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Evaluation of Alternative Contractor License Requirements for Battery Energy Storage Systems

Final Report for UC Berkeley Contract with the Contractor State License Board for contract CSLB-20-01, entitled "Energy Storage Systems Consultant Services"

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Executive Summary

A. Introduction

This report, carried out at the request of the California State Licensing Board, evaluates alternative proposals for the specific contractor license(s) that should be required for battery energy storage systems (BESS), particularly those installed in conjunction with installations of solar photovoltaic (solar PV) systems. The rapid and safe development of the BESS industry—i.e., businesses that design, install, maintain, and repair BESS—is essential for actualizing California's commitment to achieve 100% carbon-free electricity, as mandated in SB 100 and other laws and orders. Contractor license requirements, including for emerging technologies such as BESS, determine the minimum qualifications that business owners and their workforces must meet to be allowed to install specific technologies; their purpose is to ensure consumer protection, including safety and the general welfare of the public. They are therefore a fundamental component of the California state government's support for and oversight of the construction industry, including of specialty contractors who install emerging technologies such as BESS.

B. Options under Consideration by the CSLB

The California State Licensing Board (CSLB) has been addressing contractor classification jurisdictional issues for BESS since 2015. Currently, the C-10 electrical contractors license is required to perform most BESS installations; the exception to this rule is that C-46 solar contractors are permitted to install BESS in conjunction with a solar PV system. Two trade associations have been very active in arguing their positions, with the California Solar and Storage Association (CALSSA) advocating that the C-46 license include BESS under some conditions and the National Electrical Contractors Association and the International Brotherhood of Electrical Workers (NECA-IBEW) advocating to preclude the C-46 license from installing BESS. After extensive stakeholder input and internal research, the CSLB issued an RFP that called for an independent review of the issues, and in the fall of 2020 it awarded UC Berkeley the contract.

The independent review we present here analyzes the following question: Should C-46 contractors be permitted to install solar-paired BESS, and if so, under what specific conditions? Specifically, the four alternatives that the CSLB asked us to consider are:

Option 1: Preclude the C-46 Solar classification from installing battery energy storage systems.

California Code of Regulations Section (CCR) 832.46 currently defines a solar contactor as follows:

- A solar contractor installs, modifies, maintains, and repairs thermal and photovoltaic solar energy systems.
- A licensee classified in this section shall not undertake or perform building or construction trades, crafts, or skills, except when required to install a thermal or photovoltaic solar energy system.

Option 2: Permit the C-46 Solar classification to install battery energy storage systems on specified residential units with the following restrictions:

- Limit the BESS installation authority to a PV system up to 10 kilowatts on a single-family dwelling or a duplex, and the BESS must not exceed a 5-kW (backup)/20-kWh (energy);
- The BESS is installed at the same time as the solar photovoltaic energy system; and,
- No upgrade or alteration is made to the existing electrical system of the structure.

Option 3: Permit the C-46 Solar classification to install battery energy storage systems on residential units with the following restrictions:

- Limit the BESS installation authority to a PV system on a residential dwelling;
- The BESS is installed at the same time as the solar photovoltaic energy system;
- No upgrade or alteration is made to the existing electrical system of the structure; and,
- With plans drawn or approved by an electrical engineer.

Option 4: Make no change to the existing C-46 classification

- Assert that current law allows C-46 to install BESS

C. Research Results

Our recommendations are based on three related analyses:

1. A profile of the contractors involved in BESS installations in California, looking at the licenses held for BESS installations by count, capacity, customer class, rural vs. urban, and other subcategories of BESS.
2. An evaluation of the risks and hazards associated with BESS, the qualifications needed for safe and effective installation, and the qualifications that are required of C-10 and C-46 contractors *and* their workforces.
3. An evaluation of the economic implications of alternative licensing scenarios, including the availability of contractors and workers, the implications for installation costs, the transition costs, and economic co-benefits.

Our analysis is based on careful review of the public record; interviews with key stakeholders, CSLB staff, and other relevant government officials; and analysis of data from a variety of sources. The safety analysis evaluates the ongoing research on BESS by organizations such as National Fire Protection Association (NFPA), the Underwriters Laboratory,[1] DNV,[2] and FM Global.[3] We review the relevant codes and standards, which have undergone significant revision over the last five years to address BESS hazards, risks and mitigations. We examine not only the relevant

1 Underwriters Laboratory (UL) is a safety science, testing and third-party certification organization.

2 DNV—formerly DNV GL—is an international organization expert in risk management and quality assurance with corporate headquarters in Norway.

3 FM Global is a mutual insurance company that provides risk engineering services to primarily large corporations. FM Global publishes well-regarded loss prevention data sheets including ESS.

building codes adopted by regulation in California but also the consensus among experts of good practice safety standards and guidelines that have been recently developed to address BESS hazards, including safety data sheets, installation guides, emergency response guidance and battery safety testing data published by BESS manufacturers. We evaluate BESS risks utilizing data related to incident frequency and potential consequences, using recognized and generally accepted risk assessment approaches for electrical and chemical hazards. This includes risk determinations for BESS by the fire service and major insurance companies. Finally, we use existing risk mitigations developed in codes, standards, and technical reports to evaluate the knowledge, skills, and training required for safe BESS work. The economic analysis relies on a dataset produced by matching CSLB contractor license data with data on BESS projects in California from two sources, the Self-Generation Incentive Program (SGIP) dataset and the Interconnection dataset. We also employ data from the National Renewable Energy Lab (NREL) the Bureau of Labor Statistics (BLS) and the Solar Jobs Census.

Our key findings are detailed below:

The profile of contractors performing BESS installations in California reveals that:

1. **Only a very small percentage, by count and by capacity, of BESS installations have been installed by C-46 contractors without a C-10, A, or B license.** This result holds for both the 2015-2020 SGIP dataset the 2020 Interconnection dataset. This aligns with the data and analyses provided by both the NECA-IBEW and the CALSSA stakeholders. While CALSSA correctly asserts that C-46 contractors are involved in a majority of BESS installations, these contractors also hold other licenses that are inclusive of BESS in their scope. The great majority of BESS installations are carried out by contractors with both the C-10 and C-46 licenses.

2. **The very small participation of C-46 only contractors, and the concomitant dominance of contractors with both C-10 and C-46 licenses or C-10 without C-46, holds across the board for every category of BESS project.** It holds for both number of projects and capacity installed, for both residential and commercial projects, for rural as well as urban projects, for different sizes of projects, and for the largest contractors when ranked by number and capacity of installed projects.

3. **The dominance of C-10 contractors, with or without a C-46 license, signifies that the great majority of BESS projects have been carried out by contractors whose electrical workforce must be certified, according to CSLB regulations.** The C-46 contractors who are exempt from this requirement are a tiny percentage of the pool of contractors that have installed BESS in California since 2015.

4. **The very small percentage of contractors holding a C-46 but no C-10, A, or B license leads to the conclusion that precluding or restricting C-46 (no C-10, A or B) contractors will have a negligible effect on the current pool of contractors.**

The evaluation of hazards, risks, and safety issues reveals that:

1. **The hazards of BESS are significant.** The hazards associated with the predominate lithium-ion battery chemistry such as NMC include high energy density, a flammable electrolyte, and potential reactive chemical hazards. The technology poses multiple unique threats to workers, the public, and emergency responders. Serious hazards resulting from thermal runaway events may include reactive chemical hazards, fire, explosion, and venting of toxic gas. Serious electrical hazards are present such arc flash and shock. In addition to thermal runaway, emergency responders potentially face dangers such as deep-seated fires, reignition, and stranded energy.

2. **The risks associated with BESS installations can include deaths and injuries to workers, emergency responders, and occupants of buildings and facilities.** Serious incidents have occurred in all phases of the BESS lifecycle, including construction, installation, and operation. The most significant incident, showing the seriousness of BESS risk in the U.S., occurred in 2019 at the Arizona Public Service (APS) grid utility BESS facility in Surprise, Arizona, during which an LIB thermal runaway led to an explosion. Four firefighters were hospitalized with serious injuries. Other recent lithium-ion BESS incidents include another BESS fire at APS in 2012; a 2013 Port Angeles, Washington, BESS fire connected to a mall; a 2016 fire at a Franklin, Wisconsin, manufacturing plant where BESS were being assembled; a 2017 fire at an Engie Ineo BESS grid-utility facility in Belgium; 29 BESS-related fires in South Korea from 2017 to 2019; and a 2020 BESS fire at an Ørstead grid-utility facility in Liverpool, UK. In late 2020, the U.S. Consumer Products Safety Administration (CPSA) announced a recall of over 1,800 LG RESU 10H LIB related to five fires reported with minor property damage. An additional LG RESU recall was announced in May 2021. Recent documented U.S. commercial and residential BESS incidents have resulted in fires.

3. **BESS risks are significant for grid-utility, industrial, commercial, and residential applications.** Large-scale BESS with greater deployed energy capacity and larger quantities of flammable vent gas and materials have the potential for very high consequence events, but small-scale lithium-ion BESS capacity including residential applications also represents a significant risk. BESS standards and manufacturers' safety documentation acknowledge the potential for BESS hazards such as thermal runaway and arc flash that can threaten workers, occupants, and emergency responders even for smaller-scale applications. Such hazards can be triggered by pre-existing conditions, improper handling, or faulty installation.

4. **The dramatic increase in the number of residential BESS installations exposes a growing number of occupants to BESS hazards.** Compared to commercial BESS installations, residential installations can be even more vulnerable to hazards because residents are at their homes for longer lengths of time, and both day and night. Each residential building is unique with a different electrical system that must be evaluated to mitigate risks associated with BESS installation and operation. Potential residential lithium-ion BESS fires, explosions, and thermal runaway events can also threaten occupants who are unable to respond to alarms or to self-rescue. Small-scale BESS fires can threaten emergency responders and occupants, as was shown in a fire that reignited in the days following the 2013 Port Angeles, Washington, incident.

5. **BESS is a Low Frequency, High Risk technology; while incidents have been rare, they have serious consequences.** Low frequency/high risk technologies pose unique challenges for hazard prevention and mitigation. The chemical safety sector and fire service emphasize the importance of implementation of rigorous, effective safeguards when the hazard is high consequence—even with low frequency events. Available data indicate that BESS incidents are low frequency, with no identified incidents in California. However, we cannot confidently attribute this to a lack of risk, for these reasons:

   - There is no central repository of accident reports that specifically identifies BESS accidents, but lack of reporting does not mean lack of problems.
   - The lack of documented BESS accidents in California may be due to the fact that the great majority of installations have been carried out by contractors holding a C-10 electrical license, as noted above. There is no credible safety record for C-46 contractors without a C-10, A or B license because they have performed so few installations.

6. **Robust safety measures that require significant technical capacity and knowledge are critical to mitigating the risk of BESS systems.** BESS safety measures are embedded in various safety codes which are continually revised to address evolving technologies and risks. The two most relevant are the NFPA and ICC codes, which are developed by panels of subject matter experts who understand BESS hazards, risks, and necessary safeguards. The minimum safety requirements that are established in these codes apply to applications from grid utility to residential, and recognize that BESS in all applications—even in capacities as low as 1kWh—have significant risks that need mitigation. The most recent consensus safety code revisions applicable to BESS have implemented even more rigorous requirements to protect the public and emergency responders. These changes include relatively low kWh thresholds for code coverage, significantly more safety provisions, and the requirement that the design and installation of BESS be performed by "qualified persons," a definition that points unambiguously to the need for electrical training. The serious hazard of thermal runaway events has been a driver of changes to codes, standards, and industry safety guidelines.

7. **There is no specific threshold by size or customer class under which serious safety concerns are absent.** Widely accepted safety standards such as the IFC (2021) NFPA 70 (2020), 70E (2021), and 855 (2020) provide an expert, well-researched, and protective threshold for activation of BESS minimum safety requirements. In the latest codes addressing BESS, safety requirements are triggered at thresholds as low as 1 kWh. For example, the latest version of NFPA 70, the National Electric Code (2020), the California Electric Code 2021 Supplement for R3 and R4 residential occupancies (R3 and R4) and NFPA 855 (2020) for one and two family dwellings all have thresholds for important BESS safety requirements as low as 1 kWh. The codes state that their provisions are based upon minimum requirements to mitigate hazards, and the BESS provisions are needed above this threshold. As the applicable codes and standards illustrate, there is no justifiable threshold, by size or sector, to suggest less hazard or an insignificant risk to apply to BESS installation. There is therefore no basis for distinguishing BESS contractor jurisdiction based upon size or type of application.

8. **Rapidly developing BESS technologies, and codes and standards that perpetually undergo revision in response, require detailed knowledge of multiple hazards and evolving safety requirements.** A broad knowledge of NFPA 70 and 70E, and conformance with multiple sections of NFPA 70, are needed to install BESS. These are listed in existing BESS checklists for building code officials and are generally required in the BESS product installation manuals such as those for the Tesla Powerwall and LG RESU. The safety documentation for both the Tesla Powerwall and LG RESU recognize the serious hazards associated with thermal runaway for their residential use LIB. The Tesla Powerwall 2 has a 90-page installation manual with numerous steps and includes serious safety warnings requiring assessment, decision-making, and knowledge of codes and standards. Installing BESS requires a skilled assessment of the electrical system that is being connected. Manufacturer safety guidance and relevant codes underscore that BESS in any size or application is not a "plug and play" installation, largely due to BESS inherent hazards and because the variability of electrical systems to which BESS is connected requires expert site evaluation.

9. **The main difference between C-10 and C-46 license holders is that the technical capacity of the C-10 workforce is greater than that of the C-46 workforce.** C-10 contractors are required to employ certified electricians to carry out electrical work, whereas C-46 contractors are exempt from the certification requirement. Our analysis of the C-46/C-10 workforces offers a strong contrast of the documented knowledge, skills, and training required by the State of California. Workers performing electrical work under a C-10 contractor must be certified with documented requirements; these include passing a California exam, and 8,000 hours of experience to be a certified general electrician or 4,800 hours of experience to be a certified residential electrician.

10. **Certified electricians must demonstrate experience and training and must pass a test have received training in electrical safety, and have demonstrated to the State a knowledge of the breadth of the safety provisions in NFPA 70E and other codes that address electrical and BESS requirements.** Certification requires demonstrated safety competency, including methods of avoiding electrical shock hazards and arc flash, which are addressed in 70E. These methods involve performing risk assessments and protection calculations, and wearing appropriate PPE for arc flash and electrical shock, which is also referenced, for example, in the LG RESU installation manual. Other key safety concepts for BESS installation addressed in 70E, and part of the competency needed for certification, include lockout/tagout, job safety planning, audits, and incident investigation. In a recent amendment, the BESS-specific article in NFPA 70 (2020) requires installation and maintenance by qualified personnel in part as defined by NFPA 70E. Certified electricians have state-required competencies in both NFPA 70 and 70E.

11. **Solar installers under C-46 contractors have no California requirement for certification.** No experience or exam is required in California to install a solar PV system or perform any necessary incidental and supplementary work.

The analysis of the economic impact of alternative licensing scenarios reveals that:

1. **C-10 contractors, with or without C-46 licenses, are much more numerous than C-46 contractors and have entered the market in greater numbers than C-46 (no C-10) contractors.** The CSLB has on record 25,298 active licensed C-10 electrical contractors and 1,240 active licensed C-46 contractors. 447 contractors hold both licenses.4 C-10 contractors also vastly outnumber C-46 license holders in both the residential and commercial markets and for urban and rural counties.

2. **The number of certified electricians and electrical trainees also exceeds the solar workforce.** As of March 24, 2021, there were 36,550 certified electricians in California, and 11,423 electrical trainees currently enrolled in registered electrical apprenticeship programs.[5,6] Registered apprenticeship programs expand as jobs expand, so if the BESS market requires more certified electricians, the electrical apprenticeship programs can open up more placements in response. EDD data from May 2019 show 72,870 electricians, 4,740 electrician helpers, and 4,970 solar installers (Q1 2020 mean hourly wage: $23.60).[7] Our analysis of survey data from the industry-sponsored Solar Jobs Census reveals similar results.

3. **There are no significant savings in average project costs across all customer classes with installations performed by C-46 (no C-10) contractors, even though the wages of certified electricians are higher than the C-46 non-certified electrical workforce.** The SGIP data, which documents actual project costs, show that the lowest average cost storage systems are installed by contractors holding a dual C-10 and C-46 license, and the highest average cost is installed by C-46 contractors holding an A or B license. Contractors holding a C-10 license without a C-46 license have an average cost per kW just 0.6% higher than contractors holding a C-46 license without a C-10 license.

4 https://www.cslb.ca.gov/Onlineservices/DataPortal/

5 https://data.ca.gov/dataset/dir-electrician-certification-unit-ecu/resource/291bacb8-2fdb-4d9c-a330-113781ce2f59

6 https://data.ca.gov/dataset/dir-electrician-certification-unit-ecu/resource/f0b9e36d-32be-408d-8dd9-4d539becfdc8

7 https://www.labormarketinfo.edd.ca.gov/data/oes-employment-and-wages.html#OES

4. **In the residential sector, the data shows that the lowest average cost BESS is installed by contractors holding both C-10 and C-46 licenses, the contractor group that clearly dominates the market.** Compared to projects installed by C-46 (no C-10, A, or B) contractors, projects installed by C-10 (no 46) are 1.8% higher, which is directly in-line with our analysis using the National Renewable Energy Lab BESS cost benchmark data. Both C-10 (no C-46) contractors and C-46 (no C-10) contractors have higher than average project costs. C-46 contractors are 4% above average, while C-10 contractors are 5% higher than average.

5. **The minor cost increases due to requirements for certification are unlikely to constrict demand for BESS or undermine the effectiveness of government incentives.** Government and industry research documents that consumer demand is driven by end users seeking resiliency due to the increased occurrence of natural disasters and utility power shut-offs, and is not sensitive to very small cost differences. Any CSLB ruling will not change the impact of subsidies and incentives on consumers, which, averaging 37% of total costs, completely overwhelm any cost increases due to the wage differential between electricians and the PV workforce.

6. **Looking more broadly at the economic impacts of certification requirements, research shows that industry-recognized credentials for in-demand jobs, such as the electrical certification, increase workers' income and mobility.** This is reflected in support for industry-recognized credentials in the state's Unified Strategic Workforce Development Plan, where it is identified as a key strategy of the California Labor and Workforce Development Agency.8 Industry recognized credentials such as the electrical certification provide signals to public training institutions on what to train for and help the industry tap into public sources of training and education funding. The lack of a skill standard results in inconsistent training carried out by contractors on the job, poorer wages and benefits, and fewer opportunities for transferability and career advancement for workers.

7. **A CSLB ruling that C-46 (no C-10, A or B) contractors cannot install BESS systems would only minimally impact the current pool of BESS contractors in California, since the share of contractors currently installing BESS who are in this category is very small.** Restricting C-46 contractors could actually improve conditions for current workers if these businesses take advantage of the opportunity to help certify their electricians and learn to compete using business strategies that do not include a lower wage workforce.

8. **A CSLB ruling to allow C-46 to install BESS would, over time, result in downward pressure on wages for electricians and greater competitive pressures on C-10 contractors who invest in a higher skilled workforce.** These adverse impacts would likely not be offset by lower costs to consumers since C-46 contractors without a C-10 license are not consistently the lowest cost contractor group and, in most cases, have higher costs than contractors with both C-10 and C-46 licenses. We therefore conclude that over the longer run, there would be transition costs associated with a ruling to allow C-46 license holders to install BESS, as new contractors without C-10 licenses enter the market.

8 https://cwdb.ca.gov/wp-content/uploads/sites/43/2020/09/Strategic-Planning-Elements.Final_ACCESSIBLE.pdf, p. 29

D. Our recommendation

We strongly recommend that the CSLB limit the scope of the C-46 to its original scope and preclude C-46 license holders from installing BESS even when paired with solar, unless they hold another license under which BESS installation is permitted. We base this recommendation on the research summarized above and presented in detail in the body of the report. We see no public policy justification for the CSLB to encourage a future trajectory of the BESS industry with lower standards and lower requirements for worker qualifications compared to the present pool of contractors. Only a very small share of the current pool of contractors that carry out BESS installations are C-46 (no C-10, A, or B) contractors and are exempt from the requirement that individuals carrying out electrical work be certified electricians. This research result shows that the current pool of BESS installers has higher qualifications than might be the case if the CSLB rules to permit the C-46 license to include BESS.

Our hazards, risks, and safety analysis documents substantial hazards related to this rapidly evolving technology and buttresses the argument that there is a need for qualified personnel to mitigate risks. BESS are a dynamic and expanding technology with inherent hazards that are significant; they have led to continuing serious incidents; they are recognized by NFPA as a "high risk hazard;" they have led to the development of significant ongoing code and standard revisions and new safety mitigations; and they are currently predominately installed by contractors holding C-10 licenses, which requires the use of certified electricians with demonstrated skills and safety training needed to address the safety issues identified. This legal requirement regarding certification holds regardless of the license class documented on a permit application. Finally, we find that there lacks a justifiable threshold by size or sector to suggest less hazard or insignificant risk for BESS installation, and therefore we find that a C-46 license is insufficient for all sizes and customer classes of BESS installation.

While in California there have been no significant incidents with injury or death that we could identify, there are appreciable data gaps that preclude the ability to conclude that risks are low. There have been serious incidents in other regions, particularly in grid-scale BESS, but we found no evidence that the risk of BESS technologies is minimal in residential or commercial applications. Because of this, we classify the BESS technologies in the category of high consequence, low frequency risk, which requires a contractor and workforce with broad knowledge of electrical systems and electrical safety. Since such a small percentage of BESS projects have been installed by C-46 (no C-10, A, or B), we also note that the safety record is extremely limited for this group of contractors, further undermining an assessment that C-46 (no C-10, A, or B) contractors can credibly mitigate safety risks.

Since the main difference between the C-46 and the C-10 is the latter's requirement that their electrical employees be certified, we conclude that the C-10 workforce is more highly trained and trained in the broader safety and electrical system assessment knowledge than the C-46 workforce. The CSLB rule that contractors with both a C-10 and a C-46 license must adhere to the requirement that their electricians have a state certification means that only C-46 (no C-10) contractors do not have to meet the higher standard for their workforce. Our review of the curriculum of the electrical certification shows that certified electricians have the relevant skills, knowledge and experience to confidently be classified as "qualified personnel". No such review of the C-46 (no C-10) electrical workforce is possible since there is no comparable skill standard, and therefore we cannot confidently classify these workers as "qualified personnel."

We also conclude that there will be no adverse economic impacts of precluding the C-46 license from BESS. We document that C-10 contractors and certified electricians are plentiful and the pool can expand as demand for BESS increases. C-10 contractors, with or without C-46 licenses, are much more numerous than C-46 contractors and have entered this market in greater numbers than C-46 (no C-10) contractors. This is true for both the residential and commercial market and for urban and rural counties. It is also true for the certified electrical workforce, which is much greater in number than the C-46 solar workforce. We also document no significant savings in project costs with installations performed by C-46 (no C-10) contractors, even though there is agreement that the wages of certified electricians are higher than the C-46 non-certified electrical workforce. This is in part because labor costs, and particularly the costs of work that is performed by electricians (certified or not), is a small percentage of total costs, and the consequent differential in total cost is minimal. It may also be that contractors with a certified electrical workforce have developed a more efficient business model that reduces other costs or profit to compensate for higher wages for electricians. The lowest cost contractors for BESS installations hold both C-10 and C-46 licenses and are held to the certification requirement, but have apparently found cost savings that make up for the higher wages of certified electricians.

Finally, we find that the transition costs of precluding C-46 contractors from installing BESS are minimal since C-46 (no C-10) contractors and their electrical workforce are currently such a small share of all contractors and workers who have installed BESS in California. On the contrary, there would be an adverse economic impact from continuing or expanding the scope of the C-46 license with respect to BESS because that would likely undermine the electrical certification and put downward pressure on the wages of certified electricians. We also note that California supports the use of industry-recognized credentials like the electrical certification because these credentials are beneficial to workers and provide clear signals to training institutions on what skills to train for that are actually valued in the labor market.

The decision before the CSLB will shape the future trajectory of the BESS industry. A decision to allow C-46 contractors to install BESS, whatever the size or customer class, could result in lower workforce skill standards and greater risk to the public from inadequate site assessment or faulty installation. All else being equal, it is better to support the expansion of that segment of the existing pool of contractors who invest in a more skilled workforce by hiring certified electricians, rather than increase the safety risks associated with a less qualified workforce.

I. Introduction and Background

This report, carried out at the request of the California State Licensing Board, evaluates alternative proposals for the specific contractor license(s) that should be required for battery energy storage systems (BESS) that are installed in conjunction with installations of solar photovoltaic (solar PV) systems. The rapid and safe development of the BESS industry—i.e., businesses that design, install, maintain, and repair BESS—is essential for actualizing California's commitment to achieve 100% carbon-free electricity, as mandated in SB 100 and other laws and orders. Contractor license requirements, including for emerging technologies such as BESS, determine the minimum qualifications that business owners and their workforces must meet to be allowed to install specific technologies; their purpose is to ensure consumer protection, including safety and the general welfare of the public They are therefore a fundamental component of the California state government's support for and oversight of the construction industry, including of specialty contractors who install emerging technologies such as BESS. Along with building and energy codes, workplace protections, and other regulations, these regulations are designed to support a safe, healthy, efficient, equitable, and environmentally sustainable specialty construction industry.

Currently, the C-10 electrical contractors license is required to perform BESS installations; the exception to this rule is when BESS are installed simultaneously with a solar PV system. Under State law, specialty contractors that are licensed in one class are prohibited from performing work in the field of another class unless they are also licensed in that class or the work is required for and "incidental and supplemental" to the work in the craft for which the contractor is licensed.[1] The California State Licensing Board (CSLB) currently allows C-46 contractors to install BESS under the clause that this work is "incidental and supplemental" when installed with solar PV; however, this interpretation is now under review.

A. Options Under Consideration by the CSLB

The CSLB has been addressing contractor classification jurisdictional issues for BESS since 2015. On July 18, 2017, a letter from the then CSLB Classification Deputy had stated that the C-46 solar classification may install BESS in connection with a PV system and C-10 contractors may install BESS as part of a PV project or separately.[2] At a February 23, 2018, Licensing Committee meeting, the minutes noted that the CSLB staff had been meeting over the previous year discussing stakeholders' concerns related to which license classifications are authorized to install battery energy storage.[3] The CSLB has archived the extensive Board, Committee, and stakeholder discussion from

1 Bus. & Prof. Code § 7059; 16 C.C.R. § 830(b).

2 https://www.cslb.ca.gov/Resources/BoardPackets/ESS_Report20190321.pdf.

3 https://www.cslb.ca.gov/Resources/BoardPackets/CommitteeMeetingPacket20180223.pdf.

2018 to 2019 on this issue.[4] During this time, the CSLB addressed BESS at many Board and Committee meetings, and hosted a variety of events with stakeholder and public input. An 81-page report on the issue was published by CSLB staff in March of 2019. The CSLB staff conducted a survey, received educational videos, and held meetings with C-46 and C-10 contractors to discuss technical and safety issues. At the end of 2019, the CSLB Legislative Committee and the full Board passed a motion to contract for a third-party independent review of the issues.

The independent review we present here analyzes the following question: Should C-46 contractors be permitted to install solar-paired BESS, and if so, under what specific conditions? Specifically, the four alternatives that the CSLB asked us to consider are:

Option 1: Preclude the C-46 Solar classification from installing battery energy storage systems.

California Code of Regulations Section (CCR) 832.46 currently defines a solar contractor as follows:

- A solar contractor installs, modifies, maintains, and repairs thermal and photovoltaic solar energy systems.
- A licensee classified in this section shall not undertake or perform building or construction trades, crafts, or skills, except when required to install a thermal or photovoltaic solar energy system.

Option 2: Option 2: Permit the C-46 Solar classification to install battery energy storage systems on specified residential units with the following restrictions:

- Limit the BESS installation authority to a PV system up to 10 kilowatts on a single-family dwelling or a duplex, and the BESS must not exceed a 5-kW (backup)/20-kWh (energy);
- The BESS is installed at the same time as the solar photovoltaic energy system; and,
- No upgrade or alteration is made to the existing electrical system of the structure.

Option 3: Permit the C-46 Solar classification to install battery energy storage systems on residential units with the following restrictions:

- Limit the BESS installation authority to a PV system on a residential dwelling;
- The BESS is installed at the same time as the solar photovoltaic energy system;
- No upgrade or alteration is made to the existing electrical system of the structure; and,
- With plans drawn or approved by an electrical engineer.

Option 4: Make no change to the existing C-46 classification

- Assert that current law allows C-46 to install BESS.

4 https://www.cslb.ca.gov/Media_Room/Board_And_Committee_Meetings/2019/Energy_Storage_Systems.aspx.

B. What This Report Does

We approach the question of which alternative should be chosen by the CSLB by analyzing:

1. The distribution of C-46 and C-10 licenses of contractors currently installing BESS paired with solar PV;
2. The hazards, risks, and safety mitigation strategies associated with BESS;
3. The qualifications needed to ensure proper installation and mitigate the identified hazards and risks;
4. The arguments as to whether or not BESS should be considered as “supplemental or incidental” to solar PV work when BESS is installed in conjunction with solar PV;
5. The availability of C-46 and C-10 contractors and their respective workforces currently and their likely future availability;
6. The cost implications of requiring C-10 for all BESS installations compared to allowing C-46 to perform BESS installations;
7. The costs of transition of alternative licensing scenarios;
8. Any other economic co-benefits that can be associated with the alternative licensing scenarios.

The report begins with an overview of the BESS industry and the contractors involved in it, looking at the profile of contractors by the licenses they hold. The next section evaluates the risks and hazards associated with BESS and assesses the role of installation work in the identified hazards. It then evaluates the qualifications needed for safe and effective installation, and links these to the qualifications that are required of C-10 and C-46 contractors *and* their workforces. The following sections address the economic implications of alternative licensing scenarios, including the availability of contractors and workers, the implications for installation costs, the transition costs, and economic co-benefits.

Our analysis is based on careful review of the public record; interviews with key stakeholders, CSLB staff, and other relevant government officials; and analysis of data from a variety of sources. The safety analysis evaluates the ongoing research on BESS by organizations such as National Fire Protection Association (NFPA), the Underwriters Laboratory, DNV, and FM Global. We review the relevant codes and standards, which have undergone significant revision over the last five years to address BESS hazards, risks and mitigations. We examine not only the relevant building codes adopted by regulation in California but also the consensus among experts of good practice safety standards and guidelines that have been recently developed to address BESS hazards, including safety data sheets, installation guides, emergency response guidance and battery safety testing data published by BESS manufacturers. We evaluate BESS risks utilizing data related to incident frequency and potential consequences, using recognized and generally accepted risk assessment approaches for electrical and chemical hazards. This includes risk determinations for BESS by the fire service and major insurance companies. Finally, we use existing risk mitigations developed in codes, standards, and technical reports to evaluate the knowledge, skills, and training required for safe BESS work. The economic analysis relies on a dataset produced by matching CSLB contractor license data with data on BESS projects in California from two sources, the Self-Generation Incentive Program (SGIP) dataset and the Interconnection dataset. We also employ data from the National Renewable Energy Lab (NREL) the Bureau of Labor Statistics (BLS) and the Solar Jobs Census.

II. Overview of the BESS Industry and BESS Contractor Licenses in California

A. What Is a Battery Energy Storage System?

The basic purpose of a battery energy storage system (BESS) is to capture, store, and release the electricity generated by an electrical generating system so that it can be distributed as needed. The 2019 California Building Energy Efficiency Standards defines a battery energy storage system as "[a] rechargeable energy storage system consisting of electrochemical storage batteries, battery chargers, controls, and associated electrical equipment designed to provide electrical power to a building. The system is typically used to provide standby or emergency power, and uninterruptable power supply, load shedding, load sharing or similar capabilities."[5] The CPUC defines energy storage systems as "commercially available technology that is capable of absorbing energy, storing, and dispatching the energy."[6]

B. Scope of C-46 and C-10 Contractor Licenses

The scope of work a licensed specialty contractor may legally perform is set by the classification regulations adopted by the CSLB.[7]

For solar contractors—those with a C-46 license--Section 832.46 of the CSLB regulations authorizes licensees to perform the following work:

> A solar contractor installs, modifies, maintains, and repairs thermal and photovoltaic solar energy systems. A licensee classified in this section shall not undertake or perform building or construction trades, crafts, or skills, except when required to install a thermal or photovoltaic solar energy system.

For electrical contractors—those with a C-10 license—section 832.10 of the CSLB regulations authorizes licensees to perform the following work:

> An electrical contractor places, installs, erects or connects any electrical wires, fixtures, appliances, apparatus, raceways, conduits, solar photovoltaic cells or any part thereof, which generate, transmit, transform or utilize electrical energy in any form or for any purpose.

5 California Code of Regulations, Title 24, Part 6, Section 100.1 (b).

6 CPUC,20 C.C.R. § 1302 (b)(18).

7 See 16 C.C.R. § 832.

The C-46 license is much narrower in scope than the C-10. While the C-46 license allows a contractor to perform a portion of the work that is under the scope of the C-10, the C-10 license allows a contractor to perform *all* of the work that is under the scope of the C-46. Current CSLB licensing regulations require that all BESS installations be performed by C-10 contractors, except when they are done in conjunction with solar photovoltaic installations (known as solar-paired BESS).

