Zero Net Energy: 7,000 kWh/yr to Near Zero in 12 Years Flat

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ABSTRACT

In response to the environmental and economic impacts of energy consumption, in 2008 the California Public Utilities Commission proposed that the state set goals that all new homes achieve Zero Net Energy (ZNE) by 2020 and all new commercial buildings reach ZNE by 2030. This paper documents the changes to the building construction industry and the path to the California Energy Commission (CEC) adoption of the 2019 Building Energy Efficiency Standards (Title 24, Part 6) that requires all new low-rise residential construction achieve near ZNE or equivalent. This paper describes the sustained efforts to collect reliable information, develop software tools and convince decision makers that this goal was not just aspirational, but achievable and cost-effective. The Title 24, Part 6 standards are structured with California's energy "loading order" in mind; first energy efficiency, then layering on renewables and storage to comply with a minimum energy design rating (EDR) of 15-27, which is comparable to a National Home Energy Rating System (HERS) rating of 15-27. Increasing efficiency, when it is less costly than renewables, can be used to reduce the first cost of the home. The energy efficiency and renewable energy features of a minimally compliant California home permitted after January 1, 2020 are described along with a prediction of what's next for future codes. The paper summarizes lessons that could be applied in other states pursuing ZNE standards and to the fast-approaching 2030 commercial ZNE goal.

Background

Unquestionably, the hand of humanity has reshaped the face of the earth and the biosphere. Satellite images of the earth at night reveal this unequivocally. Satellite imagery in the ultraviolet spectrum illuminates the changes to the ozone layer over decades. Time lapse photography of the ice caps and glaciers, and ice cores containing ancient air dating back millennia tell a similar story about CO_2 and global warming.

Societies and governments have formed to accomplish what individuals are incapable of doing individually: defend against common threats and promote the common good. These threats may appear invisible: whether it is a microbe in the water or an invisible gas that warms the planet. Societies have successfully responded to these invisible threats. The cholera epidemics that swept through London in the mid-1800s were traced to bacteria in drinking water. At a great but necessary expense for the common good, the sewer systems and water treatment systems around the world were created.

California has a beautiful natural environment that attracts tourists to visit and many that stay here have a deep appreciation for nature. The geography of the state has prevailing westerly winds that push smog generated by its 40 million inhabitants and associated industries up against the Sierra and San Gabriel mountain ranges resulting in some of the highest particulate and Ozone levels of anywhere in the United States. California is vulnerable to significant environmental and economic threats from global warming including loss of standing forests, aquifer depletion, loss of coastal land, or crop losses. The combination of environmental ethos

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and high pollution levels have resulted in policy leadership on air pollution regulations, building and appliance efficiency regulations and greenhouse gas regulation.

AB 32 and California's Landmark Greenhouse Gas Goals Set State Policy

Passage of AB 32, the California Global Warming Solutions Act of 2006, required that state agencies develop and implement a plan that would reduce the amount of Greenhouse Gas (GHG) emissions to 1990 levels even though the population in California will have simultaneously increased by 40 percent (AB 32 Nunez). The California Air Resource Board (CARB) was designated the lead agency and with assistance from the other state agencies developed the AB 32 Initial Scoping Plan (CARB 2008) with revisions published to the plan on 5 year intervals. The scoping plan identified the end uses associated with GHG emissions in the state and developed a rough top down plan for reducing GHG's by 20 percent. Out of the 146.7 Million Metric Ton reduction target for the capped Carbon sector, 28.4 Million tons of CO_2e or 19 percent of this reduction was expected to result from appliance and building efficiency and rooftop solar.

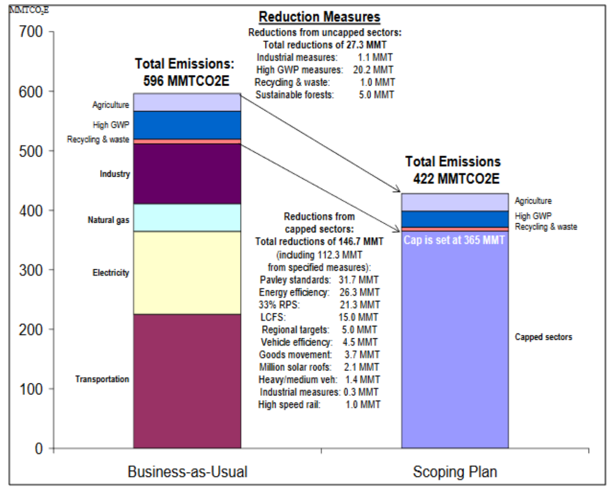

Figure 1: Scoping plan itemized GHG reductions (CARB 2008)

The 2030 Challenge,[2] issued by Architecture 2030 and supported by the American Institute of Architects, set progressively increasing energy efficiency and renewable energy goals for commercial buildings so that by 2030 all new commercial buildings will be Zero Net Energy, using the site energy definition, with no more than 20 percent of the offsets to energy consumption coming from offsite renewables. A similar concept is incorporated into the California Public Energy Commission (CPUC 2008) Big Bold Energy Efficiency Strategy (BEES) for dramatically reducing energy consumption in the building sector:

1. All new residential construction in California will be Zero Net Energy by 2020;
2. All new commercial construction in California will be Zero Net Energy by 2030;
3. Heating, Ventilation and Air Conditioning (HVAC) will be transformed to ensure that its energy performance is optimal for California's climate; and
4. All eligible low-income customers will be given the opportunity to participate in the low income energy efficiency program by 2020.

