

California Energy Commission
CONSULTANT REPORT

Phase 1 Evaluation, Measurement and Verification Framework

Lead Locally, EPIC Grant EPC-17-041

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



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Edmund G. Brown Jr., Governor



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PREFACE

Project Overview

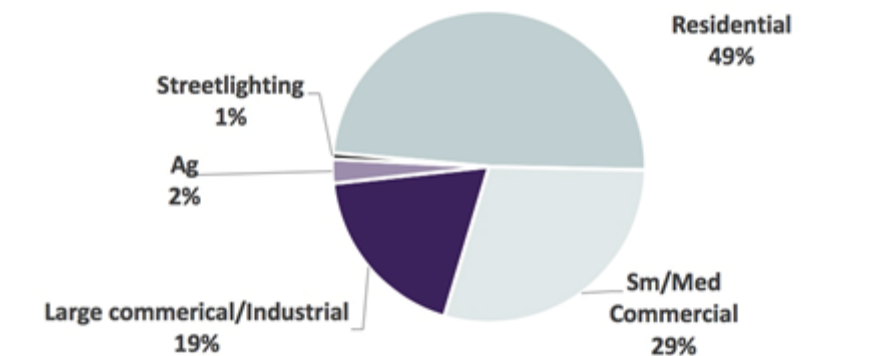
Sonoma Clean Power’s (SCP) “Lead Locally” project (Project), funded through the California Energy Commission’s (CEC) GFO-17-304, aims to identify strategies and technologies that can assist with the State’s goals of doubling the efficiency of existing buildings by 2030. The Project will include applied 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 speed deployment of energy efficiency, 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



Sonoma Clean Power Authority (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 .

Energy Docs and **Rick Chitwood** will design and install the radiant panels, air-to-water heat pumps (AWHPs), and load reduction retrofits.

Chiltrix will serve as the vendor for the AWHPs 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 1 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 1 technologies: Radiant heating and cooling combined with air-to-water heat pumps for residential applications and enhanced daylighting for commercial 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-integrated heat pump water heaters). Phase 2 technologies are not on the critical path, and will be addressed in a Phase 2 Research, instrumentation, and monitoring plan and a Phase 2 EM&V Framework. 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, radiant panels, buildings, research, measurement, verification, EM&V, air-to-water heat pumps, energy efficiency, lighting, daylighting

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TABLE OF CONTENTS

	Page
PREFACE	iii
TABLE OF CONTENTS	vi
LIST OF FIGURES	vii
LIST OF TABLES	vii
Executive Summary	viii
CHAPTER 1: Introduction	1
Purpose.....	1
Scope.....	1
Research and EM&V Coordination.....	2
CHAPTER 2: Lead Locally EM&V Approach	5
EM&V Process.....	7
Baselines.....	9
Technology Assessment	10
Benefits Questionnaire.....	12
CHAPTER 3: Radiant Panels with Air-to-Water Heat Pumps	14
Technology Description.....	14
Data Collection and Analysis.....	14
CHAPTER 4: Commercial Daylighting Retrofits	18
Technology Description.....	18
Data Collection and Analysis.....	18
CHAPTER 5: Reporting	22
Benefits Questionnaire.....	22
Technology Transfer Results.....	23
GLOSSARY	25

LIST OF FIGURES

Figure 1: Risk Reduction Strategy for Lead Locally.....	12
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LIST OF TABLES

Table 1: Applied Research Stage EM&V Roles.....	3
Table 2: IPMVP M&V Options.	6
Table 3. Market Readiness for Radiant Ceiling Panels and Air-to-Water Heat Pumps	16
Table 4: Project EM&V Schedule for Radiant Panel Air to Water Heat Pump Technology	17
Table 5. Market Readiness for Daylighting Technologies	20
Table 6 Project EM&V Schedule for Commercial Day Lighting Retrofit	20

EXECUTIVE SUMMARY

This Phase 1 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 radiant ceiling panels/air-to-water heat pumps and commercial daylighting technologies, and supplements the Phase 1 Research, Instrumentation, and Monitoring Plan.

It is anticipated that the 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.

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 1 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. Phase 1 technologies are on the critical path for Lead Locally and require an accelerated planning schedule to meet later program targets for deployment and technology transfer within the 3½ year timeframe of the grant.

Scope

This Plan addresses two Phase 1 technology categories:

1. Radiant ceiling panels with air-to-water heat pumps for residential heating and cooling applications.
2. Enhanced daylighting for commercial building applications

In the sections that follow, we will present general strategies for conducting the EM&V for the applied research phase for the Project, which will be relevant for both Phase 1 technologies as well as the Phase 2 technologies (phase change materials and optimized grid-integrated heat pump water heaters). Phase 2 technologies are not on the critical path, and will be addressed in the Phase 2 Research, instrumentation, and monitoring plan and the Phase 2 EM&V Framework. 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 1 Research, Instrumentation, and Monitoring Plan (Plan) and this Phase 1 EM&V Framework (Framework), which is a corollary to the Plan.