Under State law, specialty contractors that are licensed in one class are prohibited from performing work in the field of another class unless they are also licensed in that class or the work is "incidental and supplemental" to the work in the craft for which the contractor is licensed.[8] The Code of Regulations specifies the scope of the C-46 by explicitly underscoring that contractors with this license shall not undertake or perform building or construction trades, crafts, or skills, *except when required* to install a thermal or photovoltaic solar energy system (emphasis added).

The difference between the solar PV and BESS technologies is that a solar PV system generates and transmits electrical energy, while a BESS utilizes electrical energy, transforms that energy into a storage state, and then transmits back that stored electrical energy when needed for other uses. While these technologies can be complementary—i.e., BESS allows for the storage and use of solar-generated electricity at times when solar panels aren't producing power, and solar PV can be one of the sources of power to be stored in BESS—solar PV and BESS are different technologies with different purposes and ways of interacting with the electrical system of a structure.

This difference has implications for hazards as well as for the skills needed to ensure proper installations, as is discussed in Section IV.

C. Use of Certified Electricians

A very important difference between the C-10 and C-46 contractor licenses is that C-10 contractors who employ electricians are required to employ electricians who have been certified by California's Division of Labor Standards Enforcement (DSLE) in the Labor and Workforce Development Agency's Department of Industrial Relations, while C-46 contractors are not required to use certified electricians. Certification of electricians consists of a competency test administered by the Division of Apprenticeship Standards, based on a set of state-recognized knowledge, skills, and abilities (KSAs), including safety and broad knowledge of electrical systems. To take the general electrician's exam in California the candidate must have a minimum of 8,000 hours of documented electrical experience supervised at all times by a California state certified general electrician.[9] The residential electrician's exam requires 4,800 hours of documented electrical experience.[10] No state-recognized skill standards are required for workers carrying out electrical work who are employed by C-46 contractors.

Contractors who hold both C-46 and C-10 licenses are required to comply with these C-10 requirements, such that any employee performing electrical work must be certified. The Electrician Certification requirements are set forth in Chapter 4.5 of Division 1 of the California Labor Code.[11] Labor Code section 108.2 provides the relevant part: "Persons who perform work as electricians shall become certified pursuant to Section 108. Uncertified

8 Bus. & Prof. Code § 7059; 16 C.C.R. § 830(b).

9 https://www.dir.ca.gov/t8/291_1.html.

10 https://www.dir.ca.gov/DLSE/ECU/EleCat.html#1.

11 https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=LAB&division=1.&title=&part=&chapter=4.5.&article.

persons shall not perform electrical work for which certification is required. Certification is required only for those persons who perform work as electricians for contractors licensed as class C-10 electrical contractors under the Contractors' State License Board Rules and Regulations."[12] In addition, Labor Code section 108 (c) statutorily defines "electrician" to include "all persons who engage in the connection of electrical devices for electrical contractors licensed pursuant to Section 7058 of the Business and Professions Code, specifically, contractors classified as electrical contractors in the Contractors' State License Board Rules and Regulations." The CSLB defines the scope of electrical contractors as follows: "An electrical contractor places, installs, erects or connects any electrical wires, fixtures, appliances, apparatus, raceways, conduits, solar photovoltaic cells or any part thereof, which generate, transmit, transform or utilize electrical energy in any form or for any purpose."[13]

The research team asked the CSLB for specific clarification about how the requirement regarding certified electricians applies to contractors holding both C-10 and C-46 licenses. David Fogt, CSLB Registrar, provided us with the following answer: "The CSLB reads these provisions to mean that anyone working for an employer holding a C-10 license classification who engages in the described activities [electrical work] must use certified electricians, regardless of the other classification(s) the employer holds."[14]

12 Cal. Lab. Code,§ 108.2, subds. (a) and (b)(1).

13 Cal. Lab. Code,§ 108.2, subds. (a) and (b)(1).

14 Letter from David Fogt to Carol Zabin, April 21, 2021.

III. Profile of BESS Installations and Contractors in California

This section profiles the BESS installations in California, looking at the size of the installations, their distribution by sector, and trends in the BESS market. It then takes a very close look at the licenses held by the pool of contractors who have carried out BESS installations over the last five years, examining the overall distribution of installations by type of license(s), and then breaking this distribution down by residential vs. commercial, by specific residential contractors in terms of their relative share of the installations, by size of installations, and by location in rural vs. urban counties.

In the following analysis, we reference data from two different sources: the State of California's Distributed Generation Interconnection Data Sets and the Self Generation Incentive Program (SGIP) data (dated 4-12-2021). The data in the two datasets differs slightly. First, the Interconnection dataset is more comprehensive because it captures all distributed energy projects that are connected to the grid. This makes the dataset very large (>250MB) and difficult to work with. Additionally, with the Interconnection dataset, each utility has its own nomenclature, which makes it difficult to precisely isolate BESS. We address this by assuming that for PG&E and SoCal Edison, the categories that include both solar PV and storage are primarily BESS, and for SDG&E, the category of projects labeled "advanced energy storage" are primarily BESS as well. Second, we reference the SGIP dataset, where we can isolate data that capture only solar-paired electrochemical storage systems. Because it is so specific, the SGIP dataset relates more directly to the four policy options that we were asked to evaluate. We use the SGIP dataset for most of the analysis in this report, but we check the results with the Interconnection dataset for the most important analyses. This check ensures a fuller picture because the SGIP dataset only captures those systems that applied for SGIP incentive payments, which is about 2/3 of the solar-paired storage and advanced energy systems projects captured in the Interconnection dataset.

The SGIP dataset documents information on all energy projects that have received the program's incentive. SGIP provides incentives to support existing, new, and emerging distributed energy resources, including wind turbines, waste heat to power technologies, pressure reduction turbines, internal combustion engines, microturbines, gas turbines, fuel cells, and, since 2017, advanced energy storage systems. The CPUC has authorized funding of more than $1 billion through 2024 for SGIP. Through the Equity and Equity Resiliency budgets, this funding includes prioritization of, and higher levels of rebates for, communities living in high fire-threat areas, communities that have experienced two or more utility public safety power shutoff (PSPS) events, as well as low income and medically vulnerable customers. For the bulk of customers not fitting these criteria, the incentives cover about 25% of the average cost for residential customers and 35% for non-residential customers.[15]

15 https://www.cpuc.ca.gov/sgip/ and https://www.cpuc.ca.gov/sgipinfo/.

CALSSA provided a compiled 2020 Interconnection dataset which was small enough sort, clean, and analyze in Excel, and the electrical industry stakeholders provided a compiled 2015–2020 Interconnection dataset as well. We reference both of these versions of the Interconnection dataset to ensure that the trends captured in the SGIP data reflect those in the broader BESS market.

A. Trends in the Size of BESS Installations in California, and Distribution by Sector

There were 19,104 SGIP solar-paired BESS projects installed from 2015–2020, with 6,742 projects in 2020 alone. For reference, the electrical industry's analysis of the Interconnection data indicates there were 29,436 solar-paired BESS projects installed from 2015–2020, and CALSSA's Interconnection data show a total of 13,073 in 2020 alone. These data show a rapidly growing BESS industry in California. As we will show below, even though these datasets document different numbers of projects, the analysis shows they all produce very similar results in terms of their distribution by type of contractor license. Thus, we are confident that our analysis is robust and not dependent on the particular data extraction performed by our research team, or by the electrical industry and CALSSA.

A key trend documented in the data is that the average size of storage systems in California is declining due to the rapid growth of residential installations. While the average size of the BESS installations has declined, the number of systems has been increasing (see Figure 1). Figure 2, which is based on total storage capacity, shows that in 2017 there were fewer projects with higher total capacity compared to 2018, when there were more projects but lower total capacity. Starting in 2018, the total capacity of BESS per year starts to parallel the number of projects installed, showing that smaller storage projects have been and may likely continue to be responsible for the rapid growth of the storage industry.

Figure 1. Average Size and Total Number of Solar-Paired BESS Installed 2015–2020 (SGIP data)

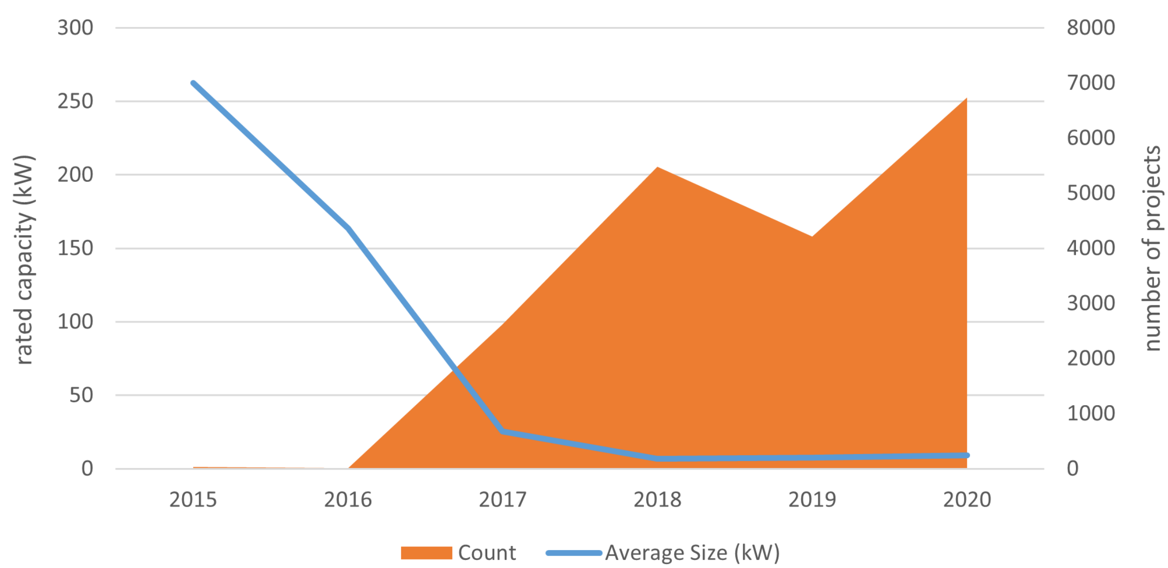


Figure 2. Total Number and Total Capacity of Solar-Paired BESS Installed 2015–2020 (SGIP data)

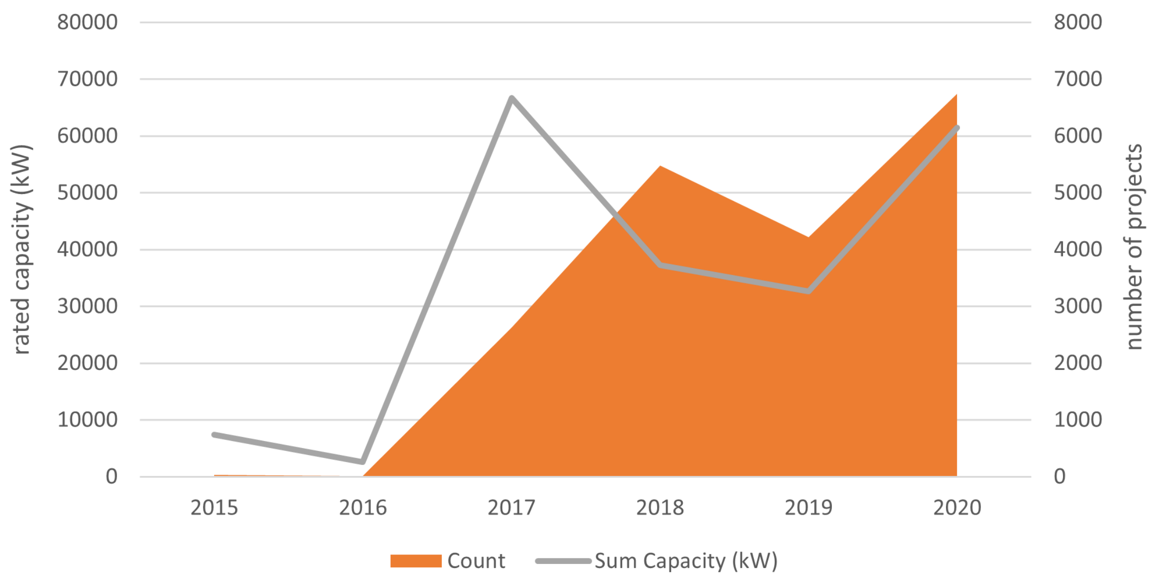
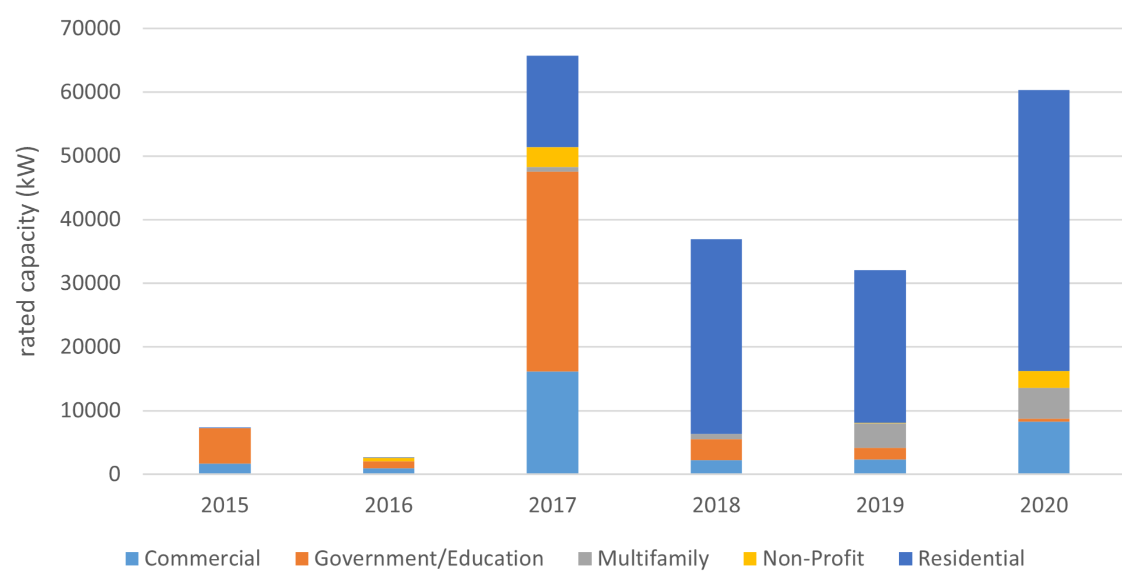


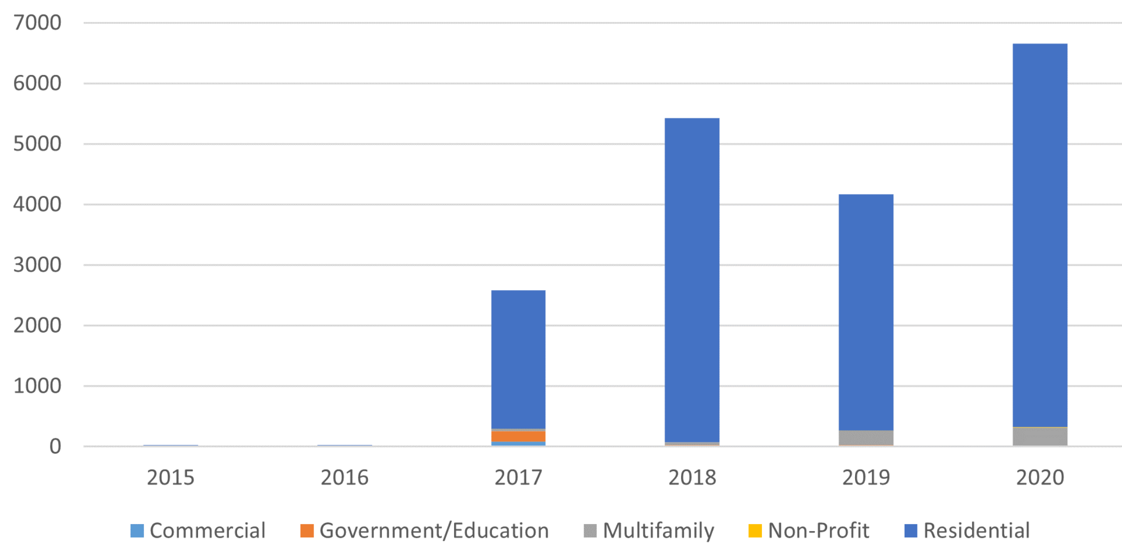
Figure 3 shows the profile of BESS by sector by year. This shows the strong growth of residential BESS and its contribution to total statewide distributed storage capacity. While there were a few government and commercial storage projects in 2015 and 2016, there was significantly more investment in all customer classes in 2017. Since 2017, the residential sector has been responsible for the majority of new BESS capacity in the state. This is all the more striking because the average size of residential systems is small—6.6 kW in 2020. The size of residential BESS is slowly getting larger: the average size in 2020 was 20% larger than in 2015.

Figure 3. Total Capacity of Installed Solar-Paired BESS Projects by Customer Sector (SGIP data)



In 2020, there were almost three times as many residential BESS installed than in 2017, as shown in Figure 4. This growth may well continue in California as more consumers are seeking storage to insulate themselves from extreme weather events or public safety power shutoffs. Other regulatory and legislative decisions, such as revisions to net energy metering and state and federal subsidies, could accelerate or slow this growth by changing the consumer economics. Lithium-ion battery pack prices have fallen 89% since 2010, and improved technologies and economies of scale are projected to continue driving down the cost of BESS, which also could accelerate growth.[16]

Figure 4. Count of BESS Installations by Year (SGIP data)



B. Who is Installing BESS Paired with Solar in California?

For the following analysis of the distribution of contractor licenses among contractors who have installed PV-paired BESS, we matched the datasets on BESS installations with the CSLB data on contractor licenses. We did this for both the 2015–2020 SGIP dataset and the 2020 Interconnection dataset, since both provide the name of the installer, allowing us to match names to CSLB licensing data. The 2020 Interconnection data also included license numbers. Please refer to Appendix A for more detail on our methodology.

The distributed energy storage systems that have been installed in the last five years have ranged in size from less than 0.5 kW for small residential units to projects over 2,500 kW for government and large commercial installations. Matching installer names to CSLB licensing data, we found that these BESS have been installed by C-46 contractors, C-10 contractors, and A and B contractors, as well as self-installs. Three-fifths of the BESS capacity has been performed by contractors holding both C-46 and C-10 licenses, as shown in Figure 5. Another 23% of capacity has been installed by C-10 contractors not holding a C-46 license (we call these “C-10 (no C-46)”). Only 3% of capacity has been installed by C-46 contractors not holding an A, B, or C-10 license (we call these “C-46 (no C-10, A, or B)”). Thus 83% of the BESS capacity was installed by contractors who are held by CSLB rules to the higher standard of using certified electricians when their employees carry out electrical work (including BESS work).

16 https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/.

Figure 5. Distribution of Licenses Held by Contractors Installing Solar-Paired BESS in CA, 2015–2020, by Capacity of BESS (SGIP data)

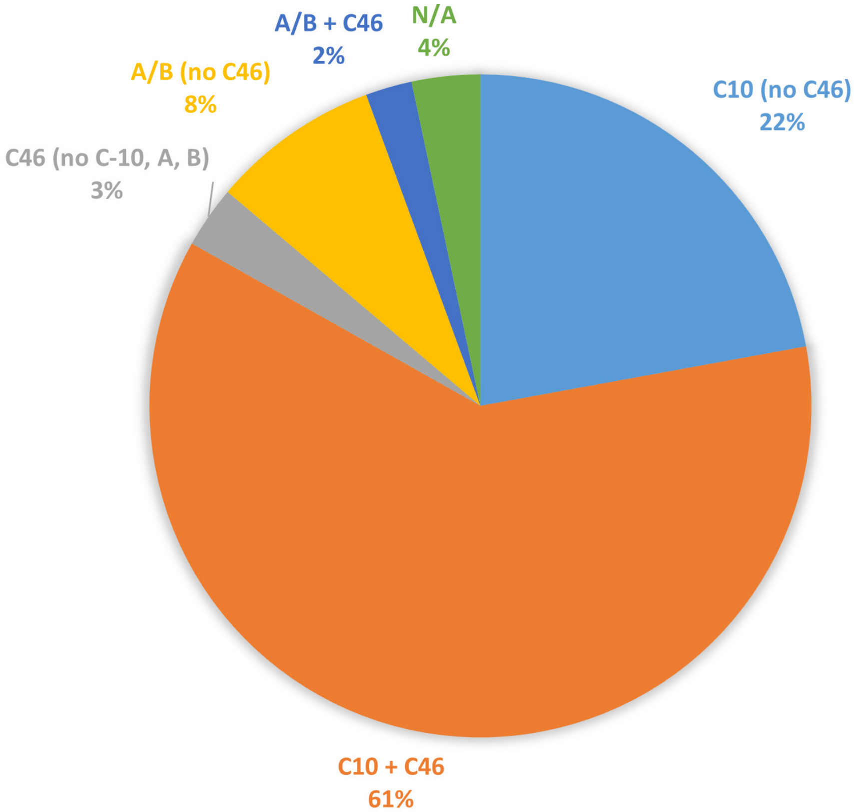


Figure 6 shows that similar trends hold when we document the profile of contractors by number of projects, rather than by capacity. The majority of projects are installed by contractors holding both C-10 and C-46 licenses. C-46 contractors holding no A, B, or C-10 licenses have installed only 6% of total projects.

CALSSA has asserted that 85% of the BESS projects have been installed by C-46 contractors (with or without other licenses). The electrical industry asserts that 89% have been installed by C-10 electricians (with or without other licenses). Our analysis shows C-46 contractors (with or without other licenses) have installed 66% of the capacity and 77% of the solar-paired BESS projects, and C-10 contractors (with or without other licenses) have installed 83% of the capacity and 87% of the projects. The majority of the installations are performed by contractors holding both a C-46 and C-10 license.

By both count and capacity, the data shows that since CSLB regulations require C-10 contractors to hire certified electricians to carry out the electrical tasks in the BESS installations, regardless of the other licenses they hold, very few BESS projects in California have been installed by contractors who are exempt from the certification requirement for their electrical workers.

Figure 6. Distribution of Licenses Held by Contractors Installing Solar-Paired BESS in CA, 2015–2020, by Number of BESS Installations (SGIP data)

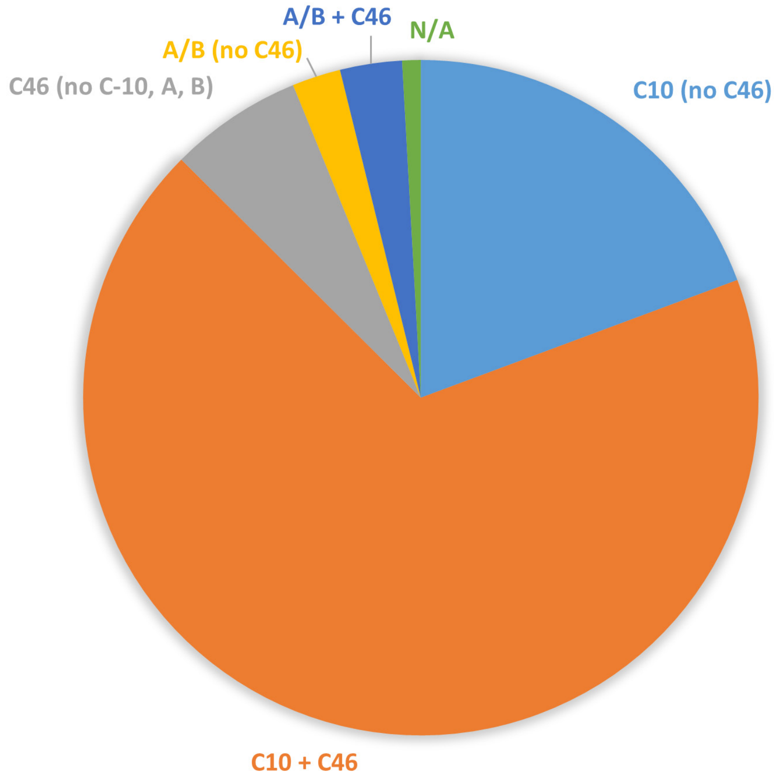


Figure 7 and Figure 8 show the same data as bar charts. In all of these figures, N/A (not available) refers most often to a self-install, although a handful of contractors who installed only a single SGIP project from 2015–2020 may also fall into the N/A category if their installer name in the SGIP data didn't match the exact name in the CSLB data.

Figure 7. Capacity of Solar-Paired BESS Installations by Contractor License, 2015–2020 (SGIP data)

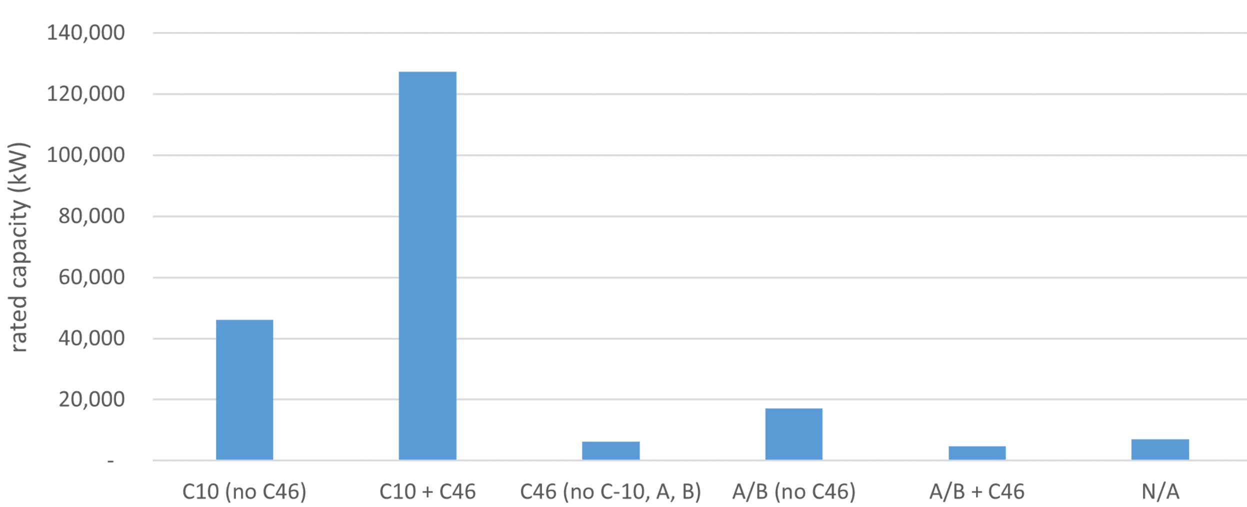


Figure 8. Number of Solar-Paired BESS Installations Projects by Contractor License, 2015–2020 (SGIP data)

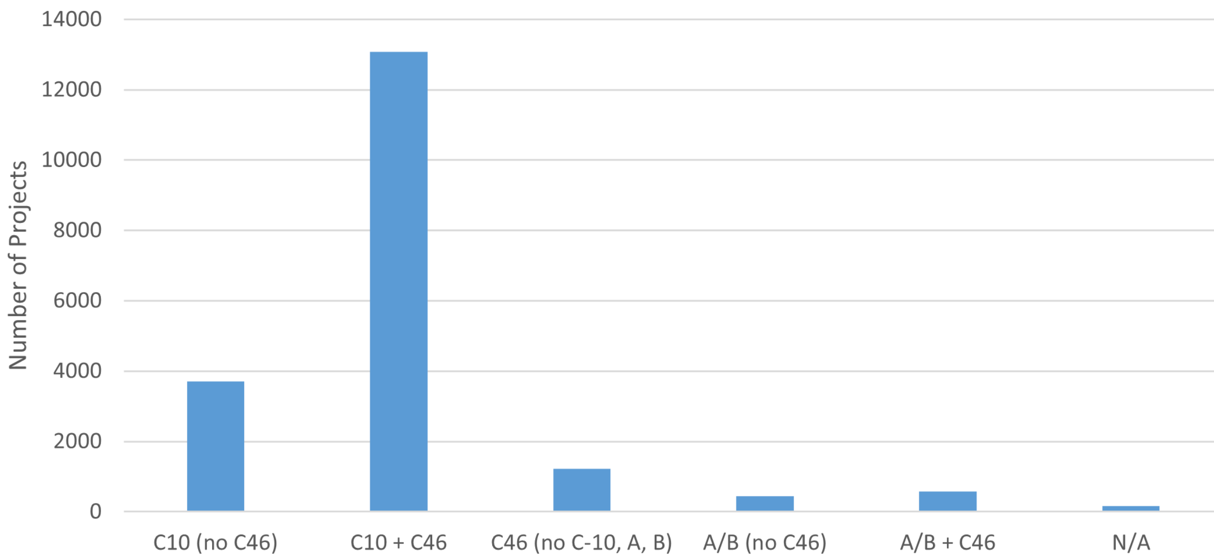


Table 1. 2015–2020 Solar-Paired BESS Data (from SGIP dataset)

License Class	Number of Installations	% Share	Installed Rated Capacity (kW)	% Share of Installed storage capacity	Average Size (kW AC)
C-10 (no C-46)	3,711	19.3%	46,167	22.1%	12.4
C-10 + C-46	13,075	68.1%	127,298	61.0%	9.7
C-46 (no C-10, A or B)	1,223	6.4%	6,299	3.0%	5.2
A/B (no C-46)	446	2.3%	17,161	8.2%	38.5
A/B + C-46	569	3.0%	4,736	2.3%	8.3
N/A	170	0.9%	6,966	3.3%	41.0
TOTAL	**19,194**	**100%**	**208,626**	**100%**	**10.9**

Table 2. 2020 Solar-Paired BESS Data (from 2020 Interconnection data)

License Class	Number of Installations	% Share	Installed Rated Capacity (kW)	% Share of Installed storage capacity	Average Size (kW AC)
C-10	1,486	11.4%	11,279	10.8%	7.6
C-10 + C-46	9,857	75.4%	76,143	72.9%	7.7
C-46 (no C-10, A or B)	601	4.6%	3,992	3.8%	6.6
A/B (no C-46)	637	4.9%	5,322	5.1%	8.4
A/B + C-46	296	2.3%	2,289	2.2%	7.7
N/A / Other / Self	196	1.5%	5,470	5.2%	60.6
TOTAL	**13,073**	**100%**	**104,495**	**100%**	**8.0**

We double checked the results from the SGIP dataset by comparing them with the data from the 2020 Interconnection dataset supplied by CALSSA and found that the two datasets have similar results. Table 1 shows all projects receiving the self-generation incentive for battery storage (SGIP data), whereas Table 2 shows all solar-paired storage and advanced energy systems projects for the year 2020 from the Interconnection dataset. Looking at both datasets together, there are some obvious similarities. First, Table 2 shows that energy storage installation is growing (a trend also reflected in charts below). Second, we see in both datasets that the vast majority of installations are performed by contractors holding both C-10 and C-46 licenses. In both datasets, contractors holding C-10 licenses are involved in 87% of storage installations (a slightly lower percentage than the 89% calculated by the electrical industry). C-46 licensed contractors are also involved in 78–82% of storage projects, but C-46 (no C-10, A, or B) are involved in only 3.0–3.8% of BESS projects. Since most C-46 contractors installing BESS also hold an A, B, or C-10 license, restricting BESS connection would affect only the small number of firms without an A, B, or C-10 license.

In sum, the SGIP data show that, for the pool of contractors who have installed solar-paired BESS in California over the last five years, only 3% of installations by capacity and 6% by number were carried out by contractors who would be excluded if C-46 contractors were precluded from or restricted in carrying out BESS installation. The result—that C-46 contractors without an A, B, or C-10 represent a very small fraction of the pool of BESS installers—is confirmed by all data sources. This means that statewide, neither restricting C-46 contractors from installing BESS nor precluding them altogether would significantly impact the current BESS industry.

C. Who is Installing BESS Projects in the Residential and Commercial Markets?

Since three of the four options CSLB has provided for us to evaluate pertain to licenses for BESS installation in the residential sector, we looked at the profile of licenses separately for the residential and non-residential markets (see Figures 9-12). In the residential market, the SGIP data show that contractors holding a C-10 license have installed 88% of small residential systems. Contractors holding a C-46 license have installed 78% of the systems. The majority of solar-paired storage systems are installed by C-10 and C-46 dual licensed contractors. C-46 (no C-10, A, or B) installed only 7% of the projects from the SGIP data and 4% from the Interconnection data.

In the commercial market, C-10 plus C-46 dual license holders are slightly less common, accounting for 45–52% of installations. A and B contractors have a larger share of the market, and self-installs are more common. C-10 contractors, with or without other licenses, installed 78% of BESS projects as recorded in the SGIP dataset and 64% in the Interconnection dataset. The SGIP data shows negligible participation of C-46 (no C-10, A, or B) while the Interconnection data shows 6% participation by the number of projects. This again confirms the result that C-46 contractors without a C-10, A, or B license are a very small percentage of BESS installers.

