**Dian M. Grueneich** *is a Senior Research Scholar at Stanford University's Precourt Energy Efficiency Center and the Hoover Institution's Shultz-Stephenson Task Force on Energy Policy. Her research areas include institutional and regulatory changes to enhance broad changes in energy and electricity systems and developing a next level of energy efficiency. She served as a commissioner on the California Public Utilities Commission (2005 to 2010) and led its efforts on energy efficiency, developing the California Long-Term Energy Efficiency Strategic Plan and a 40 percent expansion of California's energy efficiency funding, and oversaw transmission planning and permitting. Ms. Grueneich currently serves on the DOE-EPA State Energy Efficiency Action Plan Leadership Group, the National Renewable Energy Laboratory's External Advisory Committee, the Global Cool Cities Alliance, and the Advisory Board for the Cal Poly Institute for Advanced Technology & Public Policy. She also serves as a Clean Energy Education & Empowerment U.S. Ambassador and served on the U.S. Department of Energy (DOE) Electricity Advisory Committee. The author received her B.A. from Stanford University in Human Biology and holds a J.D. from Georgetown University.*

*The author thanks David Fedor, a research analyst for the Hoover Institution's Shultz-Stephenson Task Force on Energy Policy, Cara Goldenberg, and R. Edwards for assistance on this article. The author is also grateful for insights offered during development of this article by S. Borgeson, J. Cammarata, S. Cheng, J. Deason, L. Ettenson, C. Heavey, S. Kiliccote, A. Mahone, J. McMahon, J. Greenblatt, S. Martinez, A. McAllister, C. Neme, M. Rothleder, J. Sweeney, H. Sanders, R. Sudhakara, and A. Whitman.*

# The Next Level of Energy Efficiency: The Five Challenges Ahead

*To attain the 'next level of energy efficiency,' five key challenges must be overcome: increasing the magnitude of savings; diversifying energy efficiency resources; measuring and ensuring the persistence of energy efficiency savings; integrating energy efficiency savings with a carbon reduction framework; and understanding and valuing energy efficiency as part of an evolving grid.*

*Dian M. Grueneich*

## I. Introduction

The urgency of addressing climate change and the changing electric grid require a ''next level of energy efficiency'' to mobilize energy savings that go beyond historical practice and integrate with a grid characterized by high levels of intermittent resources and variable load. To reach this next level, we must first understand the challenges ahead, which is the subject of this article.[1] This article focuses on California, but the challenges discussed apply elsewhere as well. Energy efficiency has a major role to play in the 21st century grid, but unless the challenges ahead for the next level of efficiency are acknowledged and addressed, we will waste valuable time and money in the struggle to address climate change.

Since the 1970s, energy efficiency has saved Californians nearly $90 billion on their energy bills and reduced California's electricity demand by more than 15,500 megawatts

http://dx.doi.org/10.1016/j.tej.2015.07.001

(MW).[2] From 2003 through 2013, the state's overall investment in non-transportation efficiency (including the more than $1 billion annual investment in customer-funded energy efficiency programs plus savings from building codes and appliance and equipment standards) cut carbon dioxide ($CO_2$) emissions by nearly 30 million metric tons, equivalent to the emissions of nearly 6 million cars.[3] While this achievement is impressive, much more is needed. California seeks to reduce its greenhouse gas (GHG) emissions to 80 percent below 1990 levels by 2050 and energy efficiency is envisioned to play a substantial role.[4] And, as part of California's developing 2030 climate commitment plan,[5] Gov. Jerry Brown has set a goal over the next 15 years to ''double the efficiency of existing buildings and make heating fuels cleaner.''[6]

## II. The Challenges Ahead

This article discusses five specific challenges:

- The **magnitude** of energy efficiency savings must increase dramatically;
- The sources of energy efficiency savings must **diversify**;
- **Measuring** and ensuring the persistence of energy efficiency savings must become commonplace;
- Energy efficiency outcomes must be integrated with a **carbon** reduction framework, and
- Energy efficiency must be understood and valued as part of an **evolving grid**, with utility-scale renewables, distributed energy resources (DERs), and significant load variability.[7]

These five challenges collectively present two additional hurdles. First, overcoming these challenges requires not only technological innovation and enhanced market strategies, but also significant changes in energy efficiency policy framework and agency governance. Changes by agencies themselves—in terms of the way that they interact with each other and stakeholders, how they define and track efficiency results, the policy rules they adopt, and how they use market forces to harness energy efficiency—are critical. While this is not the subject of this article, our research at Stanford University is also focusing on new tools and institutional changes.

*This impact could raise the ceiling on energy efficiency cost-effectiveness and potentially open new investment opportunities.*

Second, energy efficiency traditionally has played a cost-mitigation role by both providing direct customer savings through reduced energy bills and lowering overall utility system costs. This paradigm will be pulled in different directions, however, as we begin to ask more from energy efficiency. On the one hand, obtaining higher levels of energy efficiency from ''higher-hanging'' and more diverse sources could require significant increases in utility customer funding and decrease the apparent value of energy efficiency in its traditional role as a cost-mitigation strategy. On the other hand, deep emission reduction goals of the sort California identifies for 2050 under its landmark climate change law (AB32)[8] envision deployment of low-carbon electricity generation technologies that could—unlike most energy efficiency investments today—measurably increase costs per delivered unit of energy. This impact could raise the ceiling on energy efficiency cost-effectiveness and potentially open new investment opportunities. But it would also saddle energy efficiency with the responsibility to mitigate these new costs,[9] which might otherwise make the expense of deep decarbonization politically challenging. Moreover, the timing of energy efficiency deployment is important, so that excess and more costly marginal generation—even if renewable or carbon free—is not built. The interaction among policies—energy, climate, reliability, etc.—must be anticipated and full value given to the contributions of energy efficiency, in relation to the

