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Response to Invitation to Submit Proposals- Solar Inverters

Additional submitted attachment is included below.

Solar Inverters

Codes and Standards Enhancement (CASE) Initiative
For PY 2017: Title 20 Standards Development

Response to the California Energy Commission's Invitation to Submit Proposals
Solar Inverters
17-AAER-13

September 18, 2017

Prepared for:

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1. Purpose

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update California's Appliance Efficiency Regulations (Title 20). The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and SoCalGas® – sponsored this effort (herein referred to as the Statewide CASE Team). The overall CASE program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve the energy and water efficiency of various products sold in California. This report and recommendations for the Energy Commission solar inverters roadmap are part of the overall Statewide CASE Team effort to respond to recent Energy Commission questions and provide additional information to support the roadmap effort. The Statewide CASE Team believes that the Energy Commission roadmap for solar inverters can play a valuable role by evaluating opportunities for testing, reporting, standards, and policies to overcome market barriers and achieve improved efficiency.

2. Summary

Solar energy is a very large source of power generation in California that continues to grow. In 2016, California installed over 5,200 MW of solar photovoltaic power (customer sited and utility scale) with a cumulative PV solar capacity of over 18,300 MW as of September 2017.[1] (SEIA 2017a) Solar energy use will continue to increase due to falling costs and aggressive California climate and renewable energy goals. The development of a roadmap for solar inverters has the potential to positively impact solar production in a rapidly changing industry. While many aspects of solar inverter effectiveness and efficiency have benefited from technological improvements in recent years, information gaps and potential market barriers persist in some areas. The Statewide CASE Team recommends that the Energy Commission's solar inverters roadmap consider a wide range of current and emerging technologies including traditional inverters (string and central inverters), battery inverters (which are commonly installed with solar systems) and module level power electronics (MLPE) such as microinverters and power optimizers. Additionally, the roadmap should address other ongoing policies that are also impacting inverters and associated components.

Below is the summary of recommendations for consideration in the solar inverters roadmap, which are discussed in greater detail in Section 5.

Product Scope:

- Include traditional inverters, MLPEs and solar-tied battery inverters. Additionally, consider expanding the scope to include battery inverters that can be used with a solar system or in a stand-alone application.

Test Procedure:

- Update Energy Commission testing protocols to explicitly address new technologies, such as communications capabilities needed for safety and other features, and MLPE; and

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[1] The Statewide CASE Team subtracted 1,300 MW of concentrating solar power, based on the Energy Commission "Database of California Power Plants" (available at http://www.energy.ca.gov/sitingcases/alphabetical.html on the "Power Plant" sub-tab) from the SEIA California state-wide total of 19,600 MW (as of September 2017).

- Expand Energy Commission testing protocols to explicitly address battery inverters that are coupled with solar systems, including standardization of duty cycles used for testing and "round-trip" efficiency metrics.

Reporting:

- Consider new reporting requirements to better address new communications and other features, such as capability to provide system monitoring and operate multiple Maximum Power Point Tracking (MPPT) channels;
- Consider new reporting requirements for battery inverter and power optimizer operational efficiency and standby losses; and
- Address the future of the statewide database of solar inverter efficiency, which may be affected by the phase-out of various California incentive programs that have traditionally supported the database.

Efficiency Goals/ Standards:

- Consider the results of any new test procedures and evaluate whether an efficiency standard or goal could be beneficial for battery inverters, as they appear to lag in conversion efficiency compared to grid-tied inverters;
- Consider the results of any new test procedures and evaluate the potential usefulness of efficiency goals or standards (including standby mode) for central, string and microinverters; and
- Consider coordinating this effort with the development of the California Energy Commission Low Power Modes Roadmap as it pertains to "night-tare" or standby losses from solar inverters.

Additional Policy Considerations:

- Coordinate with the Smart Inverter Working Group and Rule 21 development, National Electrical Code and California Electric Code development, and Net Energy Metering tariff revisions.

Additionally, on August 22, 2017 the Energy Commission issued further guidance on roadmap topics, including nine questions about solar inverters (CEC 2017b). The following table lists the various areas in the report where these questions are discussed.

Table 1: Energy Commission Roadmap Guidance Reference Table

Energy Commission Question	**Relevant Section in CASE Report**
1. What agencies and organizations are involved with solar inverters and what are their roles and goals with respect to solar inverters?	<u>See Section 6.</u>
2. What are the existing drivers for high performance/high efficiency solar inverters? Consider the effects of regulatory requirements,	<u>See Section 5.3.</u>

market incentives, and market drivers for performance and efficiency.	
3. Is there an existing test procedure or a group of existing test procedures that is adequate for assessing the various efficiency metrics for the range of inverter and module-level power electronics products currently available? If not, is there a recommended approach to either improve the existing test procedures or to develop improved test procedures?	See Section 5.1.
4. What performance attributes are critical for characterizing the various efficiency metrics of inverter and module-level power electronics products currently available?	See Section 3.1 and Appendix A.
5. Are there any inverter performance attributes that are critical for grid harmonization which are not expected to be addressed by the California Public Utilities Commission's Smart Inverter Working Group (SIWG)?	See Section 6.2.
6. Are cyber security issues sufficiently addressed by SIWG phase 2 recommendations?	See Appendix D.
7. SIWG phase 3 efforts are ongoing. How can the Energy Commission accou to content and timing of any requirements that are the result of SIWG phase 3 efforts?	See Section 6.2.
8. Does Rule 21 effectively apply statewide? In other words, is it reasonable to assume that the California market will be supplied only with inverters meeting the California Public Utilities Commission's Rule 21 interconnection requirements or is it likely that inverter manufacturers would supply different products to end-users in California utility territories that are not subject to Rule 21?	See Appendix C.
9. Is adequate information available to both the equipment purchaser and equipment owner regarding the various efficiency metrics (conversion, maximum power point tracking, and self-consumption) for the range of inverter and module-level power electronics products currently available? If not, how can better information be made available?	See Section 5.1.

3. Product Definition

3.1 Solar Inverters

3.1.1 Solar Inverter Functions

The Energy Commission asked (CEC 2017b) "what performance attributes are critical for characterizing the various efficiency metrics of inverter and module-level power electronics products currently available?"

Solar inverters convert direct current (DC) power from photovoltaic (PV) modules into alternating current (AC) power and adjust the voltage to a level that can be used for building loads or export to the grid. Conversion efficiency and "standby" mode power use (described later) are key performance attributes related to efficiency.

Solar inverters also optimize power production. Solar inverters are used to optimize solar power production through Maximum Power Point Tracking (MPPT), which is a critical metric for solar inverter effectiveness. MPPT is the process that identifies the Maximum Power Point (MPP), defined as the point of maximum power, as measured in watts (W), on the Current-Voltage (I-V) curve of a solar cell. Appendix A: contains an example I-V curve. Power is defined by the product of current in amperes (I) and voltage (V). The MPP varies depending on solar insolation, ambient temperature, shading, and module capacity degradation. MPPT is performed through a charge controller integrated with a microprocessor, which uses algorithms to conduct continuous sampling. The sample voltages are used to determine the real-time MPP and manipulate the PV module voltage to achieve the MPP.

One disadvantage of MPPT when performed at the string level is that the MPP can vary for individual PV modules within a string, due to shading, degradation, or orientation (some central inverters perform MPPT at the array level). The MPPT sets the voltage for a string of PV modules as a whole. Therefore, the weakest performing module in a string can reduce the efficiency of the entire string, sometimes significantly. In an ideal solar installation—where panels are unshaded, oriented in the same direction, and degrade at the same rate—an inverter can perform MPPT effectively at the string level, with the modules together as a unit. However, in installations where MPP varies for individual modules, MPPT can be conducted at the module level to improve MPPT effectiveness and system production. MPPT can be achieved at the individual module level using module level power electronics (MLPE), which include (1) stand-alone microinverters, and (2) power optimizers combined with a string inverter or a central inverter as described below. For instance, Tigo has claimed performance improvements of 8-20% and Enphase has claimed improvement of 5-25% from MLPE (Trabish 2012).

One additional criteria for effectiveness is voltage range. Solar inverters with a more limited voltage range may be less effective at maximizing solar production during times of low solar insolation.

The Statewide CASE Team notes that the Smart Inverter Working Group (SIWG), and in some cases market pressure, are leading to products with additional advanced inverter functions as described below. These features are not necessarily directly related to solar inverter efficiency and effectiveness, but some could affect overall solar inverter energy use and should be accounted for when measuring solar inverters against metrics for efficiency and effectiveness.

3.2 Product Sub-Categories

The functions of each major type of inverter or inverter component are summarized in Table 2.

Table 2: Typical Inverter Functionalities

	Power Conversion	MPPT	Remote Module Monitoring and Power Down
String or central inverter	DC to AC downstream of array	String or array level unless combined with power optimizer	Only with additional components
Power optimizer	DC to DC only	Performed at the module level in combination with string inverter	
Microinverter	DC to AC at module level	Performed at module level	
Solar AC module	Same as microinverter, with microinverter integrated into the panel by the manufacturer		
Battery inverter	DC to AC; potentially also AC to DC	Similar to string inverter	Only with additional components

Source: Statewide CASE Team.

3.2.1 Stand-alone String and Central Inverters

String inverters can serve one or more strings of PV modules. String inverters are most commonly used in residential and commercial installations, and increasingly in utility scale projects.[2] Some string inverters can separately control multiple strings, such as strings installed on different rooftop surfaces, while in other cases one string inverter per string may be installed. Larger central inverter units can serve large commercial/utility scale projects, and may be designed with housing to allow outdoor installation.

[2] https://www.greentechmedia.com/articles/read/will-string-inverters-completely-replace-central-inverters-in-the-us-solar

Figure 1: Residential string inverter and manual disconnect.

Source: http://blog.rpu.org/wp-content/uploads/2009/09/inverter-and-disconnecct.jpg

Figure 2: Central inverters.

Source: www.satcon.com

Stand-alone string and central inverters are not inherently capable of module-level functions, such as MPPT, monitoring, and remote shut-down as noted in Table 2. Therefore, models that are not designed to operate with power optimizers (described below) are losing market share and may be squeezed out of the United States (U.S.) market as MLPE market share increases (see Section 7).

3.2.2 Power Optimizers Combined with String or Central Inverters

Figure 3: Power optimizer.

Source: https://en.wikipedia.org/wiki/SolarEdge

Power optimizers are designed to integrate with compatible string or central inverters, often offered as an inverter/power optimizer package by manufacturers. Power optimizers are mounted on or adjacent to PV modules. They provide module level MPPT by controlling the PV module voltage for one or two PV modules using DC to DC power conversion as shown below in Figure 4. They rely on the string or central inverter to provide AC to DC power conversion.

Power optimizers can also facilitate important safety functions required under National Electric Code (NEC) 2017 article 690.12. The 2017 NEC code has been adopted in many states, but not yet in California, which recently adopted the 2014 NEC code.[3] Some significant changes within the 2017 NEC code relate to various required rapid shutdown functionalities to reduce risk to first responders. In order to meet standards for rapid shut-down, monitoring, and functionality, string and central inverters will likely require some type of MLPE (see Section 6).

[3] See http://www.nfpa.org/nec/nec-adoption-and-use/nec-adoption-maps

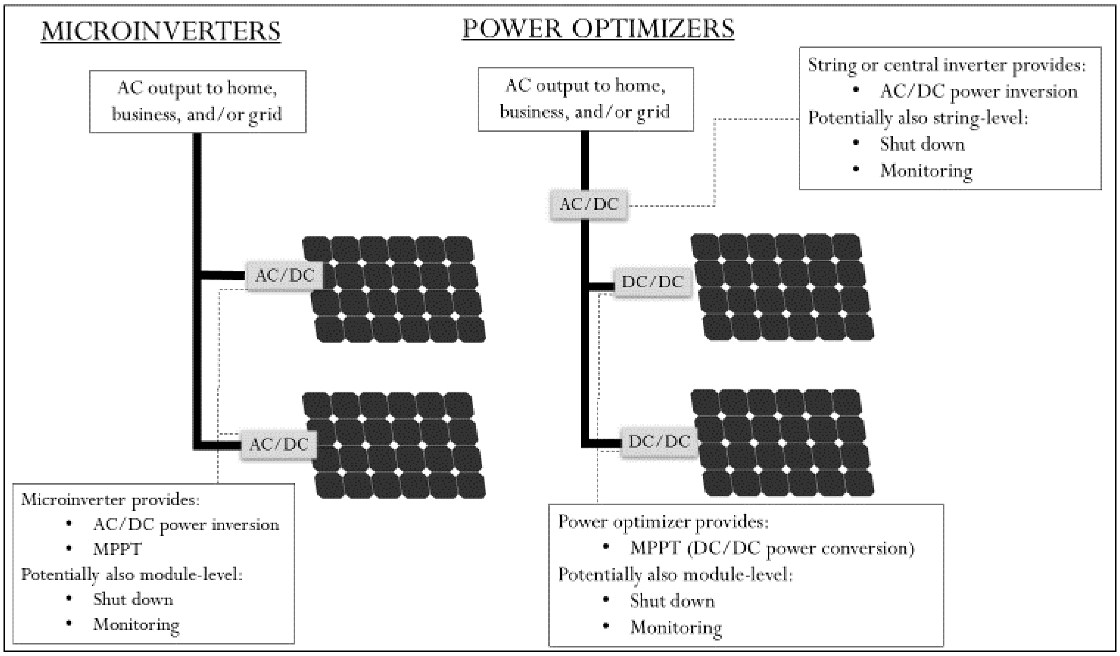

Figure 4: Microinverters and power optimizers.

