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Teaching the “Duck” to Fly

Second Edition

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Cover image by Tim Newcomb

Teaching the “Duck” to Fly

Second Edition

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Acronyms

GIWH	Grid-integrated water heating	MW	Megawatt
ISO	Independent system operator	PV	Photovoltaic
ISO-NE	New England Independent System Operator	TOU	Time-of-use
kWh	Kilowatt-hour	UPS	Uninterruptible power supplies

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Foreword to the Second Edition

The First Edition of *Teaching the “Duck” to Fly*, released by The Regulatory Assistance Project (RAP) in January 2014, posed an integrated approach to the way utilities and regulators examine the challenge of adapting to a power system with significant variable renewable resources. Prior to that time, the focus of most analysts was simply on the strained flexibility of the remaining fossil generation fleet, and the need to add flexible generation and electricity storage resources, both of which have high costs. *Teaching the “Duck” to Fly* changed this, by focusing at least equal attention on the flexibility that customer loads, low-cost thermal storage, time-varying pricing, and other simple strategies could provide in adapting to a two-way system, relying equally on supply-side and customer load management.

The First Edition was presented at meetings of US regulators, at the Florence (Italy) School of Regulation, and to utilities and their regulators in China, India, the Middle East, Africa, and Australia. It was the subject of a series of webinars, attracting a global audience. Feedback from these varied audiences was considerable, and the author, RAP as an organization, and indeed the entire industry have learned more in the intervening two years. Here are a few lessons we take away from this experience.

Some of the concepts in the First Edition proved to be of limited value. For example, concentrated solar power has not been well received in the market, mostly because of the dramatic drop in the cost of solar photovoltaic (PV) generation. West-facing solar is important where it is achievable, but the benefits are modest. In this Second Edition, these are consolidated into a strategy for “peak-oriented renewables,” that include wind sites with favorable production characteristics and more disciplined use of existing hydroelectric resources.

However, the First Edition also dramatically understated the potential of **water heating** and **air conditioning** storage technologies. These technologies have evolved quickly in recent years, and the economics are becoming

more favorable. Dozens of pilot programs for grid-integrated water heating have proven this concept and will soon be deployed in many regions. The number of ice storage and chilled-water storage air conditioning systems has grown, but still reaches less than two percent of the potential market. The Second Edition makes greater use of these highly reliable, low-cost resources to further smooth the utility load profile.

A new strategy has been introduced in the Second Edition: control of **water and wastewater pumping**. These uses consume about seven percent of total US electricity. Water is very easy to store in tanks, reservoirs, and aquifers. In many cases, all that is needed to stimulate management of these loads is a restructuring of the electricity pricing to remove demand charges and substitute time-varying energy charges. The potential can be even greater if water and wastewater utility planning is conducted interactively within electricity least-cost planning, so that, for example, increased water storage capacity can become a substitute for increased electricity generation capacity.

As in the original edition, the Second Edition starts with the load shape of an illustrative California utility, before and after addition of significant solar and wind resources. It then incrementally includes each of the strategies to produce a gradual change in the load shape. The “bottom line” of this Second Edition is a package of measures that, conservatively estimated but aggressively deployed, can dramatically reshape the electricity load that must be served by dispatchable resources. The “ending load factor” after the ten strategies is an impressive 86.5 percent, far higher than what exists today. Simply stated, it should be easy to adapt to the “Duck Curve” that emerges as variable renewables are installed on utility grids around the world.