http://dx.doi.org/10.1016/j.tej.2015.07.001

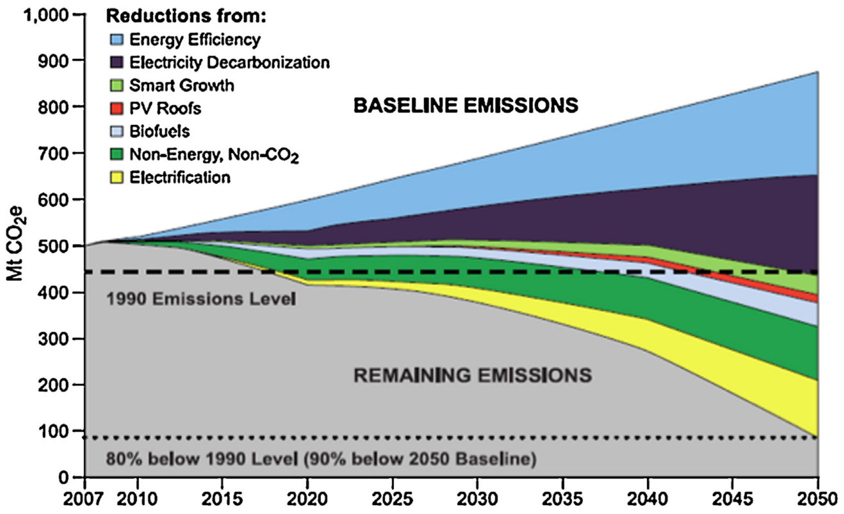


**Figure 1:** Illustrative GHG Reductions Needed by California for 2050 (*Note*: See, Williams, J., et al., 2012. The technology path to deep greenhouse gas emissions cuts by 2050: the pivotal role of electricity. Science (January).)

comparative costs of both supply side resources and other GHG mitigation strategies. Potential conflicts must be acknowledged and policymakers need to establish a consistent framework for energy efficiency's role across the state's efforts.[10]

### A. The magnitude of energy efficiency savings must increase dramatically

As noted above, California seeks to reduce its GHG emissions to 80 percent below 1990 levels by 2050.[11] Figure 1 is drawn from an illustrative economy-wide analysis done by Energy and Environmental Economics, Inc. (E3) of pathways for achieving this goal, with potential contributions from each major strategy represented by a different colored wedge.

The light blue wedge depicts the GHG emissions reductions coming from energy efficiency efforts (including transportation).[12] The analysis concluded that California needs to pursue concurrently all major strategies illustrated in the figure to meet its 2050 GHG emission reduction goal.[13] Energy efficiency savings are particularly important because they lower energy costs to customers and system-wide. Without energy efficiency, the overall cost of meeting carbon goals increases significantly.

More recent modeling done by E3 on California's GHG emissions focuses on what the state could do in the next 15 years to stay on track toward 2050 GHG emissions goals. The analysis suggests that California should target a 26–38 percent reduction in emissions by 2030, relative to the 1990 GHG level.[14] Figure 2 illustrates the reduction in energy use per capita from scenarios that reach the 2050 goal. In this particular model the decreased intensity is achieved through baseline reductions in the demand for some energy services, more efficient delivery of those services, and fuel switching—primarily electrification of transportation and heating loads. These significant energy (and cost) savings make the model's supply-side low-carbon grid technologies more affordable at

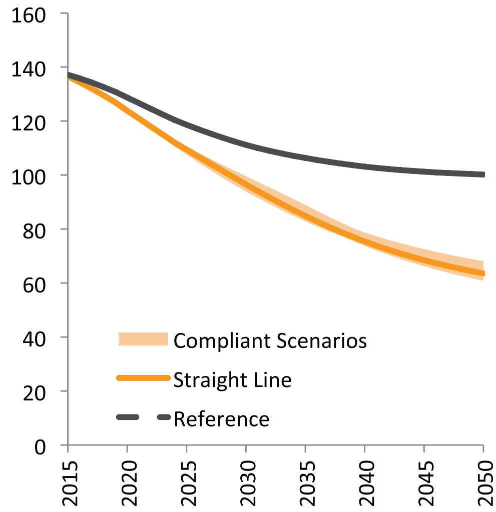


**Figure 2:** Energy Use Per Capita (2015–2050) (*Note*: Energy and Environmental Economics (E3). 2015, April 6. California PATHWAYS: GHG Scenario Results. E3 PATHWAYS. https://ethree.com/documents/E3_PATHWAYS_GHG_Scenarios_Updated_April2015.pdf.)

, http://dx.doi.org/10.1016/j.tej.2015.07.001

the consumer level. In fact, as the entire energy system decarbonizes over time, the role of energy efficiency shifts from emissions-savings to a cost-savings strategy.

Lawrence Berkeley National Laboratory (LBNL) has also released new work, modeling policy and technology scenarios in California focused on GHG emissions reductions in 2020 and 2030.[15] Using CALGAPS, a model simulating GHG and criteria pollutant emissions in California from 2010 to 2050, four scenarios are presented: (1) Committed policies, (2) Uncommitted policies, (3) Potential policy and technology futures, and (4) Counterfactual (which omits all GHG policies). Forty-nine individual policies were assessed, such as Title 24 building codes and goals included in the California Public Utilities Commission's (CPUC) 2008 Energy Efficiency Strategic Plan.[16] This modeling demonstrates the critical importance of California's current energy efficiency efforts but also reveals that additional policies leading to greater emission reductions will be needed in the longer-term.