Figure 9. Distribution of Licenses Held by Contractors Installing Residential Solar-Paired BESS in CA, 2015–2020, by Number of BESS Installations (SGIP data)

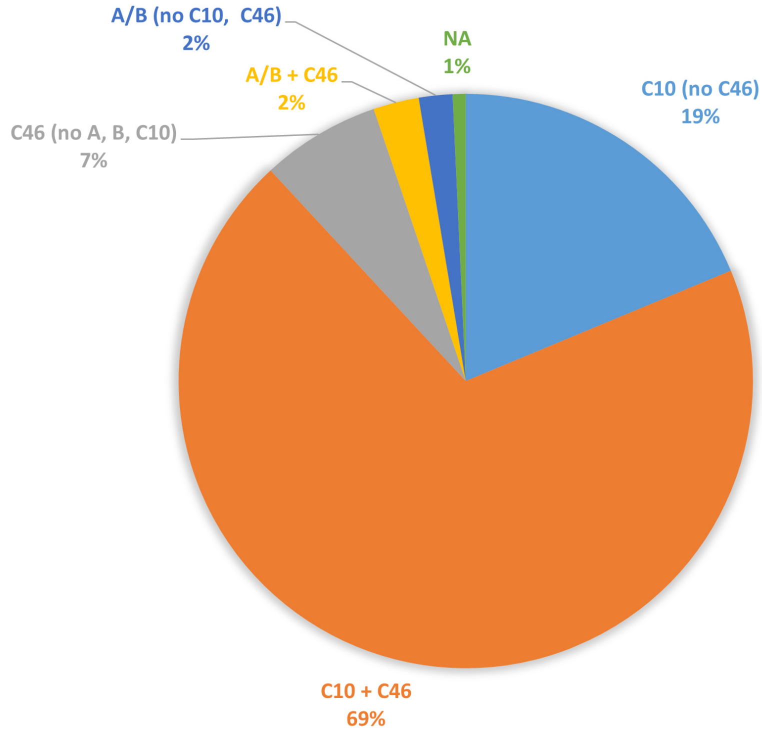


Figure 10. Distribution of Licenses Held by Contractors Installing Residential Solar-Paired BESS in CA, 2020, by Number of BESS Installations (2020 Interconnection data)

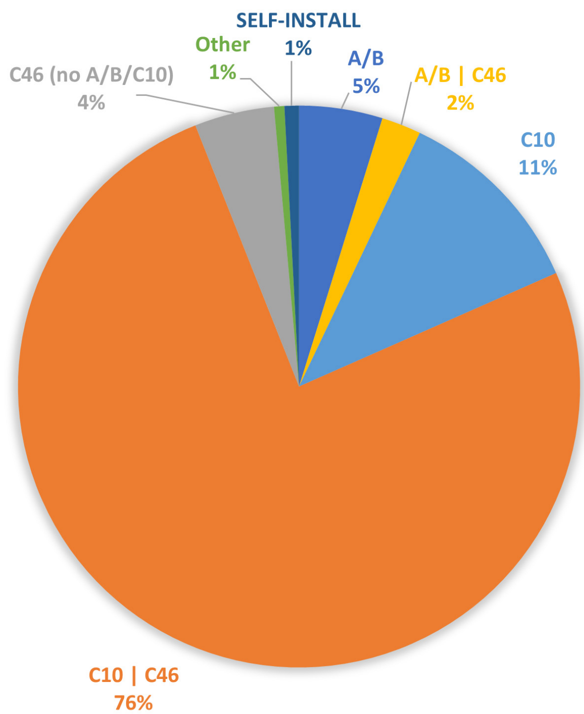


Figure 11. Distribution of Licenses Held by Contractors Installing Commercial Solar-Paired BESS in CA, 2015–2020, by Number of BESS Installations (SGIP data)

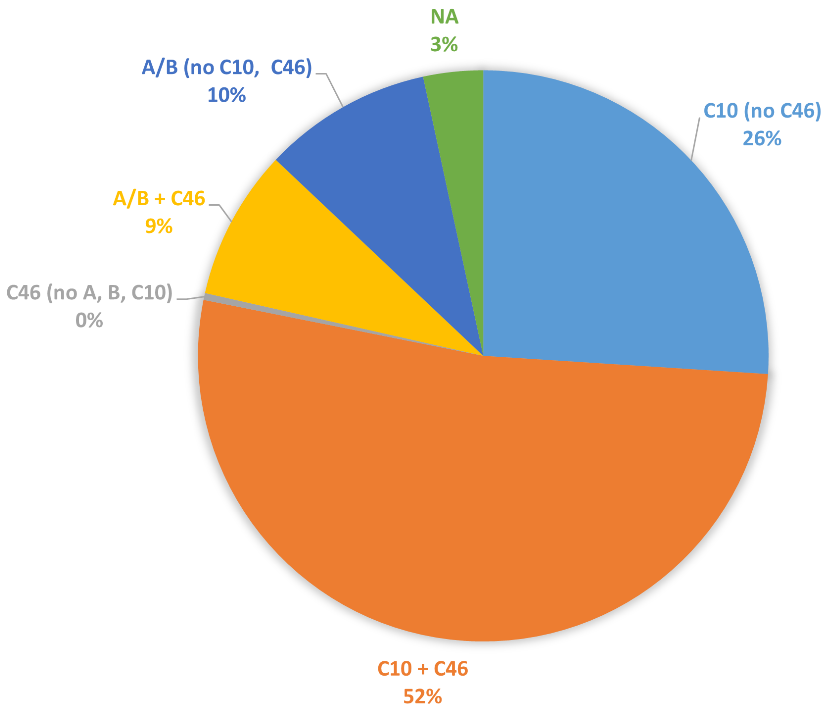
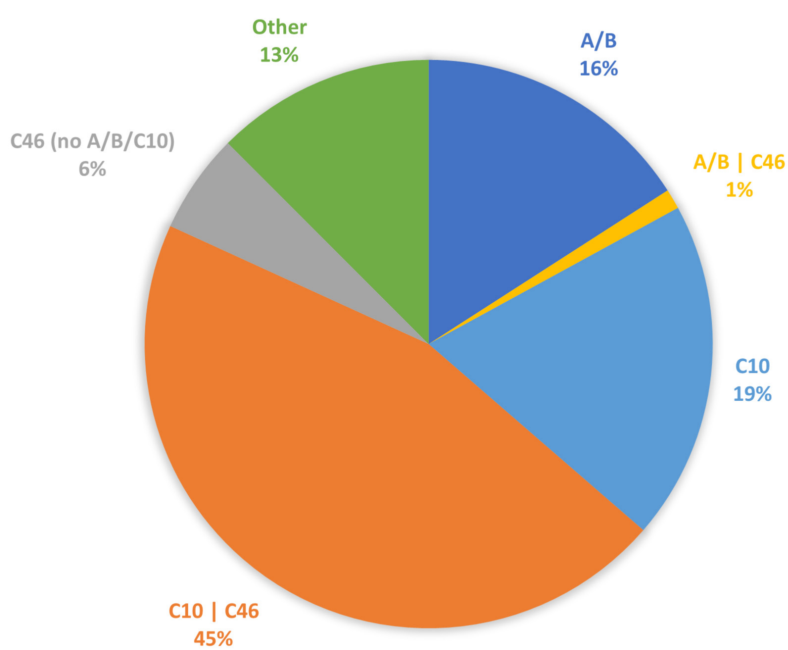


Figure 12. Distribution of Licenses Held by Contractors Installing Commercial Solar-Paired BESS in CA, 2015–2020, by Number of BESS Installations (2020 Interconnection data)



D. Which Specific Contractors are Installing the Most Residential BESS Projects, by Number of Projects and Capacity?

We also analyzed the distribution of installations by specific contractors to see which ones have carried out the bulk of the BESS installations to date, and thus which ones might be significantly impacted by any CSLB ruling. As stated earlier, our analysis (using the SGIP dataset 2015–2020) finds that C-46 contractors have installed 79% of the residential solar-paired BESS systems since 2015, but only 7% of residential solar-paired BESS systems were installed by contractors holding a C-46 license *without* an A, B, or C-10 license. Using the Interconnection dataset, in 2020 82% of residential projects were installed by C-46 contractors, but only 5% of residential projects were installed by contractors holding a C-46 license *without* an A, B, or C-10 license. About 500 different contractors installed BESS in 2020, but 190 installed only a single project, and 419 installed fewer than 10 systems.[17] This makes it critical to separate out those contractors in the top tier ranked by size, since these are much fewer in number.

We took an in-depth look at the C-46 (no A, B, C-10) contractors who have installed BESS using both the SGIP data from 2015–2020 and the Interconnection data from 2020. In the SGIP dataset, a single firm (James Petersen Industries, aka Petersen Dean and Solar 4 America) performed the majority of these installations (85% of capacity and 87% of number of installations). While this company clearly dominates the installations carried out by C-46 (no A, B, C-10), it still represents a very small share of total BESS installations by all contractors. It is important to note that since 2017, this firm has received four citations for violations related to departing from accepted trade standards or plans and specifications, and violation of building code. Since July 2020, five complaints that have been referred to legal action, and the company is at risk of losing its license.[18]

The Interconnection dataset shows less dominance by one firm in 2020, but still shows that just a very few C-46 (no A, B, C-10) contractors carry out the bulk of projects by this class of license holder. In 2020, we found that eighteen C-46 (no C-10, A or B) contractors installed at least four projects and only seven C-46 (no C-10, A or B) contractors installed more than fifteen projects. Again, these installations represent a very small percentage of total residential BESS installations.

Even for these C-46 (no A, B, C-10) contractors who are carrying out most of the BESS installations performed by this category of license holder, BESS represents a small amount of work. By way of illustration, the average cost of installed BESS in California is $15,000, and installation labor is estimated by NREL to be less than 10% of the cost. For those contractors installing fifteen projects, their labor costs would equal less than $22,500, so even firms installing fifteen projects in a year do not require even a single full-time employee to do so. The impact of restricting or precluding C-46 contractors from installing BESS would have a very small and manageable impact on contractors and their employees. Using the BESS installation labor cost estimate of $1000–$1500 per residential system, C-46 (no A, B, C-10) contractors would have spent $600,000 to $900,000 on installation labor for ALL of the BESS projects they installed in 2020. Assuming they are paying average wages of $25 per hour, this equates to 11.5–17.3 full-time equivalent jobs statewide.

17 There are spelling errors and other typos that make the same contractor show up as 2 or more contractors, so this is an estimate.

18 https://www.cslb.ca.gov/OnlineServices/CheckLicenseII/ComplaintDisclosure.aspx?LicType=LIC&LicNum=1050201.

Table 3. Ranking of C-46 Contractors Without C-10, A, or B Licenses, by Number of Projects and Capacity of Projects, SGIP and Interconnection Datasets for BESS in the Residential Sector

Residential Solar-paired BESS installers C-46 (no A, B, C-10 license)	Count of projects	Total Rated Capacity (kW)	% of total residential capacity installed by C-46 (no A, B, C-10)	Count of projects	Total Rated Capacity (kW)	% of total residential capacity installed by C-46 (no A, B, C-10
	2015–2020 SGIP			2020 Interconnection data		
James Petersen Industries Inc dba Solar 4 America	1,049	5,242.5	84.5%	138	727.0	18.5%
Solar Tech Energy Systems				125	928.4	23.5%
Sea Bright Solar Inc dba Sunpower By Sea Bright Solar	21	135.0	2.2%	34	225	5.7%
Skytech Solar	18	129.9	2.1%	26	167.9	4.3%
Phoenix Energy Fulfillment Inc dba Phoenix Solar Energy	15	103.5	1.7%	34	244.9	6.2%
Bay Area Energy Solutions Inc	15	94.8	1.5%	13	174.6	4.4%
Southern California Energy Alternatives				18	160.0	4.1%
West Coast Solar				16	108.6	2.8%
TOTAL OF TOP 8 INSTALLERS	1,118	5,705.7	92%	404	2736.4	69.5%
contractors installing 4–12 projects each	8			18		
contractors installing 2–3 projects each	10			21		
contractors installing single project*	11+			22		

*Most contractors installing a single BESS in California from 2015, who required manual license matching with CSLB licensing data, were not matched. Some of these may be C-46 only contractors.

While there are only seven C-46 contractors installing more than fifteen projects in 2020, there are seventeen C-10 (no C-46) contractors who installed more than fifteen projects in 2020, according to the Interconnection dataset. Twenty-seven dual C-10 and C-46 licensed contractors installed more than fifteen projects in 2020.

The residential BESS market is dominated by fourteen contractors, who each installed over 100 BESS in 2020. Two of these fourteen were C-46 (no A, B, C-10); two were C-10 (no C-46); and the rest were dual (C-10 + C-46) license holders. The top three firms by percent of total projects are Sunrun Installation Services, Tesla, and Semper Solaris Construction Inc. **Together these three firms have installed 41% of the BESS projects from 2015–2020 (SGIP data) and 62% in 2020 (Interconnection data). All three firms have C-10 and C-46 licenses.** This data is presented in Table 4.

Table 4. Top BESS Installers in 2020 with Number of Projects and Licenses (Interconnection data and CSLB data)

Installer	License	Number of Projects
Sunrun	C-10 + C-46	3,458
Tesla	C-10 + C-46	3,166
Semper Solaris	C-10 + C-46	1,019
V3 Electric	C-10	370
Baker Electric (Aka Swell)	C-10 + C-46	355
Vivint Solar	C-10 + C-46	212
Solar Optimum	C-10	199
Infinity Energy	C-10 + C-46	194
Hooked On Solar	C-10 + C-46	148
Freedom Forever	C-10 + C-46	135
James Petersen (Petersen Dean, Solar 4 America)	C-46 (no A, B, C-10)	132
Solartech	C-46 (no A, B, C-10)	127
La Solar Group	C-10 + C-46	110
Hot Purple Energy	A/B + C-46	106

Again, the data show that the firms doing the most work in this space would not be impacted as they are already dual license holders. This data is shown in Appendix C, drawing on both the SGIP and Interconnection datasets.

E. Does Average Size of Projects Vary by Installer License?

While residential projects are smaller than non-residential projects, and contractors holding only a C-46 license have on average small project sizes, there is not a lot of variation in project size between different installer license classes in the residential sector. A 5kW size restriction for C-46 (Option 2) would basically maintain the status quo. From 2015, such a 5kW restriction would have affected just 3% of residential projects statewide. The average size of BESS projects by contractor licenses is shown in Table 5.

Table 5. Average rated capacity (kW) by customer class

	Solar PV-paired storage SGIP Data (2015–2020)		Solar PV-paired storage Interconnection Data (2020)	
	Non-Residential/ Multi-family	Residential	Non-Residential	Residential
C-10 (no C-46)	90.2	6.2	112.3	6.4
C-10 + C-46	90.2	6.4	172.2	7.1
C-46 (no C-10, A, or B)	16.3	5.1	8.4	6.6
A/B + C-46	17.6	6.5	5.0	7.7
A/B (no C-46)	157.2	6.3	102.4	6.2
N/A	176.0	5.7	—	—
Other (no A, B, C-10, C-46)	—	—	380.2	7.2
Self Install	—	—	—	6.8

F. Who is Installing BESS Projects in Rural Counties?

One of the challenges with statewide regulations is that labor market dynamics are different in rural and urban regions of California. Restrictions that wouldn't limit the supply of qualified workers and contractors in urban areas can leave rural areas underserved. In a conversation/interview as part of this project, CALSSA expressed concern that rural C-46 contractors serve more diverse customer types and provide a wider variety of services than their urban counterparts, making a sectoral threshold (i.e., restricting C-46 contractors to the residential sector) unworkable for rural areas. They also suggested that C-46 contractors may be more willing to provide solar-paired BESS in rural counties than C-10 contractors who are less specialized. To evaluate the effect of a possible C-46 BESS restriction across California's rural and urban counties, we looked at the distribution of BESS projects across license type by county. By state definition, California has four rural counties (Alpine, Mariposa, Sierra, and Trinity), colored in green in Table 6, below, and seven mostly rural counties (Amador, Calaveras, Lassen, Modoc, Mono, Plumas, and Siskiyou), colored in blue.[19]

Table 6 is sorted by percent of BESS installed by C-46 contractors not holding a C10, A, or B license. The data do not show a correlation between rural counties and utilization of C-46 contractors. In fact, across all eleven rural or mostly rural counties, C-46 contractors have installed only thirteen SGIP projects, twelve of them installed by James Petersen Inc, which is a large statewide contractor (not a small rural contractor), and one by CalSolar, which has installed just nine BESS projects statewide in five years. Another firm, Aztec Solar, whose license is currently inactive because they recently merged with another firm but had held a B and C-46 license, also installed one project. In short, restricting BESS installation to C-10 contractors would not adversely affect California rural communities, because C-10 contractors have installed many more BESS systems than C-46 (no C-10, A or B) across all rural and mostly rural counties. Seven of California's counties have had no BESS installations, and four counties had only one or two SGIP projects. California's most rural counties represent 0.8% of all in-state solar paired SGIP BESS projects. For resiliency reasons, rural counties might seek expanded BESS investment, but even considering rapid growth, there are 17 times more C-10 contractors than C-46 contractors in rural California (see Table 7).

19 Source: https://ucanr.edu/sites/UC_CCP/files/125967.pdf.

Table 6. BESS Projects by County, sorted by license of contractor

County	% of projects installed by C-10 (no C-46)	number of projects installed by C-10 (no C-46)	% of projects installed by dual C-10 + C-46	number of projects installed by C-10 + C-46	% of projects installed by C-46 (no C-10, A, or B)	number of projects installed by C-46 (no A, B, C-10)	% of projects installed by A/B with or without C-46	number of projects installed by A/B with or without C-46*
Merced	2.63%	1	60.53%	23	34.21%	13	0.00%	0
Kings	4.35%	2	69.57%	32	23.91%	11	2.17%	1
Mariposa	**13.33%**	**2**	**53.33%**	**8**	**20.00%**	**3**	**6.67%**	**1**
Tulare	11.36%	10	67.05%	59	19.32%	17	2.27%	2
Fresno	3.57%	11	72.08%	222	18.18%	56	5.19%	16
Tehama	6.06%	2	75.76%	25	18.18%	6	0.00%	0
Madera	11.11%	8	70.83%	51	16.67%	12	0.00%	0
Stanislaus	21.21%	7	60.61%	20	15.15%	5	3.03%	1
Sacramento	20.93%	18	62.79%	54	13.95%	12	2.33%	2
Contra Costa	5.59%	49	71.72%	629	13.80%	121	8.44%	74
Solano	8.24%	29	67.33%	237	12.78%	45	11.08%	39
Tuolumne	19.15%	9	61.70%	29	12.77%	6	4.26%	2
Glenn	12.50%	1	25.00%	2	12.50%	1	50.00%	4
San Benito	8.57%	3	77.14%	27	11.43%	4	2.86%	1
Alameda	7.22%	62	74.85%	643	10.94%	94	6.29%	54
San Joaquin	6.47%	15	77.16%	179	10.78%	25	2.59%	7
Calaveras	**21.43%**	**15**	**61.43%**	**43**	**10.00%**	**7**	**7.14%**	**5**
Yuba	18.18%	10	67.27%	37	9.09%	5	5.45%	3
San Mateo	18.23%	101	69.86%	387	8.84%	49	2.71%	15
Yolo	11.11%	14	74.60%	94	8.73%	11	5.56%	7
Orange	18.82%	283	68.48%	1,030	7.91%	119	3.39%	51
San Bernardino	18.53%	149	69.90%	562	7.84%	63	3.36%	27
Sonoma	13.03%	65	70.74%	353	7.62%	38	6.61%	33
Santa Clara	17.06%	172	73.71%	743	7.44%	75	1.49%	15
Placer	9.00%	27	78.00%	234	7.33%	22	4.33%	13
Sutter	6.67%	2	80.00%	24	6.67%	2	6.67%	2
El Dorado	23.84%	72	66.23%	200	6.29%	19	2.98%	9
Los Angeles	24.60%	739	64.45%	1,936	5.99%	180	4.06%	122
Butte	4.41%	6	77.94%	106	5.15%	7	11.76%	16
Marin	11.08%	43	70.62%	274	4.90%	19	12.37%	48
Kern	3.48%	7	88.06%	177	4.48%	9	3.48%	7
Lake	25.00%	23	30.43%	28	4.35%	4	35.87%	33

CONTINUED Table 6. BESS Projects by County, sorted by license of contractor

County	% of projects installed by C-10 (no C-46)	number of projects installed by C-10 (no C-46)	% of projects installed by dual C-10 + C-46	number of projects installed by C-10 + C-46	% of projects installed by C-46 (no C-10, A, or B)	number of projects installed by C-46 (no A, B, C-10)	% of projects installed by A/B with or without C-46	number of projects installed by A/B with or without C-46*
Amador	**33.33%**	**23**	**57.97%**	**40**	**4.35%**	**3**	**4.35%**	**3**
Riverside	6.90%	103	72.72%	1,085	4.09%	61	16.02%	239
Napa	10.06%	16	74.21%	118	3.14%	5	10.69%	17
Monterey	14.18%	19	74.63%	100	2.99%	4	5.97%	8
Ventura	17.76%	111	76.16%	476	2.56%	16	2.72%	17
Nevada	31.01%	40	63.57%	82	2.33%	3	2.33%	3
San Diego	38.05%	1189	56.54%	1,767	1.95%	61	2.53%	79
San Francisco	2.00%	5	92.40%	231	1.60%	4	2.80%	7
Santa Cruz	42.76%	121	54.06%	153	1.41%	4	1.06%	3
Santa Barbara	13.45%	30	79.82%	178	0.45%	1	4.04%	9
San Luis Obispo	20.22%	73	78.39%	283	0.28%	1	0.28%	1
Humboldt	6.25%	5	68.75%	55	0.00%		21.25%	17
Mendocino	18.75%	3	75.00%	12	0.00%		6.25%	1
Shasta	37.93%	11	55.17%	16	0.00%		3.45%	1
Colusa	0.00%	0	100.00%	1	0.00%		0.00%	0
Plumas	**0.00%**	**0**	**100.00%**	**1**	**0.00%**		**0.00%**	**0**
Trinity	**0.00%**	**0**	**100.00%**	**2**	**0.00%**		**0.00%**	**0**
Inyo	50.00%	1	50.00%	1	0.00%		0.00%	0
Mono	**100.00%**	**1**	**0.00%**		**0.00%**		**0.00%**	**0**
Alpine	**0.00%**	**0**	**0.00%**		**0.00%**		**0.00%**	**0**
Del Norte	0.00%	0	0.00%		0.00%		0.00%	0
Imperial	0.00%	0	0.00%		0.00%		0.00%	0
Lassen	**0.00%**	**0**	**0.00%**		**0.00%**		**0.00%**	**0**
Modoc	**0.00%**	**0**	**0.00%**		**0.00%**		**0.00%**	**0**
Sierra	**0.00%**	**0**	**0.00%**		**0.00%**		**0.00%**	**0**
Siskiyou	**0.00%**	**0**	**0.00%**		**0.00%**		**0.00%**	**0**
BLANK							45	976
AVERAGE/ TOTAL	19.3%	3,708	68.1%	13,069	6.4%	1,223	5.29%	1,015
AVERAGE RURAL/MOSTLY RURAL	27.9%	41	63.9%	94	2.0%	3	6.1%	9

Table 7. Number of Licensed C-10 and C-46 Contractors by County

County	Active C-46 licenses	Active C-10 licenses	Active dual C-10, C-46
Merced	8	85	3
Kings	5	40	2
Mariposa		**19**	
Tulare	8	173	3
Fresno	38	423	14
Tehama	1	35	1
Madera	6	86	4
Stanislaus	12	268	3
Sacramento	43	867	17
Contra Costa	49	690	23
Solano	13	213	5
Tuolumne	4	59	1
Glenn	1	12	
San Benito	1	49	
Alameda	41	852	14
San Joaquin	17	312	6
Calaveras	**3**	**58**	**2**
Yuba	2	44	1
San Mateo	12	553	6
Yolo	7	90	
Orange	88	2,241	30
San Bernardino	43	1,163	16
Sonoma	39	524	12
Santa Clara	55	1,007	18
Placer	27	485	8
Sutter	3	65	2
El Dorado	18	234	6
Los Angeles	209	6,063	80
Butte	16	156	2
Marin	18	244	10
Kern	26	432	6
Lake	3	52	1
Amador	**9**	**55**	**3**
Riverside	89	1,601	31
Napa	5	118	

CONTINUED Table 7. Number of Licensed C-10 and C-46 Contractors by County

County	Active C-46 licenses	Active C-10 licenses	Active dual C-10, C-46
Monterey	5	272	1
Ventura	21	667	3
Nevada	14	161	5
San Diego	138	1,911	49
San Francisco	19	550	9
Santa Cruz	18	245	7
Santa Barbara	7	274	1
San Luis Obispo	16	315	10
Humboldt	8	89	5
Mendocino	11	90	4
Shasta	15	167	3
Colusa		9	
Plumas		**29**	
Trinity		**15**	
Inyo	1	13	
Mono	**2**	**21**	**1**
Alpine			
Del Norte		9	
Imperial		56	
Lassen	**1**	**17**	
Modoc		**6**	
Sierra		**4**	
Siskiyou		**34**	
BLANK	45	976	19
AVERAGE/TOTAL	1240	25,298	447

*There is a roughly even split

G. Summary of Profile of Licenses Held by BESS Contractors

In sum, after looking at the distribution of licenses of the contractors installing solar-paired BESS projects over the last five years—in terms of number of installations, installed capacity, by customer class, by project size, by the most important firms ranked by number of installations, and by rural vs. urban installation—the data consistently show the same research result. Most installations are carried out by C-10 contractors, including both those with and without C-46 licenses, and the majority of installations have been carried out by contractors holding both a C-46 and a C-10 license. Only a very small percentage of BESS projects have been installed by C-46 contractors who do not also hold a C-10, A, or B license. While C-46 (no C-10, A, or B) contractors are exempt from the CSLB standard that any employee who carries out electrical work must be a certified electrician, all contractors holding a C-10 license are held to the certification requirement, even those that also hold a C-46 license.

We therefore conclude that precluding or restricting C-46 (no C-10, A, or B) contractors will have a negligible effect on the current pool of contractors, because only a tiny fraction of current BESS installations has been carried out by contractors holding only a C-46 license without an A, B, or C-10 license. The C-46 contractors currently engaged in BESS who do not hold a C-10 licenses could of course obtain one, as have the great majority of C-46 contractors performing BESS installations. We have no specific information about why contractors obtain both licenses, but since the C-10 license covers ALL the work allowed by the C-46 license, we surmise that many C-46 contractors have found it advantageous to obtain the C-10 license as well. The large number of dual license holders indicates that, for many C-46 contractors, obtaining the C-10 license has not been an obstacle.

This research finding has significant implications for the CSLB's decision. Any ruling to restrict the scope of the C-46 license would have negligible effect on the current industry profile since so few installations have been carried out by C-46 (no C-10, A, or B) contractors. The question the CSLB is considering is thus at heart about the *future* trajectory of the industry, and whether or not it makes sense for the state to encourage a large increase in the number of BESS installations performed by contractors who hold C-46 licenses but do not hold a C-10, A, or B license. Because certified electricians are not required under the C-46 license, a CSLB ruling that allows C-46 to carry out BESS installations would represent a decision by the CSLB to encourage the growth of a non-certified workforce instead of the continued use of certified electricians and the growth of employment of certified electricians in the future.

This profile of the current pool of contractors also has significant implications for the risk and hazard analysis that follows. The fact that there are very few C-46 (no C-10, A, or B) contractors in the pool of contractors that have installed BESS to date means that we do not have data on the safety record of this set of contractors. The next section presents our safety analysis.

IV. Workplace Hazards/Risks and Needed Contractor Demonstrated Knowledge, Skills, and Training

A. Introduction and Overview of BESS Safety Issues

This section evaluates safety issues that are relevant to our assessment of which specialty contractor classifications are appropriate to perform battery energy storage systems (BESS) work. The CSLB's mission statement and enabling statute emphasizes the importance of the role of public safety to the activities and requirements of the CSLB. The mission statement provides that "(t)he Contractors State License Board protects consumers by regulating the construction industry through policies that promote the health, safety, and general welfare of the public in matters relating to construction."[20] Section 7000.6 of the California Business and Professional Code states:

> Protection of the public shall be the highest priority for the Contractors State License Board in exercising its licensing, regulatory, and disciplinary functions. Whenever the protection of the public is inconsistent with other interests sought to be promoted, the protection of the public shall be paramount.[21]

This section examines the appropriate jurisdiction of C-46 solar contractor and C-10 electrical contractor classifications for ensuring the ***safe*** construction, installation, modification, maintenance, or repair (herein after "installation") of BESS. The CSLB articulated the questions on safety that we were tasked with answering as follows:

- Considering BESS risk, hazard, size, and complexity considerations, is there an existing or prospective harm to public safety, and if so, what is the likelihood of the existing or prospective harm occurring and/or will that harm be fixed by enacting a regulation?
- Whether the solar contractor classification should be authorized in regulation to install a BESS and if so to what extent/in what way?
- Applicability of state and national standards and codes to these inquires.
- An analysis of applicable knowledge, skills and training as it relates to the installation of BESS.

20 https://www.cslb.ca.gov/About_us/.

21 https://law.justia.com/codes/california/2011/bpc/division-3/7000-7020/7000.6/.

B. Our Approach

In accordance with the mission of the CSLB, we evaluate BESS hazards and risk by examining their potential impact on public safety, reviewing the safety of workers, emergency responders, occupants, and the public. Hazard evaluation considers what can go wrong and examines potential harmful events and their impact, separate from any needed controls or mitigation actions. Risk management uses the information about hazards to consider how bad an incident can be, the likelihood of its occurrence, the state of existing technology and safety systems, and the effectiveness of preventative and mitigation measures including regulations and standards. It is important to underscore that the safety of BESS is best evaluated as a system that includes not only the battery but also associated equipment as well as potential risks to the existing electrical infrastructure that the battery connects with.

This safety analysis examines a range of BESS applications including residential, commercial, and grid-utility.[22] First, we review the key safety issues and positions raised by stakeholder parties as documented in the CSLB's BESS meetings and reports. Next, we review the determination of hazards and risks, focusing on the BESS chemistries and technologies that predominate in California. The report reviews serious BESS incidents from media and other data sources, including incident reports where available, and examines both the identified causes and the recommendations for future mitigation.

The report evaluates the ongoing research on BESS by organizations such as National Fire Protection Association (NFPA), the Underwriters Laboratories (UL),[23] DNV,[24] and FM Global.[25] We review the relevant codes and standards, which have undergone significant revision over the last five years to address BESS hazards, risks, and mitigations. We examine not only the relevant building codes adopted by regulation in California but also the consensus among experts of good practice safety standards and guidelines that have been recently developed to address BESS hazards, including safety data sheets, installation guides, emergency response guidance, and battery safety testing data published by BESS manufacturers.

We evaluate BESS risks utilizing data related to incident frequency and potential consequences, using recognized and generally accepted risk assessment approaches for electrical and chemical hazards. This includes risk determinations for BESS by the fire service and major insurance companies. Finally, we use existing risk mitigations developed in codes, standards, and technical reports to evaluate the knowledge, skills, and training required for safe BESS work. From these sources, we present conclusions and recommendations from a safety perspective on the appropriate BESS contractor classification(s) to install BESS.

22 There was some focus in the CSLB review on residential applications of BESS. However, the CSLB did not limit the review of BESS for this report to residential applications. It should also be noted that neither the C-46 nor C-10 stakeholders called for a resolution based upon residential applications.

23 Underwriters Laboratories (UL) is a safety science, testing, and third-party certification organization.

24 DNV—formerly DNV GL—is an international organization expert in risk management and quality assurance with corporate headquarters in Norway.

25 FM Global is a mutual insurance company that provides risk engineering services to primarily large corporations. FM Global publishes well-regarded loss prevention data sheets including ESS.

C. Stakeholder Positions on BESS Hazards, Risk, and Safety Standards

The CSLB has been addressing contractor classification jurisdictional issues for BESS since 2015, and has received extensive input from industry stakeholders, which we have carefully reviewed. We also held two meetings/interviews each with CALSSA and the electrical industry to better understand their concerns. In conducting the review, we interviewed relevant personnel from the CSLB, Interstate Renewable Energy Council (IREC), California Building Industry Association (CBIA), California Department of Industrial Relations/Cal OSHA, California Building Officials (CALBO), California Building Standards Commission (CBSC), and the National Fire Protection Association (NFPA).

The key safety issues and concerns that these stakeholders have highlighted both in the public record and in our interviews are summarized below.[26]

1. C-46 Contractor Stakeholder Positions

CALSSA's arguments to support their position that C-46 contractors can safely carry out BESS projects can be summarized as follows: C-46 solar contractors have been successfully installing BESS connected to PV systems for 40 years.[27] There are no known BESS incidents in residential or commercial applications.[28] Since the connection of batteries to PV systems in off-grid homes, C-46 contractors have been installing BESS.[29] Lithium-ion batteries are safer than lead acid. There are no examples of C-46 related BESS incidents.[30] BESS technologies are getting safer and are described as "plug and play," incorporating circuit protections that prevent arc flash and thermal runaway in residential and commercial applications.[31]

For residential applications, the most common BESS is a UL listed prepackaged unit that is comparable to the installation of a simple appliance unit. Installers have no access to the enclosed battery terminals. A 20% output limit prevents overloading a service panel when connected to a PV system.[32] About 20% of the PV system installs require a service panel upgrade[33]—in this situation, a C-46 would contract for a service panel upgrade with a qualified electrical contractor rather than doing it with non-certified electricians. Regarding any calculations needed to conclude that an existing electrical system can be safely installed with a BESS, C-46 workers have been performing those calculations successfully.[34]

According to CALSSA, voltage and exposure to terminals are key considerations. CALSSA stated NFPA 70 makes an important distinction between exposed BESS DC terminals over 60 volts for application of NFPA 70. If exposed DC terminals are over 60 volts and thus an electrical worker safety hazard, then BESS must be installed by a qualified

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26 The key points were gathered from information provided to the CSLB and information received by the UC Berkeley team from CSLB stakeholders.