Finally, the author wants to thank a few of the many people and organizations who helped examine, critique, and test the concepts proposed in the First Edition. These people have enhanced those ideas, tested them on real utilities and real utility customers, and helped make the

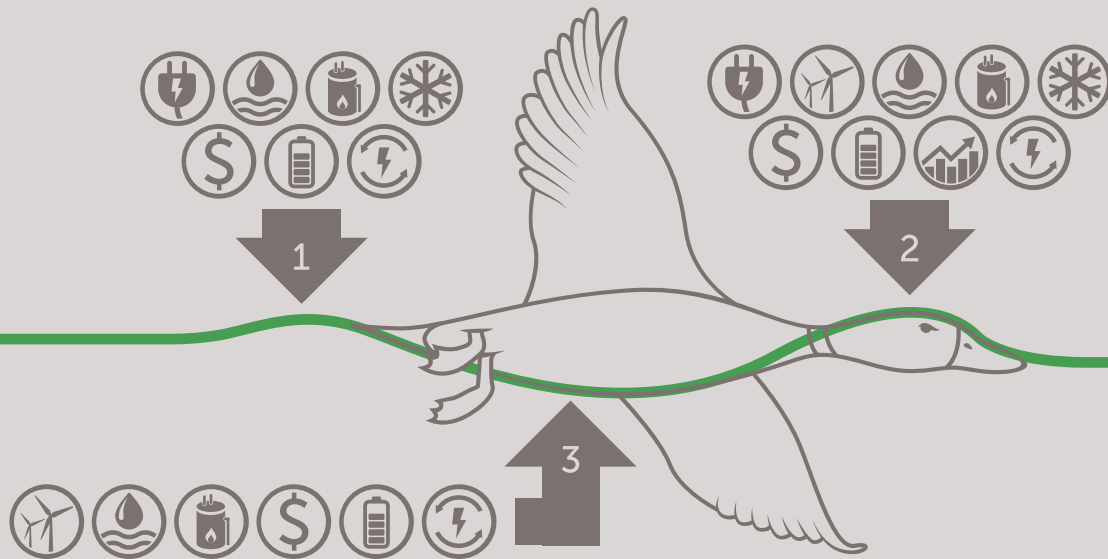
Second Edition a much better product. These include:

- Burbank Water and Power, and its General Manager Ron Davis, for quickly putting some of the concepts from the First Edition to a reality test in California as that utility expands from less than five percent renewables in 2010 to 50 percent renewables by 2030, including the strategies relating to water pumping, west-facing solar, air conditioning storage, rate design reform, inter-region power trading, and time-varying pricing for electric vehicle charging loads;
- The Hawaii Public Utilities Commission, Hawaiian Electric Company, Kauai Island Utility Cooperative, and Hawaii Energy, for embracing the concepts of *Teaching the “Duck” to Fly* and quickly expanding the state of the science in a very dynamic and challenging electricity market;
- Steffes Corporation, Great River Energy, and the Peak Load Management Association, for advancing the state of the science for water heater controls, one of the two most important emerging strategies in this paper;
- Calmac Corporation and Ice Energy, for assistance understanding the technology and economics of air conditioning storage, the other of the two most important emerging strategies;
- The Northwest Power and Conservation Council, for a 30-year disciplined approach to evaluating energy efficiency options, including the peak load value of different energy efficiency measures that makes Strategy 1 a well-recognized option; and
- Finally, my many RAP colleagues who contributed to the original concept, and have helped expand my own knowledge to make this Second Edition possible. Stimulated by our founder, David Moskovitz, to continually challenge skepticism and to hatch and promote “Big Ideas” that can change the world, RAP is an incredible group of smart, creative people. It is a joy to work with them. Visit *About RAP* on the RAP website to meet all of these amazing people.

Jim Lazar
Olympia, Washington
January 2016

Teaching the “Duck” to Fly:

10 strategies to control generation, manage demand, & flatten the Duck Curve



Targeted Efficiency

Focus energy efficiency measures to provide savings in key hours of system stress. ↓ ↓



Peak-Oriented Renewables

Add renewables with favorable hourly production. Modify the dispatch protocol for existing hydro with multi-hour “pondage.” ↓ ↑



Manage Water Pumping

Run pumps during periods of low load or high solar output, curtailing during ramping hours. ↓ ↓ ↑



Control Electric Water Heaters

Increase usage during night & mid-day hours, & decrease during peak demand periods. ↓ ↓ ↑