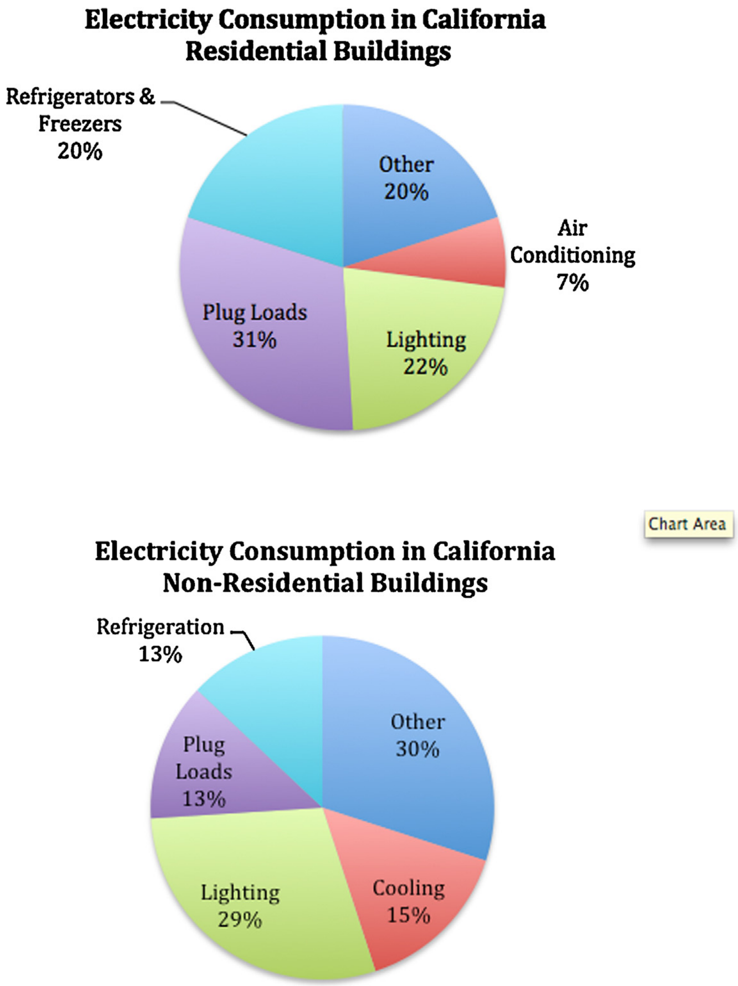


**Figure 3:** California's Building Electricity Consumption (*Note*: CPUC. California EE Strategic Plan – Research and Technology Action Plan 2012–2015. p. 4-2. Source: Residential Appliance Saturation Survey 2009 and California Commercial End Use Survey 2006.)

### B. The sources of energy efficiency savings must diversify

A second challenge is that the *sources* of efficiency savings must diversify, and focus on eliminating the waste of energy, whether caused by equipment, operation, or behavior. **Figure 3** shows electricity being consumed in California's residential and non-residential buildings.

**Figure 4** presents electricity savings reported by the California investor-owned utilities (IOUs) for their 2010–2012 residential and commercial efficiency programs.[17]

The vast majority of reported IOU customer bill-funded electricity savings for 2010–2012 are from indoor lighting measures. Lighting also continues to dominate public power energy efficiency programs, accounting for almost half of the total gross energy savings achieved (46.4 percent) for FY 2013–2014.[18] While lighting has traditionally provided the most cost-effective savings (which offsets the more costly programs or non-resource programs, thus ensuring an overall cost-effective portfolio for utility-customer funded programs), building codes and mandates are decreasing the ''low-hanging'' availability of

http://dx.doi.org/10.1016/j.tej.2015.07.001

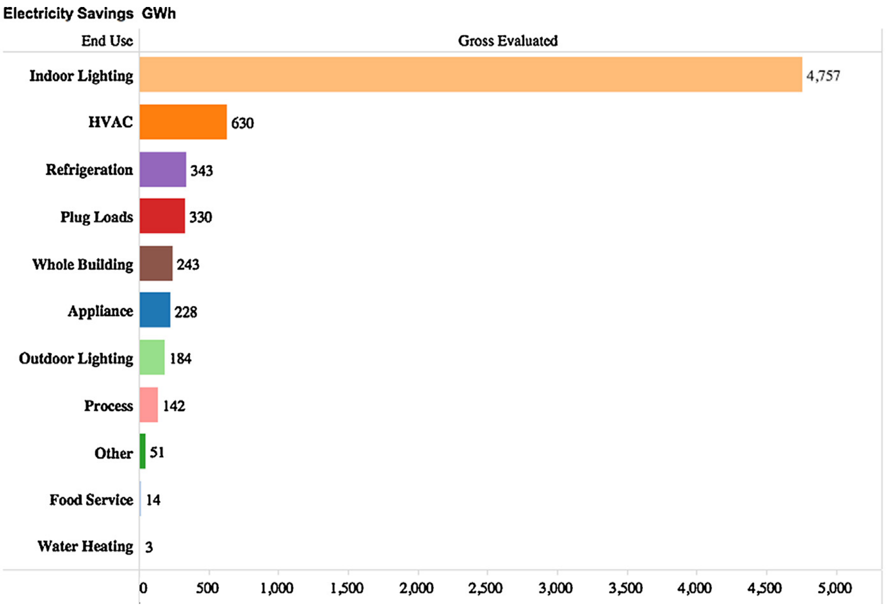


**Figure 4:** Current Efficiency Measure Savings are Not Well Diversified (*Note*: California Energy Efficiency Statistics: Data Portal. http://eestats.cpuc.ca.gov/Views/EEDataPortal.aspx. This figure is derived from IOU evaluated numbers; the numbers are presented based on gross EE savings from the IOUs' commercial and residential programs (accessed 17.06.15).)

low-cost lighting retrofits for these voluntary efficiency programs.

Lighting savings, especially through the use of LEDs, should continue to be pursued, since significant lighting savings potential remains. However, Figure 3 shows that non-lighting end uses in buildings account for approximately 78 percent in the residential sector and 71 percent in the non-residential sector. The scope of California's efficiency savings goals requires delivery of savings well beyond lighting alone. Plug loads and miscellaneous loads are the largest areas of consumption for the residential and non-residential sectors, respectively.[19] The Natural Resources Defense Council (NRDC) reports that plug-in equipment accounts for just 12 percent of efficiency program electric savings in California today, despite its two-thirds share of the state's residential electric consumption.[20] Likewise, the state's appliance efficiency standards are not keeping pace with the rapid growth in plug-in equipment usage.