Source: Statewide CASE Team.

3.2.3 Microinverters

Microinverters perform MPPT and DC to AC power conversion at the module level (typically with a 200-325 W range). They are either shipped separately and integrated with PV modules on-site, or integrated with a PV module at the factory and shipped as an “AC module” to reduce field installation time and labor costs. DC to AC power conversion allows installers to use higher gauge (smaller diameter) wire to carry AC power from the roof.

Figure 5: Microinverter installed on PV module.

Source: http://kuzyatech.com/going-solar

Newer models have the capability to provide multiple MPPT channels to optimize two or four modules from the same inverter unit. This multi-panel optimization can potentially save energy through shared “overhead” functions.[4]

Microinverters are more expensive than stand-alone string and central inverters and appear to be more expensive than combined string inverter/power optimizer and central inverter/power optimizer units. However, the price gap is closing, as can be seen in Figure 6.

[4] Typical examples of standby power loss for electronic equipment include power consumed by power supplies, any circuits and sensors needed to receive a remote signal, displays (including miscellaneous LED status lights), soft keypads for units with this equipment, and circuits that continue to be energized even when the device is "off" (LBNL 2017).

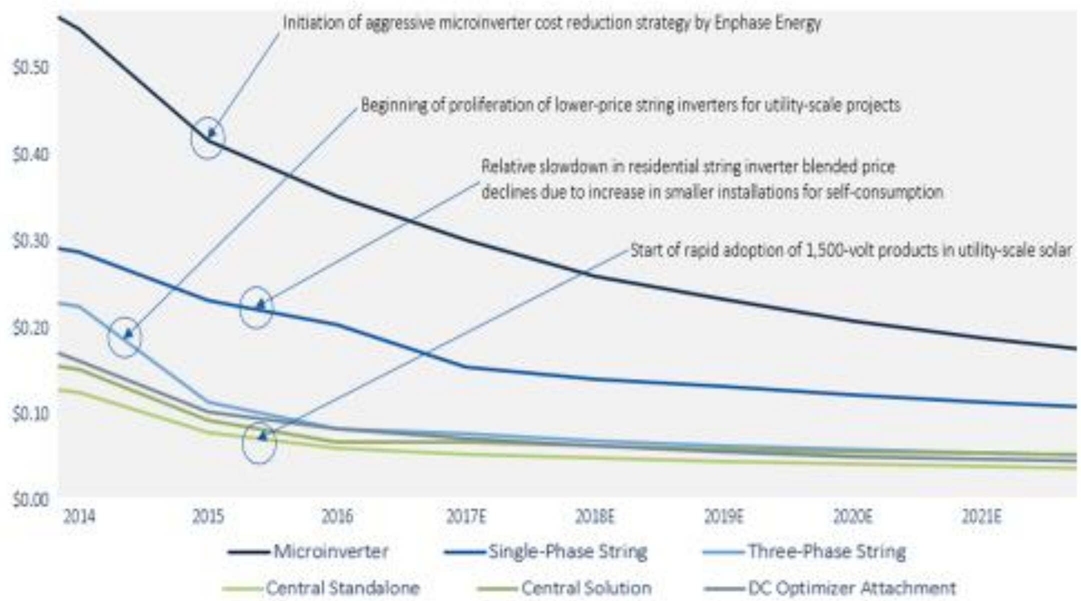

Figure 6: Global average inverter sales price by product type, 2010-2022, (2017 \$/W_{AC}).

Source: https://www.greentechmedia.com/research/report/the-global-pv-inverter-and-mlpe-landscape-h1-2017

3.2.4 Battery Inverters

Batteries and battery inverters in California are most often installed in conjunction with solar systems.[5] Storing solar energy is often cited as a solution to address the "duck curve" shown in Figure 7, by storing mid-day solar generated electricity for use during high demand time periods, such as the evening ramp up.

[5] According to data in the Self-Generation Incentive Program (SGIP) database, the project pipeline (as of August 4, 2017) contains about 250 megawatts (MW) of battery storage that are tied to renewables (historically solar), and 126 MW that are not tied to renewables.

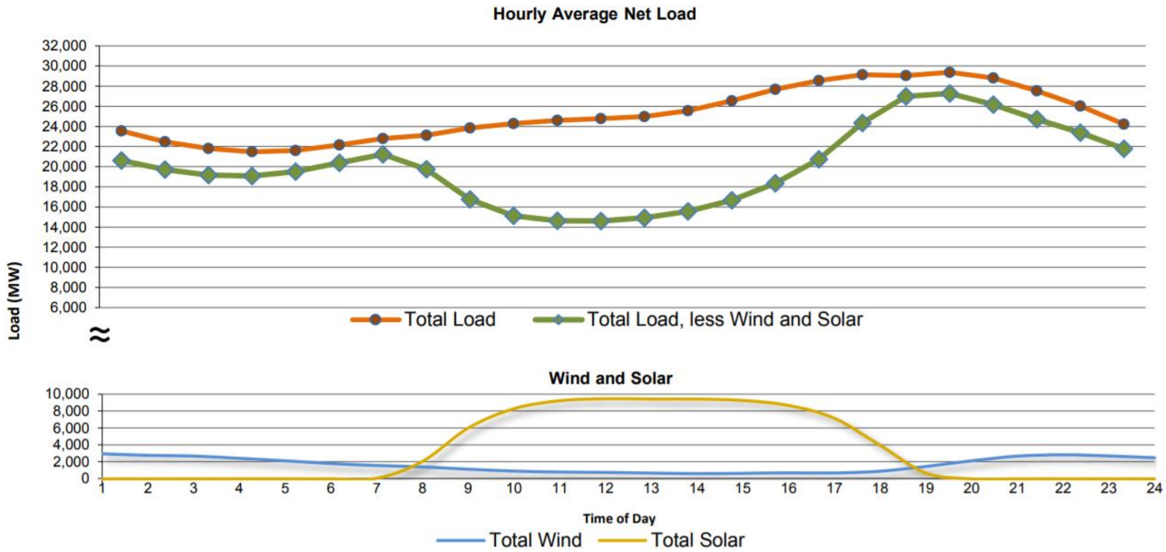

Figure 7: California net load (minus wind and solar) September 17, 2017.

Source: CA Independent System Operator http://content.caiso.com/green/renewrpt/DailyRenewablesWatch.pdf

Battery-based inverters can either replace or complement traditional solar inverters as shown below. The battery inverter on the left, commonly referred to as "DC-coupled," completely replaces the solar inverter. Output from the solar inverter flows through a charge controller that controls the amount of DC current flowing into or out of the battery and changes the voltage flowing into the battery to a typical battery voltage (i.e. 12V, 24V, 48V). The battery inverter then converts battery output DC power to AC power (battery inverters can also contain a DC power output channel). This configuration is typically the most efficient in systems where much of the PV solar array output is stored in the battery bank because minimal losses (just the charge controller and DC voltage conversion) are incurred prior to storage in the battery.

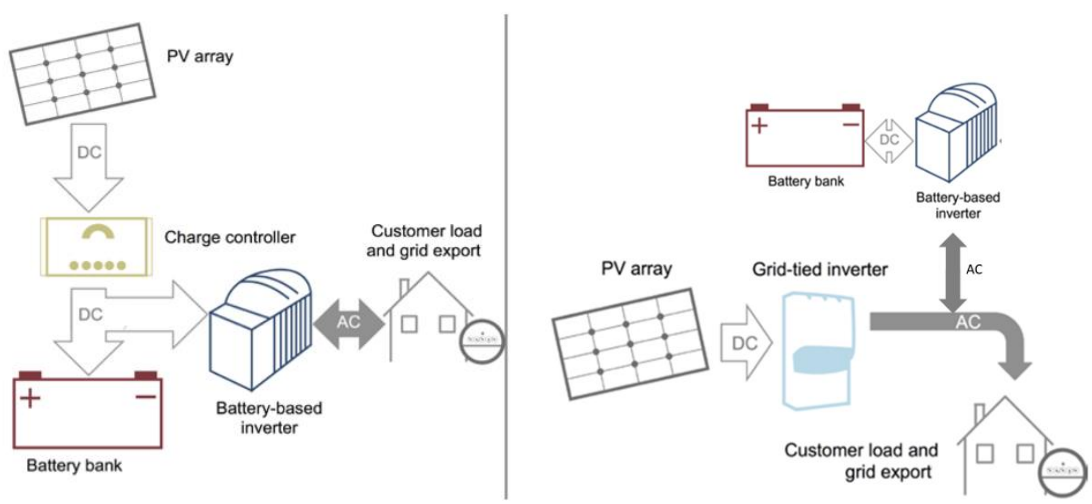

Figure 8: DC-coupled (left) and AC-coupled (right) battery inverters for solar storage.

Source: Ardani 2016; Statewide CASE Team.

Battery-based inverters can also be located downstream from solar inverters as shown on the right. This type of battery inverter is commonly called "AC-coupled." AC-coupled battery inverters can be installed with a solar system and located downstream of the solar inverter or installed independent of a solar system and charged from AC grid power or some other source. The battery inverter on the right converts AC power to DC power for storage in the battery bank and then converts it back to AC power for use locally or in the grid. AC-coupled battery inverters are more efficient where solar system power is typically used in the home or exported to the grid because power does not flow through the battery charge controller, avoiding some minor losses. However, AC-coupled batteries suffer an additional loss of up to 10% for energy stored in the battery due to the round-trip conversion of solar power from DC to AC through the solar inverter and back again to DC through the battery inverter prior to storage in the battery (Ardani, et al. 2016).

The Statewide CASE Team recommends that the Energy Commission consider DC-coupled battery inverters within the scope of the solar inverter product category because DC-coupled battery inverters perform the same functions as a solar inverter (in addition to performing battery related functions). The Statewide CASE Team does not consider AC-coupled battery inverters within the scope of the solar inverter product category since AC-coupled battery inverters complement, rather than replace, solar inverters. The Energy Commission may wish to consider expanding the scope of the solar inverters roadmap to include stand-alone AC-coupled battery inverters since their functions overlap with DC-coupled battery inverters.

3.3 Product Lifetime

Microinverters and power optimizers typically carry a warranty of 20-25 years, similar to typical PV module warranties. String and central inverters commonly carry a warranty of ten to twelve years. Battery inverter warranties appear to vary significantly from one to ten years.

Actual product lifetime may vary based on conditions. The Statewide CASE Team notes that warranties are often set so that products will survive the warranty period even during unfavorable conditions, resulting in an average product lifetime exceeding the minimum warranty period.

4. Roadmap Proposal Overview

Table 3: Summary of Proposal

Topic	Description
Description of Proposed Roadmap Topic	The Statewide CASE Team proposes that the Energy Commission prepare a roadmap for evaluating test methods, reporting processes, and efficiency opportunities for solar inverters (including string/central inverters, microinverters, power optimizers and DC-coupled battery-tied inverters for solar systems with on-site battery storage).
Technical Feasibility	Improved testing and reporting appears to be technically feasible, and the Statewide CASE Team recommends evaluating the technical feasibility of additional energy efficiency targets and/or policies.

Energy Savings and Demand Reduction	Improved testing and reporting will likely provide energy savings and demand reduction. The Statewide CASE Team recommends evaluating potential energy savings and demand reduction from energy efficiency goals and/or policies.
Environmental Impacts and Benefits	The roadmap will potentially lead to environmental benefits through energy savings and demand reduction. No adverse environmental impacts are anticipated since the roadmap will not affect the quantity or capacity of inverters sold or installed in California.
Economic Analysis	Not Applicable (no mandatory standards have been proposed).
Consumer Acceptance	The Statewide CASE Team expects that consumer acceptance will result from benefits including increased availability of information and more efficient products.
Other Regulatory Considerations	The Statewide CASE Team recommends conducting the roadmap exercise in coordination with other stakeholders and processes such as the Smart Inverter Working Group, implementation of the National Electric Code, and updates to the California Electric Code and Net Energy Metering tariffs.

Source: Statewide CASE Team.

5. Recommended Roadmap Topics

5.1 Test Procedures

The Energy Commission (2017b) asked, "Is there an existing test procedure or a group of existing test procedures that is adequate for assessing the various efficiency metrics for the range of inverter and module-level power electronics products currently available? If not, is there a recommended approach to either improve the existing test procedures or to develop improved test procedures?" This section will address existing test methods and potential revisions.