However, without a direct legislative mandate the ZNE strategies were considered "aspirational." (CPUC 2013) Pursuing these strategies had to be within the current scope of the Energy Commission's energy codes as authorized by the Warren-Alquist Act and within the CPUC's scope of Investor Owned Utility (IOU) operated energy efficiency programs.

The Warren-Alquist Act (2016) requires that updates to the California Building Energy Efficiency Standards (Title 24, Part 6), *"…shall be cost-effective when taken in their entirety and when amortized over the economic life of the structure compared with historic practice. When*

[2] http://architecture2030.org/2030_challenges/2030-challenge/

determining cost-effectiveness, the commission shall consider the value of the water or energy saved, impact on product efficacy for the consumer, and the life cycle cost of complying with the standard." The standards had to be cost-effective on a life cycle basis without impairing the amenities of a modern building.

Infrastructure for ZNE Codes

If you have built castles in the air, your work need not be lost; that is where they should be. Now put the foundations under them. — Henry David Thoreau (Walden)

Definitions of Zero Net Energy

When developing the Big Bold Energy Efficiency Strategy, the CPUC defined Zero Net Energy as: *"A ZNE home employs a combination of energy efficiency design features, efficient appliances, clean distributed generation, and advanced energy management systems to result in no net purchases of energy from the grid. The CPUC has defined "Zero Net Energy" at the level of a single "project" seeking development entitlements and building code permits in order to enable a wider range of technologies to be considered and deployed, including district heating and cooling systems and/or small-scale renewable energy projects that serve more than one home or business."(CPUC 2008)*

As simple as this definition might be, there were a number of definitional issues that had to be addressed:

- When a home is served by more than one energy source, (i.e. electricity and natural gas) are trade-offs between exported renewable electricity and imported sources based on site energy (energy delivered to the site), source energy (accounts for total upstream energy consumption including losses and fuel burned at the power plant) or TDV (time dependent valuation of hourly present value of cost of energy that accounts for energy costing more during peak periods)?
- Should exported renewable energy offset embodied energy in the structure?
- Should exported renewable energy offset transportation energy?

An analysis by McHugh (2011) identified that for a mixed-fuel (space heating and water heating provided by natural gas) house, a site energy definition would require a 50 percent larger photovoltaic (PV) system than one using a source energy definition and would be almost twice as large as the required system size when using a TDV energy definition under the 2013 Title 24 code. Additionally the sizing of the PV system using TDV was closest to that needed to offset all electrical consumption in a mixed-fuel home whereas the other definitions would result in PV system sizes that would generate more electricity than the home would consume   Net Energy Metering (NEM) credits the customer's electricity bill at the retail rate for each kWh exported that is less than the total kWh consumed over a year. If the renewable energy system is oversized, and more kWh of electricity is exported than imported (over-generation), the additional exported electricity is credited at the wholesale rate, which is one fifth of the retail rate. Renewable energy systems that are sized appropriately and do not generate more electricity than the consumer uses, are more cost-effective as all the exported electricity is credited to the customer at the higher retail rate. Though embodied energy and locational efficiency are valid considerations, (Goldstein & Bacchus 2012) the ZNE target by itself was sufficiently stringent and cities have other tools in their general plan and zoning regulations to address these important issues.

The 2013 Integrated Energy Policy Report (CEC 2013a) included this clarified definition of a TDV-based ZNE Code Building: *"A Zero-Net-Energy Code Building is one where the net* *amount of energy produced by on-site renewable energy resources is equal to the value of the energy consumed annually by the building, at the level of a single "project" seeking development entitlements and building code permits, measured using the California Energy Commission's Time Dependent Valuation metric.*

A zero-net-energy code building meets an energy use intensity value designated in the Building Energy Efficiency Standards by building type and climate zone that reflect best practices for highly efficient buildings." The second half of this definition is significant; it clarified that the ZNE policy was not just a policy to add solar to roof tops, these roofs were going to be on very efficient buildings.

Technical Feasibility and Cost-Effectiveness

In the context of requiring ZNE in the building energy code, two key questions for ZNE homes are: Will there be enough roof area for most homes to meet all loads with photovoltaics? Is the first cost low enough and are the operating cost savings high enough to render photovoltaics cost-effective?

An early answer to these questions was contained in the Arup (2012) Technical Feasibility of ZNE study, conducted on behalf of the California IOUs. This study found that it was technically feasible with technologies expected to be available by 2020 to reduce energy use by half through energy efficiency measures and to support the rest with photovoltaics. The efficiency measures needed to meet this 50 percent reduction in energy consumption included: variable-speed night ventilation cooling, ducts in conditioned space, quality insulation installation, R-60 ceiling insulation, 2-inch x 6-inch walls with R-21 cavity insulation and R-4 continuous insulation, cool roofs with 40 percent solar reflectance, high performance windows (U-0.20/S-0.25), high-efficacy lighting, condensing gas combined water and space heating, and SEER 21 air conditioning.

As an example, a single story 2,100 square foot home located in Sacramento, CA (California climate zone 12, ASHRAE Climate Zone 3B) could install efficiency measures that would cut energy production in half. After applying the energy efficiency measures, 2.5 kW of installed solar would yield zero net TDV energy; for a PV system with 15 percent panel efficiency, this would require approximately 180 square feet of PV panels for a 2,100 square foot home.

