratory scale, similar system validation in relevant environment). Our objective is to move the technologies to TRL 8 (actual system completed and qualified through test and demonstration) over the course of the program. Lead Locally has adopted a gradual risk reduction process that includes lab testing, field testing, modeling, and technology demonstration, before proceeding with large scale deployment (see Figure 1).

Figure 1: Risk Reduction Strategy for Lead Locally



The proposed projects vary in stage of research and baselines that the measurement and verification (M&V) framework must address to quantify energy savings and other benefits. The differences between the applied research and technology demonstration projects are detailed later in the Technical Approach chapters below. The M&V framework provides guidance for site-specific instrumentation and monitoring plans.

The EM&V will weigh the gains and impacts the retrofit has had on energy savings, non-energy benefits such as reliability, public safety, lower operational cost, environmental improvement, and indoor environmental quality. The results will heavily impact the market readiness assessment. The Applied research and EM&V teams will vet and discuss results. If SCP feels the findings indicate minimal non-energy impacts from the lighting retrofit and radiant heating panel with air-to-water heat pump (AWHP), the market assessment funding will be allocated to assist other profiled technologies. If meaningful benefits are realized, we will assess the scope and readiness of the profiled technologies. We will assess the number of sites with the installed technologies found in Sonoma and Mendocino counties and track equipment costs with secondary research to understand if market adoption changes prior to deployment through the Energy Marketplace. We will look at the scope and reliability of secondary research to determine if any significant conclusions about market readiness can be made from the data. If some estimates are possible, this will be reported in terms of number of sites, size and type of sites, and date range for adoption of the technologies.

Benefits Questionnaire

The EM&V also requires looking at the broader evaluation of technologies in addition to quantifying energy benefits. All M&V results will require a standard step at completion to project future program savings based on the collected data. The pre-project savings estimates must be calculated using the References for Calculating Electricity End-Use, Electricity Demand, and GHG Emissions. At a high level, we will apply the specific technology impacts to a proportion of the reference consumption based on our customer response and degree of market readiness assessment.

CHAPTER 3: Efficiency Optimizing Controls for Grid-Interactive Heat Pump Water Heaters

Grid-interactive heat pump water heaters (GIHPWHs) have been offered by manufacturers over the last few years, but there has been limited uptake in this technology in California to date. In 2016, DNV GL collaborated with the CPUC to detail costs and potential energy savings for non-grid-interactive heat pump water heaters, but those savings estimates were not based on field testing and did not study the potential energy savings and load shifting benefits that grid-integration could offer. Field testing of energy savings, load shifting/storage, and demand response potential will serve as a valuable resource for program administrators considering heat pump water heaters as a program offering.

Technology Description

Heat pump water heaters are storage tank style water heaters where the heat is provided by a compressor-powered direct expansion heat pump with electric resistance backup heat. The energy input to these water heaters is electricity, but in contrast to a conventional electric water heater with an energy factor (EF) of 0.95, the heat pump water heater has an EF of 2.5 to 3.5 due to the efficiency of the heat pump system. These water heaters tend to have a longer recovery time than the standard electric or gas storage water heaters. The grid-interactive aspect of this technology is that the water heater will communicate with the electric utility, allowing the water heater owner to participate in auto demand response events controlled by the utility. The intent of optimizing the control strategies for the HPWH is to improve the coefficient of performance (COP) of the entire hot water system by 1) reducing the use of the electric resistance element and replace it with heat pump use and 2) changing the operation of the heat pump toward more favorable ambient and water tank temperatures. Detailed descriptions of the technology and control strategies are provided in Frontier's Phase 2 Research, Instrumentation, and Monitoring plan.

This phase of the technology only includes laboratory testing of the heat pump water heater to demonstrate COP optimization using water heater control strategies. The energy savings from the improved COP can be estimated by applying change in COP to an average annual residential hot water heater load.

Data Collection and Analysis

In this section, we outline the baseline definition, analysis approach, and market readiness for grid-interactive heat pump water heaters.