5.1.1 Solar Inverters - Existing Test Methods

The Statewide CASE Team identified a single protocol used by the Energy Commission and a pair of international standards which address inverter conversion and/or MPPT efficiency (see Appendix A for more information regarding MPPT efficiency):

- European Committee for Standardization (CEN) EN 50530 Standard – Overall Efficiency of Grid Connected Photovoltaic Inverters (2010)
- International Electrical Commission (IEC) 61683 Standard (1999) – Power Conditioners – Procedure for Measuring Efficiency (also referred to as EN 61683)
- Sandia Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems (draft 2004)

The CEN EN 50530 Standard and the Sandia Inverter Performance Test Protocol are more focused on grid-tied solar PV systems while the IEC 61683 standard includes both stand-alone and grid-tied solar PV systems. The methods are summarized as follows:

EN 50530

This standard contains procedures to determine MPPT efficiency in grid tied installations based on European conditions. The standard requires the use of a set of weighted factors associated with the static MPPT efficiency. However, "[T]he dynamic behavior of the MPPT algorithm - e.g. on cloudy days with frequent and rapid changes of irradiance - is not reflected in the static figures. In locations where such conditions predominate, this dynamic behavior is also an important issue." (Jantsch, n.d.). In addition to using the static MPPT efficiency, the EN 50530 standard also contains procedures to determine and report the dynamic MPPT effectiveness. The EN 50530 standard refers to EN 61683 to determine inverter efficiency, which mirrors the procedures from IEC 61683.

IEC 61683

This standard contains procedures to determine the solar inverter conversion efficiency through direct measurement of input and output power as well as procedures to determine standby losses. The standard requires operation of MPPT when determining the total inverter efficiency, but does not address the effectiveness of the MPPT function (IEC 1999) and does not address other potential communications features or capabilities.

Sandia Inverter Performance Test Protocol (used by the Energy Commission)

This protocol is used by the Energy Commission for the Energy Commission Inverter Model database. Section 5.5 of this protocol (Bower et al. 2004) contains a process for determining weighted inverter efficiency since efficiency will vary with power output as shown in Figure 9. Table 5-5 of the protocol contains "high insolation" weighting factors for inverter efficiency to represent the Southwest U.S. irradiance and temperature conditions (as well as "low insolation" weighting factors to represent the European Union) as shown below in Table 4. Section 5.5 of this protocol requires operation of "Optional or ancillary equipment" during this test, but does not specifically address activation of features, such as monitoring and reporting and system or module level deactivation. The protocol does recommend disabling MPPT when measuring conversion efficiency. It also specifies the range of measured power levels for each operating point at different nominal loads as shown in Table 4. This variability in power level can lead to additional uncertainty in measured efficiency level accuracy. For instance, the test point representing 50 percent load could be determined using operating points between 45 percent and 55 percent load, and efficiency will likely vary within this range.

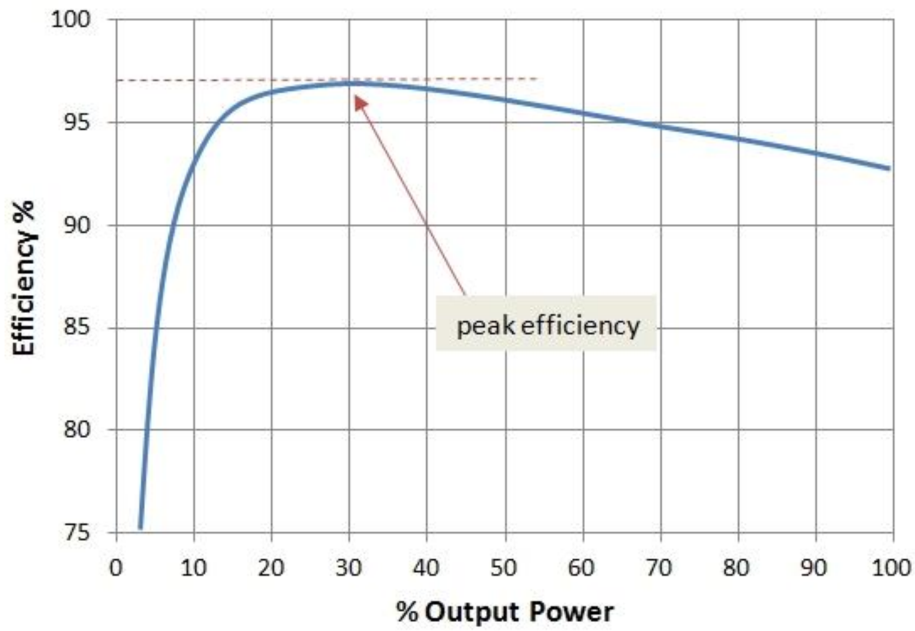

Figure 9: Example of solar inverter efficiency vs load.

Source: Fedkin 2017.

Table 4: Weighted solar inverter efficiency factors under Sandia developed protocol

Nominal Inverter Power Level	Allowable Power Range	Weighting Factor
10%	8-10%	0.04
20%	18 - 22%	0.05
30%	27.5 - 32.5%	0.12
50%	45 - 55%	0.21
75%	70 - 80%	0.53
100%	95- 105%	0.05

Source: Bower et al. 2004.

Section 5.2 of the protocol specifies the allowable measurement uncertainty for several parameters such as limits of +/- 1 percent for AC and DC voltage, current and power. The protocol recommends—but does not require—tighter constraints on measurement uncertainty.

This protocol does contain a section for determining "night tare," or standby power losses when solar inverters are not performing a primary function of power conversion or MPPT (Section 5.7), but does not discuss features such as monitoring, reporting, and system or module level deactivation.

The protocol also contains procedures related to product effectiveness. Section 5.3 contains procedures for determining an inverter's operating range in terms of voltage and current, and Section 5.4 outlines steps for determining maximum power output. These factors can affect product effectiveness, especially under low and/or high solar insolation.[6] Section 5.6 contains an incomplete draft protocol for determining MPPT efficiency under both relatively static conditions (representing gradual changes in solar insolation) and dynamic conditions (representing variable cloud cover). Section 5.6 has not been finalized. This protocol does not address the effectiveness of string vs. module level MPPT.

Table 5: Summary of Sandia Inverter Performance Test Protocol Scope

Sandia Inverter Performance Test Protocol		
Energy Efficiency Measurement	Weighted Average Efficiency	Yes
	Standby power (night tare)	Yes
MPPT Effectiveness	Static	Included, but marked "Draft"
	Dynamic	Included, but marked "Draft"
	Module-level capabilities	No
Scope of Product Types and Features	Activating communications features	No
	Battery inverters	No
	Power optimizers	No

Source: Statewide CASE Team summary; Bower et al. 2004.

5.1.1 Solar Inverter Test Methods – Potential Revisions

The Statewide CASE Team encourages the Energy Commission to evaluate several potential revisions to solar inverter test procedures to address the development of new products, technology changes and potential for increased measurement accuracy.

For instance, the existing protocols do not explicitly address battery inverters and power optimizers. The Statewide CASE Team recommends considering procedures to explicitly address these products. Additionally, the existing protocols do not explicitly address increasingly common features, such as module-level MPPT functions; and remote monitoring, reporting, and shut-off. The Statewide CASE Team recommends considering procedures to explicitly address the activation of these features for efficiency and standby power loss testing. Several ENERGY STAR® test methods (such as Test Method v1.0 for Electric Vehicle Service Equipment) contain examples of instructions on how to activate communications features during testing. Examples of potential solar inverter communications protocols include the following (Reiter 2015):

- Utility private WAN
- Cellular
- Public internet
- AMI network
- Telecom provider

[6] Voltage range will affect ability to operate at low voltages that may be needed to capture solar output during low solar insolation. Maximum power will affect ability to fully capture solar output at maximum solar insolation without "clipping" potential solar output that would exceed the inverter capacity.

The Statewide CASE Team also recommends reevaluating measurement accuracy requirements, which are increasingly important due to narrower differences in product efficiency and greatly expanded sales volumes compared to when the test protocol was developed in 2004. For instance, the Statewide CASE Team recommends reevaluating the +/- 1 percent allowable level of power measurement accuracy in the current Energy Commission approved protocol (the protocol also contains a "preferred" +/- 0.5 percent level of accuracy). One precedent is the 2016 ENERGY STAR® Test Method v1.0 for Electric Vehicle Service Equipment, which specifies allowable power meter measurement accuracy of +/- 0.1 percent of the measured value plus +/- 0.1 percent of the instrument's full span of measurement. The Statewide CASE Team similarly recommends reevaluating the allowable range of loads when testing for inverter efficiency at each nominal load factor as shown in Table 4. Otherwise, companies that test as close as possible to the intended operating level (e.g., 50 percent) could be disadvantaged compared to companies that choose the most favorable point (e.g., 45 percent) within the allowable range.

The Statewide CASE Team also suggests that the Energy Commission reassess the draft MPPT test method and consider finalizing a method to evaluate MPPT effectiveness for different applications (i.e., microinverters, small string inverters and central inverters), use cases, and climates. One challenge is assessing differences in performance between MPPT at the string level and MPPT at the module level, and how this information is used in the market. For example, NREL has developed a testing protocol and reported that MLPE performing MPPT at the module level can reduce losses associated with shading by 25 percent to 35 percent compared to shading losses that occur with string-level MPPT (Deline 2016). This information needs to be available in a manner that is clear to solar designers and others who use MPPT data. MPPT effectiveness testing typically does not account for differences in a product's capacity for module-level optimization.

5.1.2 Battery-tied inverters

The Statewide CASE Team recommends that the Energy Commission evaluate options to develop a standard test method for battery-tied solar inverters, i.e. DC-coupled. (As noted earlier, the Energy Commission could also consider expanding the scope of the solar inverter roadmap to include AC-coupled battery inverters). Based on Statewide CASE Team review of data for many products (Table 12), manufacturers typically report a maximum efficiency (typically around 20-30 percent of maximum power rating) (Perez 2006) without disclosing the test procedure nor operating conditions, such as temperature. However, maximum efficiency does not reflect the equipment efficiency at typical load. An example of how efficiency varies based on load is seen in Figure 10.

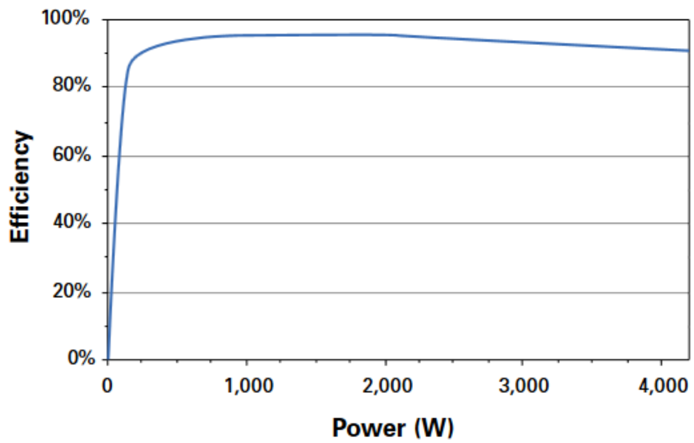

Figure 10: Example of a typical solar storage battery inverter efficiency, 4,000 W AC output.

Source: Perez 2006

A few battery inverter manufacturers also report the Energy Commission-weighted efficiency even though the test procedure (such as the duty cycle) was not designed for these types of inverters. The Statewide CASE Team recommends evaluating the possible adaptability of this test method and/or alternative methods for battery inverters. One key component of a battery inverter test method is the duty cycle. Solar inverters often operate with a gradual variation of input voltage and load throughout the day (voltages can sometimes vary significantly due to MPPT at very low levels of solar insolation). Battery inverter loads may be subject to more spikes. For example, Figure 11 shows one test cycle based on a use case of storing solar generated energy and discharging when energy supply needs are the greatest. The example also shows periods representing on-site energy use to supply local load (such as 12:00 to 13:00 and 13:00 to 14:00, using 24-hour clock time). The Statewide CASE Team notes that off-grid battery and inverter duty cycles are likely to follow end-use load more directly (after subtracting available on-site renewables), and thus fluctuate much more frequently.

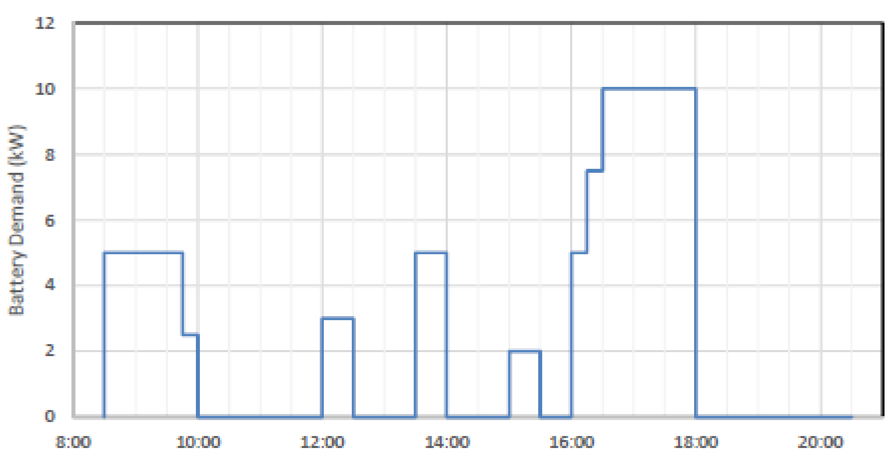

Figure 11: Example of a grid-tied battery inverter testing cycle.