As described in the Phase 1 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 somewhere in the neighborhood of 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 International Performance Measurement and Verification Protocol (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 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

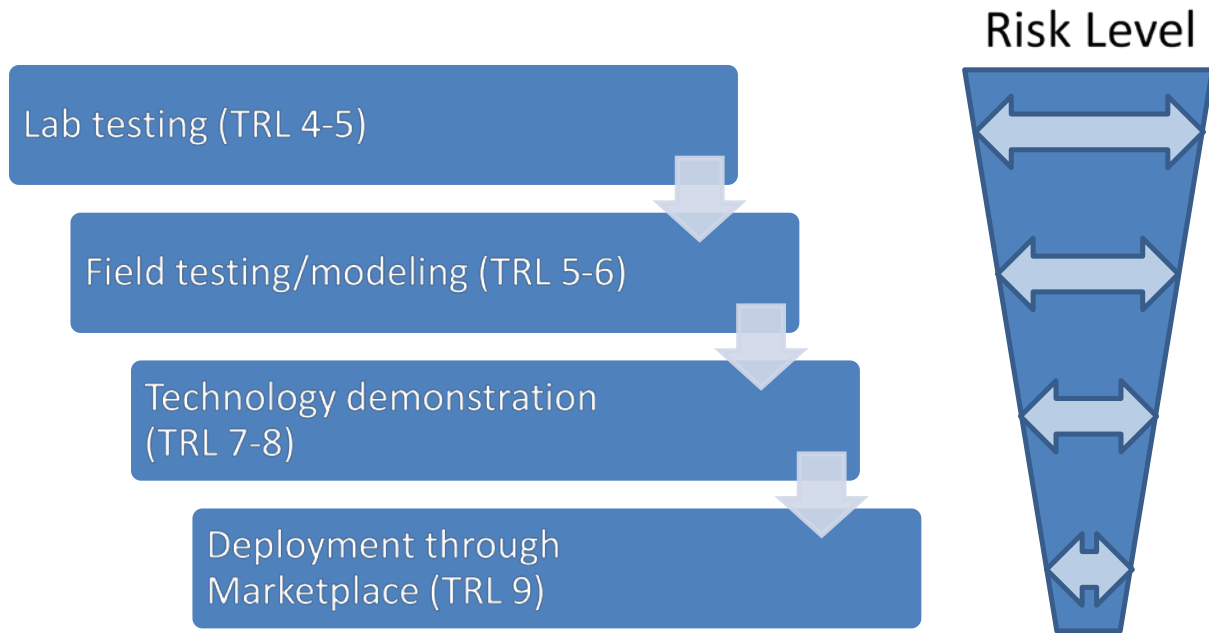
impacts will include energy savings over a baseline technology or time period, demand reductions realized, and greenhouse gas emissions impacts. The algorithm used to estimate greenhouse gas emissions will be determined in conjunction with SCP and Frontier Energy. In addition, the DNV GL will examine 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:

Radiant Panels with Air-to-Water Heat Pumps

Radiant ceiling panels with air-to-water heat pumps (AWHPs) are an energy efficient and space efficient way to heat or cool a conditioned zone. Hot or chilled water is piped from boilers, chillers, and/or heat pumps to panels installed in ceilings to provide radiant cooling or heating to a space. Radiant systems are more efficient and effective than conventional central systems due to the reduction in fan energy use and ability to affect the mean radiant temperature (MRT) in the space. Radiant systems utilizing air-to-water heat pumps are more energy efficient than radiant electric panels in heating, due to the much higher coefficient of performance, and are also able to provide cooling.

Technology Description

Hydronic radiant panels are large ceiling surfaces which are heated or cooled by water pumped through tubing imbedded in the surface. Heat is exchanged between the panel surface and individuals and objects within a room via radiative heat transfer. Some heat is exchanged between the panel surfaces and the air via natural convection. Conventional forced air systems only condition spaces by impacting the air temperature through forced convection. Radiant systems, however, condition spaces via natural convective and radiative heat transfer. This makes radiant systems capable of impacting comfort by changing both the air temperature and the mean radiant temperature. Please refer to Chapter 3 of the Phase 1 Research, Instrumentation, and Monitoring Plan for a more detailed technology description of radiant panels.

Data Collection and Analysis

In this section, we outline the baseline definition, analysis approach, and market readiness for radiant panels.