Baseline Definition

As this technology optimizes the GIHPWH, the baseline system is a standard heat pump water heater connected to a standard household water distribution system, situated in a space with temperatures between typical indoor and outdoor temperatures. In SCP's service territory, load events occur from 3:00-5:00 p.m. and shed events occur 5:00-8:00 p.m. daily. Each set of experiments should have a baseline test period when the water heater control is not optimized but maintained at a constant set point temperature. Frontier Energy will provide system performance characteristics for all the tests performed.

Analysis Approach

In this section, we outline the approach for analyzing the lab tests and the approach for future installations of the technology.

Energy Savings Analysis: IPMVP Option A, Retrofit Isolation, Key Parameter Measurement, will be used to determine energy savings of equipment installed in the laboratory. A direct measurement approach is recommended to attain COP for the baseline and for the improved system, and annual residential household water heating energy load will be determined from a source such as the Residential Energy Consumption Survey (RECS).

- GIHPWH output, $\dot{Q_{out}} = \dot{m}Cp\Delta T$
    - Where
        - $\dot{m}$ is the mass flow of water
        - Cp is the heat capacity of water
        - ΔT is the temperature difference between the water heater inlet and outlet
- GIHPWH input = measured electrical power
- Instantaneous COP = GIHPWH output / GIHPWH input
- Energy Savings = "annual residential water heating load" * [improved GIHPWH Effective COP – baseline GIHPWH Effective COP[1]]

In addition to assessing savings calculations, we will review Frontier's lab test data collection strategy for the GIHPWH and provide them feedback on adequacy of the data collection.

Market Readiness

Heat pump water heaters have been on the market since the early 2000's, but grid-interactive controls have only recently begun to gain traction. Table 3 lists the technology recommendations and their current market readiness.

[1] Effective COP" refers to the COP of the HPWH as an entire system, not solely the COP of the compressor. This calculation considers the COP of the heat pump, the energy consumed by the resistance element, and the jacket losses. It will be calculated by comparing the energy delivered to the occupants in the form of hot water to the electrical energy consumed by the device.

Table 3. Market Readiness for Grid-Interactive Heat Pump Water Heaters

Technology	Market Readiness
Grid-interactive control-enabled heat pump water heater	Less common market-ready, used in practice
Heat pump water heater	Market-ready, used in practice
Add-on heat pump for domestic hot water storage tank	Less common, but market-ready, used in practice.
Efficiency optimizing controls	Not yet developed, initial deployment during tech demo phase of Lead Locally

The applied research effort seeks to move promising technologies forward and the Energy Marketplace and technology demonstration stages will provide opportunities to discuss potential barriers to including grid-interactive heat pump water heaters in residential retrofits. The EM&V team will conduct additional interviews or a focus group to gather information from other professionals and customers outside those serving Sonoma and Mendocino counties to inform future market adoption projections.

Project Timeline

Table 4 shows high level project timelines for the grid-interactive heat pump water heater technology.

Table 4: Project EM&V Schedule for Grid-Interactive Heat Pump Water Heater Technology

Project Tasks	Completion Dates
EM&V Framework Development	December, 2018
Lab Data Collection Monitoring Strategy Review	March, 2019
Simulation Model Reviews	January, 2020
Draft Report Review	January, 2020
Final Report Review	March, 2020

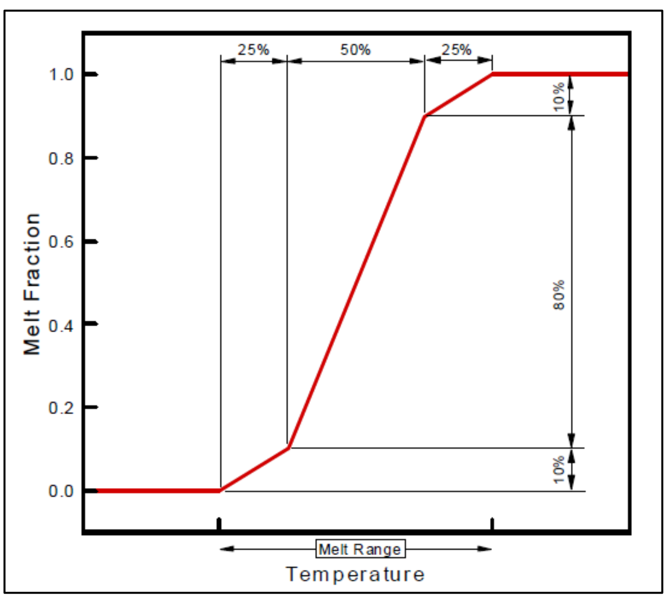
CHAPTER 4: Phase Change Materials in Residential Applications

Phase Change Materials (PCM) have been used as a building insulation component for the last 40 years and help in improving building energy performance. Encapsulated PCM can be applied in building walls, roofs, and attics and help maintain stable space temperature by acting as a buffer against large outside air temperature swings.