Source: NEXTracker 2017.

The Statewide CASE Team also recommends considering whether the typical duty cycle will vary between different types of battery inverters. Battery inverters that replace a solar inverter can serve the traditional range of solar inverter functions, in addition to converting battery power to voltage(s) compatible with the host site and/or the utility grid. They may tend to cycle more deeply to store energy generated at peak solar availability and accommodate evening and/or early morning demand ramp-ups, and will have losses from the charge controller while charging the battery as well as losses from conversion of DC power from the battery to AC power.

Other battery inverters—located downstream from and intended to supplement a traditional solar inverter—will convert power from AC to DC and back to AC again. These products are often more common when there is already an existing PV system as the retrofit costs are lower.

We also suggest developing a common definition and condition for measuring and reporting standby power losses of battery inverters. Different battery inverter manufacturers use terms such as standby, self-consumption, and search mode in product literature, and typically do not define these terms, nor the operating conditions during these measurements. (In addition, while battery efficiency test methods are outside the scope of this roadmap, we note that standby losses can vary between different batteries due to factors such as temperature, duty cycle and thermal management systems.)

5.2 Reporting

The Energy Commission asked, "is adequate information available to the both the equipment purchaser and equipment owner regarding the various efficiency metrics (conversion, maximum power point tracking, and self-consumption) for the range of inverter and module level power electronics products currently available? If not, how can better information be made available" (CEC 2017b)?

The Energy Commission currently maintains an extensive database of inverters of different sizes, both more traditional string and central inverters as well as microinverters. The database includes power conversion efficiency (when not performing MPPT) and a standby power measurement, also referred to as night tare or self-consumption (when not performing power conversion functions). The database was recently updated to include a field for UL 1741 SA certification (to comply with CPUC Rule 21 Phase 1 smart inverter requirements) and some manufacturers have updated their listing to show the certification date. Currently, this reporting system appears to be effective for providing reported power conversion efficiency and standby losses, with the caveat that improving the underlying test method may improve the accuracy of information that is reported.

The Statewide CASE Team recommends that the Energy Commission address whether the phase-out of the California Solar Initiative incentive programs (see Section 6.5) may hamper manufacturer reporting to the solar inverters to the Energy Commission database in the future. We note, for example, that the PG&E Form 79-1151A for NEM2 interconnection agreements requires use of "CEC listed" equipment (i.e., Energy Commission listed equipment).[7] SCE and SDG&E also require that applicants select from solar inverters listed in the Energy Commission database. Thus, there is a continuing need for information contained in the database. The Statewide CASE Team recommends that the Energy Commission address any anticipated reporting gaps left by expiring incentive

[7] See https://www.pge.com/includes/docs/pdfs/b2b/newgenerator/AA_Form_for_Service_Agreement_ID_Meter_Number.pdf

programs and consider policies and/or requirements for testing and reporting that could fill any anticipated gaps.

Additionally, the Statewide CASE Team has not identified any centralized resource that would allow project developers to compare the MPPT of solar inverters/ power optimizers, or the operating efficiency and standby power losses of power optimizers and solar-tied battery inverters. We recommend that the roadmap consider potential options for standardized reporting on these topics as well considering a standard requirement that manufacturers also report voltage range (which affects the inverters' ability to operate panels at low levels of solar insolation).

Lastly, while the current inverter database includes a simple field to flag whether an inverter complies with Phase 1 of Rule 21 requirements, there is no additional granularity regarding individual features such as communication functionality. While this reporting may be sufficient for Phase 1, the SIWG recently finalized Phase 3 recommendations which may benefit from more detailed reporting as some functionality is optional, not required. (See Section 6.1 for more information.)

5.3 Product Efficiency Opportunities

This section addresses the Energy Commission question: "What are the existing drivers for high performance/high efficiency solar inverters? Consider the effects of regulatory requirements, market incentives, and market drivers for performance and efficiency" (CEC 2017b). This section presents information on advancements in energy efficiency, which indicates that market drivers are effective in some areas. It also identifies potential areas to explore regarding policies to facilitate improved performance/efficiency to overcome market barriers.

5.3.1 Benchmarking Product Sub-Categories

Solar Inverters and MPLE

The Statewide CASE Team recognizes that the different solar inverter product sub-categories could add complexity to any efficiency benchmarks and suggests evaluating at least two possible approaches. One approach is to separate different product sub-categories (string and central inverters, microinverters, power optimizers) and compare products against their peers in that sub-category. Another is to compare sub-categories or groups of sub-categories with similar functionality; i.e., microinverters versus string and central inverters plus power optimizers.

The Statewide CASE Team also recommends evaluating features that are or will be required for compliance with NEC safety standards and CPUC Rule 21 requirements described in Section 6. For instance, some string and central inverters have multiple channels to control multiple strings, and several microinverter manufacturers offer units with two or four channels to control multiple PV modules. Some products may offer multiple communications options and features, such as remote monitoring and/or shutoff. Units may also have the ability to quickly "wake-up" when not in operation in response to an external command. All of these features have the potential to affect power consumption.

Battery Inverter

The Statewide CASE Team encourages the Energy Commission to consider at least two major subcategories for battery inverters when considering potential efficiency options. One major category could include inverters that perform the functions of a solar inverter, i.e. inverting solar energy for use in building or export to the grid, in addition to inverting energy used in a storage battery. These systems could have a separate charge controller for the battery as shown in Figure 8. Another could include AC-tied battery inverters. As noted earlier, the Statewide CASE Team suggests that the Energy Commission consider whether to address these battery inverters as well.

5.3.2 Efficiency Programs and Standards

Solar inverters

The Statewide CASE Team estimates that overall solar inverter power conversion efficiency appears to have improved incrementally from 2013 to 2017 based on initial analysis as shown in Table 6. The Statewide CASE Team calculated this estimate based on 3.9 gigawatts (GW) of solar inverters that (1) have been installed since January 1, 2013, (2) were reported in the California Distributed Generation Statistics database of currently interconnected net energy metering (NEM) systems in IOU territories (herein referred to as "NEM database"), and (3) match with model numbers listed in the Energy Commission solar inverter product database (CEC 2017a). For more information on the methodology for this analysis please see 1.1.1.1.1Appendix B:.

While efficiency has improved, likely in response to market pressure, the Statewide CASE Team estimates that total solar inverter losses across all types of California installations could increase to about 900-1000 megawatts (MW) at peak output by the end of 2021.[8] Some additional losses will occur from power optimizers (compared to string and central inverters without MLPE) as shown in Figure 12. However, power optimizers can significantly boost PV module-level productions compared to a string or central inverter without MLPE in many situations. We recommend that the roadmap consider whether any policies are needed to encourage continued improvement in this market. The Energy Commission could review potential technology development options, as well as whether traditional barriers to uptake of energy efficiency in the residential and commercial sectors could limit uptake of energy efficient solar inverter products.[9]

[8] The Statewide CASE Team calculated current losses based on 1) 18,300 MW of current total solar capacity (SEIA 2017a,which appears to include installations through Q2 of 2017) minus 1,300 of solar thermal (per the California Database of Power Plants; http://www.energy.ca.gov/sitingcases/alphabetical.html) resulting in 18,300 of currently operating PV solar; 2) 13,670 MW of capacity additions over the next five years (as described in Section 7); 3) a current average efficiency of 96.8percent (based on the 2013-2017 average efficiency) and 4) an efficiency of 97.2 percent (based on 2017 efficiency) for future installations. The Statewide CASE Team estimates loses of 590 from existing plants and 380 from projected future plants leading to an estimated total 960 MW of cumulative statewide losses at peak output in five years.

This calculation is approximate, because it does not account for the possibility that peak output could vary statewide from the sum of the peak output of each individual system to regional weather; nor for the higher efficiency expected for utility scale solar inverters compared to the mix of inverters reported in the CSS database. This calculation also does not include loses from power optimizers, nor for the higher efficiency expected for utility scale solar inverters compared to the mix of inverters reported in the NEM database

[9] Examples of barriers to energy efficiency include first cost, information barriers, and limited access to capital.

Table 6: Residential and Commercial Solar Inverter Operational Conversion Efficiency Trends from January 2013 to June 2017 (Initial Results)

Average Inverter Conversion Efficiency (%)						
	Average (2013-2017)	2017[A]	2016	2015	2014	2013
All Inverters	96.8	97.2	97.0	96.8	96.5	96.7
Microinverters	96.0	96.2	96.1	96.0	96.0	96.0
String/Central Inverters ≤ 10 kW	96.6	97.2	96.9	96.7	96.5	96.1
String/Central Inverters >10 kW	97.4	97.9	97.8	97.6	96.9	97.2

Source: Statewide CASE Team analysis of NEM database and inverter product test data.
[A] Through June 30, 2017.

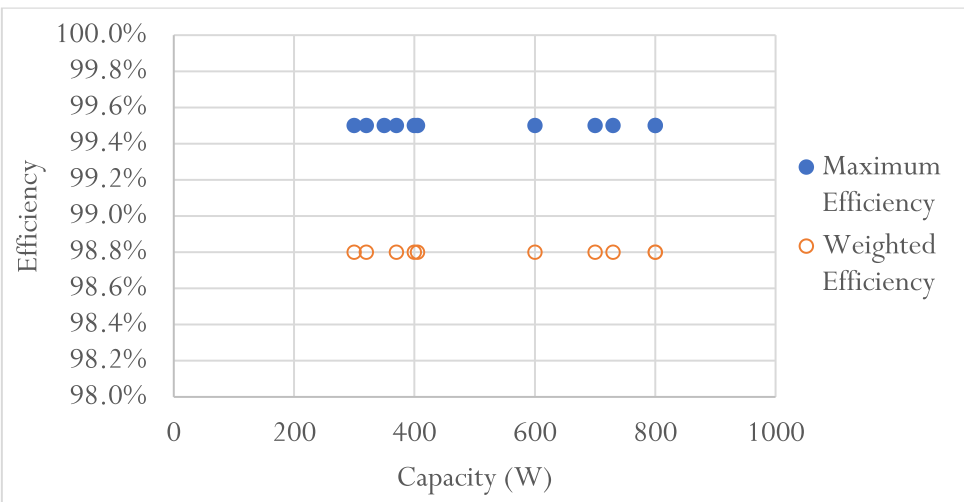

Figure 12: Examples of power optimizer manufacturer claimed maximum and weighted efficiency.

Note: Weighted efficiency refers to either CEC or Euro weighting, but was not specified in the source product specification data sheets.

Source: CASE Team analysis of manufacturer reported data.

<u>Battery inverters</u>

The Statewide CASE Team recommends that the Energy Commission consider potential policies to improve battery inverter efficiency. Installed capacity is small compared to traditional solar inverters, but ramping up very quickly in response to California policy goals and incentives. Battery inverter efficiency can lag solar inverter efficiency by up to 10 percent (NREL 2016). The Statewide CASE

Team initially reviewed several dozen products with less than 10 kW in capacity based on publicly available data sheets and found that manufacturers claim that their "typical" or maximum battery inverter efficiency of 90 percent or better as shown in Figure 13. Manufacturers typically do not list the test method used to determine this information, although some list "CEC-weighted" values that are presumably based on applying the CEC solar inverter testing protocol to this product. This information is based on an informal survey of publicly available product information and does not include sales-weighted efficiency data.

A 5 percent lag in efficiency (compared to solar inverters) for battery inverter installations equal to state targets of 1,325 MW (CPUC 2013) would increase inverter losses by about six to seven MW.[10] Any potential standards or programs should be carefully coordinated with the SIWG and potentially also with the Self-Generation Incentive Program.

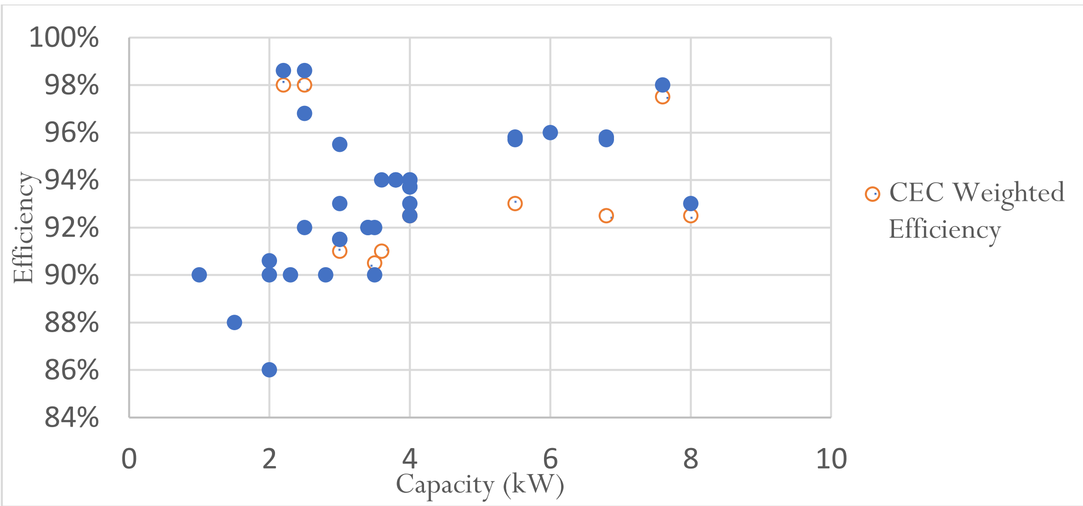

Figure 13: Examples of battery inverter manufacturer claimed efficiency (not sales-weighted).