27 https://www.cslb.ca.gov/Resources/BoardPackets/ESS_Report_revised.pdf.

28 https://www.cslb.ca.gov/Resources/BoardPackets/ESS_Follow_Up_Study_7_26.v7.pdf.

29 *Ibid.*

30 https://www.cslb.ca.gov/Resources/BoardPackets/Leg_Com_Sum_Report_amended.pdf.

31 https://www.cslb.ca.gov/Resources/BoardPackets/ESS_Report_revised.pdf.

32 *Ibid.*

33 *Ibid.*

34 https://www.cslb.ca.gov/Resources/BoardPackets/8-6-19_Leg_Com_Sum_Report_Amended.pdf.

person—and solar installers are qualified.[35] CALSSA stated that it "does not feel that there are any potential safety risks" for BESS installation connected to a PV system.[36] BESS have been part of the C-46 contractor license exam since 2002, showing that C-46 contractors have the required competencies. The exam covers a range of both PV systems and BESS issues, and has more questions related to BESS than the electrical contractor test.[37] The CSLB C-46 license exam study guide lists BESS as a topic. All of this shows that C-46 contractors have the necessary qualifications.

2. C-10 Contractors Stakeholder Positions

The electrical contractors' (NECA and IBEW) arguments to support their position that C-46 contractors should not be allowed to carry out BESS projects can be summarized as follows: Current regulations allow C-46 to install BESS only when coupled with solar PV, but BESS are separate systems from PV systems. NFPA 70 addresses them separately in different chapters. BESS and PV systems can work together or separately—one is not ancillary to the other—so the exception that allows C-46 contractors to install BESS when paired with solar PV is invalid.[38]

Most BESS installs are in existing residential and commercial applications that require an evaluation of existing electrical systems. This evaluation includes calculations to ensure the BESS can be safely installed in the existing system.[39] The existing systems may have wiring and equipment of different sizes, ages, capacities, and conditions that require an assessment by a certified electrician working for a C-10 contractor. This includes a review of the existing grounding and bonding and the condition of overcurrent devices. BESS installation can stress or exceed the existing electrical system's capabilities, leading to serious safety issues. BESS and PV systems can be connected in a variety of configurations. PV systems and BESS can be connected to the same inverter or independent of each other. They can be grid connected or able to disconnect in the event of loss of power, or constructed with the ability to reconnect if power is restored. These various configurations present technical challenges that require a certified electrician.[40]

The electrical industry stakeholders also point out that NFPA 70 requires a qualified person to install BESS.[41] The definition of "a qualified person" is based on documented training and experience. Only certified electricians can perform electrical work for C-10 contractors. Becoming a certified general electrician in California requires passing an exam and 8,000 hours of experience.[42] The experience must be documented and under the supervision of a certified electrician. Certified electricians are trained in NFPA 70E, which addresses electrical safety and worker protection.[43] Solar installers working for a C-46 contractor have no regulatory requirements for experience or testing to assess competency. The C-10 stakeholders stated the OSHA 10-hour and 30-hour trainings address generic safety concerns of which electrical hazards are only one part.

We looked for evidence for and against each of the stakeholder positions and carried out our own independent analysis of safety issues relevant to the CSLB's questions.

35 *Ibid.*
36 *Ibid.* at 11.
37 https://www.cslb.ca.gov/Resources/BoardPackets/ESS_Report_revised.pdf.
38 https://www.cslb.ca.gov/Resources/BoardPackets/CommitteeMeetingPacket2019080506.pdf.
39 https://www.cslb.ca.gov/Resources/BoardPackets/8-6-19_Leg_Com_Sum_Report_Amended.pdf.
40 https://www.cslb.ca.gov/Resources/BoardPackets/8-6-19_Leg_Com_Sum_Report_Amended.pdf.
41 https://www.cslb.ca.gov/Resources/BoardPackets/ESS_Report_revised.pdf.
42 https://www.cslb.ca.gov/Resources/BoardPackets/8-6-19_Leg_Com_Sum_Report_Amended.pdf.
43 *Ibid.*

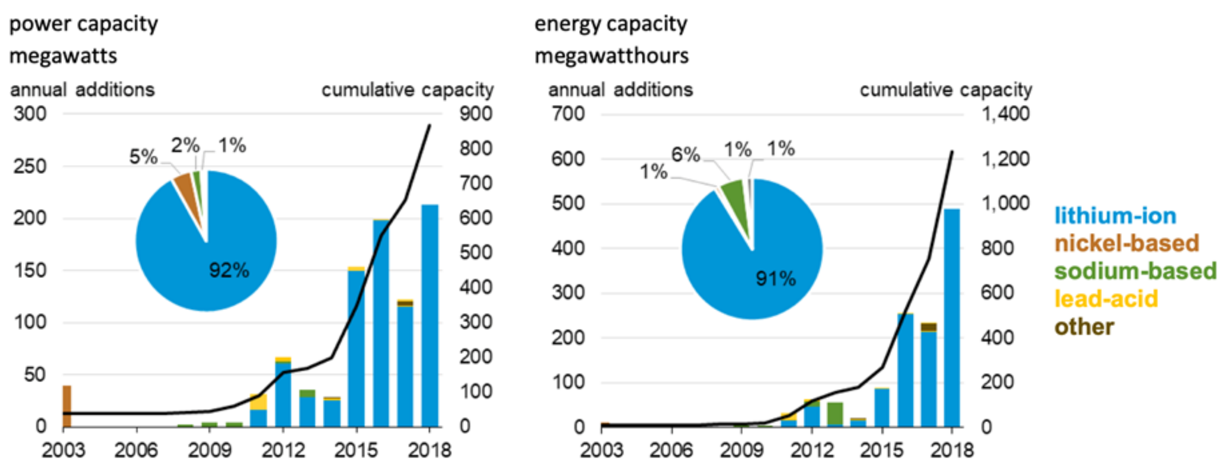
D. BESS Hazards

1. Background and Scope

Historically, energy storage systems (ESS) have varied in technology, but lithium-ion BESS predominate in current applications. This section documents the types of BESS that are relevant to California, highlighting the key role that lithium-ion batteries play. California has installed the largest share by far of small-scale[44] battery energy storage system capacity in the U.S., with 86% of all U.S. capacity in 2018.[45] California's Self-Generation Incentive Program (SGIP) has been credited with driving the state's dominance in small-scale energy storage growth.[46]

Lithium-ion is the predominant BESS technology for residential, commercial, and grid-utility applications in the U.S.[47] According to the U.S. Energy Information Administration (EIA), lithium-ion batteries (LIB) accounted for 90% of the large-scale BESS deployment in the U.S. through 2018 (Figure 13).[48] The EIA notes that most installations and retrofits have used LIB since 2011.

Figure 13. Large-Scale Battery Storage Capacity by Battery Chemistry (2003-2018)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

The LIB technology has become the nation's preferred technology due to its high energy density, efficiency in retaining energy from recharge to discharge, relatively longer life, and lower cost. Currently, lead acid and other battery technologies play a relatively minor role in all BESS applications. A variety of LIB chemistries have emerged. Lithium-manganese-cobalt-oxide (NMC) is the leading BESS chemistry followed by the increasing deployment of lithium iron phosphate (LFP) (see figure 14).[49]

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44 Residential, commercial, industrial, and direct connected. EIA defines small scale as having less than 1 MW in power capacity. Note the data on California ESS growth also reflects some non-battery storage.

45 https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf.

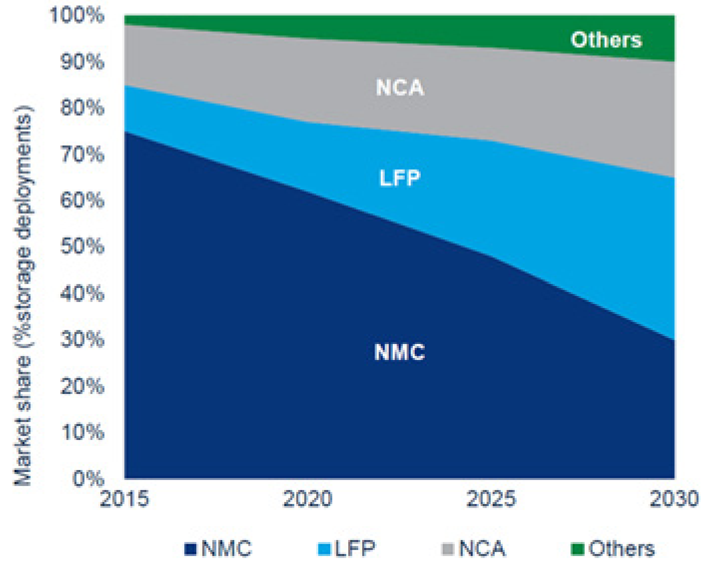
46 *Ibid.*

47 https://www.energy.gov/sites/prod/files/2020/12/f81/Energy%20Storage%20Market%20Report%202020_0.pdf.

48 https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf.

49 https://www.woodmac.com/press-releases/lfp-to-overtake-nmc-as-dominant-stationary-storage-chemistry-by-2030/.

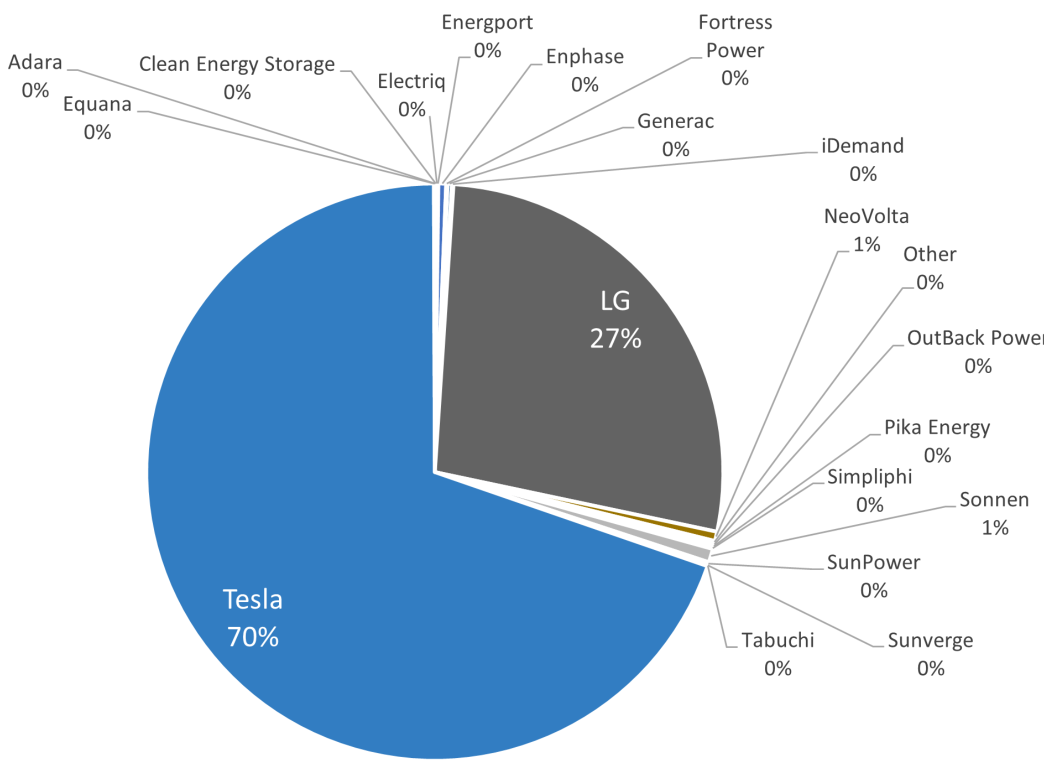
Figure 14. ESS Battery Chemistry Market Share Forecast, 2015–2030



Source: Wood Mackenzie Energy Storage Service

In the California residential energy storage market, lithium-ion batteries dominate the market, as shown in Figure 15. Lithium-manganese-cobalt-oxide (NMC) batteries from Tesla and LG account for 97% of the California residential installations based on SGIP data.

Figure 15. California SGIP Data on Residential ESS from 2015 Onward, Statewide Report (4-12-21)

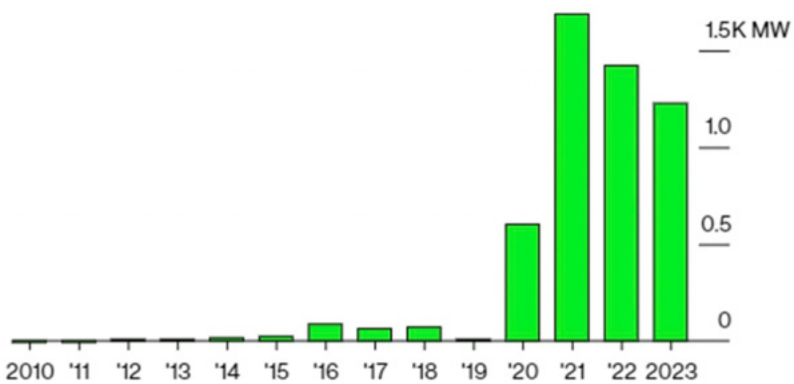


Distribution of Total Rated Capacity (kW) by Manufacturer

Tesla and LG NMC residential lithium-ion BESS also lead the U.S. market share as well.[50] The NMC LIB chemistry has long led the electric vehicle (EV) market, where high energy density in a smaller space is a priority. NMC also entered the home market with a cost advantage that occurred due to its growth in the EV market.[51] However, the higher energy density and chemistry that includes a flammable electrolyte in the NMC technology brings additional hazards. Other developing BESS chemistries are challenging NMC in part based upon safety concerns.[52]

The deployment of BESS in all sectors is rapidly growing in the U.S. California is predicted to more than double its battery energy storage from 2020 in one year, growing to 1.7 GW of new storage in 2021, as shown in Figure 16.[53] The large deployment of BESS is expected to continue through 2023.[54] In California, the demand for BESS is related to both concerns over utility power outages as well as established clean energy goals. This projection of significant growth in deployed BESS in California, with the predominance of lithium-ion chemistries, amplifies the importance of understanding and mitigating LIB hazards and risks.

Figure 16. California Projected to Install 1.7 GW of Battery Storage in 2021



Source: BloombergNEF

2. BESS LIB Chemistries and Hazards

Lithium-ion batteries are a relatively new technology utilized for BESS, so these batteries lack a lengthy track record for an evaluation of hazards and risks. Widespread deployment of LIB technologies is a recent development, with the dominance of NMC evident in 2016.[55] Sandia National Labs reports: "While many technologies have the advantage of a long track record, lithium-ion batteries are a relatively new technology

50 https://www.greentechmedia.com/articles/read/safer-batteries-residential-energy-storage-market.

51 *Ibid.*

52 The proponents of lithium iron phosphate (LFP) battery chemistry state that the risk of fire or explosion is greatly reduced due to its characteristic of requiring a higher temperature to reach thermal runaway. https://www.greentechmedia.com/articles/read/safer-batteries-residential-energy-storage-market. Other experts such as Victoria Carey, senior consultant of energy storage for quality assurance company DNV GL note "Just because the likelihood is different doesn't mean the impact is different."

53 https://www.bloomberg.com/news/articles/2021-04-01/to-avoid-blackouts-california-s-installing-more-big-batteries-than-all-of-china.

54 *Ibid.*

55 https://brandcentral.dnv.com/fr/gallery/10651/others/3f8f647936cf4fcfab7e82b45c79d9ac/3f8f647936cf4fcfab7e82b45c79d9ac_low.pdf.

that is being used in new environments and applications."[56] In response to BESS incidents and identified serious hazards, organizations such as NFPA, Underwriters Laboratories, FM Global, and DNV are conducting ongoing research on lithium-ion battery safety. This research has been leading to more effective mitigation approaches and safer technologies. New editions of codes and standards are continually addressing new BESS issues in what one California code official described as "chasing the technology."[57]

ESS are typically defined as systems that usually include multiple components. NFPA 70 (2020), the National Electric Code, defines ESS as "one or more components assembled together capable of storing energy and providing electrical energy into the premise's wiring system or an electric power production and distribution network."[58] Battery energy storage systems typically include components in addition to the battery, such as converters or inverters, that change stored energy into electrical energy. BESS are also typically provided with a battery management system (BMS). This is an electronic system that monitors and controls the BESS thermal and electronic condition in order to maintain the system within safe operating limits. If abnormal conditions arise, the BMS is designed to control the disconnection from the electrical system that the BESS is connected to.[59]

Factors that make LIB an effective battery design include high energy density and efficiency. These same qualities along with the use of a flammable organic electrolyte create the potential for significant inherent hazards.[60] A typical LIB cell[61] contains an electrolyte composed of a volatile flammable liquid which is hydrocarbon-based and lithium ions from a dissolved lithium salt.[62] Lessons from recent LIB incidents, ongoing research, and battery testing have all identified significant BESS safety issues from these chemistries. LIB chemistries such as NMC present multiple hazards including thermal runaway,[63] fire and explosion, arc flash, flammable and toxic vapor release, deep-seated fires, electric shock, and stranded energy. Inadequate design, construction, installation, maintenance, or repair can contribute to BESS failure modes and hazardous events.

a) Thermal Runaway, Fire, Explosion, and Toxic Gas Release

Of the LIB hazards, thermal runaway is the most significant. A principal engineer and spokesperson for UL[64] has called thermal runaway **"**his top safety concern related to lithium-ion batteries."[65] Thermal runaway is characterized as an uncontrolled exothermic chemical reaction that results in a rapid release of thermal energy from a battery cell at a higher rate than it can remove.[66] The internal chemical reaction can take place without oxygen or visible flame. Battery cells can be constructed to allow external venting of pressure. The thermal

56 https://www.osti.gov/servlets/purl/1662020.

57 Description from a California code official.

58 NFPA 70 (2020) 706. 2 Definitions.

59 NFPA 855 (2020) 3.3.3.

60 https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/RFFireHazardAssessmentLithiumIonBattery.ashx.

61 NFPA 70 (2020) the National Electric Code defines a cell as "The basic electrochemical unit, characterized by an anode and a cathode, used to receive, store, and deliver electrical energy.

62 *Ibid.*

63 "The condition when an electro-chemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion." NFPA 855.

64 Underwriters Laboratories (UL) is a third party safety certification agency that tests products and technologies.

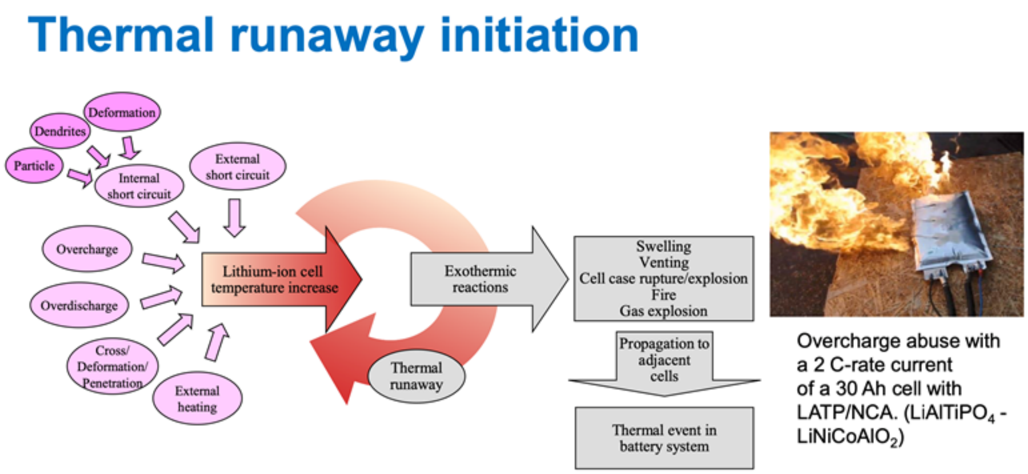
65 https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/burning-concern-energy-storage-industry-battles-battery-fires-51900636.

66 The functional electrochemical unit of a battery generally containing anode, cathode, electrolyte, terminals, etc.

decomposition of the electrolyte in the battery results in a buildup of internal pressure with the cell emitting gases prior to the start of the thermal runaway. Gases evolve from thermal decomposition and include chemical reactions of the electrolyte and electrode materials. The LIB temperatures surge to as high as 1,100°F. The cell releases flammable vapor that can result in a fire or with buildup of flammable vapor and delayed ignition—an explosion. A thermal runaway without a flame can result in a more serious buildup of flammable gases and a larger deflagration event.[67]

The thermal runaway can consume the internal cell constituents and, in the presence of oxygen, initiate a secondary fire involving the battery materials such as the electrolyte and plastic casing. The released vapor is generally toxic, with the gas composition depending on several factors including cell chemistry, the presence of fire, temperature, etc.[68] Vapor emissions can include the highly toxic hydrofluoric acid (HF).[69] The release of heat from one cell can trigger a cascade of similar failures in adjacent cells, leading to a much larger event. As Ben Ditch, a fire researcher at FM Global stated: "Lithium-ion batteries can burn. The fact is the hazard exists. ... It is something a lot of us have been worried about for some time."[70]

Figure 17. LIB Failure Modes—UL Webinar Gas Emissions at Fire, Overheating, and Overcharging Events for Lithium-ion Batteries, September 30, 2020



LIB events that can trigger thermal runaway include electrical, mechanical, environmental, and thermal abuse, as shown in Figure 17.[71] Electrical abuse failure mechanisms include overcharge, overdischarge, and internal and external short circuit.[72] Electrical abuse failure mechanisms include a component failure such as problems with the battery management system, a short circuit, or loose electrical connections. Mechanical abuse examples are penetration, crushing, and drops from sources such as tools, equipment, rough handling, or vehicle impact.

67 https://coaching.typepad.com/files/mcmicken.pdf.
68 https://ul.org/sites/default/files/2020-10/Mellander-Larsson_ULBatterySafetySeminar_Sep2020.pdf.
69 *Ibid.*
70 https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/burning-concern-energy-storage-industry-battles-battery-fires-51900636.
71 https://go.nfpa.org/l/14662/2021-01-11/8h6lwf.
72 https://ul.org/sites/default/files/2020-10/Mellander-Larsson_ULBatterySafetySeminar_Sep2020.pdf.

Environmental impacts include extreme heat, flooding, and seismic events. Thermal abuse can result from a variety of external heat sources including electrical events such as arc flash in proximity to the LIB. As summarized in Chemical Engineering Progress:

> A unique characteristic of Li-ion batteries is their flammable organic electrolytes and cathode materials that can evolve oxygen when heated. Under abuse conditions (i.e., mechanical damage, overdischarge, or overcharge), Li-ion cells may eject electrolyte and other flammable gases that can be a fire hazard if immediately ignited or an explosion hazard if delayed ignition occurs in an enclosed environment.[73]

b) Arc Flash and Electrical Shock

Another hazard that can occur in BESS is arc flash and electrical shock. Federal OSHA defines arc flash as "a phenomenon where a flashover of electric current leaves its intended path and travels through the air from one conductor to another, or to ground."[74] Arc flash temperatures can be over 20,000°F and lead to a serious overpressure event than can exceed 2,000 psi if unmitigated. Persons working with BESS or emergency responders can be exposed to arc flash and electrical shock,[75] and serious injuries and fatalities can result. The increasing power density and size of LIB increases the risk of arc flash impacts.[76]

Workers can be exposed to arc flash and electric shock from an energized BESS or electrical system. For example, the DC current within some lesser kWh capacity BESS can exceed the shock and arc flash threshold requirement of 50v AC or 60v DC.[77] BESS installation requires arc flash protection calculations, and can recommend arc flash protective PPE and propose safe working distances.[78] Emergency responders can be exposed to arc faults and electrical shock due to shorting from damaged equipment and water.[79]

c) Stranded Energy

Workers repairing or replacing a BESS can face the hazard of unquantified electrical energy that is stored in the battery.[80] Even after a fire, a LIB can still retain significant electrical energy that can be a threat to emergency responders. The BESS stranded energy can be difficult to assess or manually discharge due to hazardous conditions or terminal damage because of the fire. This remaining charge can not only present a latent shock hazard but can also serve to reignite a fire after it appeared to be quenched.

73 https://www.aiche-cep.com/cepmagazine/may_2020/MobilePagedArticle.action?articleId=1583421#articleId1583421.

74 https://www.osha.gov/sites/default/files/2018-12/fy07_sh-16615-07_arc_flash_handout.pdf.

75 https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=855.

76 https://www.solarpowerworldonline.com/2019/12/battery-energy-storage-systems-are-at-increasing-risk-for-arc-flash-hazards/.

77 For example, the LG RESU 16H Prime lists a voltage range of 350-450 VDC – "when installing the battery system, the worker shall wear arc-rated clothing in every occasions and places to protect him/her from any possible exposure to an electric arc flash." https://964176.app.netsuite.com/core/media/media.nl?id=20712500&c=964176&h=vLzN7a2AWW4fFIIPHGXKmUOZT3AaOzzGd-VIZQZrJW3kQLa6N&_xt=.pdf; NFPA 855, Standard for the Installation of Stationary Energy Storage Systems (2020), 855-34, "Electrical shock: ESS with voltages above 50 V (per NFPA 70E limits for electrical shock." https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=855.

78 *Ibid.*

79 https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=855.

80 *Ibid.*

d) Deep-Seated Fire

BESS are typically contained in a metal or plastic case, which, depending on the LIB form factor, can have many cells capable of holding a deep-seated fire. The physical structure of the case and internals designed to protect the battery from mechanical abuse can also obstruct fire water from reaching the burning battery material deep inside the LIB. It can take significant volumes of fire water and many hours to cool and extinguish a deep-seated ire. BESS fires can be a serious challenge for emergency responders due to the possibility of reignition from stranded energy and the difficulty of quenching a fire that is burning deep within the internals of a BESS.

3. BESS Incidents and Data Review

In this section we review the major incidents that have occurred in the recent past as well as other lesser incidents, and survey the major data sources on incidents, including their inadequacies.

a) BESS Major Incident History

Serious BESS incidents have occurred recently both in the U.S. and internationally. These incidents resulted in fires, explosions, and injuries to emergency responders. As major incidents, these serious events are generally well known because they have received media coverage and have been referenced in BESS safety reports.

The most significant incident in the U.S. occurred in 2019 at the Arizona Public Service (APS) grid-utility BESS facility in Surprise, Arizona. The 2019 APS event was a LIB thermal runaway that led to an explosion. Four firefighters were hospitalized with serious injuries. Other recent lithium-ion BESS incidents[81] include another BESS fire at APS in 2012; a 2013 Port Angeles, Washington, BESS fire connected to a mall; a 2016 fire at a Franklin, Wisconsin, manufacturing plant where BESS were being assembled; a 2017 fire at an Engie Ineo BESS grid-utility facility in Belgium; 29 BESS-related fires in South Korea from 2017 to 2019; and a 2020 BESS fire at an Ørsted grid-utility facility in Liverpool, UK.

In late 2020, the Consumer Products Safety Administration (CPSA) announced a recall of over 1,800 LG RESU 10H LIB due to a fire hazard.[82] The CPSA said five fires had been reported with minor property damage. LG followed up with an additional recall of residential LG RESU units in May 2021.[83] A similar recall was initiated in Australia for LG RESU LIB due to reports of overheating incidents.[84]

Concerns about LIB safety first arose from their use in the transportation and consumer electronics sectors. In late 2020 the National Transportation Safety Board (NTSB) published “Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles.”[85] This study examined LIB EV fires they had investigated, and determined emergency responders were exposed to “safety risks related to electric shock, thermal runaway, battery ignition and reignition, and stranded energy.” The NTSB found inadequacies in manufacturers’ emergency response guidance and gaps in standards and research addressing transportation-related LIB.[86]

81 The NFPA provided the team with a list of 38 BESS incidents, 37 were LIB-related and 36 were stationary BESS incidents from the U.S. and internationally. The incidents described in more detail are a subset of that NFPA list.

82 https://www.cpsc.gov/Recalls/2020/lg-energy-solution-michigan-recalls-home-energy-storage-batteries-due-to-fire-hazard.

83 https://www.energy-storage.news/news/overheating-reports-prompt-lg-energy-solution-battery-recall.

84 https://www.energy-storage.news/news/overheating-issues-prompt-recall-and-replacement-for-lg-chem-australia-batt.

85 https://www.ntsb.gov/safety/safety-studies/Documents/SR2001.pdf.

86 *Ibid.*

Figure 18. Photo (left) of the APS BESS and low-lying vapor cloud upon the arrival of the Emergency Responders; photo (right) damage to modules and racks inside the BESS container (UL Report Photos)

The 2019 APS incident led to three major reports addressing causes and recommendations. The incident also bolstered the ongoing reforms and standard revisions related to BESS safety. The battery determined to have initiated the thermal runaway was an LG Chem LIB. The battery chemistry was NMC with 28 pouch cells in a module. The BESS included a battery management system (BMS).[87] A smoke alarm led to the arrival of HAZMAT emergency responders who observed low-lying vapor (see Figure 18) near the large shipping-style containers that housed multiple modules and racks of LIB. The source of the observed toxic and flammable vapor was pressure released from the overheated LIB due to a cascading thermal runaway inside the container. Upon opening the doors of the container, the flammable gas found a source of ignition and resulted in a large explosion.

A report from DNV-GL for APS concluded that the thermal runaway initiated from an internal defect in a lithium-ion battery NMC cell.[88] The manufacturer of the battery, LG, determined that an external heat source such as an arc flash initiated the overheating of a LIB cell.[89] Identifying a complete picture of the initiating event from the suspect cell was difficult due to the damage from the thermal runaway. UL reported on lessons relating to emergency response and the serious injuries to four emergency responders.[90] One firefighter was thrown 70 feet through a fence by the force of the explosion.[91] The four firefighters were hospitalized from the BESS explosion with injuries that included broken bones, traumatic brain injury, thermal and chemical burns, spinal damage, and internal bleeding.

Lessons and conclusions from the DNV-GL APS incident report include the need for thermal protection between LIB cells to prevent a cascading failure event, the lack of guidance from manufacturers that the formation of a large flammable cloud was possible, the inadequacy of the fire suppression system to stop a thermal runaway,

87 A battery management system (BMS) “monitors, controls, and optimizes performance of an individual or multiple battery modules in an energy storage system and has the ability to control the disconnection of the module(s) from the system in the event of abnormal conditions.” https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=855.

88 https://liiontamer.com/wp-content/uploads/APS-DNV-GL-Report.pdf.

89 https://docket.images.azcc.gov/E000007939.pdf?i=1619799672409.

90 https://ulfirefightersafety.org/docs/Four_Firefighters_Injured_In_Lithium_Ion_Battery_ESS_Explosion_Arizona.pdf.

91 https://www.greentechmedia.com/articles/read/arizona-battery-fire-already-prompted-safety-improvements-in-grid-storage.

the lack of deflagration venting in the container (which was required by NFPA 69), and the lack of an effective responder plan with procedures for extinguishing, ventilation, and entry.[92] In addition, the BMS did not effectively prevent the thermal runaway event.

The DNV-GL report recommended that codes and standards should more effectively address a cascading thermal runaway. The report noted that at the time of commissioning of the APS BESS in 2017, codes and standards were still developing and lacked a thorough understanding of thermal runaway and needed mitigations. The report also identified the need for thermal barriers to inhibit thermal cascade.

The report by the battery manufacturer LG Chem[93] identified this as an external "incident initiating event" rather than a manufacturing defect, but lacked explicit preventative recommendations. UL stated that installers should assume that a BESS incident vapor cloud may be capable of an explosion and highlighted the need to define a conservative zone for potential blast radius. UL proposed developing the capacity for remote monitoring of a BESS enclosure of a flammable atmosphere, a more robust communication system for remote access to data, including the status of the BMS that may be compromised, and testing to determine the most effective fire suppression and explosion prevention systems for potential thermal runaway events.

Figure 19 The 2012 BESS electrical fire at the Arizona Public Service facility near McMillan Mesa (Josh Biggs/ Arizona Daily Sun)

A November 2012 fire occurred at an Arizona Public Service (APS) lithium-ion BESS facility near the McMicken substation, as shown in Figure 19. The fire broke out at the 4 MW facility, which had recently been commissioned in February and was undergoing testing.[94] The BESS reportedly suffered serious damage to the $3 million installation.[95]

92 https://liiontamer.com/wp-content/uploads/APS-DNV-GL-Report.pdf.

93 https://docket.images.azcc.gov/E000007939.pdf.

94 https://azdailysun.com/news/local/aps-fire-probed/article_1de2e924-ab0a-5e71-9a3a-6942c2d1c9bb.html.

95 https://www.imia.com/wp-content/uploads/2020/01/IMIA-WGP-112-19-Battery-Storage.pdf.

Figure 20. 2013 BESS Fire at the Landing Mall in Port Angeles, WA

A 2013 lithium-ion BESS fire in a 50-kWh battery room connected to the Landing Mall in Port Angeles, Washington, is shown in Figure 20.[96] The fire triggered an evacuation and closure of streets. The BESS was connected to a wind and solar array. A BESS electric fault was believed to have initiated a thermal runaway. The batteries reignited and led to another fire a few days later.

Figure 21. BESS Fire at S&C Electric Manufacturing Facility in Franklin, Wisconsin (WPI report photo)

A 2016 BESS fire started at the S&C Electric Manufacturing plant in Franklin, Wisconsin. The facility designed, assembled, and constructed BESS to be deployed in customers' facilities. The fire started within the battery manufacturer's BESS DC power and control devices and spread to the LIB. The fire was initiated when a technician was constructing the system. The LIB and related equipment burned as seen in Figure 21. The BESS was in a partially assembled state but was not operational at the time.[97] The damage was stated to exceed $3 million.