Ice Storage for Commercial AC

Convert commercial AC to ice or chilled-water storage operated during non-ramping hours. ↓ ↓



Rate Design

Focus pricing on crucial hours. Replace flat rates & demand charge rate forms with time-of-use rates. Avoid high fixed charges. ↓ ↓ ↑



Targeted Electric Storage

Deploy storage to reduce need for transmission & distribution, & to enable intermittent renewables. ↓ ↓ ↑



Demand Response

Deploy demand response programs that shave load during critical hours on severe stress days. ↓



Inter-Regional Power Exchange

Import power from & export power to other regions with different peaking periods. ↓ ↓ ↑



Retire Inflexible Generating Plants

Replace older fossil & nuclear plants with a mix of renewables, flexible resources, & storage.

Introduction: Teaching the “Duck” to Fly

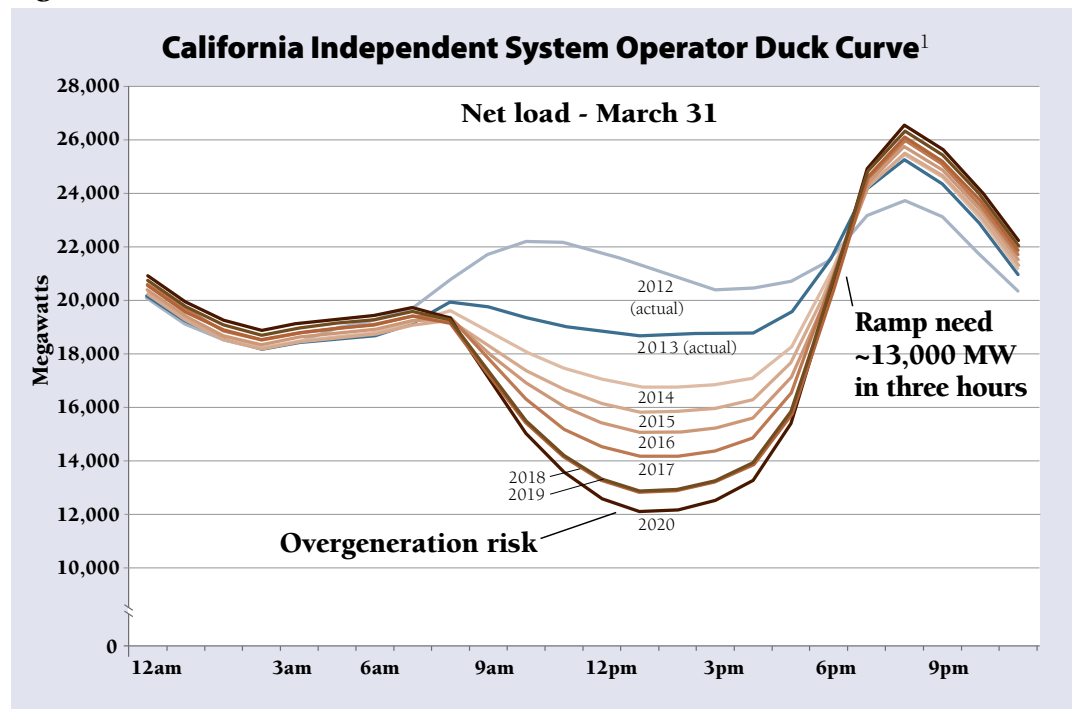
The electric sector has become very sensitive to the load shape of emerging utility requirements as increasing penetration of wind and solar energy creates challenging “ramping” issues for conventional generation in the morning and evening, as renewable energy supplies wax and wane.

Fundamentally, this issue is no different from the problem utilities have addressed for over a century: adapting the supply of energy to match changing consumer demand. The difference is that daily and seasonal usage patterns and the resources that have historically served that pattern have evolved gradually over the last 125 years, whereas the renewable energy revolution is creating new challenges in a much shorter period of time.