Source: Statewide CASE Team analysis of publicly available product data.

5.3.3 Standby Power Losses

Standby loses can be reduced through at least two complementary strategies. One is limiting the amount of power consumed when the primary function is not active (often called standby or idle mode for other types of products). Another is requiring transition to lower power consuming modes when the unit is not performing a primary function. Table 7 shows examples of how transitioning modes can lead to significant reductions in power consumption. While the power consumption levels from products offered in the past may not represent current products, they illustrate the potential for significant differences in energy consumption during no load depending on whether the product transitions to a standby mode or not. Strategies to reduce power use when not performing a primary function have been adopted for several Title 20 energy efficiency standards and ENERGY STAR® Specifications. Reductions in standby power losses can also spill over into active mode efficiency if certain "overhead" functions are active during both conditions.

[10] Five percent of 1,325 MW is just over 6.5 MW. As noted earlier, most battery inverters in the Self-Generation Incentive Program database are tied to renewable energy. While recent applications do not specify the type of renewable energy, historically solar has been the primary energy source for prior projects that reported renewable energy source to the SGIP database.

Table 7: Example Power Consumption in No Load and Standby Mode

Manufacturer	Model	Rated Power (W)	Normal Operation No-load (W)	Standby Mode (W)
Fronius	Solarix 900 I	900	9.5	2.4
Isofoton	Isoverter 1-2	1,200	10.2	2.2
Mastervolt	Dakar Combi 48/5000	4,000	37.1	5.1
Mastervolt	Dakar Combi 48/5000	4,000	39.5	6.8
Enertron	Oasis	8,000	294.5	14.8
Enertron	Oasis	8,000	287.2	14.3
Ecotecnia	Ciclops	10,000	62.5	Not reported
Average			110.0	7.6

Source: Munoz 2005.

Solar Inverters

Table 8 indicates that capacity-weighted reported standby losses are small compared to operational losses (i.e., much less than one watt per kW capacity). These conclusions are based on an initial Statewide CASE Team analysis of currently interconnected solar systems based on date of installation and the Energy Commission solar inverter product database as described earlier. These results do not include utility scale installations.

The Statewide CASE Team believes that the first step in determining whether to prioritize reductions in standby power is to determine (1) whether the current test method accurately determines standby power losses of modern solar inverter equipment, and (2) evaluating whether products typically enter standby mode promptly when not performing their primary function; even the lowest standby power levels will not save energy if a product does not transition to this mode.

Table 8: Residential and Commercial Solar Inverter Standby Power Loss January 2013 to June 2017 (Initial Results)

Average Standby Losses in Watts Per KW Capacity						
	Average (2013- 2017)	2017[A]	2016	2015	2014	2013
All Inverters	0.26	0.22	0.20	0.17	0.17	0.25
Microinverters	0.20	0.22	0.20	0.17	0.14	0.14
String/Central Inverters ≤ 10 kW	0.41	0.28	0.22	0.15	0.11	0.12
String/Central Inverters >10 kW	0.09	0.11	0.12	0.20	0.21	0.42

Source: Statewide CASE Team analysis of NEM database and inverter product test data

[A] Through June 30, 2017

Battery Inverters

Battery inverter standby power losses appear to be much greater than solar inverter standby losses for products with comparable capacity, as shown below in Figure 14.[11] Opportunities to reduce standby power losses for battery inverters may depend on the type and use of the inverter. For instance, a battery inverter used primarily to capture solar generated energy mid-day, and discharge during the evening to address the duck curve, may mostly or fully discharge and remain idle overnight while grid power supplies customer load. Batteries may also discharge during the morning load ramp-up. On the other hand, a battery inverter that is intended to continuously supply load 24 hours per day may rarely be idle, potentially reducing or eliminating opportunities to enter a low power mode.

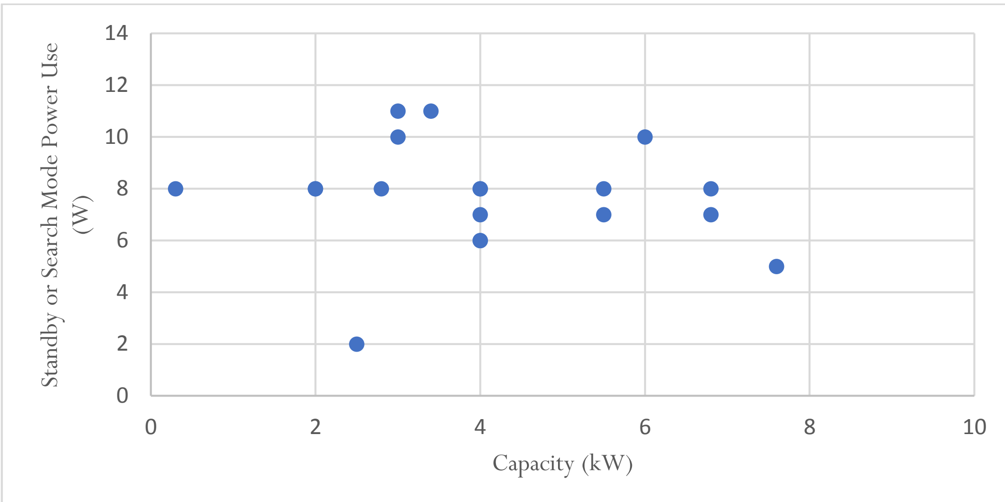

Figure 14: Examples of standby power losses from battery inverters.

Source: Statewide CASE Team analysis of product data.

6. Coordination with Other Agencies and Stakeholders

The Energy Commission (CEC 2017b) has asked, "what agencies and organizations are involved with solar inverters and what are their roles and goals with respect to solar inverters?" This section addresses key agencies and stakeholders as well as relevant venues for standards and policy development.

[11] As noted earlier, manufacturers appear to use a variety of terms to describe standby losses.

6.1 Overview of Smart Inverter Working Group & Rule 21[12]

The Smart Inverter Working Group (SIWG) grew out of a 2013 collaboration between the CPUC and the Energy Commission. This working group identified the development of advanced inverter functionality and communication as an important strategy to mitigate the impact of high penetration of distributed energy resources (DERs), such as solar PV. The CPUC reports that examples of participants include, but are not limited to the following (CPUC 2016a):

> "Advanced inverters could autonomously provide some enhanced functionality based on static set-points, which can be defined at installation and then can later be adjusted by inverter technicians. These autonomous functions do not require communications connectivity or operator dispatch. Other functions require more frequent (approaching real-team) communications to realize their full benefit… Autonomous functions that generally rely on static parameters also can benefit from adding a communications system that enables easier and more frequent adjustment of those parameters" (Reiter 2015).

- Energy Commission and CPUC staff
- Utilities (e.g. California IOUs, SMUD, HECO, PacifiCorp)
- Smart Inverter Manufacturers (e.g. Fronius, SolarEdge, Enphase)
- Industry (e.g. SolarCity, CALSEIA, IREC)
- Testing/Certification Organizations (e.g. Kitu Systems, SunSpec Alliance)

This working group of policy makers, IOUs, manufacturers and other stakeholders has pursued the development of advanced inverter functionality over three phases. Phase 1 developed requirements for autonomous safety and grid-protection functions that are now required for all new interconnections in IOU territories, beginning in September 2017 (see IOU Rule 21 section Hh for details).

Phase 2 established communication requirements, including mandating capability to use Smart Energy Protocol 2.0 (IEEE 2030.5), and encouraged communication between IOUs, Generating Facilities, and Generating Facilities aggregators. Phase 2 also requires remote update capability for inverter software and contains other specifications. These standards will go into effect "after the later of (a) March 1, 2018 or (b) nine months after the release of the SunSpec Alliance communication protocol certification test standard or the release of another industry-recognized communication protocol certification test standard (SCE 2016)."[13] Additional requirements regarding privacy and cyber security and SCE-specific requirements are in a separate handbook.

The SIWG concluded its work on the Phase 3 recommendations on advance inverter functionalities on March 31, 2017.[14] As of the writing of this Report, each of the California IOUs had filed advice letters to incorporate the Phase 3 recommendations in Rule 21 by the August 17, 2017 deadline and were in the process of receiving responses.[15] These advanced functions are designed to apply to all

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[12] See http://www.cpuc.ca.gov/General.aspx?id=4154 and http://www.cpuc.ca.gov/Rule21/.

[13] Note that at the time of this report writing (September 2017) the latter option "b" is likely.

[14] See http://www.energy.ca.gov/electricity_analysis/rule21/documents/phase3/SIWG_Phase_3_Working_Document_March_31_2017.pdf.

[15] https://www.pge.com/tariffs/assets/pdf/adviceletter/ELEC_5129-E.pdf

inverter based distributed energy resources (DERs). It is also noted in the final recommendations that the Phase 3 functions would only be enabled or permitted after contractual or market agreements are made.

6.2 Coordination with SIWG

The Energy Commission has asked "SIWG phase 3 efforts are ongoing. How can the Energy Commission account for uncertainty with respect to content and timing of any requirements that are the result of SIWG phase 3 efforts" (CEC 2017b)?

The Statewide CASE Team agrees that coordination with the SIWG is an important topic and recommends that the Energy Commission evaluate whether the SIWG can play an advisory or more substantive role in the development and potential implementation of the roadmap. In addition, the Statewide CASE Team recommends that the Energy Commission consider recent and prospective SIWG requirements when evaluating potential test method revision. While Phase 3 requirements have yet to be adopted by the CPUC, there is a list of eight recommendations related to various advanced capabilities that may ultimately be required or optional in Rule 21 as described above. Additionally, the communications capabilities that are required by Phase 2 SIWG recommendations and/or may be desired by consumers are not explicitly addressed by existing test methods and should be addressed as noted in the discussion of test methods. Any energy efficiency goals or technology development efforts should consider new features that may be required to meet Rule 21 requirements.

The Energy Commission has also asked "Are there any inverter performance attributes that are critical for grid harmonization that are not expected to be addressed by the California Public Utilities Commission's Smart Inverter Working Group (SIWG)?" (CEC 2017b). The Statewide CASE Team has not researched that question, but will continue to evaluate whether any inverter performance attributes outside of the scope of the SIWG could affect accurate test methods, reporting, and energy efficiency.

6.3 Coordination with National Electric Code and California Electric Code

The National Electric Code (NEC) is published by the National Fire Protection Association. The 2014 NEC Section 690.12 requires the availability of a shut-down mechanism for PV systems "within 5 ft of entering a building or within 10 ft of the array. During rapid shutdown, solar arrays have 30 seconds to limit voltages to no more than 30 V (considered touch-safe in wet locations)" (Solar Power World 2016).

The California Electric Code is developed by the California Building Standards Commission and several state agencies, including the Department of Housing and Community Development, Division of the State Architect, Office of the State Fire Marshal, and several others. The 2016 California Electric Code requires a mechanism to limit conductors to no more than 30 volts and 240 volt-amperes within 10 seconds of rapid shutdown initiation (Section 690.12).

The 2017 NEC requires an 80-volt limit within the system array (Solar Power World 2016), which will essentially require some type of MLPE (e.g., a microinverter, a power optimizer, or potentially a relay integrated with or attached to the PV module) for PV installations subject to fire codes. The current California Electric Code is updated on a three-year cycle, with the next update taking effect January 1, 2020. Thus, the 2017 NEC would likely take effect statewide on January 1, 2020 (local jurisdictions could recommend or require products that meet 2017 NEC before that date if they have authority to set stricter requirements). These requirements may affect solar inverter energy consumption and should be considered when evaluating test methods, reporting, and policies to encourage energy efficiency.

6.4 NEM 2.0 and Virtual Net Metering[16]

The CPUC has been working over the last few years to update net energy metering (NEM) tariffs to better account for sustainable solar growth in CA and plans to revisit various issues related to NEM in 2019.[17] There are many moving pieces with NEM reform, including virtual net metering for multifamily residential buildings, and we encourage the Energy Commission to monitor these efforts while developing the roadmap.

6.5 Statewide Incentive Programs

The Self-Generation Incentive Program (SGIP) provides incentives for self-generation projects, including battery storage. SGIP reports on certain statistics, such as the number of systems installed and various stages of the SGIP incentive application processing pipeline.

The California Solar Initiative provided incentives primarily for residential and commercial solar systems and has helped scale up those markets. The general market program has been fully subscribed, but some sub-programs are still available. For instance, in June of 2016, the New Solar Homes partnership received an additional $112 million of funding to continue providing financial incentives for homeowners, builders, and developers to install solar energy systems on new homes.[18] Additional programs include the Multifamily Affordable Solar Housing program, which is fully subscribed, and the Single Family Affordable Solar Housing program, which is authorized through 2022, and currently operating under a Phase II budget of $54 million (CPUC 2016b). These incentive programs rely on the Energy Commission established online inverter product database.