This feasibility study estimated that first cost was roughly about half of the life cycle cost savings of the efficiency and renewable energy measures. As a result the benefit-to-cost ratio of ZNE homes would be around two to one. Therefore, ZNE homes would likely be cost-effective and suitable for inclusion in a future version of Title 24, Part 6. This provided an early indication to state policy makers that the ZNE could be required by the Building Energy Efficiency Standards as it implied that feasibility and cost-effectiveness were achievable.

Of the loads that are possible to regulate through Title 24, federal preemption prevents regulation of equipment efficiency for end-uses accounting for 17 percent of total electrical loads and 83 percent of gas loads by state equipment efficiency regulation (i.e. the heating and cooling loads on these devices can be regulated by California's energy efficiency codes, but the equipment efficiencies must match the Federal minimums). Interior lighting is the largest single electrical end-use, but only the portion that is hard-wired (with the exception of some task lighting) can be regulated by Title 24, Part 6. Therefore, increasing efficiency of buildings can only partially be addressed within Title 24, Part 6. Intervention also has to occur in California's Appliance Efficiency Regulations (Title 20) and federal appliance regulations. The main opportunities in Title 24 include envelope measures that reduce heating and cooling loads, water heating and lighting efficiency.

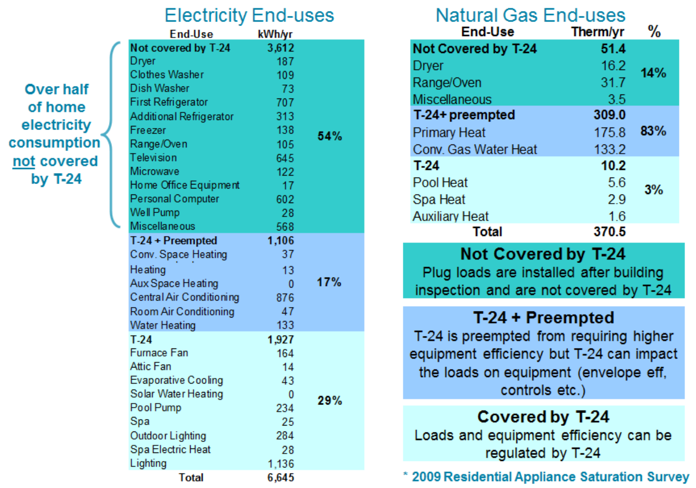

Figure 2: Components of Energy Consumption for New Homes (RASS 2009) that are regulated by Title 24, Part 6.

Moving from Aspirational to Foundational

Although the ZNE goals were not directly mandated by legislation, they were administratively interpreted to be one of the strategies used to accomplish the reduction in GHG's mandated by AB 32 as long as ZNE was found to be cost-effective and compatible with the requirements in the Warren-Alquist Act. The AB 32 Initial Scoping Plan (CARB 2008), included ZNE goals as part of the cross-cutting energy efficiency plan to reduce GHGs as well as an integral component of the Green Building Strategy with top down energy efficiency targets. The ZNE goals for homes and buildings have been repeated in all the updates to the scoping plan. The Energy Commission, with assistance from the Statewide Utility Codes and Standards program, would develop bottom-up efficiency measures in Title 20 and Title 24 to meet the top-down goals. The Integrated Energy Policy Reports (IEPR) mentioned the ZNE goals as an energy efficiency strategy for residential and commercial buildings in every version of the IEPR starting in 2007 to the present. The CPUC developed a ZNE Action plan that committed utilities to provide training and incentives for builders to install high performance attics (insulated roof deck) and highly insulated walls, which are two important energy efficiency strategies. Since the passage of AB 32, Governors Schwarzenegger and Brown, the State Assembly and the State Senate have supported GHG reductions and ZNE as long as it complies with the Warren-Alquist definition of cost-effective. This reflects the broad support for energy efficiency and renewables in California and the power of living within one's environmental footprint. High levels of public support for energy efficiency standards and renewables is also reflected in national polls, indicating that this type of approach is possible in other states. (McHugh et al. 2016, Pew Research Center 2017)

SB1 Solar Incentives, Net Metering, Cost-effectiveness Report

Roof top solar is an essential component of ZNE homes. The environment for rooftop solar in California was assisted by the passage of *SB1, Murray. Electricity: solar energy: net metering*. (SB1 2006). SB1 was the enabling legislation behind the California Solar Initiative (CSI) and the

New Solar Homes Program (NSHP), which besides providing rebates for rooftop solar systems also collected information on how much these systems cost and how much energy they were generating. SB1 also updated net energy metering (NEM) rules, which required public utilities to provide bill credits for exported solar generated electricity at values equivalent to retail rates. This legislation required new home developers to provide a solar option or build a solar system elsewhere that generated enough energy to be equivalent to 20 percent of the homes having photovoltaic systems. Finally, SB1 required that the Energy Commission *"initiate a public proceeding to study and make findings whether, and under what conditions, solar energy systems should be required on new residential and new nonresidential buildings, including the establishment of numerical targets. As part of the study, the commission may determine that a solar energy system should not be required for any building unless the commission determines, based upon consideration of all costs associated with the system, that the system is cost effective when amortized over the economic life of the structure."*

The Energy Commission's SB1 report found that in most cases, on-site solar was cost-effective. (CEC 2013b) This report assumed a 20 percent decline in the cost of rooftop solar for each doubling in installed capacity. Thus by 2020 the installed cost of solar systems smaller than 10 kW was expected to be between $3.10 and $4.00 per kW. When using the time dependent valuation (TDV) approach, rooftop solar was found to be cost-effective for most applications. Concurrently increasing renewable portfolio standards (RPS) for California and other states increased purchasing of photovoltaics for large utility scale renewable energy generation. This further increased volume of solar and resulted in even more cost reductions.