96 https://www1.nyc.gov/assets/fdny/downloads/pdf/business/cof-b28-w28-study-material.pdf.

97 https://www.sandc.com/globalassets/sac-electric/documents/sharepoint/documents---all-documents/edoc_083520.pdf?dt=637554100599978924.

Figure 22. 2017 fire at an Engie Ineo BESS facility in Belgium (IMIA Report Photo)

An Engie Ineo lithium-ion utility-grid BESS experienced a large fire in 2017 as seen in Figure 22. The incident occurred at the test facility during commissioning. The 6 MW facility was to be used for grid balancing, and was the first time such a facility was to be used for that purpose in Belgium. The damage to the BESS was considered a total loss.[98]

Figure 23. A series of 29 Lithium-ion BESS fires occurred in South Korea from 2017–2019. (IMIA Report and E2 News Photo)

In South Korea, 29 fires initiated at lithium-ion BESS facilities from 2017 to 2019 were investigated by the government (see Figure 23).[99] An expert panel determined that the incidents were caused by a variety of factors including faulty installation, inadequate procedures, insufficient protections against electrical malfunctions, overcharge, manufacturing defects, and lack of effective control systems.[100] The government report revealed that the fires were with both LIB NMC batteries and some LFP batteries. A variety of BESS form factors and system applications experienced fires.[101] As a result of the investigation, South Korea suspended over one-third of the 1,490 BESS facilities in the country. A 47 MWh facility, Daesung Industrial Gas Plant, suffered the biggest loss of $18 million. These fires are significant as South Korea is one of the largest global suppliers of lithium-ion BESS; major manufacturers include LG Chem and Samsung. After the series of fire incidents, LG Chem lost approximately $124 million in BESS business in the first quarter of 2019.

98 https://www.greentechmedia.com/articles/read/engie-investigates-source-of-belgian-battery-blaze.

99 http://www.e2news.com/news/articleView.html?idxno=222794.

100 https://www.spglobal.com/marketintelligence/en/news-insights/trending/bVy2KGU3Opsle5Vv8QG0-Q2.

101 https://liiontamer.com/wp-content/uploads/APS-DNV-GL-Report.pdf.

Figure 24. 2020 Lithium-ion BESS fire at an Ørstead grid-utility facility in Liverpool, UK (Liverpool Echo Photo)

A 2020 LIB fire broke out at a Liverpool, UK, Ørstead 20 MW grid-utility project shown in Figure 24. Residents reportedly heard an explosion[102] and the event was described as a thermal runaway.[103] It took emergency responders several hours to extinguish the blaze.

Figure 25. A BESS container lithium-ion fire at an electric substation in Ariége, France

In December 2020, a lithium-ion BESS fire erupted at the Ariége, France, 0.5 MWh electric substation seen in Figure 25. Approximately 30 firefighters were required to bring the container blaze under control. There were no injuries or fatalities.

102 https://www.liverpoolecho.co.uk/news/liverpool-news/live-updates-fire-rips-through-18934842.

103 https://issuu.com/rizzo48/docs/bat117issuu3/63.

In conclusion, BESS incidents can result in major hazardous events, including thermal runaway fire and explosions. These events have the potential for serious injuries, fatalities, and off-site consequences. BESS incidents can occur at different stages in the BESS lifecycle. Serious BESS fires and explosions can occur during construction, installation, commissioning, or operation. Larger incidents, often in grid-utility settings, are captured in media reports and technical reviews. These incidents are more likely to be identified with greater factual detail. Most BESS incidents lack publicly available investigation reports—the 2019 Arizona Public Service incident being an exception. These gaps impede identifying BESS incident details and causal factors for prevention.

b) Other BESS Incidents and Data Review

As part of the research for this report, several incident databases were reviewed, and inquiries were made to organizations concerning repositories of BESS incident data. While major BESS incidents have typically received coverage in the media and BESS technical reports, other incidents are difficult to track. This is especially true of lesser impact incidents and near misses. There is no single repository of U.S. battery energy storage system incidents or data. BESS incidents, depending on the circumstances, may or may not be tracked by any specific database. BESS incident public impacts may involve workers, emergency responders, building occupants, or the public. The data sources may lack sufficient detail to confirm a BESS event was involved.[104] The 2020 CPSA LG RESU recall reveals that BESS fire events can otherwise go unreported or lack details. The home fires referred to on the CPSA recall did not appear in any other database examined in this report.

BESS incidents may not trigger OSHA's jurisdiction. Small businesses with fewer than 10 employees may be exempt from some requirements for Cal OSHA's Injury and Illness Prevention Program.[105] Self-employed C-10 and C-46 contractors with no employees are not covered by Cal OSHA.[106] As of March 1, 2021, CSLB data shows 54% (11,328) of C-10 contractors declare they have no employees and 39% (758) of active C-46 contractors state they have no employees.

To point out some of the difficulties in BESS incident identification, we review OSHA databases as an example. OSHA has several portals to search for inspection and incident data including Fatality and Catastrophe Investigation Summaries, Severe Injury Reports, a NAICS code search, and Establishment Search. There is no specific NAICS code for battery energy storage. A review of OSHA's Severe Injury Reports from 2015–2020[107] found injuries related to battery incidents such as crushed limbs or burns where the battery served as a source of ignition. Other incident descriptions lacked sufficient detail to identify it as a BESS incident. For example, in 2018 a Tesla solar worker was testing electrical equipment and suffered electrical shock and burns from an arc flash.[108] For a 2018 electrical incident the OSHA database stated an employee was "rewiring replacement batteries in an existing battery string and created a short circuit that resulted in an arc flash."[109] In another, a worker was "taking measurements from a battery interface board" when an arc flash occurred.[110] These descriptions lack

104 Federal agencies studies have found that tracking the occurrence of specific types of incidents can be difficult. The U.S. Chemical Safety and Hazard Investigation Board in its 2002 Improving Reactive Hazard management report found it similarly difficult to track reactive incidents from existing sources. The CSB needed to examine over 40 databases to identify incidents that met the report's definition of a reactive chemical incident. Examining a wide range of databases is beyond the scope of this report. https://www.csb.gov/improving-reactive-hazard-management/.

105 https://www.dir.ca.gov/dosh/dosh_publications/iipp.html; https://www.dir.ca.gov/title8/3203.html.

106 https://www.dir.ca.gov/t8/14300_31.html.

107 https://www.osha.gov/severeinjury/. The severe incidents under the jurisdiction of states that have their own OSHA program such as California (OSHA State Plan States) are not included in the Federal OSHA's Severe Injury Report data on their website.

108 https://www.osha.gov/pls/imis/establishment.inspection_detail?id=1285745.015.

109 https://www.osha.gov/pls/imis/accidentsearch.html.

110 *Ibid.*

sufficient detail to confirm this as a BESS incident. The April 19, 2019, BESS explosion was discovered in the OSHA Establishment Search database with no mention of BESS, an explosion, or the serious injuries to the four firefighters.[111] From the details provided, no incidents could be confirmed as involving a BESS event in the OSHA databases, even though we know from other sources that some of these incidents were BESS events.

One example of fires in the residential sector illustrates both the hazards and risks associated with BESS and the difficulty of ascertaining the cause and preventative measures. In December 2020, CPSA announced the recall of over 1,800 LG Energy Solutions RESU lithium-ion batteries. The recall hazard was identified as "home batteries overheat, posing a risk of fire and emission of harmful smoke."[112] The notice identified five reports of fire associated with the recalled batteries. While it could be assumed the battery recall was related to a manufacturing or software issues, LG has not issued an incident report detailing the causal factors related to the overheating or residential fires.

E. BESS Safety Standards and Guidance

The impacts of major LIB incidents have led to significant activity by safety-related organizations to develop BESS incident mitigation strategies and new, safer technologies. Organizations such as NFPA and FM Global have conducted studies, research, and testing addressing BESS hazards and fire service mitigation approaches.[113] DNV and UL have developed BESS testing regimes. DNV has developed an annual Battery Performance Scorecard,[114] and UL publishes select BESS certification and testing results.[115] In response to all these advances of knowledge and technology, safety codes and standards addressing BESS have undergone ongoing significant revisions over the last five years. Reflecting these developments, DOE publishes a quarterly bulletin updating new developments in ESS codes and standards.[116]

Over 30 codes now address BESS issues, from the built environment in building codes, installation, and application to the BESS and its system components (Figure 26). For purposes of examining safety provisions in the standards related to the activities of solar and electrical specialty contractors, this review focuses on select BESS building and installation related standards. The standards we reviewed include the 2020 NFPA 70 the National Electric Code (NEC); the 2019 California Electric Code (CEC) and the 2021 supplement; the 2021 NFPA 70E Electrical Safety in the Workplace; the 2021 International Fire Code (IFC), the 2019 California Fire Code, and the 2021 supplement; the 2020 NFPA 855 Installation of Stationary Energy Storage Systems; and UL 9540:2020 Standard for Safety, Safety Energy Storage Systems and Equipment, and UL 9540A:2019 Standard for Safety, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems.

This review assesses both the enforceable California codes that have already been adopted in state regulation as well as more recent versions of the cited codes not yet adopted by California and voluntary consensus safety standards. California is proactive in adopting enforceable building codes into the California Code of Regulations,[117]

111 The incident was described as a "unprogram related" inspection with few details both under APS and the City of Surprise, Arizona, Fire Department Establishment Search database listings. Note that the Severe Injury Records do not include reports from states with their own state OSHA plan such as California and Arizona other than federal related facilities.

112 https://www.cpsc.gov/Recalls/2020/lg-energy-solution-michigan-recalls-home-energy-storage-batteries-due-to-fire-hazard.

113 https://www.nfpa.org/News-and-Research/Resources/Emergency-Responders/High-risk-hazards/Energy-Storage-Systems.

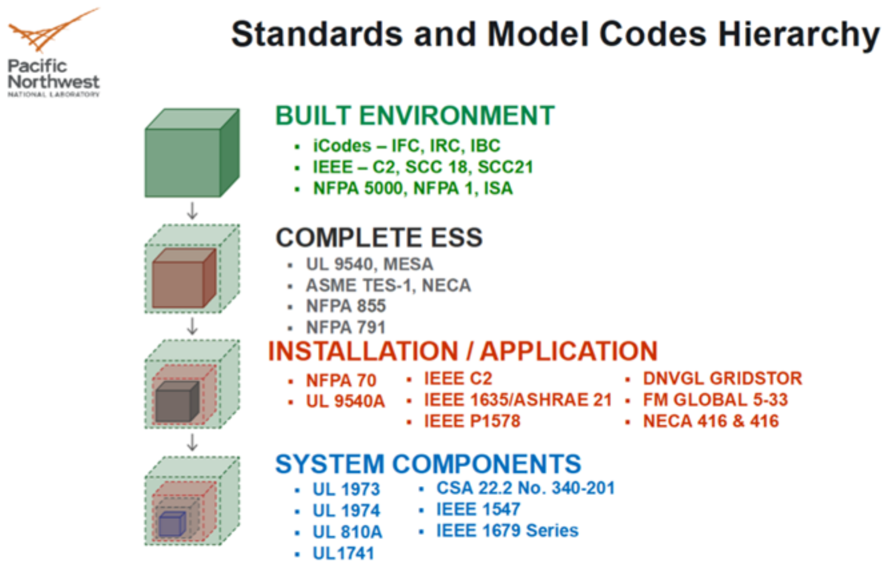
114 https://www.dnv.com/Publications/2020-battery-performance-scorecard-192180.

115 https://iq.ulprospector.com/en/_?p=10005,10048,10006,10047&qm=q:aacd.

116 https://energy.sandia.gov/wp-content/uploads/2021/02/SC-Report-by-SDO-WINTER-2021_Final.pdf.

117 California Code of Regulations, Title 24, the California Building Standards Code.

Figure 26. Hierarchy of Energy Storage System Codes & Standards (DOE Pacific Northwest National Labs, 2021)[118]



with triannual adoption and supplemental updates, but the relevant BESS codes are continually evolving. New knowledge about LIB hazards and the dynamic nature of BESS code updates makes it essential to review the latest requirements.[119] Moreover, the importance of the application of up-to-date consensus standards is well recognized for effective safety protocols, hazard prevention, and risk management.[120] The 2019 Surprise, Arizona, explosion highlights how recent serious incidents reveal new lithium-ion BESS hazards, leading to important revisions in multiple codes. The following illustrates how various codes and standards currently address BESS safety issues.

1. NFPA 70 (2020) National Electric Code and California Electric Code (2017)

The primary safety code for the electrical industry is the National Electric Code (NEC). ESS have been part of the NEC since the first edition of the code, with applications ranging from lead acid batteries, ESS connected to windmills, generators, etc., and Delco systems for low voltage appliances.[121] Due to new hazards related to evolving technologies and battery chemistries, the NEC developed Article 706 Energy Storage Systems in 2017;[122] it was significantly updated in the 2020 edition. California has not yet adopted the 2020 NEC ESS revisions into its Title 24 Building Standards Code, but likely will in the future subject to amendments as they have done in the past.

118 https://energystorage.org/wp/wp-content/uploads/2019/09/Operational-Risk-Assessment-white-paper-final.pdf.

119 Safety programs are typically evaluated by adherence to recognized and accepted industry good safety practices—consensus standards, government research and recommendations and new lessons learned from recent incidents. Regulatory minimal compliance is necessary but insufficient for effective safety prevention and mitigation.

120 For example, the National Technology Transfer and Advancement Act of 1995 requires the use of technical standards developed by consensus standard setting bodies to carry out policy objectives or activities by federal agencies. The National Technology Transfer and Advancement Act of 1995, Pub. L. No. 104-113, 110 Stat. 775 (Mar. 7, 1996.)

121 Interview with code officials.

122 *Ibid.*

In both the 2017 and 2020 editions, the purpose of the NEC is explained as "the practical safeguarding of persons and property from hazards arising from the use of electricity."[123] The inclusion of the provisions of the code is based on what is "considered necessary for safety."[124] The scope of the NEC covers the installation and removal of electrical conductors, equipment, etc., for listed applications.[125] The NEC does not cover installations under the exclusive control of the electrical utility under certain listed conditions.[126] Chapters 1-4 of the standard apply generally to all electrical installations, while Chapter 6 addresses Special Equipment including Solar Photovoltaic (PV) Systems (Article 690) and Chapter 7 covers Special Conditions with an article addressing ESS (706).

The 2020 version of the NEC made significant revisions to the 2017 edition, showing the rapid evolution of standards related to BESS. The 2020 NEC broadened the Article 706 scope to include ESS that have a capacity greater than 1 kWh, replacing the 2017 coverage of systems operating over 50 volts AC and 60 volts DC.[127] The 2020 NEC has also eliminated the 2017 system classification distinctions that called out self-contained and pre-engineered ESS. The 2020 NEC Article 706 has more detailed emergency disconnect provisions and requires a readily accessible means of disconnecting ESS outside the building for one- and two-family dwellings.

Article 706 has had mandatory listing[128] provisions that include specific safety requirements since 2017, but now has ESS system-based requirements. BESS can be listed and labeled by organizations such as UL indicating "the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose."[129] The ESS in the 2020 version of Article 706 now needs to be listed as a complete system, not just a list of separate components such as the lithium-ion cells or battery.[130] Examples of BESS UL listing safety standards are UL 9540 and 9540A, both of which have been recently updated. Other 2020 Article 706 revisions include additional listed nameplate requirements, a new section requiring ESS be maintained in safe operating condition and requirements for working spaces.

A new requirement was added in 2020 that "the installation and maintenance of ESS equipment and all associated wiring and interconnections shall be performed only by qualified persons."[131] The NEC defines a "Qualified Person" as "one who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved."[132] The definition includes an informational note referring the reader to NFPA 70E for electrical safety training requirements.

The NEC Article 706 sections are not stand-alone requirements, meaning that it is essential to address safety issues in the whole electrical system that the BESS connects to. The NEC Chapters 1-4 as well as references in 706 to other articles and chapters are important for the safe installation of BESS, which requires broad knowledge of the NEC. A review of BESS electrical checklists demonstrates the need to understand and apply a significant

123 NEC 90.1 Purpose, (A) Practical Safeguarding. The NEC is not intended as a design code or instruction manual.

124 NEC 90.1 Purpose, (B) Adequacy.

125 NEC 90.2 Scope (A) Covered.

126 NEC 90.2 Scope (B) Not Covered.

127 For example, BESS operating at less than 50 volts AC and 60 volts DC such as 48 volts would be covered by NEC (2020) Article 706.

128 For example, for UL "Listing means that UL has tested representative samples of a product and determined that the product meets specific, defined requirements. These requirements are often based on UL's published and nationally recognized Standards for Safety." https://marks.ul.com/about/ul-listing-and-classification-marks/promotion-and-advertising-guidelines/specific-guidelines-and-rules/.

129 NEC (2020) Article 100 Definitions.

130 https://www.ul.com/news/2020-nec-addresses-electrical-safety-what-code-officials-need-know. The UL standard for listing batteries used in stationary applications is UL 1173 (2018) and for lithium battery cells is UL 1642 (2020).

131 NEC (2020) 706.3 Qualified Personnel.

132 NEC (2020 and 2017) Article 100 Definitions.

number of chapters and articles that are required for BESS installation far beyond Article 706 on Energy Storage Systems. For example, the NYSERDA[133] Battery Energy Storage System Electrical Checklist[134] that is referenced by the NFPA[135] requires compliance with over 30 code provisions in addition to those in Article 706 addressing ESS. This has important implications for the technical capacity that contractors need for safe BESS installation, because it requires broader electrical knowledge than just knowledge about the specific BESS codes and technology. The broad scope and detailed requirements provided in NFPA 70 that are needed for BESS installation underscore the importance of the code-related knowledge, skills, and training of the workforce.

Requirements listed in NFPA 70 (2020) Chapters 1-4 are necessary for the safe installation of BESS and for the critical assessment of existing electrical systems. These include Article 240 overcurrent protection, Article 220 load calculations, Article 250 grounding and bonding, Article 310 wiring methods and sizes, Section 230.85. and emergency disconnect requirements for one- and two-family dwellings. Article 705 interconnected electric power production sources requirements are applicable where the ESS is interconnected to a primary power source such as the utility grid.

2. NFPA 70E (2021) Electrical Safety in the Workplace

NFPA 70E (2021) is an ANSI[136] approved standard that outlines electrical safety related practices in the workplace. 70E establishes electrical safety "policies, procedures, and program controls to reduce risk to an acceptable level."[137] It requires employers to develop an electrical safety program for employees to follow, mandating such elements as inspection, condition of maintenance, risk assessment, program procedures and controls, job safety planning, and hierarchy of risk control methods.[138]

The NFPA states that 70E provides prescriptive requirements to meet OSHA's performance-based electrical safety regulations.[139] It requires that electrical conductors and circuit parts operating over 50 volts be placed in an "electrically safe work condition" before an employee can commence work under certain defined conditions.[140] The planning includes identification of electrical hazards, an electrical shock risk assessment, and an arc flash risk assessment. NFPA 70E prescribes a defined risk assessment procedure that examines an employee's exposure to electrical hazards and implements protective risk control methods using the hierarchy of controls.[141] This method prioritizes the most effective safeguards and places an emphasis on eliminating hazards as the top priority.[142] Programs for incident investigation, lockout/tagout, and auditing of the electrical safety program are requirements under 70E.

133 New York State Energy Research and Development.

134 https://www.nyserda.ny.gov/all-programs/programs/clean-energy-siting/battery-energy-storage-guidebook. Similar to 2019 California Electrical Code, the checklist was based upon the 2017 NEC. NYSERDA states "the Electrical Checklist is intended to be utilized as a guideline for field inspections of residential and small commercial battery energy storage systems. It can be used directly by local code enforcement officers or provided to a third-party inspection agency, where applicable.

135 https://go.nfpa.org/l/14662/2021-01-11/8h6lwf.

136 American National Standards Institute.

137 https://www.nfpa.org/-/media/Files/Code-or-topic-fact-sheets/70E2021FactSheet.ashx.

138 NFPA 70E (2021) 110.5

139 *Ibid.*

140 NFPA 70E (2020) 110.3 Electrically Safe Work Condition. The defined conditions are "(1) The employee is within the limited approach boundary. (2) The employee interacts with equipment where conductors or circuit parts are not exposed but an increased likelihood of injury from an exposure to an arc flash hazard exists.

141 NFPA 70E (2020) 110.5 Electrical Safety Program, (H) Risk Assessment Procedure, risk control must implement the hierarchy of controls where elimination of hazards is prioritized over administrative controls such as training and procedures.

142 NFPA 70E (2020) 110.1 Priority; 110.5.

70E establishes training requirements where risks have not been reduced to a safe level. A qualified person is defined by training requirements to avoid hazards specific to a task such as electrical shock or arc flash. The training requires documentation including employee demonstrated proficiency in the specific work task. NFPA 70E provides for training on the safe isolation for work on electrical equipment or lockout/tagout that also requires demonstrated proficiency.

The elements of NFPA 70E require qualified workers installing BESS to perform a hazard assessment of the existing electrical system and the planned installation to identify exposure to electrical hazards and implement effective safeguards using the hierarchy of risk controls. Such an assessment involves an inspection of systems such as grounding and bonding, overcurrent protection, method and sizing of wiring, and arc flash and electric shock hazards.

3. NFPA 855 (2020) Installation of Stationary Energy Storage Systems

NFPA 855 (2020) is a recently developed standard focused on the safe installation of ESS. NFPA 855 was initiated after engagement by NFPA with the California Energy Storage Association (ESA), the state branch of a leading battery installer and manufacturer trade association.[143] One goal of 855 is to provide a consistent framework for safe ESS installation across multiple standards and building codes.[144] NFPA 855 has the stated purpose of providing "minimum requirements for mitigating the hazards associated with ESS."[145] The standard generally applies to lithium-ion BESS with an aggregate capacity of 20 kWh and over. For one- and two-family dwellings and townhouses there is a 1 kWh threshold.[146] The 2021 Supplement to the California Fire Code (CFC) allows ESS in residential R3 and R4 occupancies[147] to have an aggregate capacity of up to 80 kWh depending on the ESS location. NFPA 855 has separate safety requirements for one- and two-family dwellings and townhouse units.

NFPA 855 (2020) is a voluntary consensus safety standard and is not adopted or incorporated by reference into the California Building Standards code. However, the 2021 International Fire Code ESS provisions were revised to be consistent with NFPA 855.[148]

ESS installations over the listed threshold quantities have more stringent requirements that include approved construction plans, spacing between battery packs, a hazard mitigation analysis under certain defined conditions, approved signage, means of egress, and fire mitigation. NFPA 855 states ESS must be listed to UL 9540 to address a thermal runaway. In addition to thermal runaway, LIB need explosion control and have size and separation requirements.[149] For one- and two-family dwellings and townhouses, the NFPA 855 states that ESS installations

143 NFPA 855 (2020) Origin and Development of NFPA 855, 855-1.

144 https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=855.

145 NFPA 855 (2020) Table 1.3 Threshold Quantities

146 NFPA 855 (2020) 1.3.2. See Chapter 15 for the one- and two-family dwellings and townhouses requirements.

147 California Fire Code (2021 Supplement effective July 1, 2021 to the 2019 Edition) 1206.11.4 Energy Ratings. R3 Residential Group is defined as a residence where occupants are primarily permanent, and buildings do not contain more than two dwelling units. Occupant numbers are limited depending on the type of facility e.g., care facilities must have five occupants or fewer. R4 Residential Group are described as custodial care facilities for more than five but not greater than 16 persons. International Building Code (2018) Section 310 Residential Group R.

148 https://energy.sandia.gov/wp-content/uploads/2021/02/SC-Report-by-SDO-WINTER-2021_Final.pdf, note that the 2021 CFC supplement has incorporated the ESS provisions of the IFC (2021).

149 NFPA 855 (2020) Table 9.2 Electrochemical ESS Technology-Specific Requirements.

shall also be listed and labeled to the requirements of UL 9450.[150] Installation location is restricted to attached garages with appropriate separations from living areas, detached garages, and utility closets. Other installation provisions include fire detection, ESS protection from impact, and energy capacity limitations.

4. 2019 California Fire Code and 2021 Supplement

As noted, the Article 1206 ESS provisions of the 2021 California Fire Code Supplement (CFC) are largely aligned with NFPA 855. The requirements of the CFC apply to LIB at thresholds 20 kWh and over, with separate provisions for R3 and R4 occupancies. The CFC requires construction permits, a hazard mitigation analysis under certain conditions, an energy storage management system,[151] ESS spacing, electrical disconnects, signage, fire-resistant rated separations, and ESS listing to UL 9540. The CFC Article 1206 contains similar provisions to 855 for LIB (explosion and thermal runaway control). Explosion control can be waived based on large-scale fire testing in accordance with UL 9540A.

5. 2020 UL 9540 Energy Storage Systems and Equipment

UL 9540 (2020) 2nd Ed. was a standard developed to evaluate the safety of ESS. UL has addressed the importance of 9540 to ESS safety:

> Over the past several years, a significant effort has been made to address energy storage system (ESS) safety, especially those systems that use batteries as their source of energy. New technologies are now widely deployed in an already established infrastructure. While innovative, these technologies do not come with a long-standing history of use in our current infrastructure. This can cause concern from regulators, fire marshals, electrical inspectors, building owners and other industry stakeholders about the safety of these systems and how to best integrate them into facilities.[152]

Both NFPA 855 and the California Fire Code (2021 Supplement) as described above require a UL 9540 listing under the conditions of the standard. UL 9540 is a “system standard” that assesses the “compatibility and safety of the various components integrated into a system.”[153] The standard restricts the maximum allowable energy capacity for certain applications. For example, the standard restricts residential use ESS to a maximum of 20 kWh per individual unit.[154] UL 9540 establishes safety performance standards for electronics and safety control system software such as battery management systems that have failed to effectively prevent some previous thermal runaway incidents. The 9540 listings and approvals address ESS fire, shock, arc flash, and mechanical hazards. The standard identifies the need for an arc flash risk assessment.[155] The standard also addresses installation issues such as energy limitations, work access and egress, spacing, and fire suppression. An ESS safety and risk analysis

150 NFPA 855 (2020) 15.2 Equipment Listings.

151 The energy storage management system as required by listing “monitors and balances cell voltages, currents and temperatures within the manufacturer’s specifications. The system shall disconnect electrical connections to the ESS or otherwise place it in a safe condition if potentially hazardous temperatures or other conditions such as short circuits, over voltage or under voltage are detected.”

152 https://www.ul.com/insights/ul-9540-second-edition-understanding-impacts-required-changes.

153 UL 9540 (2020) 1.1 Scope, “NOTE Energy storage systems may include equipment for charging. discharging. control. protection. power conversion, communication controlling the system environment. air, fire detection and suppression system fuel or other fluid movement and containment, etc.”

154 UL 9540 (2020) 1.6 (b).

155 UL 9540 (2020) 10.11.

is required for analyzing failure modes and critical safety components.[156] The standard requires large-scale fire testing under UL 9540A under certain listed conditions; for example, for indoor systems with decreased separation distances and with non-residential use, the standard restricts individual ESS to 50 kWh unless the ESS has been tested under UL 9540A.[157]

6. 2019 UL 9540A Standard for Test Method for Evaluating Thermal Runaway Fire Propagation

UL 9540A was developed to respond to safety issues raised by building and fire code officials.[158] The standard establishes a test methodology for evaluating the susceptibility of a battery to undergo a thermal runaway. UL 9540A establishes testing arrangements and report requirements for thermal runaway large-scale fire testing. The testing does not yield a pass/fail result. The standard's scope states that the "data generated will be used to determine the fire and explosion protection required for an installation of a battery energy storage system" under relevant ESS codes including the International Fire Code (IFC) and NFPA 70.[159] As noted above, NFPA 9540A is used under BESS safety standards to allow for greater individual battery capacity or lesser separation requirements than would otherwise be required. The NFPA 855 and IFC allow the authority having jurisdiction (AHJ)[160] to approve departing from the standards requirements based upon a large-scale fire test conducted under UL9540A.

7. Industry Guidance and Product Safety Data Sheets

In addition to codes and standards, manufacturers' safety guidance also is an important source of information to assess hazards and mitigation controls. BESS manufacturers publish safety data sheets (SDS), installation guides, and emergency response procedures that address safety issues related to BESS installation. These documents identify specific hazards related to BESS installation and needed safety precautions and controls, including requirements for installation by a qualified person. The safety guidance documentation from LG and Tesla recognizes that their lithium-ion batteries have serious hazards including thermal runaway, arc flash, and electrical shock hazards. This report examined documentation for the Tesla Powerwall and LG RESU BESS. Those two brands account for approximately 97% of the residential BESS installed from 2015 to present. Both the Tesla Powerwall and the LG RESU utilize the NMC lithium-ion battery chemistry.

The Tesla installation manual states that "Powerwall installation must be carried out only by a competent electrician who is certified by Tesla and who has been trained in dealing with low voltage electricity."[161] It is important to note that the manual states only a **competent electrician** has the necessary skills, knowledge, and training for Tesla installation. This requirement is flagged by the warning symbol indicating failure to avoid the hazard could result in injury or death.

The Tesla emergency response guide for the Powerwall explicitly warns of a thermal runaway danger.[162] The guide warns against thermal, mechanical, and electrical abuse, the LIB events that can trigger a thermal runaway. The

156 UL 9540 (2020) 15 Safety Analysis and Control Systems.

157 UL 9540 (2020) 1.7.

158 https://www.ul.com/services/ul-9540a-test-method.

159 UL 9540A (2018) Scope 1.2.

160 NFPA 70 (2020) Article 100 Definitions – such as a governmental building code official.

161 https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall_2_AC_GW2_NA_EN_Installation_Manual.pdf.

162 https://www.tesla.com/sites/default/files/downloads/2020_Lithium-Ion_Battery_Emergency_Response_Guide_en.pdf.

guide identifies that vented gases are an indication of thermal runaway and can be flammable and toxic. The Tesla guide states that the vented gas can be hazardous and may contain the highly toxic hydrofluoric acid (HF):

> Hazards Associated with Vented Electrolyte. Lithium-ion cells are sealed units, and thus under normal usage conditions, venting of electrolyte should not occur. If subjected to abnormal heating or other abuse conditions, electrolyte and electrolyte decomposition products can vaporize and be vented from cells. Accumulation of liquid electrolyte is unlikely in the case of abnormal heating. Vented gases are a common early indicator of a thermal runaway reaction – an abnormal and hazardous condition. If gases or smoke are observed escaping from a Tesla Energy Product, evacuate the area and notify a first responder team and/or the local fire department. Gases or smoke exiting a lithium-ion battery pack are likely flammable and could ignite unexpectedly as the condition that led to cell venting may also cause ignition of the vent gases. A venting Tesla Energy Product should only be approached with extreme caution by trained first responders equipped with appropriate personal protective equipment (PPE)...[163]

The Tesla Powerwall 2 installation manual warns that the battery can "present a risk of electric shock, fire, and explosion from vented gases."[164] The manual flags steps in the procedure like the battery risks with warning symbols that signify hazards that if not avoided may lead to injury or death. In the section addressing Powerwall and Gateway 2 installation interconnection requirements, the manual states:

> AC isolation and interconnection requirements between the Powerwall system and the electrical panel are subject to local codes. Ensure that the installation meets local isolation and interconnection requirements. All U.S. and Canada electrical installations must be done in accordance with local codes and the National Electric Code (NEC) ANSI/NFPA 70 or the Canadian Electrical Code CSA C22.1.[165]

Four warnings are listed in the interconnection section, including requirements and incorrect methods for installing and connecting the Backup Gateway and the need for protection equipment including fire detection. The warnings of requirements or against incorrect actions are listed in several other sections, including appropriate installation PPE, grounding, lockout/tagout, wiring, Power Control System settings, working on current transformers, and software updates. For multi-Powerwall installations, the manual describes a number of assessments, calculations, and warnings. These include needed AC line impedance measurements, wire oversizing, properly sized overcurrent protection, and review of measurements and system designs by Tesla. For line impedance testing the manual warns:

> WARNING: Impedance tests must be performed on an energized electrical system. Impedance tests should be carried out only by trained electricians using appropriate safety equipment and safety practices.[166]

The Tesla Powerwall 2 is listed as meeting the safety requirements of a UL 9540 in the manufacturer's installation manual.[167] The edition of UL 9540 is not provided. Note that the 2020 edition of UL 9540 contains significant safety-related revisions, including requirements incorporated from NFPA 855 and the IFC, that can require thermal

163 *Ibid.*
164 https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall_2_AC_GW2_NA_EN_Installation_Manual.pdf.
165 *Ibid.*
166 *Ibid.*
167 https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall_2_AC_Datasheet_EN_NA.pdf.

runaway testing under UL 9540A under certain conditions.[168] The Powerwall 2 is not stated as listed to UL 9540A in their 2020 manual, but Tesla states their product has been subjected to full-scale fire testing and that a thermal runaway in a single cell will not propagate to neighboring cells or represent an explosion hazard.[169] It is not clear if UL 9540A was used by Tesla as the basis for the thermal runaway large-scale fire testing and if not why not.[170] Note that it is UL 9540A (2019) that develops test methodology requirements for evaluating the susceptibility of a battery to undergo a thermal runaway through large-scale fire testing. This includes test arrangements and the development of a report.