7. Market Characteristics

The market for PV solar systems and inverters continues to grow. In 2016, California installed over 5,200 MW of PV solar power (distributed and utility scale) with a cumulative PV solar capacity of over 18,300 MW as of September 2017.[19] Solar energy capacity in California is likely to continue to grow due to aggressive California climate and renewable energy goals, Senate Bill 350 and the Clean Energy and Pollution Reduction Act.[20] The California IOUs have achieved 27 percent renewables in 2016 (CEC 2016) and will need to increase further to meet goals of 33 percent by 2020, and 50 percent by 2030. The Solar Energy Industry Association predicts that California will add 13,670 MW of additional solar capacity over the next five years (SEIA 2017a) with annual estimates shown in Figure 15.

[16] See CPUC "Net Energy Metering" http://www.cpuc.ca.gov/General.aspx?id=3800.
[17] http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M158/K181/158181678.pdf.
[18] See http://www.gosolarcalifornia.org/about/nshp.php.
[19] The Energy Commission "Database of Power Plants" lists 1300 MW of operating solar thermal plants, while SEIA estimates total solar installations of 19.600 MW (SEIA 2017a)
[20] See http://www.energy.ca.gov/sb350/.

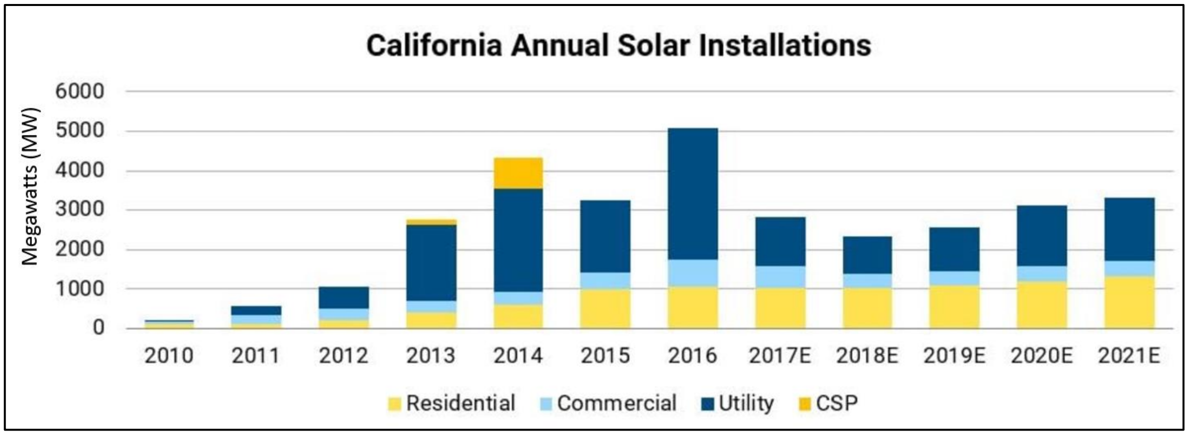

Figure 15: California solar PV deployment forecast by end use.

Source: SEIA 2017c.

7.1 Inverter Sales

Total inverter sales are likely to track total PV solar deployments as shown in Figure 15. However, inverter capacity will likely exceed system capacity because a given company will offer certain size options that may not exactly match the system capacity—thus the installer may choose the next largest size.

To determine the relative market share of different product types, the Statewide CASE Team analyzed the database of interconnected systems (which does not include utility-scale installations) in IOU service territory as described earlier. String inverters under ten kW hold the largest market share of the residential/commercial market. Microinverters appear to hold about 20-30 percent market share (based on capacity), with over 90 percent of sales (based on capacity) occurring in the residential sector.[21] While the NEM database does not include utility-scale installations, we expect that the microinverter utility-scale market is negligible in this sector. The Statewide CASE Team is continuing to refine this initial analysis of market share for various products using the process described in 1.1.1.1.1Appendix B:.

[21] 513,400 kW of microinverters that were matched between the two databases described in Appendix B were installed in the residential market, 18,800 kW were installed in the commercial market and 2,500 kW in the industrial market.

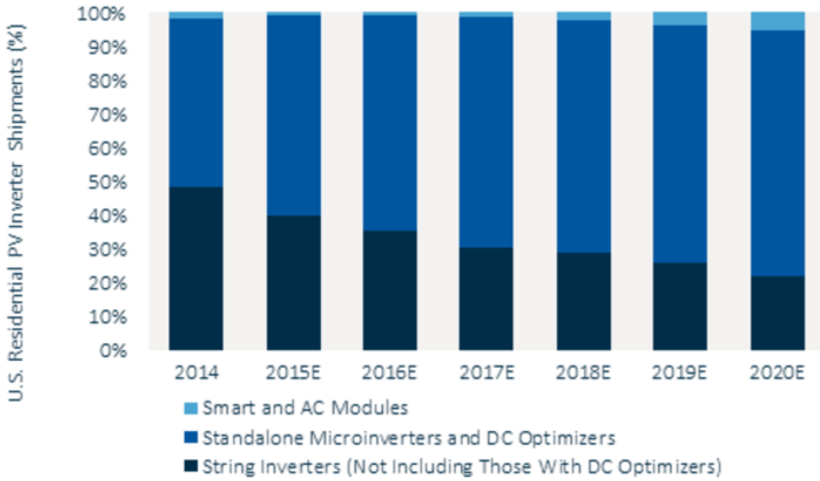

Figure 16: U.S. residential inverter product mix.

Source: Wesoff 2015.

Stand-alone string inverters are expected to lose market share in the residential market as shown in Figure 16, which could shift the market further towards microinverters or string inverters that integrate with power optimizers. The NEM database does not report on the use of power optimizers. However, as of 2015, power optimizers appeared to have roughly double the market share of microinverters globally as shown below in Figure 17. These trends could impact the utility market as well.

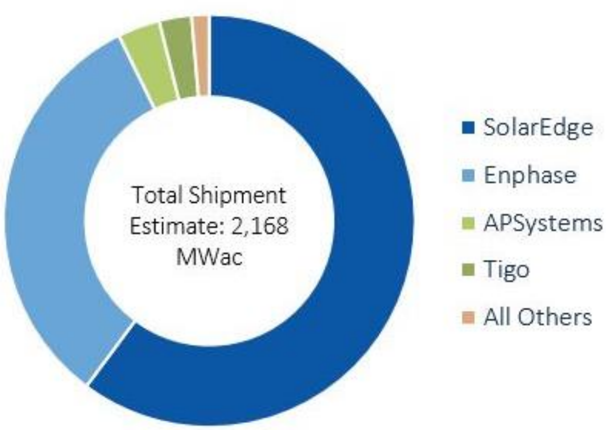

Figure 17: 2015 Global module-level power electronics market shares.

Note: Power optimizers are mainly represented by SolarEdge and Tigo while microinverters are represented by Enphase in this figure.

Source: Moskowitz 2015.

The Statewide CASE Team estimates that 55.9 MW of battery projects funded by SGIP have been installed in California. The total installed capacity will exceed this value because some projects do not receive an SGIP incentive. Installed inverter capacity will likely match or exceed total project capacity (since inverters come in discrete sizes, installers may use the next size up if they do not have an exact match). Of the approximately 250 MW of battery projects in the SGIP pipeline, about two thirds of this capacity are tied to renewables and the Statewide CASE Team assumes that these projects are almost entirely solar. As of August 2017, there are 767 systems installed and 3,253 systems pending for SGIP incentive. Thus, the size of the California market appears primed for a significant growth.

7.2 Employment

California has just over 2,000 companies in the solar industry with $24.7 billion in 2016 sales and just over 100,000 employees as shown in Figure 18.

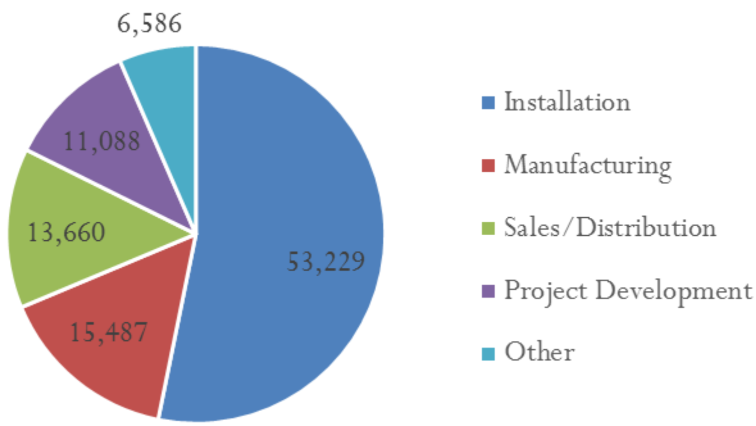

Figure 18: California solar industry jobs.

Source: Solar Foundation 2016.

The average California solar company has 50 employees and an annual revenue slightly less than $13 million per year based on state-wide totals of about 2,000 companies operating in California (Solar Foundation 2016). The California Department of General Services defines a small business as a business with its principal office in California and 100 or fewer employees (companies must also meet other requirements). Non-manufacturing firms must also have average annual gross receipts of $15 million or less over the last three tax years (DGS 2017). The vast majority of California solar jobs are not in the manufacturing sector. Since the average firm would have sales just under the small business threshold for nonmanufacturing jobs, some California solar jobs are in small businesses while others will be located in larger businesses.

The Statewide CASE Team did not find any information to indicate that conducting the roadmap process would harm California jobs, small businesses, or employment in disadvantaged communities. Well-designed policies that encourage continued increase in availability of information and efficiency of products seem likely to provide benefits to the industry. Roadmap development—to a point of recommending specific potential policy actions—will allow for feasible analysis of any potential employment impacts.

8. References

Ardani, Kristen, Eric O'Shaughnessy, Ran Fu, Chris McClurg, Joshua Huneycutt, and Robert Margolis. 2016. "Installed Cost Benchmarks and Deployment Barriers for Residential Solar Photovoltaics with Energy Storage: Q1 2016." National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/67474.pdf

Bower, Ward. Whitaker, Chuck. Erdman, William. Behnke, Michael. Fitzgerald, Mark. 2004. "Performance Test Results for Inverters." California Energy Commission. http://www.gosolarcalifornia.ca.gov/equipment/documents/2004-11-22_Test_Protocol.pdf

California Distributed Generation Statistics. 2017. "Interconnection Application Data Set" http://www.californiadgstats.ca.gov/downloads/

CEC (California Energy Commission). 2016. "Tracking Progress." http://energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf

______. 2016b. "Single-Family Affordable Solar Housing Handbook." http://www.gosolarcalifornia.ca.gov/affordable/sash.php

______. 2017a. "Inverters List - Full Data." May 15. http://www.gosolarcalifornia.ca.gov/equipment/inverters.php

______. 2017b. "Additional Guidance on Roadmap Proposals." http://docketpublic.energy.ca.gov/PublicDocuments/17-AAER-05/TN220851_20170822T150516_Additional_Guidance_on_Roadmap_Proposals.pdf

CEN (European Center for Standardization). 2010. "CSN EN 50530." European Standards. Accessed June 1, 2017. https://www.en-standard.eu/csn-en-50530-overall-efficiency-of-grid-connected-photovoltaic-inverters/

Clover, Ian. 2017. "SolarEdge Q2 2107 financials show record 35% gross margin." PV Magazine. https://www.pv-magazine.com/2017/02/15/solaredge-q2-2017-financials-show-record-35-gross-margin/

CPUC (California Public Utilities Commission). 2013. "CPUC Sets Energy Storage Goals for Utilities". http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M079/K171/79171502.PDF

______. 2016a. "Workshop Notes." http://www.cpuc.ca.gov/General.aspx?id=4154

CUNY (City University of New York). 2016. Resilient PV Retrofit and Storage Ready Guidelines. NY Solar Mart DG Hub. New York: City University of New York. https://nysolarmap.com/media/1655/dghubresiliencyretrofitfactsheet_8_8_16.pdf

Deline, Chris, Jeyna Medbray, and Matt Donovan. 2016. "Photovoltaic Shading Testbed for Module-Level Power Electronics: 2016 Performance Data Update". National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy16osti/62471.pdf

DGS (Department of General Services). 2017. "Small Business Eligibility Requirement." http://www.dgs.ca.gov/pd/Programs/OSDS/SBEligibilityBenefits.aspx

Fedkin, Mark. 2017. "EME 812: Utility Solar Power and Concentration." https://www.e-education.psu.edu/eme812/

Fong, Ken. 2015. "New Requirements for Advanced Inverters in Hawaii." https://www.nrel.gov/esif/assets/pdfs/highpenworkshop_fong.pdf

Hawaiian Electric Industries. 2017. "About Hawaiian Electric Company." http://www.hei.com/CustomPage/Index?keyGenPage=1073751873

IEC (International Electrochemical Commission). 1999. "Photovoltaic Systems - Power Conditioners - Procedure for Measuring Efficiency." Geneva, Switzerland: International Electrotechnical Commission.