Four years later, when the cost-effectiveness of rooftop photovoltaics was revisited for the Energy Commission proposal for the 2019 Building Energy Efficiency Standards, the current incremental installed construction cost had dropped to $2.93 per DC rated Watt for the entire system including panels, inverters, balance of systems, labor etc. As the time to 2020 shortened, PV costs fell and the certainty that these costs would be valid in 2020 increased. However, due to the growth of solar for meeting California's RPS, the relative value of electricity during times when rooftop solar is exporting electricity has dropped. (E3, 2016) Nonetheless, under the 2017 net energy metering rules (NEM 2.0), projected cost-effectiveness was easily achieved with benefit to cost ratios around 2.0. Even when the customer received bill credits for exports of PV generated electricity valued at marginal avoided costs, and the reduction in electricity purchases (imports) were valued at the full retail rate, the benefit to cost ratios would be 1.5. Since cost to benefit ratios were greater than 1.0, this was deemed to be cost-effective. (E3 2017)

Photovoltaic Modelling in 2016 CBECC-Res Residential Performance Method Software

In California most low-rise residential new construction demonstrates energy code compliance using the performance approach.[3] The performance approach makes use of whole building simulation software (in California, this software is CBECC-Res) to compare the TDV energy consumption of proposed design against a base case "standard design" that is minimally compliant with the energy code. TDV energy is a present valued costing of energy on an hourly basis that accounts for energy costing more during times when loads are high relative to how much energy capacity is available.

The CBECC-Res software automatically generates the base case from the description of the proposed design and compares the energy budget of the proposed design with that of the

[3] http://cabec.org/wp-content/uploads/2012/01/T-R_workingWithYourClients.pdf

standard design. The energy budget in this context is the energy consumption of prescriptively regulated energy measures: HVAC and water heating. Lighting is regulated, but since lighting requirements are mandatory and not prescriptive they are not subject to trade-offs and not simulated as regulated loads. Plug loads (refrigerators, washing machines, dryers, dishwasher, consumer electronics etc.) are not regulated by the building standards and they are not simulated as regulated loads.

The simulation of photovoltaics in CBECC-Res was first introduced to support the 2016 Title 24, Part 6 code cycle. This was a necessary pre-condition for developing a performance based Zero Net Energy code whether for the entire state or as a reach code. Prior to 2016 the reach codes that included photovoltaics requirements were limited to prescriptive photovoltaic approaches. Using the performance approach provides an estimate of total electricity loads, including both regulated loads and non-regulated loads, and allows the designer to maximize cost-effectiveness of their solar system by making sure the system does not generate more electricity than is used annually. A net energy target is then calculated to determine the required PV system size to offset estimated electricity loads. Integrating the PV calculations into the performance software in the prior code cycle provided the opportunity for practitioners to use the feature in advance of the code requirement. Reported issues were exposed and corrected, and this increased the confidence of the building community that the PV requirements were feasible.

Net Energy Standards Incent Higher Equipment Efficiency without Being Preempted

A net energy target provides a financial incentive to reduce energy consumption further than what would be allowed by Federal preemption in an energy efficiency code without photovoltaics. The more efficient the building is, the less PV is needed to meet the net energy target. As long as the incremental cost of energy efficiency measures are less expensive than the incremental cost of PV, there is a financial incentive to increase the number of energy efficiency measures. This includes *voluntarily* increasing the efficiency of the HVAC and water heating equipment to reduce the size of the PV system needed. Federal preemption law prohibits energy codes from *requiring* the higher efficiency equipment than the minimum Federal appliance efficiencies prescriptively, or as the basis of the standard design for the performance approach. (Chase et al. 2012) A competitive market opportunity for manufacturers of high efficiency equipment and PV is created when builders are comparing higher efficiency equipment incremental costs against PV costs as a way to reduce their costs while complying with code.

Limited Trade-off between Energy Efficiency and PV in 2016 Energy Code

The following energy efficiency measures were added to 2016 Title 24, Part 6: all high-efficacy lighting, gas tankless water heater baseline, added insulation in exterior walls and added insulation in attics above or below the roof deck. To provide builders time to get used to the new standards and simultaneously prepare the market for subdivision-scale photovoltaics, the Energy Commission allowed a limited performance approach trade-off between photovoltaics and energy efficiency. The size of the trade-off was designed to be no greater than the added energy savings from the additional insulation value added to walls and to roof decks for the 2016 standards. This trade-off was retired in the 2019 standards. The 2019 Standards include a limited credit for battery storage, discussed in a subsequent section.

2016 CALGreen ZNE Tier

Title 24, Part 11 refers to the California Green Building Standards Code, which is also known as CALGreen. This section of the code has two parts: a mandatory portion required for all buildings and a voluntary portion that is designed to be used as a basis to propose reach codes for cities and jurisdictions that seek to meet local objectives, including climate action plans, using an advanced model building code. When a jurisdiction adopts the voluntary tier as a reach code, that tier is no longer voluntary but is required for construction in that jurisdiction's territory. The voluntary portion of CALGreen traditionally had two energy tiers. Tier 1 suggested a goal of requiring 15 percent beyond the statewide code. The proposed design had a TDV energy budget that was 85 percent or less than the TDV regulated load consumption of the standard design. Tier 2 required 30 percent beyond code, where the TDV allowed energy budget was 70 percent or less of the TDV consumption of the standard design. The energy budget, in this context, is the energy consumption of prescriptively regulated energy measures: HVAC and water heating.