Technology Description

PCM absorb energy and melt when exposed to warm temperatures or solar radiation. This reduces the cooling and heating demand on the building Heating ventilating and Air Conditioning (HVAC) system. PCM absorb heat when they melt from solid to liquid, and release heat when they solidify from liquid to solid. Using PCM alters the temperature profile through the attic and reduces the building cooling need. Further, it shifts the time of peak load to a time when the building air conditioning system operates more efficiently, thereby reducing energy costs if time-of-use rates are in place. As shown in Figure 2, any PCM has a defined melt-start and end temperature, and the majority of the melting occurs at the middle of this melting range. During day time, the heat flux through the PCM in the attic increases, and it changes its phase from solid to liquid. The absorbed heat is stored inside the PCM and given back to the attic space and to the indoor conditioned space at night. As the temperature drops at night, the PCM freezes back to solid phases. This is how PCM helps both in reducing the heat transport and shifting the load to non-peak hours.

Figure 2: Typical Melt Curve of PCM



The effectiveness of the proposed PCM depends on various variables:

- Type of PCM material used
- Amount of PCM used
- Climate zones
- PCM application, wall, attic or floor
- Midpoint of PCM melting and freezing range compared to indoor temperature setpoints
- Time delay in heat transfer

One of the primary challenges associated with the effectiveness of PCM is having adequate air volume to transport heat between the PCM and the indoor conditioned space. By placing PCM inside the attic, insufficient attic air space may limit the transfer of heat from the PCM. This may not facilitate a completion of the freeze cycle during low attic temperature period. But as attic volume and outside air temperature profiles vary from site to site, PCM impacts may be different for different sites. We can assess the suitability of attic insulation quantity and attic temperature profile change after this evaluation.

PCM technology will be installed in five separate houses, potentially in different climate zones, to verify its effectiveness at reducing building energy consumption and to verify its impact during occupied versus unoccupied periods, and during summer versus winter months.

For a more detailed description of this technology, please refer to Chapter 4 of the Phase 2 Research, Instrumentation, and Monitoring Plan.

Data Collection and Analysis

In this section, we describe the baseline definition, analysis approach, and market readiness for PCM.

Baseline Definition

The baseline insulation will be based on the climate zone of the test homes that will be retrofitted with PCM. Title 24 defines the minimum roofing insulation at various climate zones. Section 150.0 of 2016 Title 24 provides the mandatory features and devices for low-rise residential buildings. The baseline insulation is R-38.

There will be five houses retrofitted with PCM in attics. Baseline attic insulation will be checked for its thickness, amount, its specification and its installation appropriateness. This evaluation effort should ensure that both baseline and retrofitted conditions maintain similar leak tightness and installation practices. However, as PCM are not marketed with a designated thermal resistance R value, the evaluation process will ensure that both base and retrofitted conditions will have similar insulation characteristics. Frontier Energy will either use manufacturer’s test results or conduct its own experiments to develop the weighted average R value using parametric analysis at different temperature gradients. This analysis can use one-dimensional analysis with a typical sinusoidal operational acceptance testing (OAT) profile to generate corresponding R values at different temperatures. Both base and post case will have identical insulation thickness. If Frontier Energy cannot establish test conditions at different temperature gradients to establish the weighted R value, the manufacturer's test values can be used for the same purpose.

Analysis Approach

IPMVP Option A, Retrofit Isolation will be used for our evaluation. The key Parameter Measurement will be the heating (kW or therms) and cooling kW of the building air conditioning unit to determine savings associated with PCM retrofits.