Jantsch, M. 1997. "Measurement of PV Maximum Power Point Tracking Performance." Rochester Institute of Technology EDGE: Engineering Design Guide and Environment. http://edge.rit.edu/edge/P12407/public/MPPT%20Testing.pdf

John, Jeff St. 2015. "A State-By State Snapshot of Utility Smart Solar Inverter Plans." Greentech Media. https://www.greentechmedia.com/articles/read/a-state-by-state-snapshot-of-utility-smart-solar-inverter-plans

LADWP (Los Angeles Department of Water and Power). 2017. "Facts & Figures." Accessed May 31, 2017. https://www.ladwp.com

____. 2017b. City of Los Angeles Go Solar Guide. Accessed May 31, 2017. http://www.gosolarcalifornia.ca.gov/resources/socal_jurisdictions/cities/City_of_Los_Angeles.pdf

LBNL (Lawrence Berkeley National Laboratory). 2017. "Stand-by Power Frequently Asked Questions." http://standby.lbl.gov/faq.html#what

Moskowitz, Scott. 2015. "Will the US Mandate Module-Level Power Electronics in 2017?" Greentech Media. https://www.greentechmedia.com/articles/read/will-the-us-mandate-module-level-power-electronics-in-2017

Munoz, Javier and Eduardo Lorenzo. 2005. "On the Specification and Testing of Inverters for Stand-along PV Systems." https://www.researchgate.net/publication/227898495_On_the_specification_and_testing_of_inverters_for_stand-alone_PV_systems

Musser, George. 2009. "Invert your thinking: Squeezing more power out of your solar panels." Scientific American (blog). https://blogs.scientificamerican.com/solar-at-home/invert-your-thinking-squeezing-more-power-out-of-your-solar-panels

NextTracker. 2017. "Request for Proposal (Phase 1). Decapitate the Duck."

Perez, Richard. 2006 "Off-Gird Inverter Efficiency. "https://www.homepower.com/article/?file=HP113_pg36_Perez

Pickerel, Kelly. 2016. "What are National Electric Code Fire Safety Requirements for PV Arrays?" Solar Power World. https://www.solarpowerworldonline.com/2016/09/national-electrical-code-fire-safety-requirements-pv-arrays/

Reiter, Emerson, Kristen Ardani, and Robert Margolis. 2015. "Industry Perspectives on Advanced Inverters for U.S. Solar Phtovoltaic Systems: Grid Benefits, Deployment Challenges, and Emerging Solutions." National Rewewable Energy Laboratory. https://www.nrel.gov/docs/fy15osti/65063.pdf

SCE (Southern California Edison). 2015. “SCE Online Interconnection Application System.” https://www.sce.com/wps/wcm/connect/21666712-4d1a-4556-a523-ca8cd36c7a9a/SCE_NEM_Applicant_User_Guide_2015-04-13a.pdf?MOD=AJPERES

___. 2016. "Rule 21 Generating Facility Interconnections." https://www.sce.com/NR/sc3/tm2/pdf/Rule21_1.pdf

SEIA (Solar Energy Industry Association). 2017a. "California Solar." Accessed August 17, 2017. https://www.seia.org/state-solar-policy/california-solar

_____. 2017b. "Solar Market Insight Report 2017 Q2." http://www.seia.org/research-resources/solar-market-insight-report-2017-q2

_____. 2017c. "Solar Industry Data." https://www.seia.org/solar-industry-data

SMUD (Sacramento Municipal Utility District). 2015. "Rate Policies and Procedures - Service Connection and Collection - Interconnection Guidelines." Accessed May 31, 2017. https://www.smud.org/assets/documents/pdf/11-01-Interconnection-Guidelines.pdf

___. 2017. "Company Profile." Accessed May 31, 2017. https://www.smud.org/en/about-smud/company-information/company-profile.htm

Solar Foundation. 2016. "California Solar Jobs Census 2016. "http://www.thesolarfoundation.org/solar-jobs-census/economic-impacts-report-2016/

Trabish, Herman. 2012."To Microinvert or to Power Optimize That is the Question." Greentech Media. https://www.greentechmedia.com/articles/read/To-Microinvert-or-To-Power-Optimize-That-is-the-Solar-Question

Trabish, Herman K. 2016. "17% of Hawaiian Electric Customers now have rooftop solar." Utility Dive. http://www.utilitydive.com/news/17-of-hawaiian-electric-customers-now-have-rooftop-solar/413014/

UL LLC. 2016. "Energy & Power Technologies." http://industries.ul.com/wp-content/uploads/sites/2/2016/08/UL-1741-SA-Advanced-Inverters.pdf

_____. 2017. "UL 1741 & Rule 21: Advancements in the Integration of PV and Distributed Generation for Grid Support Applications." UL LLC webinar, 56:56. Accessed May 24, 2017. http://connect.ul.com/CIEPTNA170502InvertersUL1741OnDemandWebinar_LP-WebinarVideo.html?aliId=14726079

Wesoff. Eric. 2015. "SMA Takes 27% Stake in Tigo's PV Panel Electronics for $20 Million." Greentech Media. https://www.greentechmedia.com/articles/read/SMA-Takes-27-Stake-in-Tigos-PV-Panel-Electronics-for-20-Million

Zipp, Katie. 2017. "Dual Solar MPPT Defined." Solar Power World. URL or volume/page needed.

Appendix A: MPPT Efficiency

This Appendix provides a description of MPPT effectiveness, a key performance metric for characterizing inverter and module-level power electronics, in response to the Energy Commission question: "What performance attributes are critical for characterizing the various efficiency metrics of inverter and module-level power electronics products currently available" (CEC 2017b)?

MPPT algorithms are based on load curves such as the one in Figure 19 below. The voltage that provides maximum power output will vary with time of day for a given module based on factors such as temperature and solar irradiance, requiring a dynamic response due to changing environmental conditions.

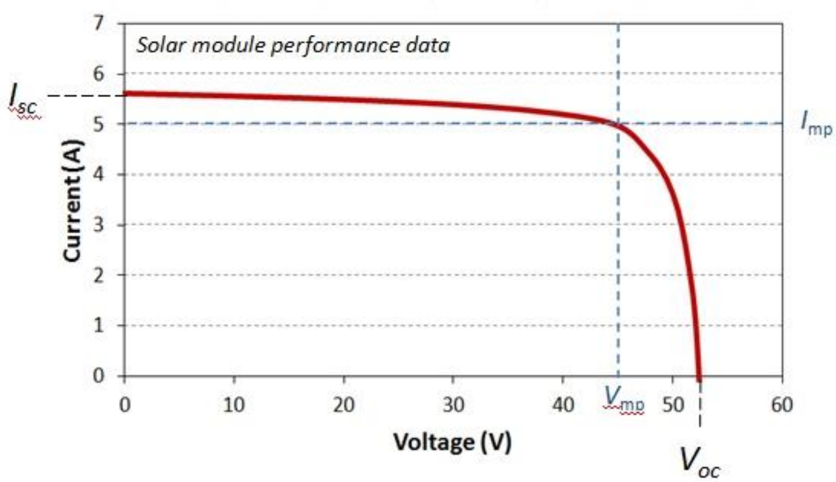

Figure 19: Example of a PV solar power curve.

Source: Fedkin 2017

Microinverters

Microinverters can be used to conduct MPPT at the module level via integration with a charge controller and microinverter. Module-level MPPT creates increased opportunity for customization of the module due to factors such as shade and degradation with age. Module-level customization capabilities may be especially valuable in rooftop applications, where there is larger potential for shading (from buildings, trees, etc.).

Microinverter module-level MPPT also creates flexibility to match panels that are not identical, such as a replacement module or expansion that may not exactly match the original panels, without sacrificing individual maximum efficiency operating conditions.

Central/string inverters with and without power optimizers

String inverters typically control MPPT at the string level (often controlling multiple strings simultaneously), allowing for individual string MPP optimization. Central inverters may perform MPPT at the array level, though central inverters may have multiple MPPT channels. As an example, in a configuration where shading from panels, vegetation, structure, or cloud cover occurs during the day, an inverter with string-level MPPT can maximize inverter efficiency across different strings of PV solar modules with similar azimuthal and tilt angles in a north-south orientation. However, adjustment at the string level will not optimize the performance of individual panels that are affected by shading or aging differently. Furthermore, a single sub-optimal module can limit production of an entire string.

Power optimizers that are installed at the module level in combination with central and string inverters can maximize individual module production like microinverters (though without also providing inverter functions). However, the inverter must be designed or modified to be compatible with power optimizers.

Appendix B: Matching NEM Database to Energy Commission Solar Inverter Product List

The California Distributed Generation Statistics website maintains the "Interconnection Application Data Set" with a log of all solar installations in California IOU territory from 1993 to present day referred to as the Net Energy Metering (NEM) database. Each line item listed in the database contains information on the location of the installation, the capacity of the installed project, the model numbers of both the PV panels and inverters, as well as the quantity of inverters and panels installed.

The Statewide CASE Team matched the NEM database to the Energy Commission Inverter Model database to determine weighted average solar inverter efficiency and standby losses. Many NEM database numbers did not exactly match Energy Commission model numbers listed in the Energy Commission Inverter Model database. The Statewide CASE Team identified common model name variations in the NEM database and revised them to match the model listed in the Energy Commission Inverter Model database. Most common model number inconsistencies in the NEM database were simple fixes. Often entries repeated the manufacturer name, which is a separate field, in the field for the model number (along with the model number). Other inconsistencies between NEM database entries and the Energy Commission Inverter Model database included addition or omission of voltage requirements, voltage described as "V" vs. "V_{AC}", and inconsistency in spacing.

The most common types of inconsistencies, in terms of total capacity, are listed below in Table 9. The Statewide CASE Team was able to match 3.9 GW from the NEMs database from 2013 through March 31, 2017; which is close to the total interconnected project capacity with this timeframe.[22] These results are preliminary and subject to potential revision after further review, which may lead to matching additional NEM projects with solar inverters listed in the Energy Commission Inverter Model database. The Statewide CASE Team may also produce a revised methodology to detect and remedy inconsistencies in inverter model numbers formatting in the NEM database.

Table 9: Examples of Variations Between NEM database and Energy Commission Product Database Model Numbers

NEM database model original entry	Revised product database model name	Capacity (kW)	Units
M215-60-208-S2x or M215-60-240-S2x	M215-60-2LL-S2X	196,765	915,188
M250-60-2LL-S2X (-ZC) (-NA) (240V)[23]	M250-60-2LL-S2X-ZC-NA(240V)	172,338	718,074
S280-60-LL-X (240V)	S280-60-LL-X(240Vac)	14,687	54,397
M250-72-2LL-S2X (240V)	M250-72-2LL-S2X(240Vac)	7,879	32,830
SE3800(240V)w/-ER-USorA-US	SE3800(240V)	90,119	23,778
SE6000(240V)w/-ER-USorA-US	SE6000(240V)	116,332	19,421
PVI-6000-OUTD-US(240V)	PVI-6000-OUTD-US(240V)	63,162	10,527

[22] This is the installed inverter capacity that was matched. We note that inverter capacity exceeds total project capacity because inverters are available in discrete sizes, which in many cases leads to installation of inverters with overcapacity (i.e. a 3.0 kW inverter installed at a smaller residential home as part of a 2.6 kW system).

[23] Note this is the Energy Commission nomenclature for the M250 Enphase Microinverter, but was edited for matching purposes.

FroniusPrimo3.8-1@240VAC	FroniusPrimo3.8-1(240V)	38,619	10,163
STP24000TL-US-10	STP24000TL-US-10(480V)	187,450	7,778
PVI-3.0-OUTD(-S)-US(-A) (240)	PVI-3.0-OUTD-S-US-A(240V)	22,212	7,404
SPR-X21-335-C-AC(240V)	SPR-X21-335-C-AC	1,804	5,639

Source: Statewide CASE Team.

Appendix C: Implementation of Rule 21

The Energy Commission (CEC 2017b) asked, "does Rule 21 effectively apply statewide? In other words, is it reasonable to assume that the California market will be supplied only with inverters meeting the California Public Utilities Commission's Rule 21 interconnection requirements, or is it likely that inverter manufacturers would supply different products to end-users in California utility territories that are not subject to Rule 21?"

The Statewide CASE Team believes that several factors are relevant for addressing this question. First, the Statewide CASE Team recognizes that the California IOUs have been directed to implement Rule 21 requirements by the CPUC, but that California publicly owned utilities (POUs) are not regulated by the CPUC or the Energy Commission in the same way. The Statewide CASE Team has summarized requirements for the two largest California POUs below.

The Statewide CASE Team has also described examples of other states that have implemented standards that overlap with Rule 21 Phase I inverter requirements. State level implementation of Rule 21 or similar requirements could lead to a de facto national standard if enough states adopt similar standards (or are expected to eventually adopt them). Manufacturers and distributors may decide to sell only products that meet Rule 21, to avoid the economic burden of maintaining separate supply chains for products that do and do not meet the requirements.