A Zero Net Energy Design tier was introduced to support the 2016 Standards that required the low rise residential building regulated energy consumption meet Tier 1 or Tier 2 criteria, depending upon climate zone, and have an Energy Design Rating of 0. The Energy Design Rating (EDR) accounts for all energy consumption of the building including regulated loads, lighting and plug loads calculated in TDV energy units. The EDR rating is normalized so that a rating of 100 is equivalent to the energy consumption of the building if it was minimally compliant to the 2006 version of the International Energy Conservation Code(IECC). The national RESNET rating system also uses a similar normalized value of 100 for a 2006 IECC baseline home. In this manner, the EDR rating is roughly comparable to a RESNET rated home. This provides a point of reference of the efficiency of a new California home relative to homes in other states. The Tier 1 and Tier 2 energy budgets complied with the Title 24, Part 6 rules and the amount of credit received for PV was limited. For the EDR rating, there was no limit on the amount of credit received for PV. The ZNE tier was designed to require an energy efficient building that had enough PV to offset all building energy consumption (including gas consumption for mixed-fuel homes) using the TDV metric. The 2016 CALGreen ZNE tier was intended to prepare the market for the structure of the 2019 standards – a very efficient building with enough PV to offset energy consumption.

Local Government Reach Codes with PV

All definitions of ZNE contain a common component: to locally produce enough electricity to offset the consumption of the building on an annual basis. PV attached to residential properties is widely viewed as a critical component to reaching ZNE homes. Utilizing the foundations set in CALGreen, consumer interest, as well as housing industry enthusiasm for adding PV to home packages, localities encourage or mandate PV installation through the adoption of local ordinances as part of the effort to define the region as making progress toward sustainability and climate action goals.

Local jurisdictions have the authority to adopt local energy efficiency ordinances, or reach codes, as long as they hold public hearings, and demonstrate that the requirements of the proposed ordinance are cost effective and more stringent than the state energy code. For the ordinance to be legally enforceable, the jurisdiction must obtain approval from the Energy Commission and file the ordinance with the Building Standards Commission.[4] In the past, reach codes were primarily focused on additional energy efficiency requirements. As the costs for photovoltaics declined, several cities incorporated rooftop solar into their reach codes including

[4] Public Resources Code Section 25402.1(h)2 and Section 10-106 of the California Administrative Code (Title 24, Part 1).

Culver City (multifamily, 2008), Lancaster (single family, 2013) and Sebastopol (2013). (LADCP 2017)

To support on-site solar requirements in reach codes during the 2016 code cycle and to prepare the low rise residential construction market for on-site PV generation in the 2019 code cycle, a draft local solar model ordinance was released by the Energy Commission.[5] This draft ordinance included prescriptive requirements for PV generation on residential new construction buildings sized to offset 80 percent of projected annual electricity use based on conditioned floor area and climate zone, with an alternative performance approach (using CBECC-Res). Additionally, this draft ordinance increases the energy efficiency stringency of the current code by including two additional energy efficiency features: 1) required quality insulation installation (QII) and 2) on-site renewable energy credits could not be used to offset efficiency measures, as described earlier. For proactive jurisdictions responding to climate action plans, this toolkit provides support to pass an ordinance that included PV requirements for residential new construction.

The creation of the draft model solar ordinance was supported by a local PV ordinance cost effectiveness study published by PG&E's Codes and Standards Program. (CA Codes & Standards 2016a) The C&S Program also prepared several other cost-effectiveness studies to provide flexibility to local jurisdictions by offering optional structures, including efficiency measures and PV requirements. Local jurisdictions can use the cost effectiveness study and the draft model ordinance to create a package that is customized to the region to which a resulting ordinance would apply. The cost effectiveness study also examined methods of simplifying administration of the standard while being aligned with the overall state strategy for energy efficiency and ZNE.

The analysis included detailed building simulations and costing of solar and efficiency measures on two single family prototypes and one multifamily prototype. The on-site PV generation target in this analysis was that the PV system would provide 80 percent of the expected electricity consumption of the home or dwelling unit. This would assure that in most cases the system would not be over-generating, which impacts electrical grid stability and reduces the cost-effectiveness of the PV system. The report found the solar PV ordinance to be both feasible and cost effective using existing utility rates, while reducing energy demand in all 16 California climates zones.

Additional cost effectiveness studies and draft code language was developed and published by the Statewide Utility Codes and Standards Program which incorporated cost-effective building efficiency targets in conjunction with PV for all sixteen climate zones (CA Codes & Standards 2016b).

The PG&E C&S Reach Codes team worked with the Bay Area Air Quality Management District, BayREN and others to provide assistance and support local government initiative and action, several jurisdictions began the process of adopting an ordinance. Southern California Edison, San Diego Gas and Electric, and Southern California Gas Company worked with local jurisdictions to support reach codes in their service areas. At the time this paper was written, thirteen jurisdictions had approved local ordinances to reach beyond the 2016 Standards, as listed

[5] http://docketpublic.energy.ca.gov/PublicDocuments/17-BSTD-01/TN217291_20170425T110520_Draft_Model_Local_Solar_Ordinance_v5.pdf

on the Energy Commission website.[6] Of those, nine include PV and eight of those nine combine PV requirements with efficiency measures.