The guide notes that under normal conditions of use the battery product is sealed and does not present an electrical shock risk but under conditions of abuse the guide warns of hazards of "significant high voltage and electrocution risk."[171] Even in a discharged condition, a Tesla battery pack "is likely to contain substantial electrical charge and can cause injury or death if mishandled."[172]

The LG RESU10H Gen 2 400V installation manual requires the BESS installation be conducted by a qualified person with specific skills and experience:

> This guide for the tasks and procedures described herein is intended for usage by skilled workers only. A skilled worker is defined as a trained and qualified electrician or installer who has all of the following skills and experience:
>
> - Knowledge of the functional principles and operation of on-grid and off-grid (backup) systems.
> - Knowledge of the dangers and risks associated with installing and using electrical devices and acceptable mitigation methods.
> - Knowledge of the installation of electrical devices
> - Knowledge of and adherence to this guide and all safety precautions and best practices.

A skilled worker is defined as a qualified electrician or installer with specific defined knowledge, skills, and training. These include topics specifically addressed in NFPA 70 and the safety requirements of 70E.

The LG RESU product safety guidance warns against fire, explosion, arc flash, and shock hazards. The LG RESU10H Gen 2 400V installation manual does not specifically reference the term thermal runaway but appears to refer to this danger, noting if heated over 300°F the hazard of explosion and venting of "poisonous gases."[173] The installation manual warns that "over-voltages or wrong wiring can damage the RESU I OH (hereinafter "battery pack") and cause deflagration, which can be extremely dangerous."[174] The LG RESU is not listed to UL 9540 or 9540A.[175]

168 https://collateral-library-production.s3.amazonaws.com/uploads/asset_file/attachment/25784/CT26157086_UL9540A-whitepaper_vDIGITAL1.pdf.

169 *Ibid.*

170 UL has a publicly available database of UL 9540A thermal runaway evaluation reports. See https://iq.ulprospector.com/en/_?p=10005,10048,10006,10047&qm=q:aacd; Only nine reports are listed. There is no report listed for Tesla. There is a report listed for LG Energy Solutions but it is unclear whether the report is for a RESU battery.

171 *Ibid.*

172 *Ibid.*

173 https://www.lgessbattery.com/us/home-battery/product-info.lg.

174 *Ibid.*

175 The LG RESU Gen2 400V is listed to UL 1973 (2018) Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications. UL 1973 addresses a variety of battery technologies and safety issues including topics such as construction, mechanical, electrical and environmental requirements. UL 1973 includes a single cell failure tolerance test. The standard is not comprehensively focused on thermal runaway protections and testing requirements compared to UL 9540 and 9540A that are specifically called out in recent code development.

The LG RESU10H has a charge voltage range of 400 to 450v DC.[176] The manual warns against arc flash and high voltage shock. The installation manual contains detailed instructions for arc flash protections. The installation manual provides arc flash working distances and references NFPA 70E for Incident Energy Calculations and PPE guidance. Appropriate arc flash personal protective equipment is required for LG RESU installation. The manual specifically warns that when installing the RESU10H, "the worker shall wear arc-rated clothing on every occasion" and establishes a working distance "to protect him/her from any possible exposure to an electric arc flash."[177]

The Tesla and LG safety guidance and installation manuals clearly identify potential serious BESS hazards such as thermal runaway, fire, explosion, arc flash, and electrical shock. The BESS are not described as "plug and play" appliances that are devoid of safety risks. The manufacturers' safety guidance emphasizes the importance of broad knowledge of electrical codes by the installer, particularly NFPA 70 and the safety requirements of NFPA 70E. The installer is warned that "over-voltages or wrong wiring" may lead to an explosion. The competence of the installer is clearly linked to worker and public safety by the manufacturers' own safety documentation. The guidance emphasizes the installation must be conducted by a "competent electrician" or "qualified electrician or installer" with specific electrical knowledge, skills, and training.

Lithium-ion batteries are a relatively new technology utilized for BESS and lack a lengthy track record for evaluation of safety and risk. This rapidly proliferating technology has the potential to introduce new hazards on a larger scale. Organizations such as NFPA, DNV, Underwriters Laboratories, and FM Global are conducting ongoing research and testing on lithium-ion battery hazards and researching safer technologies. New chemistries and technologies will themselves introduce uncertainty and potentially new risks. The dominant lithium-ion battery chemistry for BESS in the U.S. has serious inherent hazards beyond high voltage and arc flash. These include thermal runaway, reactive chemical hazards, the venting of toxic and flammable gas, fire, and explosion. Recent incidents such as the 2019 Arizona Public Service utility explosion that seriously injured four firefighters have highlighted that BESS hazards can result in grave potential consequences for workers, occupants, and emergency responders. The NFPA has stated:

> [A]s the Arizona fire illustrates, this technology is not risk free. BESS technologies, which are typically large configurations of chemical batteries, can explode, catch fire, and release toxic gases under certain conditions. They are also subject to the phenomena of thermal runaway, which means they can burn intensely for significant periods of time. These hazards are dangerous for firefighters and for anyone else nearby an emergency incident. Policymakers must make sure first responders and other officials have the tools necessary to deploy BESS safely.

BESS incidents have occurred throughout the lifecycle of LIB, including construction, installation, and operation.

BESS incidents can be described as infrequent but high hazard. Modern building and fire codes have recently highlighted these hazards and developed mitigation provisions in their code requirements. Manufacturer safety data sheets, installation manuals, and emergency response guides have called out these same hazards and cited codes such as NFPA 70 and 70E for safe installation.

176 https://www.lgessbattery.com/us/home-battery/product-info.lg.

177 *Ibid.*

F. BESS Risks

The evidence reviewed for this report suggests that serious BESS accidents are infrequent. While there is no single repository of BESS incidents, available data show no high consequence BESS-related incidents in California. However, because the hazards are significant and can have serious consequences, BESS falls into the category of high consequence, low frequency risk, and should be evaluated with this framework in mind.

Modern approaches to risk assessment go beyond traditional formulas that focus solely on factors like frequency and consequence for all hazards. Hazards that could result in high consequences but are low frequency events pose unique challenges for prevention and mitigation. A primary focus on frequency in evaluating the risk of such events can leave public safety vulnerable to the impacts of known serious hazards. Where the hazard is high consequence, more rigorous approaches are taken that emphasize the importance of implementation of effective safeguards—even with low frequency events. From the incidents reviewed in this report, lithium-ion BESS incidents have the potential for high consequence, including chemical reactive hazards, thermal runaway, fire, and explosion. This is true for residential, commercial, and utility-scale applications.

1. Risk Methodologies

Risk assessment tools from the chemical process safety field are appropriate to employ to BESS because they address some of the same significant hazards of fire, explosion, and chemical reactivity.[178] In the chemical process safety sector it is recognized that the occurrence of these serious chemical safety events is infrequent compared to personal safety incidents.[179] These are typically referred to as "low frequency/high consequence events."[180] The fire service also has a risk category for hazards that are significant and reflect new technology or seldom encountered dangers. They are referred to as "high risk/low frequency" incidents.[181] The NFPA categorizes BESS as a "high risk hazard" for emergency responders.[182] Both of the risk methodologies employed in these two sectors (chemical process safety and the fire sector) will be examined.

Both risk methodologies incorporate safety good practice guidelines. The consensus safety guidelines addressing risk management look at the complexity of effectively managing risk. A key initial step is defining the scope, context, and criteria of risk.[183] The risk context and criteria can include the choice of risk approach, tools, and techniques. These can be customized to the specific subject matter.[184] This allows an appropriate approach that considers the accepted risk methodology for the fire service, chemical, and electrical safety sectors. Risk identification should review causes and events, limitations of knowledge and reliability of information, and emerging risks.[185] The risk analysis should include not only the likelihood and magnitude of consequences, but

178 https://www.aiche-cep.com/cepmagazine/may_2020/MobilePagedArticle.action?articleId=1583421#articleId1583421.

179 Personal safety incidents are often characterized as "slips, trips and falls."

180 Center for Chemical Process Safety (CCPS), Process Safety: Leadership from the Boardroom to the Frontline, American Institute of Chemical Engineers (AICHE), New York, New York (2018), p.17. CCPS is a corporate alliance of the chemical engineering professional society AICHE.

181 https://www.fireengineering.com/firefighting/developing-a-successful-approach-to-high-risk-low-frequency-events/#gref; https://www.firerescue1.com/preparing-new-officers-be-incident-commanders/articles/tips-for-ics-managing-high-risklow-frequency-incidents-twYow6R0HcUM4It9/; https://www.firefighternation.com/firerescue/high-risk-low-frequency/#gref.

182 https://www.nfpa.org/News-and-Research/Resources/Emergency-Responders/High-risk-hazards.

183 International Standards Organization (ISO), 31000:2018, Risk Management – Guidelines, p.10.

184 *Ibid.*

185 *Ibid.* at 11.

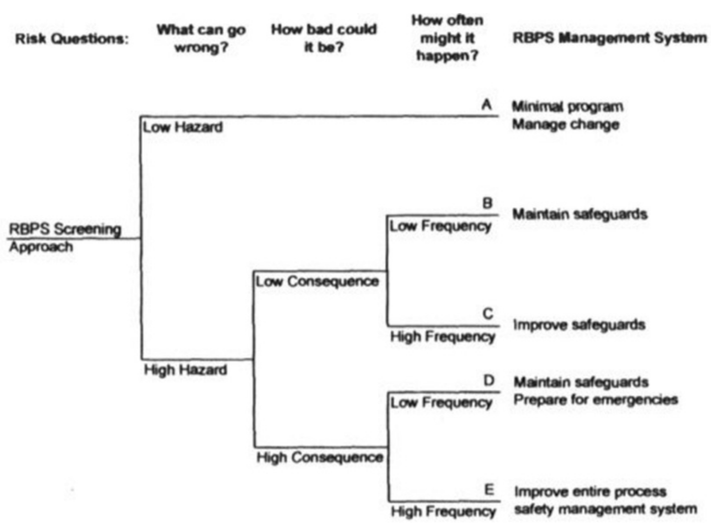
also the complexity of multiple hazards and the effectiveness of existing controls.[186] The ISO standard states, "highly uncertain events can be difficult to quantify" which is "an issue when analyzing events with severe consequences."[187]

In light of the above, it is clear that lithium-ion BESS are an emerging risk with limitations of knowledge. They have multiple hazards, and recent incident findings and causes are not fully understood. Some preventative measures are still in the process of evaluation and implementation. The occurrence of incidents is infrequent but difficult to quantify with no single repository for BESS events.

a) Risk Methodology—Chemical Safety

Chemical safety risk methodologies address events like those possible with BESS, such as fire, explosion, toxic release, and reactive chemical hazards.[188] In this sector, high hazard, high consequence risks—even with low frequency—are treated very seriously. As illustrated in Figure 27, risk alternatives that move toward high consequence require greater attention and reliable system controls to manage.

Figure 27. Risk Diagram showing low frequency/high consequence events receive greater risk management attention. (CCPS, 2007)[189]



The importance of receiving greater preventative focus and maintaining safeguards is elevated for emerging risks where technology and knowledge of multiple BESS hazards is evolving. This is especially true with a rapidly expanding market as seen with BESS deployment in California. California.

186 *Ibid.* at 12.

187 *Ibid.*

188 The U.S. Chemical Safety and Hazard Investigation Board (CSB) defines a reactive hazard incident "as a sudden event involving an uncontrolled chemical reaction–with significant increases in temperature, pressure, and/or gas evolution–that has caused, or has the potential to cause, serious harm to people, property, or the environment."

189 https://onlinelibrary.wiley.com/doi/book/10.1002/9780470925119, CCPS Guidelines for Risk Based Process Safety "provides guidelines for industries that manufacture, consume, or handle chemicals, by focusing on new ways to design, correct, or improve process safety management practices."

b) Risk Methodology—Fire Service

The fire service has also adopted the risk framework of low frequency/high risk events. These incidents are infrequent but have the potential for serious consequences including novel hazards. These new or emerging hazards confront emergency responders with threats they have not experienced or trained for.[190] The NFPA concludes that BESS are a "high risk hazard" and states: "New technologies continue to emerge that have an increased fire safety risk, and new hazardous events or situations become concerning to emergency responders."[191] The NFPA has developed a comprehensive training program and website with links to BESS reports, testing, and code development such as NFPA 855. **The ongoing significant code development and more rigorous protections for BESS by standard-setting bodies is an explicit acknowledgement of the significance of BESS risks.**

Other organizations examining BESS risk have determined that lithium-ion BESS represent a significant risk that needs to be addressed through effective safeguards to prevent incidents. Dr. Josh Lamb, principal technical staff member at Sandia National Laboratories, states that LIB hazards are inherent, and any chemical fuel has "significant risks, so we should understand how to handle fires safely."[192] Marsh Commercial refers to BESS as a "significant emerging risk" where knowledge is still developing.[193] AIG Energy Industry Group states, "The rapid rise of Battery Energy Storage Systems (BESS's) that utilize Lithium-ion (Li-ion) battery technology brings with it massive potential—but also a significant range of risks. At AIG, we believe this is one of the most important emerging risks today."[194]

c) Large-Scale BESS Risks

BESS risks are significant for grid-utility, industrial, commercial, and residential applications. Large-scale BESS with greater deployed energy capacity and quantity of flammable vent gas and materials subject to combustion releasing toxic vapors have the potential for much higher consequence events. Explosions and fire can impact workers and emergency responders as noted in the BESS incident descriptions. Some incidents led to offsite consequences to the public like shelter-in-place orders in the surrounding community.

d) Small-Scale BESS Risks

Small scale lithium-ion BESS capacity, including residential applications, also represents a significant hazard. While the deployed energy capacity and quantity of released hazardous material at a given location would be much less for smaller scale installations, BESS standards and manufacturers' safety documentation acknowledges the potential for thermal runaway, arc flash, and deep-seated fires that can threaten workers, occupants, and emergency responders. Recent U.S. commercial and residential BESS incidents have resulted in fires but no injuries.

190 https://www.firerescue1.com/preparing-new-officers-be-incident-commanders/articles/tips-for-ics-managing-high-risklow-frequency-incidents-twYow6R0HcUM4It9/.

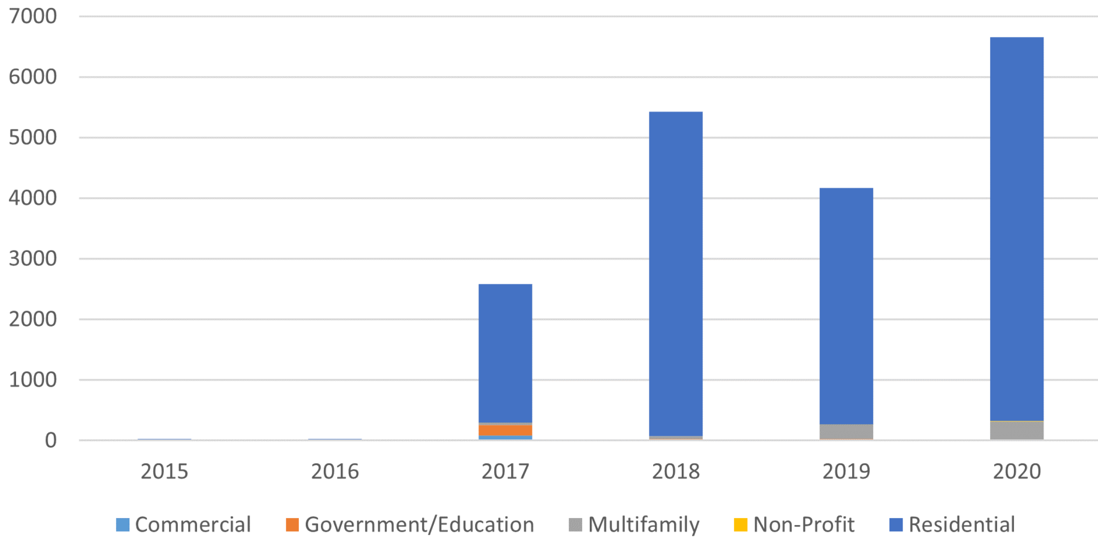
191 https://www.nfpa.org/News-and-Research/Resources/Emergency-Responders/High-risk-hazards/Energy-Storage-Systems.

192 https://www.energy-storage.news/news/safe-lithium-ion-energy-storage-begins-with-knowing-what-to-do-when-things.

193 https://www.marshcommercial.co.uk/articles/battery-energy-storage-fire-risks-explained/.

194 https://www.aig.co.uk/content/dam/aig/emea/united-kingdom/documents/Insights/battery-storage-systems-energy.pdf.

Figure 28. Total Count of California Solar-Paired BESS Projects by Customer Sector 2015–2020



The dramatic increase in the number of residential BESS installations to over 6,500 residential and multi-family projects in 2020 exposes a larger number of occupants to BESS hazards (Figure 28).[195] Residents who are at home for longer periods, day and night, can be more vulnerable to BESS hazards than people near commercial or grid-scale BESS installations. Potential residential lithium-ion BESS fires, explosions, and thermal runaway events can also threaten occupants who are unable to respond to alarms or self-rescue. Small-scale BESS fires can threaten emergency responders and occupants, as was shown in a fire that reignited days later in the 2013 Port Angeles, Washington, incident.

Building codes recognize the serious risks of BESS and establish minimum requirements to mitigate the hazards. NFPA 70 (2020) provides a 1kWh threshold for coverage of application of its ESS safety provisions that would cover nearly all smaller-scale lithium-ion BESS installed in California commercial and residential applications. NFPA 855 has BESS safety requirements for one- and two-family dwellings and townhouse units. The California Fire Code (2021) supplement covers lithium-ion BESS over 20kWh in aggregate. The CEC has a separate section setting requirements for Group R3 and R4 occupancies over 1 kWh.[196] Both NFPA 70 and 855 establish "the minimum requirements for mitigating the hazards associated with ESS." The inclusion of the code provisions in NFPA 70 is based on what is "considered necessary for safety."[197] The CEC has a stated intent of establishing minimum requirements to provide a reasonable level of life safety and property protection from the hazards of fire, explosion and dangerous conditions."[198]

195 Requirements for fire detection systems, restrictions for installation locations and use of non-combustible construction are intended to provide warning and time for escape. Note that some grid-utility projects can be unoccupied or with limited occupancy during work hours.

196 CEC (2021 Supplement) 1206.1, Exceptions 2.

197 NEC 90.1 Purpose, (B) Adequacy.

198 CEC (2021 Supplement) 101.3 Intent.

NFPA and ICC codes are developed by panels of subject matter experts who understand BESS hazards, risks, and necessary safeguards. These codes establish important minimum safety requirements that apply to applications from grid-utility to residential. The low thresholds for building code coverage are a recognition of the significant risk even for small-scale applications. These provisions are not arbitrary but rather recognize that BESS in all applications have significant risks that need mitigation through the provisions of the code. This includes BESS installation. In fact, the focus of NFPA 855 is establishing needed safety requirements for installation to mitigate the hazards associated with ESS.

2. Risk Treatment

The NFPA has adopted a rigorous approach to BESS risk treatment with the use of the hierarchy of risk controls approach to preventing and mitigating electrical hazards in NFPA 70E. The hierarchy identifies risk control methods and examples from most effective to least. That approach prioritizes eliminating the hazard or substituting a less hazardous material, technology, or activity for a more hazardous one (see Figure 29). The approach identifies the most effective risk control method or a combination for a particular hazard. This approach is appropriate for the multiple hazards with lithium-ion BESS addressed in NFPA 70.

Figure 29 the Hierarchy of Risk Controls (NFPA 70E)[199]

The purpose of specifying and adhering to a hierarchy of risk control methods is to identify the most effective individual or combination of preventive or protective measures to reduce the risk associated with a hazard. Each risk control method is considered less effective than the one before it. **Table F.3** lists the hierarchy of risk control identified in this and other safety standards and provides examples of each.

Table F.3 The Hierarchy of Risk Control Methods

Risk Control Method	Examples
(1) Elimination	Conductors and circuit parts in an electrically safe working condition
(2) Substitution	Reduce energy by replacing 120 V control circuitry with 24 Vac or Vdc control circuitry
(3) Engineering controls	Guard energized electrical conductors and circuit parts to reduce the likelihood of electrical contact or arcing faults
(4) Awareness	Signs alerting of the potential presence of hazards
(5) Administrative controls	Procedures and job planning tools
(6) PPE	Shock and arc flash PPE

A lack of higher order risk controls for some LIB NMC hazards highlights the need for even more effective controls lower on the hierarchy. For the predominate lithium-ion BESS chemistry in California, NMC, the flammable electrolyte and reactive chemical hazards are inherent to the design.[200] There are new LIB designs that are in development that may address these issues such as substituting the flammable electrolyte for a less hazardous material.[201] However, for the LIB NMC chemistry the hazards are present—the design is not foolproof or without risk.

199 https://link.nfpa.org/publications/70E/2021/annexes/F#ID00070E000997.

200 DNV-GL reviewing previous L-I incidents in its report of the 2019 APS thermal runaway found “The lessons the industry has learned from these incidents is that Li-ion batteries are inherently fragile, and any electrical, thermal, or mechanical abuse, along with internal defects, can potentially initiate cell failure and thermal runaway.” https://liiontamer.com/wp-content/uploads/APS-DNV-GL-Report.pdf

201 https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/burning-concern-energy-storage-industry-battles-battery-fires-51900636; one of many examples of attempts at safer BESS technology is Lockheed Martin Corp.’s development of a BESS with an aqueous electrolyte: “Unlike lithium-ion, we don’t have a flammable electrolyte.”

Figure 30. Hierarchy of Controls showing less effective controls such as active and procedural safeguards on the right of the figure. From *Process Plants: A Handbook for Inherently Safer Design Second Edition*; Kletz, Trevor Amyotte, Paul; CRC Press 2010.

The NMC design typically has active safeguards such as a battery management system (BMS) that monitors and controls LIB with the ability to isolate battery racks to help mitigate overheating and a thermal runaway. Active engineering controls are distinguished from passive design controls in that the BMS requires active, electrically powered intervention in order for the design to function properly (see Figure 30). We have seen from LIB incidents such as the 2019 Surprise, Arizona, explosion that BMS controls can fail to arrest a thermal runaway. DNV noted in its 2020 Battery Performance Scorecard that "accurate voltage balancing of cells is important for lifetime and safety reasons, and not all battery management systems detect individual cell imbalances." BMS are an important LIB design feature but are lower on the hierarchy than passive design controls, substitution, or elimination of the hazard. The Energy Storage Association guidance supports the implementation of "design for passive safety" approach to BESS hazard mitigations.[202]

The lack of higher order controls for some lithium-ion battery hazards, such as elimination of the flammable electrolyte or reactive hazards, requires that lower order controls, such as effective work practices and training, be more effective and reliable. The effectiveness of **both** active engineering controls such as the BMS **and** administrative controls such as procedures and training then become key for incident prevention. The importance of a trained, skilled workforce is critical for evaluations of the existing electrical system because the trigger for accidents may extend beyond the battery itself. Our assessment of the appropriate CSLB contractor classification for BESS installation places a much greater focus on the knowledge, skills, and training of the licensed contractors and their workforce to protect public safety, because of the lack of higher order BESS controls.

G. CSLB Classifications and Safety Analysis

1. Introduction and Background

This analysis has concluded that BESS have significant safety hazards and risks that are rigorously addressed with requirements in applicable codes and standards. The risk analysis also identified the importance of knowledge, skills, and training for safe BESS installation. This section reviews knowledge, skills, and training of CSLB C-46/C-10 specialty contractor classifications and their associated workforce. That information is examined and then related to the BESS hazards, risks, and safety standards outlined above. The section presents our conclusions of the implications of the evidence on hazards, risks, and safety measures on what is the appropriate CSLB contractor classifications for BESS installation.

202 https://energystorage.org/wp/wp-content/uploads/2019/09/Operational-Risk-Assessment-white-paper-final.pdf.

2. CSLB Specialty Contractor Classifications

The CSLB has established over 40 specialty contractor classifications including the C-46 Solar Contractor and the C-10 Electrical Contractor.[203] Under the CSLB's current interpretation of its enabling statute and regulations, BESS can be installed by C-46 contractors when it is installed in conjunction with a solar installation. C-46 contractors cannot install a stand-alone BESS. C-10 contractors can install a solar system, a solar-paired BESS, or a stand-alone BESS. C-46 contractors are specifically prohibited from performing other building and construction trades crafts and skills.

C-46 and C-10 contractor license requirements both include experience and an exam. The experience requirement is the same for both classifications. A contractor applicant must have four years of experience as a "journeyman," foreman, supervisor, or contractor in the relevant classification within the last ten years.[204] "Acceptable training in an accredited school or completion of an approved apprenticeship program" can count for up to three of the required four years of experience. Specialty contractors must take two exams: one addresses topics related to the relevant classification, and the other addresses law and business topics, and is the same for all specialty contractors.

We could not discern large differences in the competency test for C-10 and C-46 contractors with respect to BESS, although the C-10 exam clearly covers a broader scope of electrical work than the C-46. For specialty contractor exams, the CSLB develops a bank of 800 questions and randomly selects 100 for a test session. The bank of 800 questions is renewed every five years through a process of consultation, workshops, and surveys with licensed contractors in that classification. The questions go through a validation process.

For the relevant classification subject matter exam, the CSLB has developed study guides for each specialty classification.[205] In the study guide for the C-46 exam, BESS is a subtopic, and safety accounts for 15% of the exam questions. Safety topics are generic, including unsafe working conditions, protecting the public, and hazardous materials. For the C-10 study guide, 20% of the questions address safety, including lockout/tagout, PPE, tools and equipment, and hazardous materials. The resources for both exams included references to the 2019 California Electric Code and 2019 California Fire Code. The report team was informed in interviews that both the C-46 and C-10 contractors had questions on BESS. The team was informed the C-46 exam typically had more questions on solar and BESS, and the C-10 exam more broadly covered topics beyond solar and BESS related to NFPA 70, the National Electric Code. The C-10 exam was said to include questions related to NFPA 70E, Standard for Electrical Safety in the Workplace, although neither the C-46 nor C-10 study guides list NFPA 70E. The team was not able to review the questions to further analyze topics or sections of code material covered.

3. Certified Electricians and Solar PV Workforce

From a safety perspective, electrical work and the installation of BESS requires effective management systems, including a proficient licensed contractor and a highly trained and experienced workforce. An analysis of the requirements of the C-46 compared to the C-10 electrical workforce presents a much stronger contrast of documented knowledge, skills, and training as required by the State of California than the contractor license

203 16 CA ADC § 832.46 and § 832.10 https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=I-13C856A0D48C11DEBC02831C6D6C-108E&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default).

204 16 CA ADC § 825(a).

205 https://www.cslb.ca.gov/Resources/StudyGuides/C46StudyGuide.pdf.

test itself. Workers performing electrical work under a C-10 contractor must be certified electricians,[206] whereas contractors holding only a C-46 (but no C-10, A, or B) are not required to employ certified electricians. Because of this, the difference between these two contractor types boils down to a difference in the requirements regarding their workforces. It is worth repeating that contractors holding both a C-46 and a C-10 license are mandated by law to follow the requirements of hiring certified electricians as laid out in CSLB regulations.

Certification as a general electrician in California requires specific experience and an exam.[207] The experience requirement can be met by successful completion of an approved apprenticeship program or 8,000 hours of on-the-job experience "for a C-10 electrical contractor installing, constructing or maintaining electrical systems covered by the National Electrical Code."[208] Residential electrician certification requires 4,800 hours of on-the-job experience, and the experience must cover a variety of listed work topics. All applicants must pass an exam that is validated by an independent test validation organization.[209] The subject matter areas for the exam include safety, determination of electrical system requirements, installation, maintenance, and repair. The references for the test include NFPA 70 (2017) and the safety requirements of NFPA 70E (2015).[210]

In contrast, persons performing BESS electric work under a solar contractor with a C-46 license and no C-10 license do not have to be certified electricians. California has no requirements for certification for solar workers. There is no accredited solar-specific installer apprenticeship program listed on the California DIR/DAS website.[211] No experience and no exam are required in California for workers to install a BESS in conjunction with a solar installation. The solar industry does have a voluntary certification program under the North American Board of Certified Energy Practitioners (NABCEP), but it is not a state requirement and is often not required by solar contractors.[212]

NABCEP has a PV Associate and more advanced PV Installer program. The PV Installer certification requires 10 hours of OSHA construction training and 58 hours of advanced PV training in which workers accumulate credits through completion of two to three installations, depending on size, and then they must pass an exam.[213] The California Energy Commission encourages NABCEP certification in their solar incentive program but it is not mandated.[214] Several states require NABCEP certifications for solar installations to be eligible for the state rebate program.[215] In California that is not the case, and there is no publicly available data on the percentage of California solar installers that have received certification.

Our review of the certification requirements clearly demonstrates that the technical capacity of certified electricians includes the knowledge and skills needed to address the safely issues involved in BESS projects. Certified electricians have the training to avoid BESS incidents that could arise due to faulty system wiring,

206 https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=LAB&division=1.&title=&part=&chapter=4.5.&article=.

207 https://www.dir.ca.gov/t8/291_3.html.

208 https://www.dir.ca.gov/t8/291_1.html.

209 https://www.dir.ca.gov/t8/291_3.html.

210 https://candidate.psiexams.com/bulletin/display_bulletin.jsp?ro=yes&actionname=83&bulletinid=343&bulletinurl=.pdf.

211 https://www.dir.ca.gov/databases/das/aigstart.asp; in 2011 the California Department of Industrial Relations, Division of Apprenticeship Standards (DIR/DAS) created the category of a photovoltaic installer in 2011 but the occupation category is not currently listed on the DAS "Find an Apprenticeship Program website. https://www.prnewswire.com/news-releases/dir-establishes-californias-first-green-apprenticeship-occupation-118188704.html.

212 https://www.nabcep.org/about-us/ NABCEP states it "is the most respected, well-established and widely recognized certification organization for professionals in the field of renewable energy."

213 http://www.nabcep.org/wp-content/uploads/2018/02/NABCEP-Certification-Handbook-V2018.compressed.pdf#page=14.

214 https://www.labormarketinfo.edd.ca.gov/file/OccGuide/Solar-PV-Installers-Green.pdf.

215 https://www.solarenergy.org/state-licensing-requirements/.

undetected non-code alterations, electrical faults, and weaknesses in bonding and grounding. The items that need to be evaluated in order to assure safety are provided in Chapters 1-4 in NFPA 70 (2020), which apply generally to electrical installations. NFPA requires that certified electricians evaluate these and other issues prior to the initiation of work, including a risk assessment of an employee's exposure to electrical hazards including the potential for human error prior to the start of work,[216] and an evaluation of the condition of maintenance of existing electrical equipment.[217] NFPA 70E states "Without proper maintenance, equipment cannot be depended upon to perform its required safety functions, such as interrupting fault currents within its characteristic time–current curves."[218] In addition, NFPA 70E requires that, under certain conditions, an electrical shock and arc flash risk assessment be performed.[219] This assessment is also required in LG's safety guidance. These evaluations must be performed by a qualified person with demonstrable proficiency under 70E. Because the electrical certification includes this proficiency, it clearly meets this skill standard, whereas there is no comparable standard to ensure that C-46 workers can demonstrate such proficiency.

Failure to perform these assessments can lead to not only a danger to workers but also to a potential LIB thermal runaway. The Tesla and LG manufacturers' safety guidance has numerous warnings against improper installation actions and the need for qualified electricians or persons to conduct the installation. For example, the LG RESU installation manual warns that "over-voltages or wrong wiring can damage the RESU 10H … and cause deflagration, which can be extremely dangerous." One of the immediate causes stated in one of the investigation reports for the 2019 Surprise, Arizona, disaster was overheating initiated by an external arc flash. One of four cited causes of the 29 Korean BESS fire incidents was faulty installation. Again, only certified electricians have demonstrable experience and a California exam validated by the state of California covering codes such as NFPA 70 and 70E to more effectively prevent BESS incidents.

UL 9540 (2020) requires a system evaluation of all BESS components and whether they are compatible and function safely as a system.[220] Mismatched BESS components may lead to a "fire and electrical shock hazard."[221] UL 9540 (2020) requires a safety analysis of the BESS. This analysis may be performed by the installer that integrates the components together:

> A safety analysis consisting of a hazard identification. risk analysis and risk evaluation including a safety analysis such as a failure modes and effects analysis (FMEA) that identifies critical safety components and circuits of the system shall be conducted on the equipment forming the ESS and components of the ESS considering any interactions that provide a safety function. The analysis shall consider the compatibility of the parts of the ESS (e.g. battery system, charger, inverter. Etc.) with regard to safety of the overall system.[222]

216 NFPA 70E (2021), 110.5(H)(1) and (2).

217 NFPA 70E (2021) 110.5(C).

218 *Ibid.* From NFPA 70E's enhanced content for 110.5(C). The section also cites NFPA 70B R*ecommended Practice for Electrical Equipment Maintenance*.

219 NFPA 70E (2021), 130.1, 130.4 and 130.5. "Safety-related work practices shall be used to safeguard employees from injury while they are exposed to electrical hazards from electrical conductors or circuit parts that are or can become energized."

220 https://code-authorities.ul.com/about/inspection-resources-for-code-authorities/energy-storage-systems/can-pv-inverters-be-used-with-battery-energy-storage-systems/.

221 *Ibid.* "However, for ESS system components such as inverters—unless they are Certified (Listed) for use with a specific input source type such as a battery in this case and have the appropriate input short circuit current rating—the installation of mismatched system components may present a catastrophic fire and electric shock hazard if there is a short circuit condition on the battery output."