8.1 California Publicly Owned Utilities Implementation of Rule 21

Of the publicly owned utilities, the Los Angeles Department of Water and Power (LADWP) and the Sacramento Municipal Utility District (SMUD) have the largest market share—and thus the greatest influence on this question. These two POUs have over two million electric power customers across their respective territories (SMUD 2017; LADWP 2017). The remaining 26 POUs are organized into the Northern California Power Agency (NCPA) and the Southern California Public Power Authority (SCPPA), the latter of which also includes LADWP. While the Statewide CASE Team has not catalogued all of the public utility interconnection requirements across the state, a brief examination of SMUD and LADWP indicate that California public utilities do not consistently require full compliance with UL 1741 SA at this time, or at least have a different process to do so. The UL 1741 standard is an equipment safety standard that is used to certify that a specific piece of equipment is safe for a given use (Reiter 2015). In the case of SMUD, all distributed generation resources connecting to the utility distribution system are required to comply with the mandatory requirements outlined in Rule 21. SMUD policy and procedure document 11-01 outlines interconnection guidelines and specifically requires in Section 14.2 the use of equipment certified by both UL 1741 SA and IEEE 1547 for interconnection to their system (SMUD 2015).

LADWP may require some of the same standards, but follows a different process in defining interconnection standards for inverters. Unlike SMUD explicit interconnection requirements, LADWP interconnection requirements are integrated into the permitting process for the host facility and solar incentive program in which they intend to participate (LADWP 2017). In the Statewide CASE Team initial review, the interconnection requirements do not explicitly state that the system must meet Rule 21 or UL 1741 SA requirements to interconnect. Rather, the system must meet the zoning, permitting, and fire safety requirements outlined in the City of Los Angeles distributed solar resource guide.[24]

The LADWP interconnection permitting requirements are spread across various Los Angeles Department of Buildings & Safety (LADBS) permitting guidelines. These guidelines vary based on the type of permit required, and the planning conditions that must be met. For LADWP customers installing systems smaller than 10 kW-AC, an interconnection agreement is not required, and these systems may qualify for an express permitting process if a standard set of conditions is met. While the permitting guidelines may have some overlap with Rule 21 and UL 1741 SA, especially around fire safety, the Statewide CASE Team did not find any general requirement to meet the UL 1741 SA or Rule 21 requirements.

8.2 Hawaii and Arizona implementation of UL 1741 SA

The Statewide CASE Team has identified Hawaii and Arizona as additional examples of states that have mandated or are evaluating advanced inverter functions required by or related to UL 1741 SA. In addition, representatives from both states participated in the SIWG to establish the test procedures for autonomous functionality that are the foundation of UL 1741 SA.[25]

The state of Hawaii is a leader in the adoption of smart inverter functionality mandates in the United States. Hawaii has greater than 15 percent penetration of distributed energy resources (DERs) on many parts of its grid, greatly increasing the need for standards related to smart inverter functionality for grid tied inverters— providing a good model for states with high levels of DER (Trabish 2016). Standards implementation is easier in Hawaii than in some other states. For example, Hawaii essentially has a single IOU, the Hawaii Electric Company (HECO), serving 95 percent of the state load with the remaining 5 percent provided by the Kauai Island Utility Cooperative (KIUC) (Hawaiian Electric Industries 2017). Hawaii has fully adopted both the seven required standards and the two optional standards under UL 1741 SA, shown in Table 10, as well as two additional inverter standards for system disconnect/reconnect and remote configurability not covered in UL1741 SA (Fong 2015; UL LLC 2016).

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[24]See http://www.gosolarcalifornia.ca.gov/resources/socal_jurisdictions/cities/City_of_Los_Angeles.pdf.

[25] See the list of participants in the "Smart Inverter Working Group Phase 2 Recommendations" available at http://www.energy.ca.gov/electricity_analysis/rule21/documents/SIWG_Phase_2_Communications_Recommendations_for_CPUC.pdf.

Table 10: Comparison of the Hawaii Smart Inverter Requirements and UL 1741 SA Inverter Standards

Hawaii Smart Inverter Requirements	UL 1741 SA Test Standards
Anti-Islanding	Anti-Islanding
Low/High Voltage Ride-Through	Low/High Voltage Ride-Through
Low/High Frequency Ride-Through	Low/High Frequency Ride-Through
Volt-VAR Control	Volt-VAR Control
Ramp Rate	Ramp Rate
Fixed Power Factor	Fixed Power Factor
Soft-Start Reconnection	Must Trip Test
Frequency Watt	Frequency Watt (Optional)
Voltage Watt	Volt Watt (Optional)
Remote Reconnect/Disconnect	N/A
Remote Configurability	N/A

Source: Fong 2015; UL LLC 2016

Arizona offers an example of a more decentralized approach. Arizona's two major public and investor owned utilities, Salt River Project (SRP) and Arizona Public Service (APS), are launching pilot programs to study smart inverter functionality, efficiency, and grid benefits in response to a large amount of solar penetration on their distribution and transmission network. Collectively, these two utilities make up about 85 percent of Arizona retail residential, commercial, and industrial electricity sales.

APS has created an inverter study pilot as part of its Solar Partner Program. The program will test a utility ownership model for solar resources deployed in Phoenix to delay transmission and distribution grid upgrades (John 2015). The program aims to install up to 1,500 solar systems and inverters on primarily westerly facing single-family rooftops and a smaller number of systems on southwest and south-facing study control groups to determine the efficacy of smart inverters in meeting grid stability requirements (John 2015). The program will use the APS automated control system in conjunction with these utilities-owned smart inverters to evaluate the ability of fully autonomous functions and smart inverters to accomplish the following:

- Use the inverter to respond during contingency events;
- Improve overall power quality;
- Develop a better understanding of solar output and system demand; and
- Evaluate capabilities of grid-tied battery storage at the distribution feeder level.

SRP has designed and implemented a similar program called the Advanced Inverter Project. This project links 1,000 smart inverters to existing PV systems to study their benefits to the grid and unlock more value from solar. SRP will be testing capabilities of several inverters through autonomous control schemes (John 2015).

Appendix D: SIWG Cyber Security Recommendations

The Energy Commission has asked, "are cyber security issues sufficiently addressed by SIWG Phase 2 recommendations" (CEC 2017b)? The Statewide CASE Team has summarized the SIWG Phase 2 recommendations (draft v9) for cyber security below for consideration when considering potential test methods, reporting and/or policies to promote efficiency.[26] Evaluation of the SIWG recommendations is outside of the scope of the Statewide CASE Team roadmap recommendations.

General requirements for cyber security shall be covered in IOU's Rule 21. Specific cyber security requirements may be included in utility handbooks or auxiliary documents.

This document also recommends that "Basic cyber security requirements include:

- Cyber security requirements shall be end-to-end, including across any intermediary systems.
- The implementation of these cyber security requirements shall be validated before data exchanges are commenced with utilities.
- Cyber security requirements include Authentication, Authorization, Accountability, and Data Integrity at a minimum. Other cyber security requirements, such as confidentiality shall be supported but may be enabled only when needed.
- Stored cyber security data, such as cryptographic keys and passwords, shall be secured from unauthorized access, including in any intermediary systems between the utility and DER systems
- Privacy policies shall clearly define what types of data shall be not available publicly, including individual data elements and aggregations of data."

The SIWG has also identified a list of additional questions and recommended identifying a venue in which they will be answered.

[26] See http://www.energy.ca.gov/electricity_analysis/rule21/documents/SIWG_Phase_2_Communications_Recommendations_for_CPUC.pdf.

Appendix E: Battery Inverter and Power Optimizer Data

Table 11: Example Power Optimizer Data

Manufacturer	Model	Rated Capacity (watts)	Manufacturer Stated Maximum or "Typical" Efficiency	Manufacturer Stated Weighted Efficiency
APSystems	OPT700	310	99.5%	Not Reported
SolarEdge	P300	300	99.5%	98.8%
SolarEdge	P320	320	99.5%	98.8%
SolarEdge	P370	370	99.5%	98.8%
SolarEdge	P400	400	99.5%	98.8%
SolarEdge	P405	405	99.5%	98.8%
SolarEdge	P600	600	99.5%	98.8%
SolarEdge	P700	700	99.5%	98.8%
SolarEdge	P730	730	99.5%	98.8%
SolarEdge	P800p	800	99.5%	98.8%
SolarEdge	P800s	800	99.5%	98.8%
Tigo	TS4-O	475	Not Reported	

[a]SolarEdge did not report the weighting system used

Due to lack of a standardized test protocol for power optimizers, the test method and duty cycle used to determine the efficiency were established by each respective manufacturer, and were rarely reported on the product specification data sheet. The "weighted efficiency" likely refers to the CEC or Euro weighting protocol, but was not specified by the manufacturer.

Table 12: Example Battery Inverter Data

Manufacturer	Model	Rated Capacity (kW)	Manufacturer Stated Maximum or "Typical" Efficiency	CEC Efficiency	Low Power Loss Rating #1 (W)	Manufacturer Stated Low Power Loss #1 Description	Low Power Loss Rating #2 (W)	Manufacturer Stated Low Power Loss #2 Description
Dynapower Company	MPS-250 60 Hz operation	250	96.0%					
Dynapower Company	MPS™-250 50 Hz Operation	250	96.0%					
EPC Power	HY LC12/6-7	200	98.4%					
Ingeteam	Ingecon Sun Storage 1Play 3TL	3	95.5%		10	Maximum Standby Consumption		

Ingeteam	Ingecon Sun Storage 1Play 6TL	6	96.0%		10			
Magnum Energy	MS 2000/12	2	90.6%		8	Power Consumption-searching	8	Power Consumption-inverting (no load)
Magnum Energy	MS2024	2	86.0%		8		8	
Magnum Energy	MS 2812	2.8	90.0%		8		8	
Magnum Energy	MS4024	4	93.7%		8		8	
Magnum Energy	MS4024RE	4	93.7%		7	Search mode (typical)	25	
Magnum Energy	MS4024PAE	4	93.0%		6		27	
Magnum Energy	MS4048	4	94.0%		8	Power Consumption-searching	8	
Magnum Energy	MS4448PAE	4	94.0%		6	Search mode (typical)	25	No load (120VAC output, typical)
Outback Power	FXR2012A	2	90.0%					
Outback Power	FXR2524A	2.5	92.0%					
Outback Power	FXR3048A	3	93.0%	91.0%				
Outback Power	VFXR3524A	3.5	92.0%	90.5%				
Outback Power	VFXR3648A	3.6	94.0%	91.0%				
Outback Power	Radian G S4048A	4	92.5%	92.5%			34	Idle Consumption (Invert Mode, No Load)
Outback Power	Radian G S8048A	8	93.0%	92.5%			34	
Princeton Power	BIGI-250	250	95.3%	94.5%				
Samlex	PST-1000-12		≥85.0%					
Samlex	PST-1000-24		≥85.0%					
Samlex	PST-1500-12	1.5	≥85.0%					
Samlex	PST-1500-24	1.5	≥85.0%					
Samlex	PST-3000-12	3	≥85.0%					
Samlex	PST-3000-24	3	≥88.0%					
Schneider Electric	SW2524 120/240	3	91.5%				24	Tare Loss
Schneider Electric	SW2524 230	3	91.5%		11	Idle Consumption Search Mode		
Schneider Electric	SW4024 120/240	3.4	92.0%				29	Tare Loss
Schneider Electric	SW4048 120/240	3.8	94.0%				27	Tare Loss
Schneider Electric	SW4024 230	3.4	92.0%		11			

Schneider Electric	SW4048 230	3.8	94.0%		11	Idle Consumption Search Mode		
Schneider Electric	Conext XW+ 7048 E	5.5	95.8%		7			
Schneider Electric	Conext XW+ 8548 E	6.8	95.8%		7			
Schneider Electric	XW+ 5548 NA	5.5	95.7%	93.0%	8			
Schneider Electric	XW+ 6848 NA	6.8	95.7%	92.5%	8			
SMA	SUNNY BOY STORAGE 2.5	2.5	96.8%		2	Standby	10	Self-consumption with no load and battery consumption
SMA	Sunny Central Storage 2200	2.2	98.6%	98.0%	300	Self-Consumption (Standby)	2000	
SMA	Sunny Central Storage 2500 EV	2.5	98.6%	98.0%	300	Self-Consumption (Standby)	2000	
Solar Edge	SolarEdge Single Phase StorEdge Inverter for North America SE7600-US	7.6	98.0%	97.5%	5	Typical Nighttime Power Consumption		

Source: Statewide CASE Team review of manufacturer product data

The products included in the table above all have DC-coupled inverter capabilities. Therefore, they are capable of performing the functions of a solar inverter, and thus substituting for a typical solar inverter in a PV system.

Due to lack of a standardized test protocol for battery inverters, the test methods and duty cycle used to determine the efficiency and power loss in the table above were established by each respective manufacturer, and were rarely reported on the product specification data sheet. The data also do not indicate whether the values describe the "round-trip" efficiency through the charge controller (DC/DC power conversion) into the battery and out of the battery (AC/DC) or describe only a "one-way" efficiency.

One possible exception to this lack of standardized testing protocol is the CEC Efficiency reported by some manufacturers. These manufacturers may be using the CEC testing protocol required for solar inverters; however, the CEC testing protocol does not address efficiency losses in the charge controller and thus may not address round-trip inverter losses.