Preparing the Market for ZNE Homes

In addition to the rebates provided to rooftop solar systems under the California Solar Initiative (CSI) and the New Solar Homes Program (NSHP), several other investor-owned and municipal utility-funded programs have provided both incentives and design assistance to builders and early adopters of ZNE. These incentive programs include ZNE pilots, demonstration sites, and production builder demonstration sites. The current statewide new construction incentive program, California Advanced Home Program (CAHP) includes incentives for builders building to the 2019 ZNE goals. From these programs, utilities, stakeholders and builders have benefitted from lessons learned from early adoption of ZNE and real-world performance of buildings participating in these programs. Data from these projects helped document to the Energy Commission's standards setting process, the feasibility and costs of as-built ZNE homes.

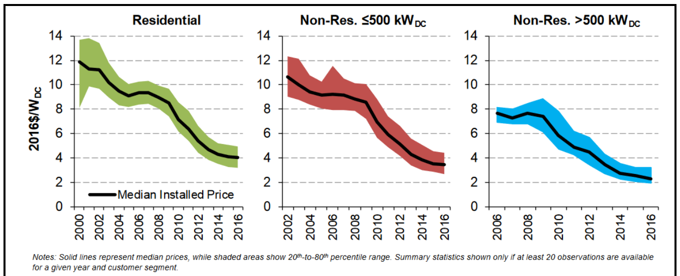

Figure 3: PV Cost Curve 2000-2016 (LBNL 2017)

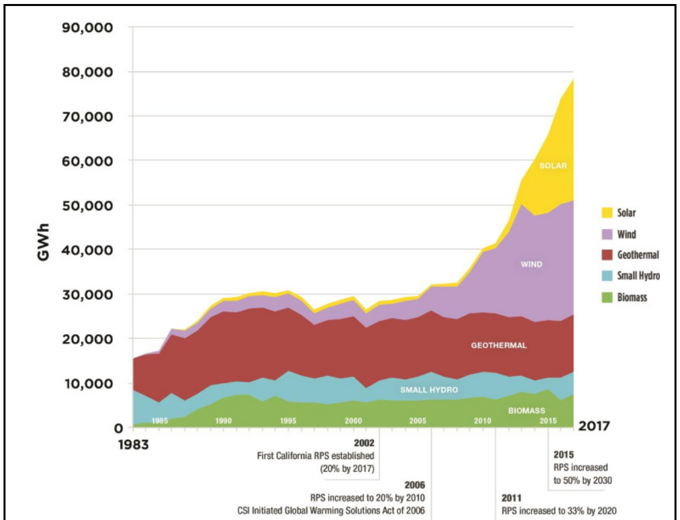

Figure 4: Renewable Energy Generation 1983- 2017 by Resource Type (CEC 2017)

Cross-Cutting Events

For large scale goals that can take a decade of more to realize, the economic, technical and physical context changes and thus efforts to support these goals must evolve according to changing conditions. As concerns about global warming intensify, the state government is doing more to address these concerns. The renewable portfolio standard (RPS) goals have accelerated, with RPS requirements calling for 20 percent renewable production by 2010, 33 percent by 2020, 50 percent by 2030, with some demands to do even more.

Simultaneously, the cost of solar PV has dropped by two thirds or more in the last 10 years (see Figure 3). Thus, an increasing fraction of renewables added to the grid to satisfy the state's RPS policy have shifted from wind to solar (see Figure 4). Since utility scale production is becoming increasingly coincident with production from rooftop solar, the value of energy in the middle of the day during peak solar production has less value. This is reflected in time-of-use utility rates and in the TDV value of solar production offsetting energy consumption of the home.

What was a concern ten years ago, peak demand on hot afternoons, has been increasingly displaced with the "duck curve" the swift rise in "net demand" (total demand minus the

[6] http://www.energy.ca.gov/title24/2016standards/ordinances/

contribution of rooftop PV or on utility-scale PV installations) soon after sunset[7]. Grid integration has become increasingly important as PV becomes a larger part of the generation portfolio. In addition to energy efficiency for keeping loads lower, grid stabilization concerns result in greater value being placed on demand flexibility and energy storage.

2019 Standards Development

The 2019 standards are structured to pave the way for achieving a true Zero Net Energy in future code cycles by maintaining the energy "loading order" of energy efficiency first, followed by appropriately sized renewables to minimize negative impacts on the utility grid. The 2019 standards also adopted the energy design rating (EDR) score, which includes both regulated and non-regulated energy consumption. Compliance consists of meeting two separate EDR targets: one for efficiency measures and the second for efficiency plus renewables. Under this process, increasing PV does offset efficiency. However, additional efficiency measures, and demand flexibility measures (i.e. energy storage), can reduce the size of PV required to comply.

New Residential Energy Efficiency Measures in 2019 Building Energy Code

The following items represent selected measures from the recently adopted 2019 Standards:

- High performance attics in all but the mildest climates (1 through 3, 5 through 7), consisting of R-38 ceiling insulation, R-19 underdeck insulation (increased from R-13), and R-8 duct insulation.
- High performance walls in all climates but the southern California coast (6 and 7), with wall assembly U-factor equal to 0.048 Btu/hr-ft2-ºF (decreased from 0.051 Btu/hr-ft2-ºF)
- High performance windows: NFRC rated U-factor ≤ 0.30 Btu/hr-ft2-ºF in all climates and SHGC ≤ 0.23 in all climates except heating dominated climates (1, 3, 5, and 16).
- Insulated exterior doors with NFRC U-factor ≤ 0.20 Btu/hr-ft2-ºF.
- Quality Insulation Inspection (QII) is a visual inspection of insulation and air sealing by a "third party" certified HERS Rater to verify that the installation meets the criteria defined in the code and meets the rated values.