Energy Savings Analysis: A direct measurement approach is recommended to attain annual energy savings for zones receiving PCM insulation technologies. Both baseline and post-retrofit conditions include continuous power measurement of the residential air conditioning along with measurement of outside weather (dry-bulb temperature and wet-bulb temperature) collected from local weather stations at the same interval. Both baseline and post-retrofit measurement periods should be for a minimum 6 months, which should include sufficient coverage of outside dry-bulb conditions.

The following steps will be utilized to calculate the impact of the PCM technology from the data collected from the test sites:

1. Base HVAC system kW will be compared to the actual ambient temperature to develop the relationship between the weather and the kW and use that relationship along with the typical meteorological year (TMY) to develop normalized annual baseline kWh consumption.
2. Once the PCM is installed, repeat the same steps with the actual weather and post kW data to determine the normalized annual post kWh consumption
3. Normalized kWh savings is the difference between normalized baseline kWh consumption and normalized post case kWh consumption.

    Normalized annual kWh savings = Normalized baseline kWh consumption – Normalized post case kWh consumption

    Baseline annual kWh = Based on baseline correlation of kW Vs. OAT, with TMY3 weather data

    Post case annual kWh = Based on post correlation of kW Vs. OAT, with TMY3 weather data

A similar process will be used to quantify the heating savings of the PCM technology by utilizing the monitored baseline and post-retrofit BTU and weather data.

System Performance Verification Review: As part of the PCM system performance review, we will compare the space temperatures of baseline (without PCM) and post-retrofit (with PCM) periods to evaluate the changes in room temperature profiles due to the PCM retrofit. The same sets of comparison will be carried out for the ceiling temperatures and attic temperatures to assess the impact of the PCM technology on the temperature profiles. Our team will also compare the monitored baseline and post-retrofit heat flux to observe the lowering of heat flux due to installation of PCM.

Market Readiness

The PCM which will be employed ranges from completely market-ready, meaning they are used on many new and retrofit commercial projects throughout the state of California in a given year, to “research and development phase,” meaning they are rarely used in facilities in 2018 or are being tested for the first time through this pilot project. Table 5 lists the technology recommendations and current market readiness for PCM. The evaluation will compare the evaluation outcome with available manufacturer’s indices, such as temperature gradient, heat flux, etc. The evaluation will come up with winter and summer months savings at climate zones 1 and 2.

Table 5. Market Readiness for PCM Technologies

Technology	Market Readiness	Typical Application
PCM attic mats	Market-ready, used in practice	Interior surface of ceiling below attics

The applied research effort seeks to move promising technologies forward and the Energy Marketplace and technology demonstration stages will provide opportunities to discuss potential barriers to including PCM in retrofits. The EM&V team will conduct additional interviews or a focus group to gather information from other professionals and customers outside those serving Sonoma and Mendocino counties to inform future market adoption projections.

Project Timeline

Table 6 shows high level project timelines for the said technology.

Table 6 Project EM&V Schedule for Residential PCM Retrofit

Project Tasks	Completion Dates
EM&V Framework Development	December, 2018
Field Test-Pre-monitoring Strategy Review	January, 2019
Program Participants Survey review	July, 2020
Field Test-Retrofit Monitoring Strategy Review	July, 2020
Model Reviews	March, 2020
Market Readiness Interviews	April, 2021
Draft Report Review	August, 2020
Final Report Review	September, 2020

CHAPTER 5: Reporting

Below the approach to reporting on the Benefits Questionnaire and Technology Transfer Results is documented.

Benefits Questionnaire

Benefits of the project will be evaluated through completing benefit questionnaires. This task will include the following:

- Complete three Project Benefits Questionnaires that correspond to three main intervals in the Agreement: (1) *Kick-off Meeting Benefits Questionnaire*; (2) *Mid-term Benefits Questionnaire*; and (3) *Final Meeting Benefits Questionnaire*.
- Provide all key assumptions used to estimate projected benefits, including targeted market sector (e.g., population and geographic location), projected market penetration, baseline and projected energy use and cost, operating conditions, and emission reduction calculations. Examples of information that may be requested in the questionnaires include:
    - **For Product Development Projects and Project Demonstrations:**
        - Published documents, including date, title, and periodical name
        - Estimated or actual energy and cost savings, and estimated statewide energy savings once market potential has been realized; identify all assumptions used in the estimates
        - Greenhouse gas and criteria emissions reductions
        - Other non-energy benefits such as reliability, public safety, lower operational cost, environmental improvement, indoor environmental quality, and societal benefits
        - Data on potential job creation, market potential, economic development, and increased state revenue as a result of the project
        - A discussion of project product downloads from websites, and publications in technical journals
        - A comparison of project expectations and performance; discuss whether the goals and objectives of the Agreement have been met and what improvements are needed, if any
        - **Additional Information for Product Demonstrations:**
            - Outcome of demonstrations and status of technology