Deeper savings also require approaches focused on capturing whole building and systems-wide savings, which involves spanning multiple end uses and looking at all savings potential in buildings. Diversification in the sources of efficiency savings includes increasing building operation efficiencies, particularly related to the usage of miscellaneous loads and equipment, and focusing on all savings in existing building, not just from an ''above code'' baseline. Existing programs are not seriously pursuing these areas, hampered by cost-effectiveness and other rules that do not allow all savings to be counted and do not value all services provided.[21]

### C. Measuring and ensuring the persistence of savings must become commonplace

As energy efficiency plays an increasingly significant role in climate change efforts and the development of the changing electricity system, the efficiency savings must be dependable over time for purposes of system planning and procurement, achievement of GHG goals, and system reliability. Most approaches to measuring energy efficiency only identify projected savings based on engineering calculations or by estimating initial savings. Measuring initial real-time metered savings in buildings after measures are installed (or behavioral changes made) is still rare, let alone assessing persistence of those savings over time. The most obvious approach to measuring aggregate savings—developing robust energy consumption baselines and measuring changes across entire market segments in real-time—is also rare.

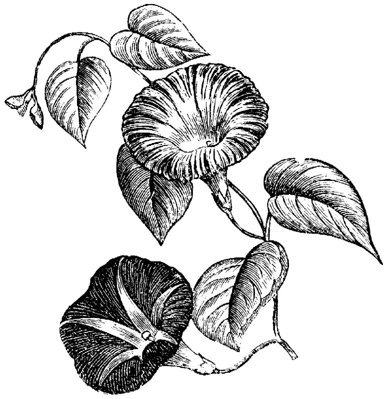
With increased smart meter data and sophisticated data analytics, we now have the ability to identify changes in building energy usage and track the

, http://dx.doi.org/10.1016/j.tej.2015.07.001

magnitude and persistence of whole building savings, as well as measure changes in consumption across all market segments.[22] Advanced analytics can enable cost and scale efficiencies and quicker feedback loops between projects, programs, and utility planning. Customer alerts can send notifications through email and mobile when actual savings are not tracking as expected. However, moving toward whole building real-time monitoring of efficiency and away from widget-based deemed savings will require a paradigm shift. In so doing, we will come to a better understanding of the most effective drivers of savings and also enable pay-for-performance approaches to encouraging energy efficiency.

### D. Energy efficiency outcomes must be integrated with a carbon reduction framework

Even though energy efficiency is central to California's climate goals, the framework for energy efficiency exists largely separate from the state's carbon reduction framework. In part this is an accident of history, as efficiency programs first developed at scale in response to the energy crisis of the early 1970s, while policy to reduce GHG emissions only began to emerge 20 years later. As such, while state and national carbon policy contemplates efficiency as a major source of emissions reductions, GHG emission reduction impacts are only loosely incorporated into the efficiency regulatory framework. In the next level of energy efficiency, greater integration is needed, particularly given the national carbon reduction framework that the U.S. Environmental Protection Agency (U.S. EPA) is developing under section 111(d) of the Clean Air Act.



In California, the CPUC hosts an interactive Web portal that displays the IOUs' reported energy efficiency savings in both energy and carbon reduction metrics.[23] However, there is no similar dashboard information for energy efficiency savings (or the associated carbon emission reductions) from the state's codes and standards, publicly owned utility programs, or private efforts. In fact the methodologies for counting energy efficiency savings are not uniform across utilities, codes and standards, and private actions, thus affecting the reliability of carbon reduction calculations from energy efficiency activities. AB32's Scoping Plan emphasizes the critical role of energy efficiency in reducing GHG emissions[24] but no agency is tasked with reporting statewide verified savings.

The benefits and costs of energy efficiency are generally valued in terms of electricity and natural gas systems, not in the larger context of avoiding or reducing carbon dioxide or even other pollutant emissions.[25] Compensation (utility rebates, customers' bill savings) for successful energy efficiency efforts is similarly allocated according to benefits to the energy system rather than larger carbon mitigation goals.

Tracking efficiency savings will be increasingly important with the upcoming 111(d) national carbon rules. California policymakers have recommended that the U.S. EPA allow states to count only net savings and only from state efficiency programs.[26] Gross—not net—savings matter when counting the impact of energy efficiency. If only net savings are counted, the missing savings under a gross savings approach may never be accounted for, thus understating the role of energy efficiency in carbon reduction. And, savings from all energy efficiency efforts—both public and private—should be counted, not just those from state-sponsored programs. Care must, of course, be taken to avoid double counting, but that issue is separate from purposefully ignoring entire categories of efficiency savings that can lower state carbon emissions.[27]

### E. Energy efficiency must be understood and valued as part of a larger grid

The purpose of the electric grid today is the same as it was nearly a century ago when it was first conceived: ensure that adequate, reliable, and useful sources of energy are available to homes, businesses, and industries. The way that the grid achieves this goal, however, is changing fundamentally. Utility decoupling, rising integration of distributed generation, implementation of carbon prices, and smart grid technologies are altering the supply system, the functionalities of the grid, and the role of customer loads and resources. As the grid makes this transition, we must likewise alter our view of energy efficiency and its value to the grid. Properly targeted demand-side load reductions and flexibility will ensure grid reliability, optimizing use of grid investments, minimizing grid costs, and unlocking value to end users. Below we address this evolving role of energy efficiency in two regards:

#### *1. Energy efficiency can defer transmission and distribution system and generation investments*[28]

Energy efficiency, targeted in location and by load shapes, can be useful in dealing with grid constraints, both assisting in reliability and by deferring more expensive supply side investments.[29] California was a pioneer over 20 years ago in an early transmission and distribution (T&D) deferral project. Pacific Gas & Electric Company (PG&E) developed the ''Delta project'' that produced sufficient energy efficiency savings to defer a planned substation for several years.[30] After that initial effort, little attention was paid to the role of efficiency in deferring T&D projects and understanding the value offered by such deferrals.