Addressing this problem will require a change in the way utility power supply portfolios are formulated, but solutions are at hand. Fortunately, we have technologies available to us that our great-grandparents did not.

Previously, the utility’s role was to procure a least-cost mix of baseload, intermediate, and peaking power plants to serve a predictable load shape. Today, utilities have to balance a combination of variable generation power sources, both central and distributed, together with dispatchable power sources, to meet a load that will be subject to influence and control through a combination of policies, pricing options, and programmatic offerings. This now includes the capability to dispatch customer loads, including water heating, air conditioning, and water pumping, strategies at the heart of this paper.

Figure 1

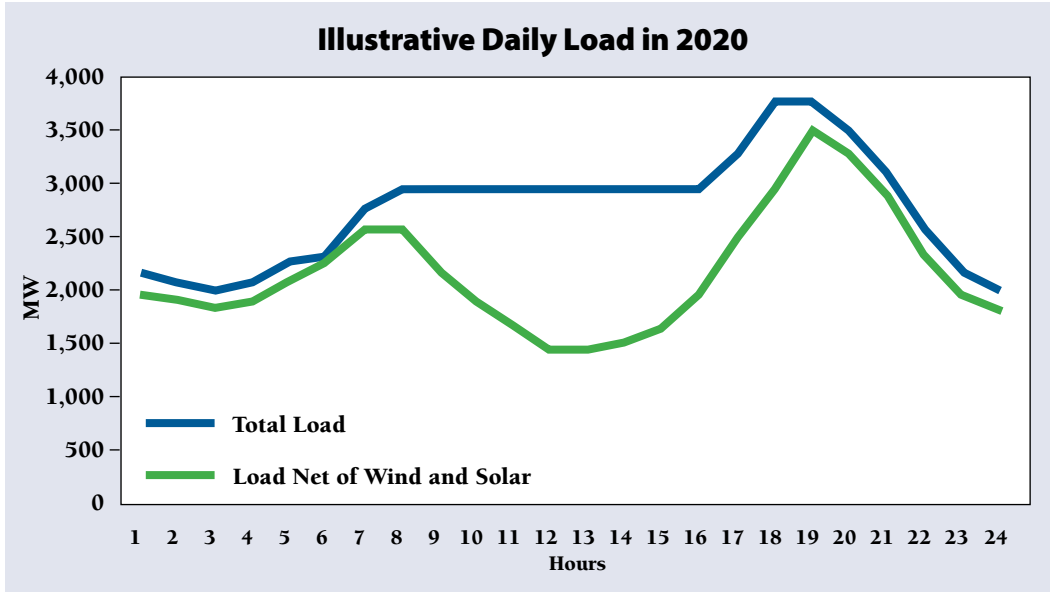


What is now being referred to as “the Duck Curve” (Figure 1) is a depiction of this emerging change that has become commonly recognized throughout the electric sector. Over time, as more solar and wind energy are added to the grid, the “net load” to be serviced from dispatchable resources (the duck’s belly) sags in the middle of the solar day when solar generation is highest, but the load to be served in the early evening after the sun goes down continues to grow (the head) and the transition between the two gets more severe (the neck).

This paper attempts to model the options for a hypothetical, illustrative electric utility facing its own duck curve. Our illustrative utility is expected to add 600 megawatts (MW) of distributed solar, 1,250 MW of utility-scale solar, and 725 MW of wind capacity in response to a state

1 California ISO. (2013). What the duck curve tells us about managing a green grid.

Figure 2



renewable portfolio standard by the year 2020. Figure 2 illustrates an hourly demand and net demand (net of solar and wind) analysis for this utility on a sample day, before any of the options are considered.²