222 UL 9540 (2020) 15.1.

Installing BESS requires an assessment of the entire system that is being connected, which certified electricians are trained and certified to do. Solar workers under a C-46 contractor installing BESS do not have the demonstrated knowledge, skills, and training related to NFPA 70 and 70E.

Rapidly developing BESS technologies and ongoing codes and standards revisions require detailed knowledge of multiple hazards and evolving safety requirements. Manufacturer safety guidance and relevant codes underscore that BESS in any size or application is not a "plug and play" installation. A broad knowledge of NFPA 70 and 70E is required as well as compliance with multiple sections of NFPA 70. Certified electricians are trained in all these areas of knowledge of electrical systems.

In sum, the main distinguishing characteristic between the C-10 and C-46 licenses that is relevant to this report is the difference in the required skill standard for their electrical workforces. C-10 contractors, whether or not they hold other licenses, are held to the requirement that their electrical workforce must be certified, whereas C-46 contractors are exempt from this requirement. Electricians certified by the state of California have the demonstrated knowledge, skills, and training to address the multiple safety considerations and are best suited to perform BESS installation from a public safety perspective. There are no equivalent California requirements or necessary demonstration of knowledge, skills, and training for installers working under a contractor with solely a C-46 license.

H. Is BESS Incidental and Supplemental to Solar PV?

The CSLB asked us to investigate whether or not BESS should be seen as "incidental and supplemental" to solar PV. Specialty contractors are permitted to perform work in other classifications if it is "incidental and supplemental," defined in the regulatory language as being "essential to accomplish the work in which the contractor is classified."[223] The CSLB made a determination that a BESS installation in conjunction with a solar installation is allowed as "incidental and supplemental," but has asked us to review this determination.

BESS is not essential to solar installation. BESS is not included in the C-46 solar contractor regulatory description, which states "a solar contractor installs, modifies, maintains, and repairs thermal and photovoltaic solar energy systems."[224] The C-46 Contractor regulatory provision has an explicit requirement to "not undertake or perform building or construction trades, crafts, or skills, except when *required* to install a thermal or photovoltaic solar energy system" (italics added).[225] While § 834, Limitation of Classification, restricts specialty contractors from performing work of another classification, the restrictive language in the C-46 Contractors description is uniquely specific and explicit compared to all the other specialty contractor descriptions. BESS is not a thermal or photovoltaic solar energy system. BESS is listed as a distinct system in a separate Chapter 7 Special Conditions of NFPA 70 (2020) from solar photovoltaic (PV) systems in Chapter 6 Special Equipment.[226] BESS is not essential or required to be installed with a PV system. BESS can be installed as a stand-alone system or with other equipment including wind turbines, PV systems, or engine generators. Examples of supplemental and incidental work that is essential to solar installation include flashing and sealing roof penetrations from rack attachment, installing poles and tracking systems for ground mounted solar systems, and installing required photovoltaic system signage.

223 16 CA ADC § 831.
224 16 CCR § 832.46.
225 *Ibid.*
226 https://link.nfpa.org/publications/70/2020.

Unlike BESS, these installations may be required for solar installation. Our review of code and of the regulations determining scope for the C-46 leads us to conclude that BESS is therefore not "incidental or supplemental" to solar work.

Most importantly, the hazards and risks associated with BESS are significantly different than PV systems. Lithium-ion BESS have a high energy density and a thermal runaway hazard that can lead to fires, explosions, and venting of toxic gas. The public safety underpinnings of California regulations requiring certified electricians to perform electrical work under C-10 contractors also support the interpretation that BESS installations should be performed by C-10 contractors.

I. Conclusions from Safety Analysis

In conclusion, the review of the hazards, risks, and safety strategies, as well as the differences in the workforce requirements between C-10 and C-46 contractors, point to a preponderance of evidence in favor of restricting C-46 contractors from BESS work even when paired with solar PV. This report's review of the hazards and risks inherent to BESS underscores the importance of technical and safety capabilities necessary for safe BESS installation. Since the main difference between contractors is the certified electrician requirement, and in California certified electricians working under a C-10 contractor have significantly greater documented regulatory requirements for knowledge, skills, and training to safely perform electrical work and BESS installations, the CSLB can best ensure safety by requiring the C-10 license for all BESS installations.

We recommend that C-10 contractors be required for installing all residential, commercial, and utility-scale BESS for the following summary reasons: BESS are a dynamic and expanding technology with inherent hazards that are significant; they have led to serious incidents; they are recognized by NFPA as a "high risk hazard;" they have led to the development of significant ongoing code and standard revisions and new safety mitigations; they are currently predominately installed under C-10 contractors requiring the use of certified electricians with demonstrated skills and safety training needed to address the safety issues identified; only a tiny percentage of BESS projects have been installed by C-46 contractors without a C-10, A, or B license and therefore a significant safety record for these contractors simply does not exist. Finally, we find that there lacks a justifiable threshold by size or sector to suggest less hazard or insignificant risk for BESS installation, and therefore we recommend C-10 licenses be required for all sizes and customer classes of BESS.

V. The Economic Impact of Alternative Licensing Scenarios

The overriding purpose of the CSLB contractor license requirements is to protect public safety, but it is also critical to ensure that changes in requirements do not have significant adverse economic impacts that could impede the growth of the BESS market or hurt California businesses and workers. This section first presents an analysis of contractor and worker availability and then turns to an analysis of the installation costs of different contractor types, the transition costs of alternative scenarios for license classifications, and other economic considerations.

A. Contractor and Workforce Availability

It is important to document both the availability of contractors as well as of workers, particularly because of the certifications needed for electricians hired by C-10 license holders.

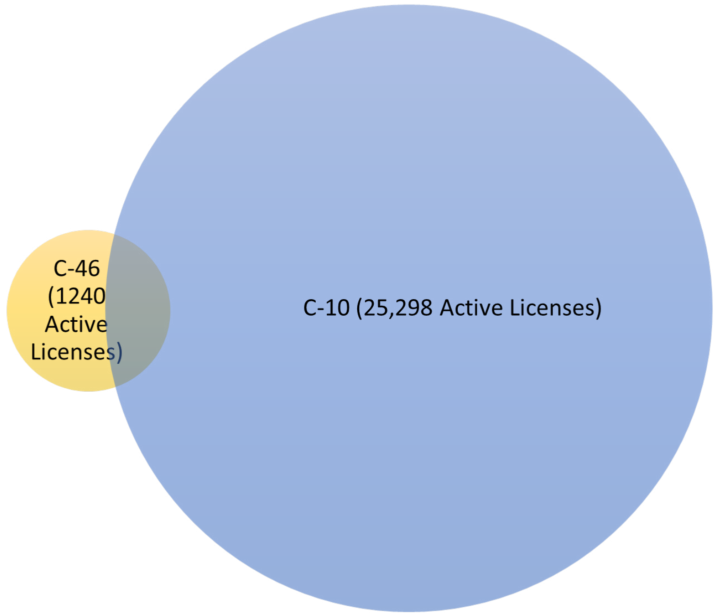
1. Availability of C-46 and C-10 Contractors

As of this writing, the CSLB has on record 25,298 active licensed C-10 electrical contractors and 1,240 active licensed C-46 contractors; 447 contractors hold both licenses.[227] More than a third (36%) of C-46 contractors hold a C-10 license, while just 2% of C-10 contractors hold a C-46 license. The low share of C-10 contractors who hold C-46 licenses makes sense since a C-10 license holder can already perform all the work under the scope of the C-46 license. Figure 31 presents a Venn diagram showing the respective pools of C-10 and C-46 contractors. The overlap represents those holding both licenses. This diagram is drawn generally, but not precisely, to scale, showing that a little over one-third of C-46 license holders also have a C-10 license. For every C-46 contractor in the state, there are 20 electrical contractors. Both C-46 and C-10 contractors engage in work other than solar-paired BESS; in fact, given that the BESS industry is still in its infancy, BESS makes up a small portion of the business of both C-46 and C-10 contractors. As stated earlier, the majority of BESS projects are installed by contractors holding both licenses. Contractors holding neither a C-46 nor C-10 license have also installed BESS.

While growing demand for BESS could increase the labor market demand for contractors and skilled workers ready and able to carry out this work, the large pool of C-10 contractors throughout the California and the relatively low labor demand associated with BESS installation should put to rest concerns about labor shortages being caused by restricting the BESS work of C-46 contractors. As covered above, the great majority of BESS are already installed by C-10 contractors (with or without a C-46 license), showing their interest in this market. Over one-third of C-46 contractors have already obtained a C-10 licenses, indicating that obtaining a C-10 license is possible for C-46 contractors and has been seen as advantageous for many of them.

227 https://www.cslb.ca.gov/Onlineservices/DataPortal/.

Figure 31. Active C-46 and C-10 Licenses in California, CSLB, 2021



We also looked at the distribution of BESS contractors in rural areas to examine differences in the relative availability of C-10 and C-46 contractors in areas that can be harder to serve. This confirms the result presented in Section III. F. showing the much smaller participation of C-46 (no C-10, A, or B) in rural counties, compared to the participation of C-10 contractors and dual C-46 plus C-10 license holders. The distribution of BESS-installing contractors by license that have installed solar-paired BESS in California's eleven rural counties is shown in Table 7. In California's rural counties, C-46 (no A, B, C-10) contractors installed 8% of SGIP projects from 2015–2020 and only 3% of BESS projects from the Interconnection dataset for 2020. The decline is attributable to reduced activity by James Petersen Industries (aka Petersen Dean and Solar 4 America). Interestingly, in rural counties in 2020, it was C-10 contractors (not holding a C-46 license) who installed 42% of the projects (a share equal to that held by dual C-10 plus C-46 contractors).

Table 8. Rural Storage Installers by Number of BESS Installations, 2015–2020 (SGIP)

Contractors by Licenses	Storage Project Count in CA's Rural Counties (SGIP data)	Storage Project Count in CA's Rural Counties (Interconnection data 2020)
C-10	**41**	**64**
Berger Solar Electric	1	1
SST Construction LLC dba Sunsystem Technology	1	
V3 Electric Inc	36	53
Kurios Energy	1	
Offline Solar	2	5
Gold Rush Energy Solutions		2
Sunpower Corporation		1
Sbrega Electric		1
Porter Graham Construction		1

CONTINUED Table 8. Rural Storage Installers by Number of BESS Installations, 2015–2020 (SGIP)

Contractors by Licenses	Storage Project Count in CA's Rural Counties (SGIP data)	Storage Project Count in CA's Rural Counties (Interconnection data 2020)
C-10 + C-46	**94**	**65**
1st Light Energy Inc	2	1
Apex Solar Inc	1	
Freedom Forever LLC	2	2
Future Energy Corporation dba Future Energy Savers	1	
Hooked on Solar Inc	21	10
I Love My Solar	1	1
Infinity Energy Inc	14	5
La Solar Group Inc dba A P Electrical	1	
Luminalt Energy Corporation	1	
Semper Solaris Construction Inc	7	3
Sunrun Installation Services Inc	26	24
Swell Services Inc dba Swell Contractors	2	1
Technical Specialty Solutions	2	
Tesla Energy Operations Inc	5	11
Valley Solar Inc	1	1
Westhaven Inc dba Westhaven Power	7	4
California Solar Innovators		1
SIG Solar		1
C-46 (no A, B, C-10)	**13**	**5**
CalSolar	1	
James Petersen Industries Inc dba Solar 4 America	12	2
ACR Solar International		1
West Coast Solar		1
SolarUnion		1
A/B	**10**	**17**
Ambrose Construction Inc	2	1
Quality Home Services	2	1
Sunworks	4	1
Acosta and Daughters	1	
Aztec Solar Inc (also C-46)	1	
Sol Sierra		5
Kirk Reuter		1
Tomsik Greg		1
Solar Savings Direct (also C-46)		1
High Point Solar (also C-46)		2
Solar Energy Collective		2
Infinite Energy Construction		1
Capital Remodel and Design (Also C-46)		1

In terms of contractor availability for a future market, across the state and in every county, including rural counties, there are far more C-10 electrical contractors than there are C-46 solar contractors. Ten California counties have no C-46 contractors with active licenses. Alpine County is the only county without any active C-10 contractors, and four counties have fewer than ten C-10 contractors. In Table 9, the green color indicates a rural county and the blue indicates counties that are mostly rural.

Table 9. Number of Active Contractor License Holders by Type of License, Rural and Urban Counties

County	Active C-46 licenses	Active C-10 licenses	Active dual C-10, C-46
Alameda	41	852	14
Alpine			
Amador	9	55	3
Butte	16	156	2
Calaveras	3	58	2
Colusa		9	
Contra Costa	49	690	23
Del Norte		9	
El Dorado	18	234	6
Fresno	38	423	14
Glenn	1	12	
Humboldt	8	89	5
Imperial		56	
Inyo	1	13	
Kern	26	432	6
Kings	5	40	2
Lake	3	52	1
Lassen	1	17	
Los Angeles	209	6,063	80
Madera	6	86	4
Marin	18	244	10
Mariposa		19	
Mendocino	11	90	4
Merced	8	85	3
Modoc		6	
Mono	2	21	1
Monterey	5	272	1
Napa	5	118	
Nevada	14	161	5
Orange	88	2,241	30
Placer	27	485	8
Plumas		29	
Riverside	89	1,601	31
Sacramento	43	867	17

CONTINUED Table 9. Number of Active Contractor License Holders by Type of License, Rural and Urban Counties

County	Active C-46 licenses	Active C-10 licenses	Active dual C-10, C-46
San Benito	1	49	
San Bernardino	43	1,163	16
San Diego	138	1,911	49
San Francisco	19	550	9
San Joaquin	17	312	6
San Luis Obispo	16	315	10
San Mateo	12	553	6
Santa Barbara	7	274	1
Santa Clara	55	1,007	18
Santa Cruz	18	245	7
Shasta	15	167	3
Sierra		4	
Siskiyou		34	
Solano	13	213	5
Sonoma	39	524	12
Stanislaus	12	268	3
Sutter	3	65	2
Tehama	1	35	1
Trinity		15	
Tulare	8	173	3
Tuolumne	4	59	1
Ventura	21	667	3
Yolo	7	90	
Yuba	2	44	1

1. Availability of Certified Electricians and PV installers

In addition to the number of contractors who are available to perform BESS installations, it is also important to document the size of their workforces, particularly since the main impact of any change in license requirements is most fundamentally about whether or not contractors are held to the rule that certification is required for their electricians installing solar PV-paired BESS (or BESS generally, since Option 4 would allow C-46 license holders to install BESS even when not paired with solar). It should also be noted that with solar PV and BESS alike, there are both electrical and non-electrical tasks, and the certification requirement in the C-10 license only applies to electrical tasks.

There are several ways to capture information on the number of certified electricians and PV workers. The workforces of C-10 and C-46 include both sole proprietors who work for themselves and employees of C-10 and C-46 contractors. As of March 1, 2021, CSLB data shows that the C-10 class has 13,700 active licensees with workers' compensation (WC) exemptions on file (claiming they have no employees and are therefore self-employed) and 11,328 with a certificate of WC insurance on file, indicating they have employees. The C-46 class has 478 WC exemptions and 758 with a policy. According to this CSLB data, 54% (11,328) of C-10 contractors claim to have no employees and 39% (758) of active C-46 contractors claim to have no employees.

Although some C-10 contractors are self-employed and do not have employees, C-10 contractors who do have employees carrying out electrical work are required by law to employ certified electricians. A key data point required for this analysis is the number of certified electricians in the state, which we obtained from the certifying body, the Division of Labor Standards Enforcement in the Department of Industrial Relations in the California Labor and Workforce Development Agency. As of March 24, 2021, there were 36,550 certified electricians in California, and 11,423 electrical trainees currently enrolled in registered electrical apprenticeship programs.[228,229]

Since there is no parallel skill standard or training pathway for workers employed by C-46 contractors, there is no comparable data to document how many workers there are. However, we can turn to Employment Development Department (EDD) occupational data that includes both electricians and solar installers for an apples-to-apples comparison. EDD data from May 2019 shows 72,870 electricians (Q1 2020 mean hourly wage $34.89), 4,740 electrician helpers (Q1 2020 mean hourly wage $19.71), and 4,970 solar installers (Q1 2020 mean hourly wage: $23.60).[230]

Another data source is the National Solar Jobs Census by the Solar Foundation. This survey reports 74,255 solar jobs in California in 2019, a figure that includes manufacturing, sales, administration, and management staff in addition to installation and repair workers. The survey methodology used by the Solar Foundation differs from government data collection methods, so it does not allow for a reliable comparison.[231] However, to approximate an apples-to-apples comparison, we estimated the installation workforce from this data source by applying the Solar Jobs Census estimate that 29.8% of solar workers are involved in installation and repair occupations. Calculating this share of the total number of 74,255 solar workers produces an estimated 22,128 solar installation and repair workers in CA.[232] The Solar Jobs Census also reports that of installation employees, 19% work in the field as electrical installers.[233] Again, using these percentages to estimate the size of the California solar workforce, we estimate there are 6,317 non-electrical solar installers (a figure close to the EDD data) and 4,204 electrician solar installers.

Both sources of data indicate that the electrical workforce vastly outnumbers the PV workforce in California. There is no evidence to suggest that workforce availability will limit the growth of BESS installations were the CSLB to restrict or exclude sole license C-46 contractors since C-10 vastly outnumber C-46 contractors both in general and specifically in their participation in BESS projects.

Finally, it is important to note that the number of electricians, as with all construction workers, fluctuates with the business cycle. Scholars have noted that skilled trades workers who have gone through apprenticeship programs, like many certified electricians, have strong attachments to their occupation even when they are laid off during a recession.[234] This attachment is due to the significant investments they have made in the five-year training period during their apprenticeship. While we have no comparable data for the PV workforce, in general workers with less training show less attachment to their occupation when demand for their labor fluctuates during the business

228 https://data.ca.gov/dataset/dir-electrician-certification-unit-ecu/resource/291bacb8-2fdb-4d9c-a330-113781ce2f59.

229 https://data.ca.gov/dataset/dir-electrician-certification-unit-ecu/resource/f0b9e36d-32be-408d-8dd9-4d539becfdc8.

230 https://www.labormarketinfo.edd.ca.gov/data/oes-employment-and-wages.html#OES.

231 https://www.thesolarfoundation.org/national/.

232 https://www.thesolarfoundation.org/wp-content/uploads/2020/03/SolarJobsCensus2019.pdf, Appendix A and Table 16.

233 https://www.thesolarfoundation.org/wp-content/uploads/2020/03/SolarJobsCensus2019.pdf, Figure 13.

234 Philips, P., & Bosch, G. (Eds.). (2002). *Building Chaos: An International Comparison of Deregulation in the Construction Industry* (1st ed.). Routledge. https://doi.org/10.4324/9780203166130.

cycle. This indicates that the certified electrical workforce might be more stable over time and will come back to their careers even if laid off during a recession. This is a benefit to the industry, consumers, and the workers themselves. We also underscore the fact that the number of apprentices in electrical apprenticeship programs fluctuates with demand, and that there are always many more applicants than can be accepted into the limited slots. If BESS grows and significantly increases the demand for certified electricians, the apprenticeship programs will be able to expand accordingly.[235]

B. Cost Differentials between Contractors by License Type

We analyze the cost differentials of C-46 (no C-10, A, or B) and C-10 contractors to assess whether or not a change in the scope of the C-46 license would have adverse impacts on the cost of BESS systems, possibly impeding the growth of the industry. We used two data sources, the cost benchmark modeling data from the National Renewable Energy Lab (NREL) and the SGIP dataset, which provides project cost data for all BESS incentive applications. The SGIP provides total project costs and incentives amounts, which we used to estimate costs per kW.

1. Cost Differential Analysis from NREL models

The NREL model allowed us to calculate the share of total costs of a BESS system installation that are attributable to installation labor. As illustrated in Table 10, installation labor ranges from 6% to 12% of total costs, depending on the specific technology used. This small percentage of installation labor as a share of total costs confirms that higher wages paid to installation workers can only have a minimal impact on total project costs. The NREL model does not permit a comparison between contractors with different licenses, nor does it provide the breakdown of work between electricians and laborers. We created bookends by comparing total project costs if all installation labor were paid at an electrician's wage versus at a laborer's wage. This provides a range of estimates between more expensive labor and less expensive labor, which sheds light on the difference between C-46 contractors, who do not hire certified electricians, and C-10 contractors, whose electrical workers must be certified, thus generally commanding higher wages. The model shows that hiring all laborers would lower costs from the mean by 1% to 2%, and that hiring all electricians would raise costs by 1% to 2%. This is a very small cost differential that is unlikely to slow or reduce consumer demand. A detailed explanation of our calculations is presented below.

The NREL cost data is shown in Table 10 and is illustrated for different storage technologies in Figure 32. We adjusted NREL's cost data to reflect the wage premium enjoyed in California by workers, compared to the national averages employed in the original NREL model.

As shown in Figure 32, the equipment (kit) for a 3kW/6kWh storage system costs approximately $4,200 to $4,600, with a total installed cost of $11,823 (DC-coupled) to $12,287 (AC-coupled). The kit for a 5-kW/20-kWh storage system costs approximately $10,400 to $10,800, with a total installed cost of $21,471 (DC-coupled) to $22,041 (AC-coupled). The figure also shows that BESS that are designed to be AC-coupled require slightly more labor hours than BESS that are DC-coupled.

235 Zabin, C, et al. 2020. "Putting California on the High Road: A jobs and Climate Action Plan for 2030. UC Berkeley Labor Center and California Workforce Development Board. https://laborcenter.berkeley.edu/wp-content/uploads/2020/09/Putting-California-on-the-High-Road.pdf.

Table 10. NREL Solar + Storage Cost Benchmarks[236]

NREL Category	NREL Modeled Value	CA Labor Cost Adjustor	NREL Description
Supply chain costs	5% of cost of equipment	—	Includes costs of inventory, shipping, and handling of equipment
Sales tax	5.1% (national average)		Sales tax on equipment
Installation labor cost	Electrician: $27.47 per hour Laborer: $18.17 per hour AC systems require more hours of work to integrate with an existing inverter and monitoring system	Electrician: $34.89 per hour (mean per EDD Q1 2020) [27% higher than NREL average] Laborer: $24.61 per hour (mean per EDD Q1 2020) [35% higher than NREL average]	Assumes national average pricing
Engineering fee	$99		Engineering design and processional engineer-stamped calculations and drawings
Permitting, Inspection, Inter-connection	$297 permit fee $594 - $951 in labor		20–32 hours (DC-coupled/AC-coupled) of commissioning and interconnection labor, and permit fee
Sales and marketing (customer acquisition)	$0.61/W DC		20 hours more time for DC system, and 32 hours more for AC system, per closed sale, associated with selling a storage system versus selling a PV system
Overhead (general and admin)	$0.28/W DC		Rent, building, equipment, staff expenses not directly tied to PII, customer acquisition, or direct installation labor
Profit (%)	17%		Fixed percentage margin applied to all direct costs including hardware, installation labor, direct sales and marketing, design, installation, and permitting fees

236 https://www.nrel.gov/docs/fy21osti/77324.pdf.

Figure 32. NREL Installed Cost of Residential Storage Only

The NREL model does not provide the ratio of electrician to laborer hours, but we assume that 50% of installation is performed by laborers and 50% by electricians. Under this assumption, the average NREL wage would be $22.82 per hour, and the average California wage would be $29.75. Since the California electrician wage is 27% above the national average and the laborer wage is 35% above the national average, we assume that California installation labor is approximately 30% more than the NREL-reported amount.

Table 11. Installation Labor Costs from NREL BESS Models

	DC- coupled 3 kW, 6kWh	AC- coupled 3 kW, 6kWh	DC- coupled 5 kW, 20kWh	AC -coupled 5 kW, 20kWh
Installation Labor Cost (California)	$1,182	$1,557	$1,308	$1,804
Total Cost	$12,098	$12,650	$21,776	$22,461
Installation Labor as Percent of Total Cost (California)	9.8%	12.3%	6.0%	8.0%
Installation Labor Cost (no electricians)	$978	$1,288	$1,082	$1,492
Reduced total cost	1.7%	2.1%	1.0%	1.4%
Installation Labor (100% electricians for installation labor)	$1,386	$1,826	$1,534	$2,116
Increased total cost	1.7%	2.1%	1.0%	1.4%

In order to bookend the range of cost differentials for lower- and higher-wage labor, we looked at the costs if all the installations were done either at the laborers' wage rate or at the electricians' rate. If all installation were performed by general laborers, the low end of the cost range, there would be a potential cost savings of 1.0% to 2.1%. Conversely, if all installation were performed by licensed electricians on the expensive side, the potential increase in total BESS costs ranges from 1.0% to 2.1%.

We also reviewed the study carried out by Peter Philips, which was submitted in the record to CSLB, based on NREL cost models.[237] Philips estimated the cost impacts using NREL solar benchmark data. (The storage benchmark data from NREL only became available this year.) Philips estimated a 3% cost increment due to higher potential labor costs that would occur if the CSLB restricted the scope of the C-46 license. Compared to solar installations where installation labor represented an average of 9.9% of total costs in 2018 (the year evaluated by Philips), BESS is even less labor intensive (6% to 12%, with a mean of 9%). Furthermore, as battery storage systems get bigger, installation labor becomes a progressively smaller percentage of total costs, because, according to NREL, labor costs are a fixed cost and not a function of the size of the system.

Our California-adjusted labor cost increases of up to 1–2% are likely overestimates for a few reasons. First, the size of residential BESS is likely to increase generally, as consumers are installing BESS for resiliency purposes and want to be able to run their homes during power outages. Larger systems do not correlate with higher labor costs, so the project cost increase due to hiring electricians will shrink as average size increases. Second, there are facets of BESS installation that do not involve the electrical connections requiring C-10 contractors to hire certified electricians or apprentices. The law is clear that electrical connections over 100 volt-amperes must be performed by certified electricians. Since not 100% of the work will require electricians, assuming 100% electrician wages is likely an overestimate.

Moreover, our finding that most installations are performed by contractors with both C-46 and C-10 licenses means that the change in workforce will be limited to the very few C-46 (no C-10, A, or B) contractors doing BESS installations, and the C-46 contractors who also hold C-10 licenses and who are illegally employing non-certified electricians to do electrical work. As Phillips notes,

> …certified electricians are already used to install some percentage of ESS units that are installed concurrently with a solar photovoltaic system. C-10 contractors also install both solar photovoltaic systems and ESS units; and they are required by law to use certified electricians. Contractors with both a C-10 and a C-46 license employ both certified electricians and solar installers. While not required by law, C-46 contractors can employ certified electricians as part of their installation crews. In those cases, there is either no swap-out of high-wage for low-wage labor or only a partial swap-out.

He goes on to write,

> for non-electrical installation work, lower-wage labor may continue to be used as part of the installation crew for units above the threshold. The estimated solar photovoltaic and ESS labor costs cited above include both electrical and nonelectrical work. Only the electrical work would have a potential labor cost increase. Thus, the estimated 3% cost impact of the proposed

237 Philips, Peter. 2019. "The Economic Impact of Limiting C-46 Contractors to 10kW/20kWh Thresholds in Installing Energy Storage Systems" CSLB public record.

> thresholds is a conservative, high-end estimate. Due to 1) the falling share of labor costs compared to total cost, 2) the continuity in some use of certified electricians on larger units, and 3) the continuity of use of less-paid labor on non-electrical tasks, the future cost impact of the proposed regulation is likely to be less than 3% of total costs.

While our analysis generally draws the same conclusions as Philips's, the potential cost impact we arrive at is even smaller because the NREL's reported installation labor costs for BESS are lower than what Philips had estimated. Additionally, unlike with solar, many labor costs in BESS installation don't increase with the capacity of the system. A Stanford study on the costs of BESS installations reports that some "installation costs, which consist of permitting, inspection/commissioning and workforce mobilization are considered fixed costs, FC, which do not scale with the size of the system."[238] This is based on the authors' review of customer feedback within online forums related to Tesla Energy Powerwall, which presented the actual cost of installations, and on interviews with three Tesla Energy employees. The Stanford authors estimate $400 in fixed costs for the installation of a residential system.[239]

2. Cost Differentials Between Contractors with Different Licenses in California, SGIP Dataset

This section analyzes the costs of BESS installation by contractor license type using real cost data for contractors in California who reported their installations for the SGIP reporting requirements. It relies on individual project data rather than modeling data as in the NREL dataset, and thus is a particularly credible data source for this analysis. The analysis includes an examination of all BESS installations and also breaks down costs for residential and commercial installations separately. Using the cost data provided in the SGIP data, we determined an average cost per kW for solar PV-paired BESS across different licenses. We examined whether a C-10 license correlated with higher BESS costs, and if so, what the cost differential across different license types is. Our analysis confirms very small cost differentials by contractor license type, as explained below.

Our analysis shows an average BESS installation project cost of $25,538, with an average cost per kW of $2,348 and an average size of 10.9 kW. On average, across all customer classes, the data shows that the lowest average cost storage systems are installed by contractors holding a dual C-10 and C-46 license, and the highest average cost is installed by C-46 contractors holding an A or B license. In addition, contractors holding a C-10 license without a C-46 license have an average cost per kW just 0.6% higher than contractors holding a C-46 license without a C-10 license, as shown in Figure 33 and Table 12. This is less than the modeled impact using NREL data.

Of course, averages across customer classes don't tell the whole story, so we used the same data to separately examine projects for commercial and residential customers. The average size of a residential system is 6.3 kW and the average cost is $14,255. The average size of a commercial system is 216.2 kW and the average cost is $532,400.

In the residential sector, the data show that the lowest average cost BESS is installed by contractors holding both C-10 and C-46 licenses, the contractor group that clearly dominates the market. Compared to projects installed by C-46 (no C-10, A, or B) contractors, projects installed by C-10 (no 46) are 1.8% higher, which is directly in line with our analysis using NREL cost benchmark data.

238 Comello, Stephen and Stevan J. Reichelstein, 2018. "The Emergence of Cost Effective Battery Storage." Working Paper No. 3696, p. 24, https://www.gsb.stanford.edu/gsb-box/route-download/463541.

239 *Ibid.*, p. 28

Figure 33. Average Cost per kW by Contractor License Type, 2015–2020 (SGIP data)

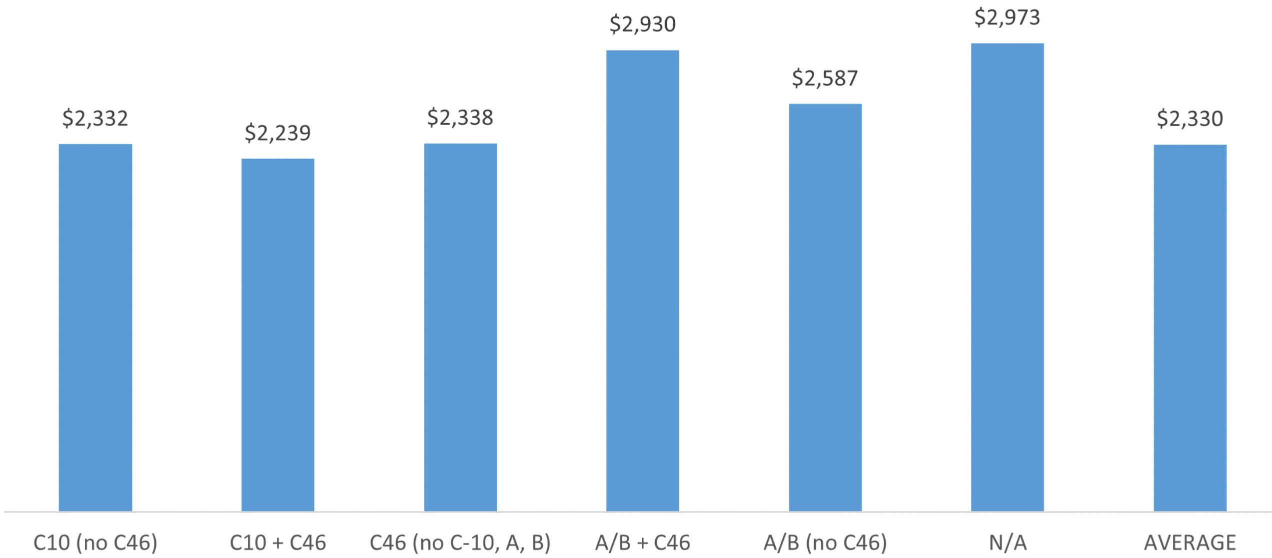


Table 12. Average Cost per kW by Contractor License Type, 2015–2020, SGIP data

	C-10 (no C-46)	C-10 + C-46	C-46 (no C-10, A, or B)	A/B + C-46	A/B (no C-46)	NA	AVERAGE
Grand Total	$2,332.12	$2,239.10	$2,337.71	$2,929.96	$2,586.71	$2,973.25	$2,330.29
percent of average	100.1%	96.1%	100.3%	125.7%	111.0%	127.6%	100.0%

Both C-10 (no C-46) contractors and C-46 (no C-10) contractors have higher than average project costs. C-46 contractors are 4% above average, while C-10 contractors are 5% higher than average. A and B contractors also had much higher than average costs for residential BESS, regardless of whether they held a C-46 license.

In the commercial sector, the data show that the lowest average cost BESS installation projects were self-installs (depicted by the blue bar labeled “N/A” in Figure 34), followed by C-10 contractors. C-46 contractors who hold an A, B, or C-10 license have higher than average costs, as do A or B contractors without a C-46 or C-10 license. No commercial BESS installations performed by C-46 contractors without an A, B, or C-10 license were found in the SGIP dataset.