California is again seeking to use energy efficiency as a T&D resource, partially in response to the decommissioning of the San Onofre Nuclear Generating Station (SONGS), but also as part of a larger energy efficiency locational targeting effort. In 2013, the CPUC directed the IOUs to adjust their energy efficiency portfolios to target transmission-constrained areas affected by the outage of SONGS and more broadly, noting that it may be appropriate to accelerate overall programs targeted regionally or by customer groups.[31] In response, the IOUs have begun several pilots, all of which include increasing use of sophisticated analytics and smart grid data. Southern California Edison has launched a Preferred Resource Pilot to test and demonstrate the capacity of energy efficiency (and other preferred resources) to provide local grid reliability within a defined area on an integrated basis in place of conventional power plants.[32] PG&E has selected four projects, using its current efficiency programs, but with significantly larger incentives and additional marketing.[33] These efforts have identified challenges in working across traditional utility organizational structures that typically have system planners operating in isolation from demand management and energy efficiency staff. Utility system planners are often uncomfortable with the perceived level of uncertainty in non-wires solutions as compared with poles and wires.[34]

The CPUC currently uses standard avoided costs embedded in its cost-effectiveness calculators to value savings from the pilot locational programs.[35] However, the CPUC has acknowledged that it may be appropriate to depart from those

http://dx.doi.org/10.1016/j.tej.2015.07.001

default values to fully capture the locational value of such projects.[36] PG&E is developing tools that can project ''distributed'' marginal pricing (DMP) at the circuit or even customer level, with far greater precision than the locational marginal pricing (i.e., avoided costs) used currently to evaluate demand-side management (DSM) programs.[37] Analytical tools are also able to model the impact of large individual customers on specific substations and target energy savings to reduce those impacts.

Beyond California, Consolidated Edison Company of New York (Con Edison), the electric utility serving New York City and nearby Westchester County, provides a leading example of how energy efficiency can be used as a grid-level resource. Between 2004 and 2012, Con Edison deployed geographically targeted energy efficiency programs to defer T&D system upgrades in more than one-third of its distribution networks and provided more than $300 million in net benefits to its customers.[38] Con Edison has now embarked upon a major new deferral project, proposing to invest up to $200 million on non-traditional solutions, including DERs, in a targeted portion of Brooklyn and Queens, to defer or avoid distribution system upgrades related to sub-transmission feeder capacity constraints. Three aspects of Con Edison's approach are noteworthy:

- Continued evolution of Con Edison's internal approach to higher-level management involvement and integrated/inter-disciplinary staffing;
- Research into and development of new data-driven analytical tools; and[39]

- A proposed earnings mechanism to enable utility shareholders to profit from investment in non-wires alternatives.

### 2. *Energy efficiency can help integrate high levels of renewables and intermittent resources into the grid*

The electric grid is changing to manage high levels of renewable resources whose power output varies with physical conditions (wind and sun) in a way that conventional fossil resources do not. This evolving grid requires handling of new supply-side intermittency to reduce costs and ensure reliability. Understanding energy efficiency's role and value in this is just beginning. California is now targeting 50 percent renewable procurement by 2030.[40] The CAISO has produced its well-known ''Duck Curve,'' which represents the net load on the grid (e.g., total demand minus wind and solar generation) on a spring day (March 31), culminating in 2020, when California has brought on line renewable energy to meet 33 percent of its retail energy sales, as currently legislated (**Figure 5**).

The problem shown in the duck curve is the increasing supplies of wind and solar that do not coincide with daily peak energy demand. Just as the sun is going down and solar panels are producing less power, people are going home and turning on their lights and televisions.

The duck curve illustrates two areas of concern. First is the possibility of excess generation in the middle of the day due to the inability of the thermal fleet to integrate large amount of solar generation, resulting in solar generation being curtailed and over-generation. The second area of concern is the need for resources to ramp up quickly enough to meet the evening peak. In particular, the steep ramp seen between about 5 and 8 p.m. poses challenges for California's current electricity market structure.

The CAISO, California state agencies, and a number of experts

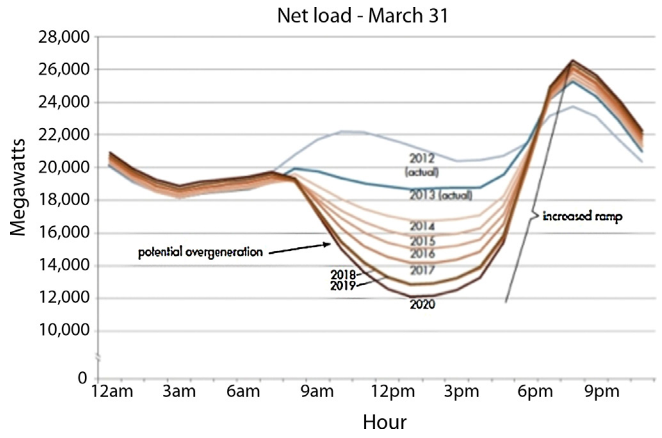


**Figure 5:** CAISO's 'Duck Curve' (*Note*: CAISO. Fast Facts: What the Duck Curve Tells us About Managing a Green Grid. http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.)

have identified energy efficiency as a key solution to these issues.[41] The use of energy efficiency (and other strategies such as demand response and storage) collectively are described as ''teaching the duck to fly.''[42] Energy efficiency can help in two ways. First, energy efficiency programs focused on elements of the evening peak can permanently bring down the ''duck's head''.[43] The second way is to target energy efficiency to the hours when load ramps up sharply. Energy efficiency measures have differing savings over time (both day and annually) and thus have their own ''ramp rates'' that can help (or even hurt) in mitigating the ramping shown in the duck curve.