Baseline Definition

The baseline system should be a central, ducted heat pump or AC/furnace system, with ducts located in vented attics. At least six months of monitored baseline data will be collected prior to the retrofits. Frontier Energy will provide pre-retrofit energy audit information regarding systems and building characteristics. Baseline system performance characteristics will be measured during the energy audits described in the Phase 1 Research Plan (please see Chapter 3 of the Phase 1 plan for further details).

Analysis Approach

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

Analysis of Field Tests

Energy Savings Analysis: IPMVP Option A, Retrofit Isolation, Key Parameter Measurement, will be used to determine energy savings of equipment installed in field test locations. A direct measurement approach is recommended to attain annual energy use for the new system. Baseline system electricity and fuel usage should be directly measured.

- Baseline Energy Use = “Baseline condensing unit kWh” (includes compressor as well as condenser fan) + “baseline fan kWh” + “baseline heating fuel usage” (converted from therms to kWh)
 - Measured baseline kWh
 - Measured fuel usage.
- New system energy use = measured kWh of each major system component (AWHP, fan coil, secondary water pump, etc.)
- Energy savings = “normalized baseline energy use” - “normalized new system energy use”

Thermal Comfort Analysis: Changes in thermal comfort should be directly measured by using a variety of metrics, including dry bulb temperature and relative humidity. Requirements for thermal comfort, such as the dry bulb temperature deviations from thermostat setpoint as specified in ACCA Manual RS, should be determined before instrumentation is finalized so that all required data points for the analysis can be collected.

- Baseline thermal comfort: measure dry bulb temperature and relative humidity for the entire duration of the baseline and retrofit monitoring periods. Hours outside a given deviation from setpoint should be considered *baseline unmet load hours*.
- Post-retrofit thermal comfort: measure dry bulb temperature and relative humidity for the entire duration of the baseline and retrofit monitoring periods. Hours outside a given deviation from setpoint should be considered *proposed unmet load hours*.
- Increase in thermal comfort performance = percentage decrease in unmet load hours = $[(\text{baseline unmet load hours}) - (\text{proposed unmet load hours})] / (\text{baseline unmet load hours})$

Energy Simulation Model Review for Field Test

IPMVP Option D, Calibrated Simulation, is the proposed approach for future installations of the technology, if it is shown to be successful during this pilot phase. The Frontier team will develop building simulation models for the test sites and will size Radiant and AWHP systems using these models to determine the performance of the technology.

As part model review process, DNV GL’s EM&V team will verify the baseline model input parameters and cross check these parameters with the data collected at the test sites to ensure the accuracy of the parameters in the model. The EM&V team will then confirm that the energy models are calibrated to the baseline period building energy consumption so that the model represents the actual building characteristics and operations.

Similarly, after the Retrofit monitoring period, the technology operational characteristics will be verified in the model and confirm that the model is calibrated to the Post retrofit period building energy consumption data. The EM&V team will ensure that the model follows the following guidance while performing simulations:

1. Comparing baseline against Actual Meteorological Year (AMY) data for the corresponding 6-month data collection period
2. Comparing retrofit against AMY data for the corresponding 12-month data collection period
3. Normalizing both baseline and retrofit energy simulation files to Typical Meteorological Year (TMY3) data to determine relative savings

Market Readiness

Hydronic radiant ceiling systems have been used in building design since the 1960s, but coupling them with air-to-water heat pumps at the residential scale has only recently gained traction. Table 3 lists the technology recommendations and their current market readiness.

Table 3. Market Readiness for Radiant Ceiling Panels and Air-to-Water Heat Pumps

Technology	Market Readiness
Hydronic radiant ceiling panels	Less common market-ready, used in practice
Air-to-water heat pumps	Market-ready, used in practice
Hydronic radiant ceiling panels coupled with air-to-water heat pumps in a residential retrofit.	Less common, but market-ready, used in practice.
Pre-retrofit envelope load reduction	Market-ready, used in practice

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 these features in HVAC retrofits. Hydronic radiant systems may be common in new custom homes, but radiant ceiling panels as a retrofit measure are rare. 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 radiant panel air to water heat pump technology.

Table 4: Project EM&V Schedule for Radiant Panel Air to Water Heat Pump Technology

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

CHAPTER 4:

Commercial Daylighting Retrofits

For thousands of years, commercial buildings were lit almost exclusively by natural daylight. After the electrification of cities and advent of widespread lighting in the early part of the twentieth century, architects slowly removed daylight from their design requirements. A century later, lighting became the biggest electricity use in commercial buildings, and many spaces do not function without continuous electric lighting, even on the sunniest of days.¹

Improving daylight in buildings will provide an opportunity to bring lighting energy use to zero during many occupied hours, and also provide a more comfortable and effective work environment. The Project proposes to test many daylight technologies, improve daylight in “dark interior spaces” in two commercial buildings, and to test a new control algorithm to integrate lighting, blinds, electrochromic windows, and other building features.