The total load line in Figure 2 shows the utility’s projected total load, by hour, during the day. The “load net of wind and solar” line shows the load that the utility will face after expected wind and solar generation serve a portion of the total load. Figure 2 shows that the overall load has a moderate diurnal shape, but when the wind and solar energy expected by 2020 are added to the mix,

the ramping down of conventional supply in the morning (as solar generation increases) and rapid ramping up in the afternoon hours (as loads increase but solar energy supplies drop off quickly) is even more sharp, creating operational concerns for the utility. This “net load” to be served by conventional dispatchable generating resources must be met with the existing or emerging generation fleet. This challenge is causing some utilities to assert that the proportion of energy needs met by variable generation resources needs to be limited. Although some utilities may argue that variable renewable energy can be relied on

Figure 3

Duck Sitting in Water



Figure 4

Duck in Flight



2 It should be noted that this illustrative day is a light load: a heavy renewable energy generation day such as one that might be experienced in the spring or fall. It is not intended

to represent a “normal” or “summer peak” day. It is selected to illustrate the opportunities available to meet a particularly challenging situation.

only for a small portion of daily energy requirements, this paper discusses strategies that enable high levels of energy needs to be served, provided that pricing and technology to increase the flexibility of loads are employed.

This paper identifies a number of low-carbon strategies that can be applied to meet this challenge. These strategies are generally limited to existing commercially available technologies, but perhaps deployed in ways that have not been done on a commercial scale to date. These strategies not only enable greater renewable integration, they enhance system reliability and reduce generation and transmission capital and fuel costs by modifying the load profiles and better utilizing existing transmission assets. Not every strategy will be applicable to every region or utility around the country, and every region will have additional strategies that are not among these ten.

Specific implementation plans, which are beyond the

scope of this paper, will need to be tailored to address local resource capabilities, system constraints, and other considerations.

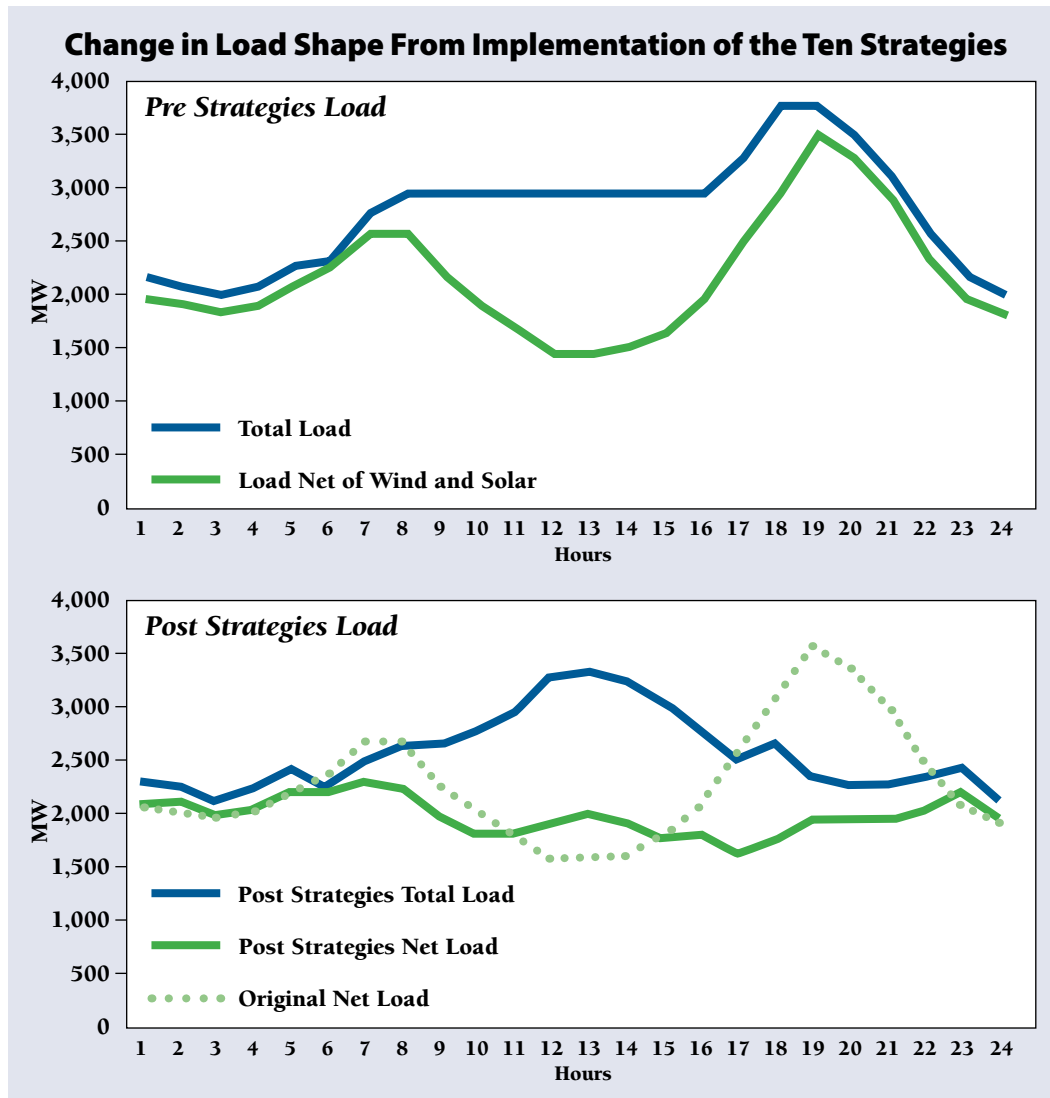
Depictions of future load like those in Figure 1 have entered the industry vernacular as “the Duck Curve” for obvious reasons. In actuality, however, ducks vary their shape depending on different circumstances, and as explained here, utility load shapes can do the same.