In one of the few studies on the subject, the Natural Resources Defense Council (NRDC) has tried to measure how effective a particular energy efficiency measure is during a peak ramping period relative to its average effectiveness.[44] NRDC also utilized energy efficiency measure load shapes that show the shape of energy savings (as opposed to end use load shapes that show the shape of total consumption). NRDC concluded that because residential lighting is a major contributor to the extreme evening ramps in the duck chart, more efficient resident lighting (in their analysis, the use of residential CFLs) appears to be particularly effective in mitigating that ramp (though it may also make the morning downward ramp more demanding) (Figure 6).[45] Stanford research is exploring this issue and initial analysis confirms the important role of residential lighting efficiency savings. While this initial research gives a general sense of the ability of energy efficiency measures to address ramp rates, more is required to determine precisely how specific energy efficiency measures can reduce ramp rates.

In this area, the integration of energy efficiency and demand response are particularly important. Smarter appliances, better controls (better usability as well as more appropriate control algorithms), and related efforts can be used for both energy efficiency and demand response. This overlap is a strength only if policies and programs acknowledge the need for and value of both. Another interesting aspect of evening loads—cooking, lighting, entertainment, etc.—is that they are significantly under the direct control of occupants. Behavioral methods are also likely to be important here.

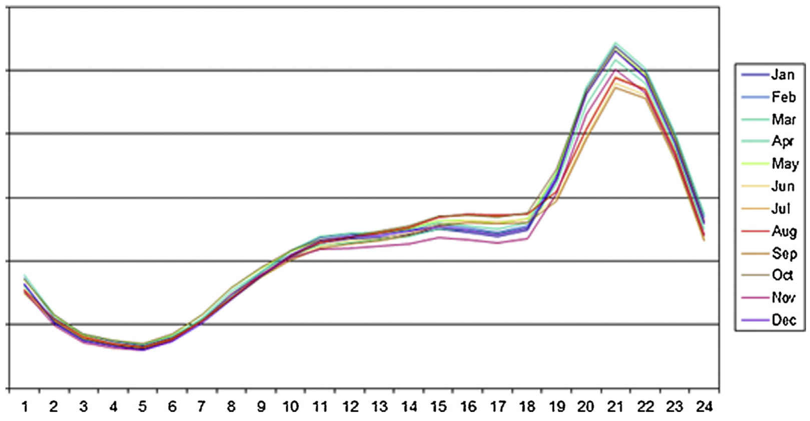


**Figure 6:** Average Hourly Residential CFL Weekday Usage Pattern. The *Y*-axis shows the fraction of annual measure savings that occur in an hour of an average day.

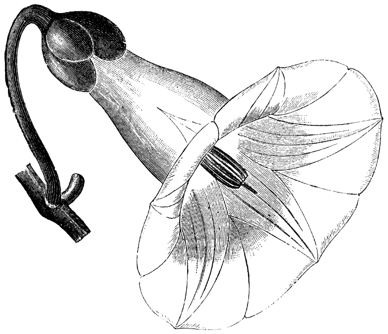
http://dx.doi.org/10.1016/j.tej.2015.07.001

In addition to greater research, policy changes are needed to recognize this potential. The current policy framework assessing the value of energy efficiency does not incorporate benefits of energy efficiency for integrating non-dispatchable renewables. Just as the current cost-effectiveness methodologies include avoided energy and peak generation capacity costs, they should be expanded to include ''net peak savings'' and ''ramp rate reductions''.[46]

The above discussion examined energy efficiency savings curves based on average load shapes. However, recent research by Stanford's Ram Rajagopal suggests that customer load profiles vary widely and can be categorized into more than 250 different typical load shapes.[47] The CAISO duck curve represents the aggregate of these load shapes, but energy efficiency measures are implemented individually. Thus, the timing and effectiveness of a particular energy efficiency measure will be highly dependent on a customer's load shape. Furthermore, the value of a particular energy efficiency measure on a particular load profile varies. Taking customer-specific load shapes into account can potentially revolutionize the way that utilities determine which customers they target with which energy efficiency programs. Though energy efficiency is not dispatchable, strategically targeting customers for particular energy efficiency (and demand response) measures based on their load curves has the potential to control the grid level load profile in ways that benefit the entire system.[48]

## III. Conclusions

For over four decades, energy efficiency has contributed significantly in reducing customer and utility costs, creating jobs, and decreasing environmental impacts. Its role is becoming even more important as we focus on the urgent need to reduce GHG emissions and to ensure reliable and affordable grid operations. This article describes five key challenges for this ''next level'' of energy efficiency: (1) the ***magnitude*** of energy efficiency savings must increase dramatically; (2) the sources of energy efficiency savings must ***diversify***; (3) ***measuring*** and ensuring the persistence of energy efficiency savings must become commonplace; (4) energy efficiency outcomes must be integrated with a ***carbon*** reduction framework; and (5) energy efficiency must be understood and valued as part of an ***evolving grid***. Unless these challenges are understood and addressed, we will fall short in achieving this next level of efficiency and deep decarbonization goals. Simply put, none of the deep decarbonization pathways are affordable without very significant energy efficiency.



Our research at Stanford is focusing on the steps—a combination of technology, policy, and markets—needed to overcome these challenges. There are new tools—e.g., intelligent efficiency, financing, advanced technologies, better understanding of how to use behavioral interventions—that are becoming available. How to rapidly integrate these new opportunities into the historic efficiency framework and ensure they address the challenges discussed above is a critical issue. Institutional agency governance affects both strategy and execution around each of these elements and therefore merits further investigation as well.■

**Endnotes:**

**1.** Once the challenges facing the next level of efficiency are understood, the second step is identifying new tools and opportunities to address those challenges. The third step is developing and implementing a policy and market framework to support this next level of efficiency.