Technology Description

Daylight technologies will be installed in three buildings to improve daylight effectiveness in the occupied spaces and reduce lighting energy use. Two conditions will be tested:

- In two non-residential buildings, several approaches for extending daylighting into dark interior spaces will be implemented, including fiber optic daylighting systems, tubular skylights, low solar gain skylights, high reflectivity surfaces, and transparent partitions.
- In a separate test building with substantial existing daylight, the team will verify the ability of the CLTC control algorithms to manage the operation of automated blinds, electric lighting, electrochromic windows, and other technologies to optimize the overall energy efficiency of the building and reduce peak demand while maintaining comfort. Any comfort or operational issues will be identified monthly through regular surveys of building owners, occupants, and facility managers.

For more detailed descriptions of technologies, please refer to Chapter 4 of the Phase 1 Research, Instrumentation, and Monitoring Plan.

Data Collection and Analysis

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

¹ InformeDesign. 2005. “Daylight in Buildings.” *Implications*. Volume 3, Issue 3. https://www.informedesign.org/_news/mar_v03-p.pdf

Baseline Definition

Baseline conditions, energy use, and lighting energy use for each building receiving a daylight retrofit will be based on the existing conditions and existing performance of that building's lighting and daylight systems. When evaluating daylight systems, it is important to measure existing lighting usage without making overarching assumptions about typical occupancy profiles and fixture-by-fixture use. This is especially true in dark interior spaces, which may have very low annual hourly usage.

Two (2) Buildings Receiving Daylight Upgrades: Baseline system will be the lighting, lighting energy use, and existing daylight characteristics of buildings before daylighting technologies are implemented. The existing conditions should be well documented and baseline lighting energy use measured over a period of at least six months. Performance will be specifically analyzed in the “dark interior spaces” which receive retrofits.

Building Receiving dynamic fenestration systems and CLTC Control Algorithms: The baseline system will be the current lighting and HVAC energy use within the space as measured over a previous period of at least six months.

Analysis Approach

IPMVP Option A, Retrofit Isolation, Key Parameter Measurement will be used with lighting circuits specifically measured to determine savings associated with daylighting technology retrofits.

Energy Savings Analysis: A direct measurement approach is recommended to attain annual energy savings for zones receiving daylighting technologies. Energy savings analysis can be derived directly from measured kWh for each “dark interior zone” or zones controlled with the CLTC algorithm. Energy savings will be compared against simulated energy savings within a capable software.

- Baseline fixture kWh = measured baseline fixture kWh
- Daylighting improvement savings = (measured improved zone fixture kWh) - (Baseline fixture kWh) + (HVAC interactive savings)

Daylight Analysis Review: Daylight analysis review will be performed to ensure the accuracy of the inputs to the analysis and to determine estimated daylight effectiveness and associated energy savings. The results of the analysis should be compared against the measured results after installation of daylight technologies.

Market Readiness

The daylight strategies which will be employed range 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 4 lists the technology recommendations and current market readiness for daylighting technologies.

Table 5. Market Readiness for Daylighting Technologies

Technology	Market Readiness	Typical Application
Fiber Optic Daylighting Systems	Research and Development Technology	Central zones with no direct access to side-lighting or roof-lighting
Tubular Skylights	Market-ready, used in practice	Central zones with no direct access to side-lighting, direct vertical access up to two levels below building roof
Sun-Tracking Skylights	Market-ready, used in practice	Central zones with direct access to roof
High Reflectivity Surfaces	Market-ready, used in practice	All well daylit spaces adjacent to darker spaces
Transparent Partitions	Market-ready	Central zones with indirect access to side-lighting
CLTC Control Algorithm	Research and Development Phase	All spaces with dynamic daylighting systems

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 these features in lighting designs and 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 daylighting technology.

Table 6 Project EM&V Schedule for Commercial Day Lighting Retrofit

Project Tasks	Completion Dates
EM&V Framework Development	November, 2018
Field Test-Pre-monitoring Strategy Review	July, 2019
Program Participants Survey review	December, 2020

Field Test-Retrofit Monitoring Strategy Review	December, 2020
Simulation Model Reviews	March, 2021
Market Readiness Interviews	April, 2021
Draft Report Review	October, 2021
Final Report Review	November, 2021

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	Phase 1 EM&V Framework
HVAC	Heating, Ventilation, and Air Conditioning
IPMVP	International Performance Measurement and Verification Protocol
LED	Light-Emitting Diode
MSHP	Mini-Split Heat Pump
PCM	Phase Change Materials
Plan	Phase 1 Research, Instrumentation, and Monitoring Plan
SCP	Sonoma Clean Power
Team	All Lead Locally Program Partners
TMY3	Typical Meteorological Year
TRL	Technology Readiness Level