Using the performance method with the approved software, a project can comply using a variety of efficiency measures, including high efficiency space conditioning and water heating equipment, as well as a higher performance building enclosure and including the ducts in the conditioned space.

Figure 5 illustrates how updates to the 2013, 2016 and 2019 Title 24 codes have reduced residential energy consumption, which results in a reduction in

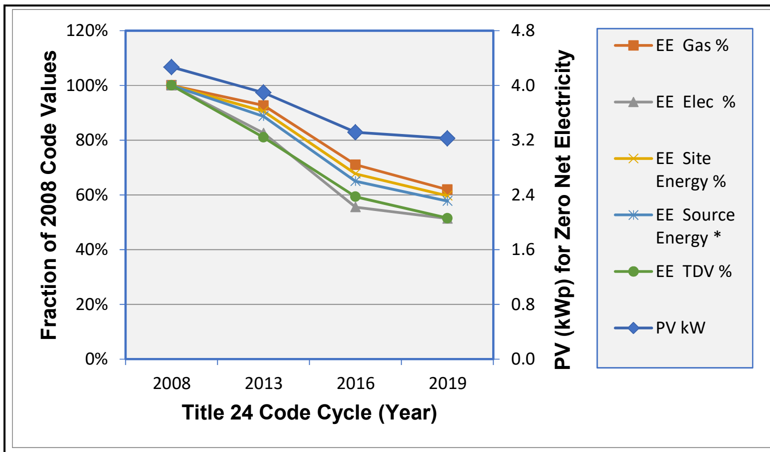

Figure 5: Regulated Loads % Reduction by Code Cycle and PV System kW for 2,700 ft² Mixed Fuel Home to Offset Electricity Consumption

[7] California ISO *Fast Facts: What the duck curve tells us about managing a green grid.* https://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf

the PV system size needed to displace all electricity consumption in the home. Regulated loads have been reduced by 40 percent or more. Since PV sizing also includes non-regulated electrical loads, PV size reductions are less, around 24 percent over this same time period.

PV Requirements and Cost-effectiveness

For the first time, the 2019 Standards require a PV system that is sized to offset the kWh usage of a mixed-fuel house. Considering that California's IOUs must follow Net Energy Metering (NEM) and cost-effectiveness rules, the Energy Commission found that PV systems sized to displace annual electrical consumption of the buildings are cost effective in all 16 climate zones, even if the NEM2 rules are changed in the future to compensate hourly exported electricity at avoided cost. In both prescriptive and performance approaches, the PV sizes in all 16 climate zones displace the annual kWh of that home. Typical PV system sizes for 2019 code compliant homes vary from 2 to 4 kW DC, depending on the house size.

Battery Storage and Grid Harmonization

The over-abundance of utility and building-based PV generation on mild and sunny days often results in curtailment of renewable resources in the middle of the day, while later in the evening, when solar resources become limited or nonexistent, the grid must rely on traditional natural gas fired power plants to meet the evening peak loads, resulting in adverse environmental and energy cost consequences that are commonly known as the "duck curve". Also, since the highest peak Time-Of-Use (TOU) tiers tend to occur when the solar resources are limited or nonexistent, a "PV only" system tends to have limited financial benefits for the building occupants.

To alleviate the impacts of rooftop PV systems on the grid, the Standards encourage installation of measures that harmonize the PV system with the grid. Grid harmonization strategies are defined as measures that harmonize customer-owned distributed energy resources assets with the grid to maximize self-utilization of PV array output, and limit grid exports to periods beneficial to the grid and the ratepayer; examples of grid harmonization strategies include PVs used in combination with battery storage, demand response/flexibility, thermal storage, and in the future, electric vehicle harmonization.

In the 2019 Standards, there are no prescriptive requirements for battery storage in the residential units; however, the prescriptive approach encourages battery storage by reducing the, the required PV by 25 percent if the PV system is coupled with a battery storage system having a capacity of at least 7.5 kWh. Under the performance approach, a variety of grid harmonization strategies can be used to not only reduce the size of the PV system, but also provide a limited performance tradeoff credit that allows the builders to trade away some building efficiency measures. In addition, the combination of PVs and storage may be used to meet more aggressive efficiency targets established by reach codes and other beyond code programs, with the smallest PV sizes possible.

Grid harmonization strategies help avoid the duck curve issues, including mid-day overgeneration, evening ramp, and critical peak issues, by making the house "invisible" to the grid during afternoon and evening hours. Grid harmonization strategies also enable the home owners to take advantage of the TOU rate differential by storing the PV's output during low value hours when solar is plentiful and discharging later in the day to satisfy the load during the highest value peak hours. Grid harmonization strategies also minimize CO_2 emission by lessening the grid's reliance on combustion turbines to meet critical peak needs during hottest hours of the day.

Community Solar

In situations where builders prefer to not install PV on the roofs of their homes or where the roofs are too complicated or not well oriented to support onsite PVs, it may be desirable to install those PV panels off-site. The proposed Standards allow shared solar resources to be used as an alternative to installation of the onsite PV panels. To qualify, the community solar resources must provide equal reduction in energy consumption or equal energy bill reduction to each home that receives community solar power, in lieu of what the homes would have received from the a PV system attached to the individual home and compliant with the Standards. Under California's NEM rules, community solar programs for single family homes served by the IOUs would not qualify for this compliance credit. It is possible that municipal utilities or Community Choice Aggregators could design programs that would provide equal energy consumption reductions or equal energy bill reductions. The Energy Commission will consider applications from administrators of qualifying community solar programs that meet all requirements, including the expectation that the offsite resources provide the energy consumption reductions or energy bill reductions to each designated home for a period of not less than 20 years.