**2.** Source for $75 billion total savings: California Energy Commission (CEC). 2013. 2013 Integrated Energy Policy Report, p. 28. www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf (accessed 06.06.15). The CEC reports codes and standards benefits as a total, not accounting for the cost of the programs. Source for $12 billion net savings: See Appendix 1: ''Net Benefits Sources'' (benefits are net of the cost to run the programs). Source for 15,500 MW: CEC, 2013. California Energy Demand 2014–2024 Final Forecast, vol. 1. p.77; Figure 38, p. 78. www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC-200-2013-004-V1-CMF.pdf (accessed 06.06.15).

**3.** Source for savings: CPUC evaluation reports (http://eestats.cpuc.ca.gov/Views/EEDataPortal.aspx), IOU 2013 annual reports (http://eestats.cpuc.ca.gov/Views/EEDataPortal.aspx), POU annual reports (http://www.ncpa.com/policy/reports/energy-efficiency/), Overall C&S savings for 2003–2013 are from CEC, 2013. California Energy Demand Forecast 2014–2024. ''Table A-8: Electricity Efficiency/Conservation Consumption Savings'' (www.energy.ca.gov/2013_energypolicy/documents/demand-forecast/mid_case/). In order to avoid double counting of C&S savings, the C&S savings attributed to the utilities were subtracted. Source for $CO_2$: Energy and Environmental Economics (E3). Developing a Greenhouse Gas Tool for Buildings in California, p. 11 (mean of marginal emission intensities for electricity = 0.51 metric ton $CO_2$/MWh); p. 39 (on-site natural gas emission intensity = 117 lbs $CO_2$/MMBtu), ethree.com/GHG/GHG%20Tool%20for%20Buildings%20in%20CA%20v2%20April09.pdf (accessed 06.06.15). 117 lbs $CO_2$/MMBtu converts to 0.00531 metric ton $CO_2$/therm using 1 therm = 0.1 MMBtu. Source: U.S. Energy Information Administration, ''Frequently Asked Questions: What Are Ccf, Mcf, Btu, and Therms?'' www.eia.gov/tools/faqs/faq.cfm?id=45&t=8 (accessed 06.06.15); 1 lb = 0.0004536 metric ton. Source for cars equivalent: Calculation assumes 214,691 passenger vehicles driven for 1 year per million metric tons of carbon dioxide equivalent. Note that passenger vehicles include passenger cars, class 1 light trucks, and class 2 light trucks. CARB, *Emissions Factors Database* (EMFAC), run for 2014, www.arb.ca.gov/emfac/ (accessed 06.06.15). 2009–2013 cumulative electricity savings were 16,804 GWh.

**4.** Executive Order (E.O.) S-3-05: http://gov.ca.gov/news.php?id=1861; E.O. B-16-2012: http://www.gov.ca.gov/news.php?id=17472.

**5.** Gov. Brown's new E.O. B-30-15: http://gov.ca.gov/news.php?id=18938.

**6.** Gov. Brown's inaugural address: http://www.gov.ca.gov/news.php?id=18828. NRDC reports that residential and commercial buildings currently use 69 percent of all electricity in California, equivalent to the output of 70 large (500 MW) power plants. NRDC. Plug-In Equipment Efficiency: A Key Strategy to Help Achieve California's Carbon Reduction and Clean Energy Goals. http://switchboard.nrdc.org/blogs/pdelforge/Plug-in%20Eff%20IB-15-02-D_14.pdf. Increasing the savings in existing buildings is thus a major focus of California's GHG emission reduction strategy.

**7.** This discussion focuses on energy efficiency. However, demand response plays a critical role in the changing grid and going forward, greater integration of demand-side management (DSM) resources is needed for both planning and implementation.

**8.** Assembly Bill (AB) 32: http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.pdf.

**9.** McKinsey published its first global GHG abatement curve in February 2007 and created a comprehensive update with version 2 in January 2009. In August 2010 McKinsey released its findings of the impact of the financial crisis on carbon economics, called version 2.1. See: http://www.mckinsey.com/client_service/sustainability/latest_thinking/greenhouse_gas_abatement_cost_curves.

**10.** Grueneich, D., Carl, J., 2014 April. California's Electricity Policy Future: Beyond 2020. Shultz-Stephenson Task Force on Energy Policy, Stanford University.

**11.** See FN 4, *supra*.

**12.** In Figure 1, energy efficiency accounts for 33 percent of the emissions reductions projected in 2030 (223 MMT CO2e) and 28 percent of reductions (102 MMT CO2e) in 2050. This figure is illustrative and numbers depend on the order assigned to emission reductions.

**13.** See, Williams, J., et al., 2012. The technology path to deep greenhouse gas emissions cuts by 2050: the pivotal role of electricity. Science (January).

**14.** Energy and Environmental Economics (E3). 2015, April, 6. California PATHWAYS: GHG Scenario Results. E3 PATHWAYS. https://ethree.com/documents/E3_PATHWAYS_GHG_Scenarios_Updated_April2015.pdf.

, http://dx.doi.org/10.1016/j.tej.2015.07.001

**15.** Greenblatt, J., 2014. Modeling California policy impacts on greenhouse gas emissions. Energy Policy (December). http://www.sciencedirect.com/science/article/pii/S0301421514006892.

**16.** CPUC, 2008, September. California's Long Term Energy Efficiency Strategic Plan. http://www.cpuc.ca.gov/NR/rdonlyres/D4321448-208C-48F9-9F62-1BBB14A8D717/0/EEStrategicPlan.pdf.

**17.** California does not publish information on achieved or forecasted savings in the end-use categories shown in Figure 4 across utility programs, codes and standards, and private market effects. Figure 4 provides publicly available information on end-use measure savings from California IOU-customer funded programs.

**18.** California Municipal Utilities Association. Energy Efficiency in California's Public Power Sector A 2015 Status Report, p. 27. http://cmua.org/wpcmua/wp-content/uploads/2015/03/2015-FINAL-SB-1037-Report.pdf.

**19.** 2010–2012 gross savings by end use from plug loads and appliances, California Energy Efficiency Statistics: Data Portal. http://eestats.cpuc.ca.gov/Views/EEDataPortal.aspx.