Figure 34. Residential and Commercial Average Cost per kW, Solar-Paired BESS, 2015–2020 (SGIP data)

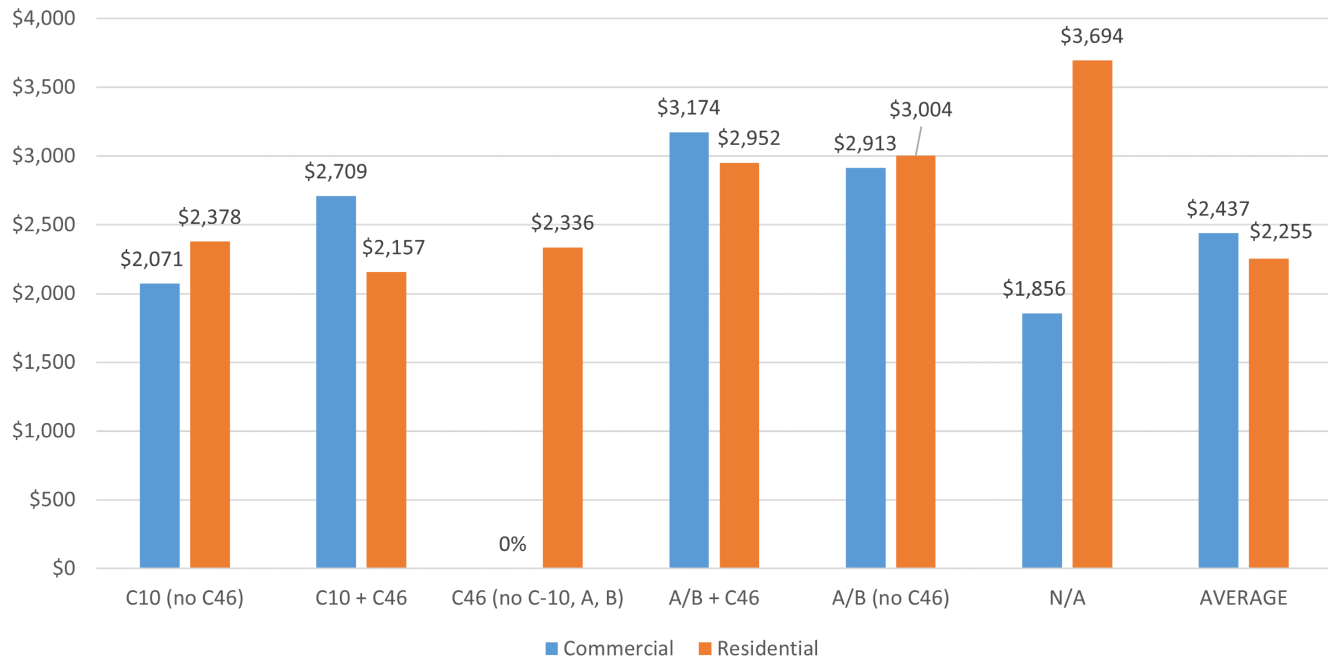


Table 13. Average Cost per kW of BESS in California, 2015–2020 (SGIP data)

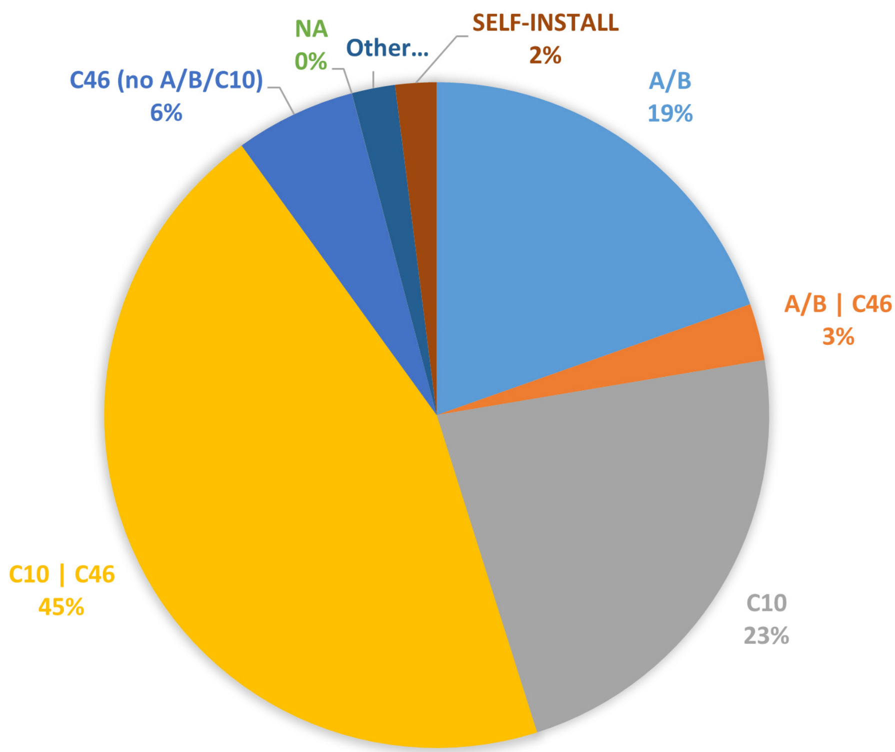
	C-10 (no C-46)	C-10 + C-46	C-46 (no C-10, A, or B)	A/B + C-46	A/B (no C-46)	NA	AVERAGE
Commercial	$2,071	$2,709	—	$3,174	$2,913	$1,856	$2,437
Residential	$2,378	$2,157	$2,336	$2,952	$3,004	$3,694	$2,255
Commercial percent of average	85%	111%	—	130%	120%	76%	100%
Residential percent of average	105%	96%	104%	131%	133%	164%	100%

3. Would the Cost Differential Change if a Ruling to Restrict C-46 Contractors Would Also Change their Solar Workforce?

CALSSA has made the argument that requiring certified electricians to connect battery storage systems when they aren't required to connect solar PV systems would have ripple costs on the solar industry, where solar contractors would also change their hiring practices. If they had to obtain C-10 licenses, then solar contractors would be required to use certified electricians for solar connections as well, putting upward pressure on costs.

The data from the Interconnection dataset shows that contractors holding a C-46 (no A, B, C-10) license install only 6% of residential solar-only systems, as shown in Figure 35. For projects approved in 2020, C-46 contractors installed 54% of residential solar projects, but most of these were installed by C-46 contractors holding another license, usually a C-10. Thus, even in solar installations without battery storage, only a small minority of installations are carried out by sole license C-46, and only these would have the cost advantage of not hiring certified electricians. Any differential in costs between those who are required to hire certified electricians and those who are not has little significance if most contractors have both licenses.

Figure 35. Residential Solar PV Installations by Contractor License Type (Interconnection Dataset, 2020)



4. The Impact of Small Cost Differentials on Consumer Demand, including the Impact of Subsidies

CALSSA stakeholders also expressed concern that CSLB restrictions of C-46 contractors will add costs to projects that are already price-sensitive. The above analysis of both modeled and actual cost differentials shows that these concerns are not borne out by the evidence.

Furthermore, price alone is not driving BESS growth. NREL interviews show that storage customers are not particularly cost-sensitive.

> Based on our industry interviews, increasing numbers of end users are willing to pay a premium for larger, more-resilient PV-plus-storage systems with enhanced back-up power capabilities, owing to the increased occurrence of superstorms and natural disasters. This decision may not always be driven by economics, given the higher costs of PV-plus-storage systems today;

however, consumer-adoption motivations extend beyond economics to concerns about security, safety, and resiliency (EuPD Research and Greentech Media 2016)."[240]

Other industry analysis draws the same conclusion. A January 2021 articled in Solar Power World Online states, "[t]he residential storage market has been growing steadily every quarter since early 2019. Wood Mackenzie is predicting that the sector will expand by six-times through 2025, *largely attributed to the desire for resiliency*."[241] [italics inserted for emphasis].

CALSSA also expressed concern that cost increases associated with the use of certified electricians could undermine the impact of governmental subsidies on the BESS market. There are several types of subsidies for BESS. The Investment Tax Credit applies to battery storage systems that are charged at least 75% of the time with renewable energy. California's Self-Generation Incentive Program also provides subsidies for storage, with a focus on resiliency. Both the federal and state incentives are subsidizing the BESS market, and some of these incentives are decreasing, expiring, or their funds exhausted.

Reviewing the SGIP data, which provides total costs for solar-paired BESS as well as incentive amounts, we found that the SGIP incentives average 37% of total costs. CALSSA's argument that contractor restrictions would raise costs enough to counteract this entire incentive does not appear to be accurate since the modeled cost impact of C-46 restrictions are 1–2% of project costs, a fraction of the incentive. The total of the residential incentives as of the April 12, 2021, weekly report was $101.5 million. Even estimating a 2% cost increase in residential BESS costs if C-46 contractors were restricted from BESS (and the 2% increase is the maximum modeled increase and higher than the actual project cost data), the potential impact would have been only $5.3 million to date, accounting for only 5% of the state subsidy. When we evaluate actual project cost data, the most reliable data we have, we see no cost impact of C-46 contractor restrictions, since the contractors conducting the majority of the BESS installations at the lowest cost already hold a C-10 license.

Table 14. SGIP Incentive Data (as of April 12, 2021)

	Sum of Current Incentive ($)	Sum of Total Eligible Costs	Incentive as % of total cost
Commercial	$ 28,433,527	$ 88,225,316	32%
Government/Education	$ 37,881,529	$ 111,415,520	34%
Multifamily	$ 7,213,802	$ 26,041,367	28%
Non-Profit	$ 11,440,426	$ 22,530,896	51%
Residential	$ 101,486,207	$ 262,622,383	39%
Grand Total	**$ 186,455,490**	**$ 510,835,481**	**37%**

In sum, the increase in wages, if it in fact occurs, is unlikely to change consumer behavior or dampen demand for BESS. Moreover, it will certainly not wipe out the impact of subsidies and incentives on consumers, which at 37% of total costs completely overwhelm any cost increases due to the wage differential between electricians and the PV workforce.

240 https://www.nrel.gov/docs/fy21osti/77324.pdf, p.52.

241 https://www.solarpowerworldonline.com/2021/01/the-energy-storage-market-is-blowing-up-in-the-united-states/.

5. The Costs of Training and Turnover

CALSSA has argued that there are other, potentially more significant, costs to consider such as higher employee turnover. Their argument is that since solar installers are trained by their employers (rather than formally) with a highly specialized skill set, they are less likely to leave their employer for work elsewhere, and this reduces turnover and benefits the industry. Certified electricians, on the other hand, have a range of skills and a wider choice of employment options. This means that if there is a better paying job, they are likely to pursue it, leaving the solar employer without a skilled worker. There are a few arguments against this point. First, if required to hire a certified electrician, the training required of the employer decreases because there is a certification process that employers can rely on to verify knowledge and skills. Second, according to government data and best available industry data, there are far more certified electricians than solar installers in California. We reason that any cost to employers of higher turnover would be mitigated by the reduced training needs and higher availability of workers. We also note that if all contractors are held to the same standard in terms of the qualifications of the workforce, this is likely to increase the wages of electricians who were formerly not certified and avoid competition based on lower wages for non-certified electricians. Also, it should be noted that higher wages reduce turnover.

We both acknowledge and agree with CALSSA's position that employer-based training can reduce employee turnover and associated costs. A U.S. Department of Labor synthesis of research on many different styles of job training reports that employers often benefit from workplace training. "For employers, who are more likely to provide firm-specific training than general training that could be valuable in the labor market outside the firm, firm training can reduce worker turnover and associated costs, and improve productivity."[242]

However, from a broader look at the economic impacts of certification requirements, our concern extends beyond industry and employer impacts to include impacts on workers and the broader economy. Through that lens, we reference research showing that broader occupational training, "particularly a degree or industry-recognized credential related to jobs in demand, is the most important determinant of differences in workers' lifetime earnings and incomes."[243] The DOL report cites research showing that individuals (with less than a bachelor's degree) with professional certifications or licenses earned more than those without these credentials, and that post-secondary training programs that result in credentials related to technology, state licensure, and in-demand occupations are associated with particularly positive outcomes.[244] The electrical certification falls into this category.

While task-specific or employer-specialized skill training can help employers, it does so by limiting the options, flexibility, and career mobility that would better serve workers in both the short term and over the course of their careers. Restricting worker mobility might keep wages low and benefit the BESS businesses, but the short- and

242 https://www.dol.gov/sites/dolgov/files/OASP/legacy/files/jdt.pdf (Citing Wagner, Shelbye (2004). An Examination of the Utility of Training: Relationships with Turnover and Promotion. Emploria State University Department of Psychology and Special Education. Unpublished manuscript; and Wagner, Richard and Robert Weigand (2004). Can the Value of Training be Measured? A Simplified Approach to Evaluating Training. Health Care Manager, Vol. 23, Issue 1, pp. 71-77. And Laurie J. Bassi, Jens Ludwig, Daniel P. McMurrer, and Mark Van Buren (2000), "Profiting From Learning: Do Firms" Investments in Education and Training Pay Off?" Research White Paper, ASTC and SABA; and Almeida, Rita and Pedro Carneiro (2008). The Return to Firm Investments in Human Capital. The World Bank Social Protection and Labor Discussion Paper No. 0822.).

243 *Ibid.*

244 *Ibid.,* citing (Holzer, H. J. & Lerman, R. I. (2009). The Future of Middle-Skill Jobs. Brookings Institution. https://www.brookings.edu/research/the-future-of-middle-skill-jobs/; and Jacobson, L. S., LaLonde, R. J., & Sullivan, D.G. (2005). Estimating the Returns to Community College Schooling for Displaced Workers. *Journal of Econometrics*, 125(1-2). Retrieved from http://repec.iza.org/dp1017.pdf; and Jepsen, C., Troske, K., & Paul Coomes. 2009. The Labor-Market Returns to Community College Degrees, Diplomas, and Certificates. University of Kentucky Center for Poverty Research Discussion Paper Number 2009-08. Retrieved from http://www.ukcpr.org/Publications/DP2009-08.pdf.)

long-term economic benefits of broader occupational training and industry-recognized credentials need to be weighed against the benefits that accrue to employers from the restriction of such training. We do not find there to be a compelling argument or evidence that enhancing worker mobility by requiring the use of certified electricians for the electrical work associated with battery installation will have devastating consequences for the BESS industry.

On the contrary, skills certifications help California workers and the economy. This is reflected in support for industry-recognized credentials in the State's Unified Strategic Workforce Development Plan, where it is identified as a key strategy of the California Labor and Workforce Development Agency.[245] Industry recognized credentials such as the electrical certification provide signals to public training institutions on what to train for and helps the industry tap into public sources of training and education funding. The lack of a skill standard results in inconsistent training carried out by contractors on the job, poorer wages and benefits, and fewer opportunities for transferability and career advancement for workers.

Further, while not all certified electricians have been trained through registered apprenticeship, the DOL report indicates that registered apprenticeship is particularly valuable to workers, resulting in $8,000 higher earnings initially and over $200,000 in their lifetime more than a comparison group of individuals who did not participate in registered apprenticeships.[246] The Newsom administration has identified expanding the number of apprentices in registered apprenticeship programs, like the electrical apprenticeship programs, as a key goal of his labor and workforce development policy.[247] Although apprenticeship is not the only path to obtaining an electrical certification, it is a common path and one that can help disadvantaged workers access earn-while-you-learn training into a middle-class skilled construction career, especially when paired with pre-apprenticeship. The electrical certification also aligns with the state's policies to support increased equity through its investments in and commitment to registered apprenticeship and pre-apprenticeship programs. This is reflected in the state's commitment to its High Road Construction Careers program.

6. Transition Costs for Alternative Rulings by the CSLB

Whenever a State regulation changes the status quo, there can be transition costs as companies adjust their business and labor practices. We analyze the likely costs of transition for two scenarios: 1) Prohibiting C-46 license holders from installing BESS projects, no matter their size or customer class, and 4) Allowing C-46 license holders to install BESS. Since the safety analysis showed that there was no logical threshold at which risks were minimal and at which lower worker qualifications would be unnecessary, we do not evaluate transition costs for these partial restrictions.

a) Transition Costs for Restricting BESS Installations by C-46

Because C-46 contractors without an A, B, or C-10 license install such a small number and percentage of distributed BESS installations, we anticipate very small transition costs. The firm with the most at stake in terms of

245 https://cwdb.ca.gov/wp-content/uploads/sites/43/2020/09/Strategic-Planning-Elements.Final_ACCESSIBLE.pdf, p. 29.

246 *Ibid.*, citing Kleinman, Liu, Mastri, Reed, Reed, Sattar, & Ziegler (2012). An Effectiveness Assessment and Cost-Benefit Analysis of Registered Apprenticeship in 10 States. Mathematica Policy Research. Prepared for the U.S. Department of Labor, Employment and Training Administration.

247 https://cwdb.ca.gov/wp-content/uploads/sites/43/2020/09/Strategic-Planning-Elements.Final_ACCESSIBLE.pdf, p. 23.

the size of their BESS work is James Petersen Industries (aka Solar 4 America and Petersen Dean), the only large C-46 (no A, B, C-10) contractor installing a fair number of BESS. This contractor already has several violations and problems that will require changes if the firm hopes to stay in business.

It is also important to note that C-46 contractors who would be affected by a CSLB ruling to restrict the use of C-46 licenses for BESS could obtain C-10 licenses, as have so many other C-46 contractors already. In addition, these employers could assist their non-certified electricians by supporting them to becoming certified electricians, which would benefit the workers.

CALSSA has expressed concerns about the costs of transition if the CSLB rules that BESS is not within the scope of C-46 license. This seems to stem from the fact that some solar companies who hold both C-46 and C-10 are following the practice of hiring non-certified electricians for solar and BESS electrical work, justifying this by asserting that this work is carried out under their C-46 license. As stated earlier, we asked for clarification about this practice from the CSLB, who stated unequivocally that contractors holding both C-46 and C-10 licenses are legally required to use certified electricians for all electrical work, including the specific electrical tasks associated with solar PV and BESS. We were not able to ascertain how many contractors with both C-46 and C-10 are violating the law by employing non-certified electricians, and it appears enforcement is limited. Enforcement of the regulation requiring certified electricians for contractors with both a C-10 and a C-46 is a separate issue which is outside the scope of this study. For these dual license holders, a ruling by the CSLB to restrict the C-46 license from installing BESS would not affect their businesses since they already have C-10 licenses. The cost impact of a transition would only be significant if a CSLB ruling to restrict C-46 was accompanied by more vigorous enforcement of the certified electrician requirement, and if violations of this requirement were widespread.

As noted in Section III. D., restricting C-46 (no A, B, C-10) contractors will affect very few jobs. Even for those contractors who are carrying out most of the BESS installations performed by this category of license holder, BESS represents a small amount of work. To repeat the illustration, the average cost of installed BESS in California is $15,000, and installation labor is estimated by NREL to be less than 10% of the cost. For those contractors installing 15 projects, their labor costs would equal less than $22,500, so even firms installing 15 in a year do not require even a single full-time employee to do so. Restricting or precluding C-46 contractors from installing BESS would have a very small and manageable impact on contractors and their employees. Using the BESS installation labor cost estimate of $1,000 – $1,500 per residential system, C-46 (no A, B, C-10) contractors would have spent $600k – $900k on installation labor in 2020. Assuming they are paying average wages of $25 per hour, this equates to 11.5 – 17.3 jobs measured in full time equivalent (FTE) statewide.

It is also important to note that while the project costs vary only slightly between projects using certified vs. non-certified electricians, job quality varies substantially, with certified electricians earning substantially more than non-certified electricians. While there is no data source that credibly specifies this wage differential, both CALSSA and the electrical industry confirmed that it is substantial. Evidence from government data as well as both CALSSA and NECA show higher wages for certified electricians than the solar workforce including non-certified electricians. Restricting C-46 contractors would help support companies that hire, invest in, and remunerate a higher skilled workforce, as is the goal of the state's high road strategy as expressed in the Strategic Workforce Plan.[248]

248 https://cwdb.ca.gov/wp-content/uploads/sites/43/2020/09/Strategic-Planning-Elements.Final_ACCESSIBLE.pdf, p. 29.

We therefore conclude that the transition costs for restricting C-46 contractors would be minimal. Restricting C-46 contractors could actually improve conditions for current workers if these businesses take advantage of the opportunity to help certify their electricians and learn to compete using business strategies that do not include a lower wage workforce.

b) Transition Cost for Allowing BESS Installations by C-46

Since the share of contractors currently installing BESS who are C-46 (no A, B, or C-10) is small, a ruling that these contractors cannot install BESS systems would only minimally impact the current pool of BESS contractors in California. It would, however, impact the future trajectory of the industry, because it would likely expand the number of C-46 (no A, B, or C-10) contractors. Evidence from government data as well as both CALSSA and NECA show higher wages for certified electricians than the solar workforce including non-certified electricians. In a competitive market, lower wages provide a competitive edge, all else being equal. This could result in downward pressure on wages for electricians and greater competitive pressures on C-10 contractors who invest in a higher skilled workforce. These adverse impacts would likely not be offset by lower costs to consumers since C-46 contractors without a C-10 license are not consistently the lowest cost contractor group and, in most cases, have higher costs than contractors with both C-10 and C-46 licenses. We therefore conclude that there are transition costs associated with a ruling to allow C-46 license holders to install BESS.

VI. Conclusion

In conclusion, we strongly recommend that the CSLB limit the scope of the C-46 to its original scope and preclude C-46 (no C10) license holders from installing BESS. We see no public policy justification for the CSLB to encourage a future trajectory of the BESS industry with lower standards and lower requirements for worker qualifications compared to the present pool of contractors. Only a very small share of the current pool of contractors that carry out BESS installations are C-46 (no C-10, A, or B) contractors and are exempt from the requirement that individuals carrying out electrical work be certified electricians. This research result shows that the current pool of BESS installers has higher qualifications than might be the case if the CSLB permits the C-46 license to cover BESS.

Our hazards, risks, and safety analysis shows substantial hazards related to this rapidly evolving technology and buttresses the argument that there is a need for qualified personnel to mitigate risks. BESS are a dynamic and expanding technology with inherent hazards that are significant; they have led to continuing serious incidents; they are recognized by NFPA as a "high risk hazard"; they have led to the development of significant ongoing code and standard revisions and new safety mitigations; they are currently predominately installed under C-10 contractors requiring the use of certified electricians with demonstrated skills and safety training needed to address the safety issues identified. Finally, we find that there lacks a justifiable threshold by size or sector to suggest less hazard or insignificant risk for BESS installation, and therefore we recommend C-10 licenses be required for all sizes and customer classes of BESS. While in California there have been no significant incidents with injury or death that we could identify, there are significant data gaps that preclude definitive statements that risks are low. There have been serious incidents in other regions, particularly in grid-scale BESS, but we found no evidence that the risk of BESS technologies is minimal in residential or commercial applications. Because of this, we classify the BESS technologies in the category of high consequence, low frequency risk, which requires a contractor and workforce with broad knowledge of electrical systems and electrical safety. Since such a small percentage of BESS projects have been installed by C-46 (no C-10, A, or B), we also note that the safety record is extremely limited for this group of contractors, further undermining an assessment that C-46 (no C-10, A, or B) contractors can credibly mitigate safety risks.

Since the main difference between the C-46 and the C-10 is the latter's requirement that their electrical employees be certified, we conclude that the C-10 workforce is more highly trained and trained in the broader safety and electrical system assessment knowledge than the C-46 workforce. The CSLB rule that contractors with both a C-10 and a C-46 license must adhere to the certified electricians requirement means that only C-46 (no C-10) contractors do not have to meet the higher standard for their workforce. Our review of the curriculum of the electrical certification shows that certified electricians have the relevant skills, knowledge, and experience to confidently be classified as "qualified personnel." No such review of the C-46 (no C-10) electrical workforce is possible since there is no comparable skill standard, and therefore we cannot confidently classify these workers as "qualified personnel."

We also conclude that there will be no adverse economic impacts of precluding the C-46 license from BESS. We document that C-10 contractors and certified electricians are plentiful and can expand as demand for BESS increases. C-10 contractors, with or without C-46 licenses, are much more numerous than C-46 contractors and have entered this market in greater numbers than C-46 (no C-10) contractors. This is true for both the residential and commercial markets and for urban and rural counties. We also document no significant savings in project costs with installations performed by C-46 (no C-10) contractors, even though there is agreement that the wages of certified electricians are higher than the C-46 non-certified electrical workforce. This may be because labor costs, and particularly the costs of work that is performed by electricians (certified or not), is a small percentage of total costs, and the consequent differential in total cost is minimal. The lowest cost contractors have both C-10 and C-46 licenses and are held to the certification requirement, but have apparently found cost savings that make up for the higher wages of certified electricians. Finally, we find that the transition costs of precluding C-46 contractors from installing BESS are minimal since C-46 (no C-10) contractors and their electrical workforce are currently such a small share of all contractors and workers who have installed BESS in California. There would be an adverse economic impact from allowing C-46 contractors to install BESS because that would likely undermine the electrical certification and put downward pressure on the wages of certified electricians.

The decision before the CSLB will shape the future trajectory of the BESS industry. A decision to allow C-46 contractors to install BESS, whatever the size or customer class, could result in lower workforce skill standards and greater risk to the public from faulty installations. All else being equal, it is better to support the expansion of that segment of the existing pool of contractors who invest in a more skilled workforce by hiring certified electricians, rather than increase the risks associated with a less qualified workforce.

VII. Appendices

A. Data Sources and Methodology for Profile of Contractors by Licenses

This analysis was conducted by mapping the CSLB contractor database against the California Self Generation Incentive Program (SGIP)[249] (for electrochemical projects paired with solar PV) with program years from 2015 onward. The SGIP dataset lists project data, including manufacturer, size of system, location, and customer sector as well as the name of the installer. In addition, we analyzed the 2020 Interconnection data provided to us by CALSSA at our request, and matched all contractors to their license using the SGIP file and the CSLB data. The Interconnection dataset includes more information on the installers that could be used to identify the contractor license, including phone numbers and, starting in 2020, license numbers. The sheer size of the Interconnection dataset across 5 years, however, made it difficult to properly clean the data to match installers against the CSLB files.

The electrical industry stakeholders conducted license matching analysis on the Interconnection dataset and provided their data as well as a summary. We compare the trends in our findings from the SGIP dataset against the electrical industry's summary findings using the Interconnection dataset for 2015 – 2020.

To match the installer provided in each dataset to the CSLB contractor databased, we first cleaned the installer record to a single name that match the CSLB file. In some cases, this meant adding or removing a period from "Inc," and for firms using "doing business as" (dba) names, we made the names consistent with the CSLB data. Several firms such as James Petersen Inc (dba Solar 4 America), Tesla, Baker Electric, and others use a wide range of names; these were standardized manually. Once cleaned, we applied VLOOKUP function in MS Excel to then the installer names with the CSLB active license file. And then, for those records that showed no results, we manually searched the CSLB database to find the appropriate licenses for each installer.

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B. Contractors Installing 15 or More Storage Projects

Table 15. Contractors Installing 15 or More Storage Projects

C-46 (no C-10, A or B) Contractors who've installed more than 15 projects since 2015 (SGIP dataset)	**C-46 (no C-10, A or B) Contractors who installed more than 15 projects in 2020 (Interconnected dataset)**
James Petersen Industries Inc dba Solar 4 America	James Petersen Industries Inc dba Solar 4 America
Sea Bright Solar Inc dba Sunpower By Sea Bright Solar	Solar Tech Energy Systems Inc
Skytech Solar	Phoenix Solar Energy
Bay Area Energy Solutions inc	Sea Bright Solar Inc
Phoenix Energy Fulfillment Inc dba Phoenix Solar Energy	Southern California Energy Alternatives Inc
	West Coast Solar Inc
	Skytech Solar
A/B + C-46 Contractors who've installed more than 15 projects since 2015 (SGIP dataset)	**A/B + C-46 Contractors who installed more than 15 projects in 2020 (Interconnected dataset)**
Hot Purple Inc dba Hot Purple Energy	Hot Purple Inc dba Hot Purple Energy
Sun First! Inc	Sun First! Inc
Green Air Heating and Air Conditioning Inc	Green Air Heating and Air Conditioning Inc
Treeium Energy Inc	
Ho So Po Corp dba Horizon Solar Power	
C-10 Contractors who've installed more than 15 projects since 2015 (SGIP dataset)	**C-10 Contractors who installed more than 15 projects in 2020 (Interconnected dataset)**
Sullivan Solar Power Of California Inc	Sullivan Solar Power Of California Inc
Solare Energy Inc	Solare Energy Inc
V3 Electric Inc	V3 Electric Inc
Cobalt Power Systems Inc	Solar Optimum Inc dba Solar Optimum Design & Electrical
Sunlux	Stellar Energy GP Inc dba Stellar Solar
Joe Anthony Flores	Kuubix Energy Inc
Tlp Electric Integrations Inc dba Infinity Electric	AM Sun Solar

Plug It In Systems Inc	Tlp Electric Integrations Inc
Solar Forward Electric Inc	Gold Rush Energy Solutions
SST Construction LLC dba Sunsystem Technology	Sunergy Construction
AM Sun Solar	Quality Home Services
California Solar Electric Cooperative Corp dba California Solar Electric Co	Green Convergence
Jilbert Electric Inc	Coastal Constructors
SolarCo Inc	American Solar Corporation
Stellar Energy GP Inc dba Stellar Solar	Northern Pacific Power Systems Inc
Sunergy Construction Inc	Your Energy Solutions
Photon Brothers Inc	Sunlux
G C Electric Corporation dba G C Electric Solar	
Summit Technology Group Inc	
Perk Solar Inc dba Perk Solar Electric	
Renewable Energy Advantage	
Solar Optimum Inc dba Solar Optimum Design & Electrical	
Allterra Environmental Inc dba Allterra Solar	
Green Convergence	
Pacific Electric Solar	
Northern Pacific Power Systems Inc	
Santa Cruz Westside Electric Inc dba Sandbar	
Synergy Power	
N R G Clean Power Inc	
Gold Rush Energy Solutions	

C-10+ C-46 dual license contractors who've installed more than 15 projects since 2015 (SGIP dataset)	**C-10 + C-46 Contractors who installed more than 15 projects in 2020 (Interconnected dataset)**
Sunrun Installation Services Inc	Sunrun Installation Services Inc
Tesla Energy Operations Inc	Tesla Energy Operations Inc
Semper Solaris Construction Inc	Semper Solaris Construction Inc
Swell Services Inc dba Swell Contractors	Baker Electric Inc

La Solar Group Inc dba A P Electrical	Vivint Solar
Baker Electric Inc	Infinity Energy Inc
Infinity Energy Inc	Hooked on Solar Inc
Hooked on Solar Inc	Freedom Solar Co
Xero Solar	LA Solar Group
Luminalt Energy Corporation	Westhaven Inc dba Westhaven Power
Renova Energy Corp	Swell Services Inc dba Swell Contractors
Solarponics Inc	Simply Solar dba Rockin Roofers
Freedom Forever LLC	Xero Solar
Westhaven Inc dba Westhaven Power	Renova Energy Corp
Clean Solar Inc dba Clean Electrical	Luminalt Energy Corporation
Home Energy Systems Inc	Solarmax Renewable Energy Provider Inc
Alternative Energy Systems Inc	Home Energy Systems Inc
Future Energy Corporation dba Future Energy Savers	Asi Hastings, Inc
Jaj Roofing dba Citadel Roofing And Solar	Pure Power Solutions
Distribugen Inc dba Pure Power Solutions	Got Watts Electric & Solar
Solarmax Renewable Energy Provider Inc	Clean Solar Inc dba Clean Electrical
Home Networks Electric & Solar Incorporated	Jaj Roofing dba Citadel Roofing And Solar
Synergy Solar & Electrical Systems Inc	Precis Solar
Simply Solar dba Rockin Roofers	Solar Technologies
Solar Technologies	Sunpro Solar Inc
Sunpro Solar Inc	Synergy Solar & Electrical Systems Inc
Valley Solar Inc	Solarponics Inc
Rochlin Corporation dba Blue Sky Energy	
1st Light Energy Inc	

About the Authors

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Carol Zabin directs the UC Berkeley Labor Center's Green Economy Program. She is a labor economist whose research has addressed low-wage labor markets, labor standards, workforce development, and other economic development and labor issues in the United States and Mexico. Dr. Zabin has consulted with numerous unions and non-profits on strategies and policies to improve jobs in human services and the green economy. Her current research focuses on the impact of climate and clean energy policy on California's economy, workers, and labor unions. Recent publications include *Diversity in California's Clean Energy Workforce*, *Advancing Equity in California Climate Policy*, and *Workforce Issues and Energy Efficiency Programs*. Appointed by Governor Brown, Dr. Zabin sits on the executive council of the California Workforce Development Board and chairs the board's Green Collar Jobs Council. Before joining the Labor Center, Dr. Zabin was on the faculty at Tulane University and UCLA. She earned her PhD in economics at the University of California, Berkeley.

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Don Holmstrom has over 35 years of experience conducting incident investigations for industry and US government involving technical, regulatory, and organizational analysis of hazards, risks, and needed preventative actions. He led or managed investigation and recommendations activities for over 70 incidents at the US Chemical Safety Board (CSB), retiring as the Director of the Western Regional Office in 2016. Holmstrom managed many of the largest and most significant chemical incident investigations in recent US history, including the 2005 BP Texas City explosion; the 2010 Tesoro Anacortes, Washington, oil refinery fire; the 2010 Deepwater Horizon offshore fire and explosion; and the 2012 Chevron Richmond, California, oil refinery fire.

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