Building Electrification and GHG Reduction Goals

ZNE goals were primarily conceptualized as a strategy for reducing GHGs and other pollutants. As the state is approaching achieving much of the residential ZNE goals, California policy makers are shifting their focus towards zero GHG goals. Shifting away from mixed-fuel buildings and encouraging all-electric buildings is a component of this strategy. As the electricity grid becomes greener with the approach of the 50 percent RPS goal by 2030, all-electric buildings compliant with the 2019 efficiency standards and equipped with rooftop solar PV systems and battery storage systems can achieve low CO_2 emission levels.

The 2019 Standards make it easier for all-electric buildings to comply with code by allowing an electric baseline for heat pump space heating, heat pump water heating, and electric appliances, regardless of the availability of natural gas. This practice allows an independent compliance path for both mixed-fuel homes and all-electric homes by eliminating the gas baseline for all-electric homes, even if gas service is available.

The required minimum size of a PV system in the 2019 standards is based on offsetting all electricity consumption (zero net electricity) in a mixed-fuel home where natural gas provides space heating and water heating. This required PV size is the same for either a mixed-fuel home or an all-electric home. Target EDR rating that all homes have to meet is the same regardless of whether they are mixed-fuel or all-electric. If the standards required all-electric homes to be zero net electricity, this would discourage all-electric homes as the required amount of PV would be larger, increasing initial costs. As the renewable portfolio standard results in the electricity grid being increasingly decarbonized, electrification may become increasingly attractive.

Updated Solar Model and Integration of PV and Storage into 2019 Title 24, Part 6

The version of CBECC-Res designed to support the new Standards has PV, battery storage, and demand flexibility modules integrated into the software. The software can model several PV arrays facing different orientations with different number of modules with corresponding attributes, including impacts of shading on the PV array. The software allows the user to tradeoff more energy efficiency for less PV; it allows grid harmonization strategies to be used to get to a desired target EDR with smallest possible PV system. As a result, CBECC-Res now integrates energy efficiency, PV, battery storage, demand response, and grid harmonization into one design tool. The software can be used to assess the energy and CO_2 consequences of building designs and appliances choices. The CBECC-Res software tool is also designed to be compatible with the non-mandatory CALGreen requirements that may be adopted by local jurisdictions.

Public Reception

The 2019 Standards represent a complex package with a mixture of energy efficiency, PV, and grid harmonization strategies that are designed to reach ZNE and low CO_2 emission levels. The package received support from the California Building Industry Association (CBIA), environmental advocacy groups, and the PV and battery storage industries. There was no major opposition to the fundamental energy efficiency measures in the 2019 Standards package at the close of the rulemaking process. The adoption of the 2019 Standards received significantly more media attention than the prior few cycles. At the time this paper was written, over 100 publications have reported on the 2019 Standards with most of the focus on the PV requirements. Most of this reporting has discussed only rooftop solar and not the provisions for community solar, or other measures in the standards. Opinions on both sides of the advisability of the proliferation of residential rooftop solar surfaced in articles and op-eds nationwide, and globally. The significant amount of media attention underscores the pioneering spirit of the Standards and the timeliness of the update as the energy landscape of the state and nation evolves. The 2019 Building Energy Efficiency Standards will be watched as a bellwether for what will follow in other states.

Conclusions

This brief history of the transition of the concept of Zero Net Energy homes to an organizing principle of the California Building Energy Efficiency Standards illustrates concepts that may be of value to other states considering similar paths:

- Deliberate and focused effort over the long term can result in aspirational goals being accomplished. California's environmental and progressive ethic maintained steady effort through two governors from two different political parties and six legislatures. This reflects the high value citizens' place on energy efficiency and renewable energy.
- Though the 2019 Standards will not be Zero Net Energy per se, they will be zero net electricity for mixed-fuel homes and require an equivalent amount of renewables for all-electric homes. A very efficient home with most of its energy loads being met with renewable energy will result, which matches significant portions of the ZNE goals.
    - The cost structure of renewable energy provides incentive for homes to reduce energy consumption further voluntarily through equipment efficiency than what the state is allowed to require under federal preemption. Federal preemption law only allows state building codes to mandate minimum federal equipment efficiencies.
- The traditional belief concerning diffusion of innovations did not apply. The Energy Commission did not have to wait for the late majority to adopt a technology before it was codified. Instead, a critical mass of information that reliably indicates that the new standard of designing homes is feasible, cost-effective and does not reduce amenity catalyzed the decision. To implement it, there must be enough design professionals, energy analysts, equipment and trained installers to deliver the new code requirements. Building departments must also understand and embrace the requirements to enforce it.
- In the case of PV, a number of activities helped this technology get to scale, including: rating methods, production simulation tools, incentives (Federal and state), PV permitting streamlining, rating of inverters and inverter databases, requirements for minimum

inverter warrantees to receive incentives, net energy metering, consumer demand, falling prices and the renewable portfolio standard.
- Reach codes are an effective tool for working through the administrative issues of enforcing a ZNE standard with jurisdictions that are motivated to pursue an advanced code. Including ZNE tiers in CALGreen gave builders advance notice that a similar requirement would likely transition to the mandatory sections of the code.

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