**20.** NRDC estimates that plug-in equipment is responsible for approximately two-thirds of California's residential electricity consumption. NRDC. Plug-In Equipment Efficiency: A Key Strategy to Help Achieve California's Carbon Reduction and Clean Energy Goals. http://switchboard.nrdc.org/blogs/pdelforge/Plug-in%20Eff%20IB-15-02-D_14.pdf.

**21.** Research at Stanford is exploring the disconnect between the current policy framework and the challenges of the next level of efficiency.

**22.** Grueneich, D. Jacot, D., 2014. Scale, speed, and persistence in an analytics age of efficiency. Electr. J. (April).

**23.** California Energy Efficiency Statistics: Data Portal. http://eestats.cpuc.ca.gov/Views/EEDataPortal.aspx.

**24.** California Air Resources Board (CARB), 2014, May. First Update to the Climate Change Scoping Plan, pp. 37–39. http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf.

**25.** The CPUC does use a carbon adder in calculating the cost-effectiveness of energy efficiency but not in payment of customer incentives.

**26.** CARB, Comments on U.S. EPA's Docket Number EPA-HQ-OAR-2013-0602 (Standards of Performance for Greenhouse Gas Emissions from Existing Stationary Sources: Electric Utility Generating Units), Nov. 24, 2014. http://www.arb.ca.gov/cc/powerplants/ca-comments-2014-clean-power-plan.pdf. See, p. 34 (Appendix B): ''U.S. EPA should require state or regional plans to only count toward compliance those EE savings that are additional and incremental to savings that would have occurred without state EE programs. However, the U.S. EPA should require states to report both gross and net EE savings, each of which provides different but equally valuable information that can help U.S. EPA compare the achievements and effectiveness of various state efforts.''

**27.** Calculating net savings matters for state-level evaluation to determine if programs are functioning well and to inform future improvements. However, a federal requirement for states to report both net and gross estimates adds an unneeded level of complexity and technical burden to states' compliance reporting, and may lead to undercounting.

**28.** This discussion focuses on energy efficiency to defer distribution investments. California has made significant strides in incorporating planned energy efficiency savings into the CAISO's transmission planning process.

**29.** CPUC, D.14-10-016, Decision Establishing Energy Efficiency Savings Goals and Approving 2015 Energy Efficiency Programs and Budgets, R. 13-11-005, Oct. 16, 2014, p. 79.

**30.** See, Neme, C., Grevatt, J., 2015, January. Energy Efficiency as a T&D Resource: Lessons from Recent U.S. Efforts to Use Geographically Targeted Efficiency Programs to Defer T&D Investments [EE as a T&D Resource]. Northeast Energy Efficiency Partnerships (NEEP). p. 17. http://www.neep.org/sites/default/files/products/EMV-Forum-Geo-Targeting_Final_2015-01-20.pdf.

**31.** CPUC, R.13-11-005, Order Instituting Rulemaking Concerning Energy Efficiency Rolling Portfolios, Policies, Programs, Evaluation, and Related Issues, Nov. 2013, p. 7.

**32.** SCE's Preferred Resources Pilot website: http://www.edison.com/home/innovation/preferred-resources-pilot.html#. SDG&E is also exploring ways to expand energy efficiency's role in the changing grid as part of T&D system planning. Email correspondence with Caroline Winn, SDG&E, May 26, 2015.

**33.** EE as a T&D Resource, p. 44; CPUC, D.14-10-046, p. 80.

**34.** EE as a T&D Resource, p. 44.

**35.** CPUC, D.14-10-046, p. 88.

**36.** Id., p. 165.

**37.** EE as a T&D Resource, p. 45; confirmed by R. Aslin, PG&E.

**38.** Id., p. 20; confirmed by R. Sudhakara, Con Edison.

**39.** Con Edison has created an Integrated DSM (IDSM) Potential Model that analyzes potential deployments of all commercially available and near-term available technologies potentially applicable in the Con Ed territory, across various DSM scenarios, and on a geographically- specific basis. Id., p. 33.

**40.** Gov. Brown's inaugural address: http://www.gov.ca.gov/news.php?id=18828; Senate President pro Tempore, Kevin De Leon's website: http://focus.senate.ca.gov/climate/saying.

**41.** See, e.g., CAISO, 2013, December. Demand Response and Energy Efficiency Roadmap: Maximizing Preferred Resources, p. 7. http://www.caiso.com/documents/dr-eeroadmap.pdf.

**42.** Lazar, J., 2014 January. Teaching the 'Duck' to Fly. Regulatory Assistance Project (RAP). http://www.raponline.org/document/download/id/6977.

**43.** Hogan, M., Paulos, B., 2014. Dealing with the duck. Fortn. Mag. (January), 22. http://www.fortnightly.com/fortnightly/2014/01/dealing-duck?authkey=8d9326788f4c1bbf193a29cddfe0657b49208a211b4abab24e9f0421fc58ce64.

**44.** Sullivan, D., Martinez, S., 2014. Using Energy Efficiency to Meet Flexible Resource Needs and Integrate High Levels of Renewables into the Grid. https://www.aceee.org/files/proceedings/2014/data/papers/5-1012.pdf.

**45.** Id., p. 5-264.

**46.** EE as a T&D Resource, p. 10.

**47.** Kwac, J., Flora, J., Rajagopal, R., 2014. Household energy consumption segmentation using hourly data. IEEE Trans. Smart Grid 5(1), 420–430.

**48.** See, for example, Stanford's Visualization and Insight System for Demand Operation and Management (VISDOM) as described in this conference paper: Borgeson, S., Flora, J., Kwac, J., Tan, C., Rajagopol, R., 2015. Learning from Hourly Household Energy Consumption: Extracting, Visualizing and Interpreting Household Smart Meter Data (in press). Presented at the HCI International, Los Angeles, CA, 2015.

, http://dx.doi.org/10.1016/j.tej.2015.07.001