        - Number of similar installations
        - Jobs created/retained as a result of the Agreement
    - **For Information/Tools and Other Research Studies:**
        - Outcome of project
        - Published documents, including date, title, and periodical name
        - A discussion of policy development; state if the project has been cited in government policy publications or technical journals, or has been used to inform regulatory bodies
        - The number of website downloads
        - An estimate of how the project information has affected energy use and cost, or have resulted in other non-energy benefits
        - An estimate of energy and non-energy benefits
        - Data on potential job creation, market potential, economic development, and increased state revenue as a result of project
        - A discussion of project product downloads from websites, and publications in technical journals
        - A comparison of project expectations and performance; discuss whether the goals and objectives of the Agreement have been met and what improvements are needed, if any
- Respond to the California Energy Commission Agreement Manager's (CAM) questions regarding responses to the questionnaires.

Technology Transfer Results

As part of the technology transfer activities a plan will be developed to make the knowledge gained, experimental results and lessons learned available to the public and key decision makers.

The Project team will:

- Prepare an Initial Fact Sheet at start of the project that describes the project.
- Prepare a Final Project Fact Sheet at the project's conclusion that discusses results.
- Prepare a Technology/Knowledge Transfer Plan that includes:
    - An explanation of how the knowledge gained from the project will be made available to the public, including the targeted market sector and potential outreach to end users, utilities, regulatory agencies, and others
    - A description of the intended use(s) for and users of the project results

    - Published documents, including date, title, and periodical name
    - Copies of documents, fact sheets, journal articles, press releases, and other documents prepared for public dissemination; these documents must include the Legal Notice required in the terms and conditions; indicate where and when the documents were disseminated
    - A discussion of policy development; state if project has been or will be cited in government policy publications, or used to inform regulatory bodies
    - The number of website downloads or public requests for project results
    - Additional areas as determined by the CAM
- Conduct technology transfer activities in accordance with the Technology/Knowledge Transfer Plan; these activities will be reported in the Progress Reports
- When directed by the CAM, develop Presentation Materials for an Energy Commission-sponsored conference/workshop(s) on the project
- When directed by the CAM, participate in annual EPIC symposium(s) sponsored by the Energy Commission
- Provide at least (6) six High Quality Digital Photographs (minimum resolution of 1300x500 pixels in landscape ratio) of pre- and post-technology installation at the project sites or related project photographs
- Prepare a Technology/Knowledge Transfer Report on technology transfer activities conducted during the project

GLOSSARY

Term	Definition
AMI	Advanced Metering Infrastructure
AMY	Actual Meteorological Year
AWHP	Air to Water Heat Pump
CAM	California Energy Commission Agreement Manager
CCA	Community Choice Aggregator
CEC	California Energy Commission
CLTC	California Lighting Technology Center
CPUC	California Public Utilities Commission
EE	Energy Efficiency
EM&V	Evaluation, Measurement and Verification
EMS	Energy Management System
EPIC	Electric Program Investment Charge
Framework	EM&V Framework
GIHPWH	Grid-Interactive Heat Pump Water Heater
HVAC	Heating, Ventilation, and Air Conditioning
HPWH	Heat Pump Water Heater
IPMVP	International Performance Measurement and Verification Protocol
LED	Light-Emitting Diode
MSHP	Mini-Split Heat Pump
OAT	Outside Air Temperature
PCM	Phase Change Materials
Plan	Research, Instrumentation, and Monitoring Plan
SCP	Sonoma Clean Power
Team	All Lead Locally Program Partners
TMY	Typical Meteorological Year

TRL	Technology Readiness Level