A duck in water tends to center its weight in the water, floating easily. Figure 3 shows the duck shape commonly associated with the graph in Figure 1.

A duck in flight, however, stretches out its profile to create lower wind resistance in flight. This is illustrated in Figure 4.

Metaphorically, our goal is to teach the “duck” in Figure 2 to fly, by implementing strategies to both flatten the load and to introduce supply resources that can deliver

Figure 5



more output during the late afternoon high load hours. Many of these strategies are already used on a modest scale in the United States and European Union, whereas others use technologies that have been proven in pilot programs but are not yet deployed on a commercial scale. None require new technology and each has a small (or negative) carbon footprint.

Figure 5 shows the change in shape of the Duck Curve from the cumulative application of the ten strategies we propose below. Like an actual duck, it becomes more streamlined and better able to “take flight.”

We include the following ten strategies in our analysis:

- Strategy 1.** Target energy efficiency to the hours when load ramps up sharply;
- Strategy 2.** Acquire and deploy peak-oriented renewable resources (Strategies 2 and 3 in the original paper);
- Strategy 3.** Manage water and wastewater pumping loads (new in the Second Edition);

Strategy 4. Control electric water heaters to reduce peak demand and increase load at strategic hours;

Strategy 5. Convert commercial air conditioning to ice storage or chilled-water storage (greatly increased in magnitude in the Second Edition);

Strategy 6. Rate design: focus utility prices on the “ramping hours” to enable price-induced changes in load;

Strategy 7. Deploy electrical energy storage in targeted locations;

Strategy 8. Implement aggressive demand-response programs;

Strategy 9. Use inter-regional power exchanges to take advantage of diversity in loads and resources;³ and

Strategy 10. Retire inflexible generating plants with high off-peak must-run requirements.

3 For a complete set of regional strategies consistent with this step, see: Schwartz, L., Porter, K., Mudd, C., Fink, S., Rogers, J., Hogan, M., Lamont, D., & Kirby, B. (2012).

Meeting Renewable Energy Targets in the West at Least Cost: The Integration Challenge. Western Governors’ Association.



Strategy 1: Target Energy Efficiency to the Hours When Load Ramps Up Sharply

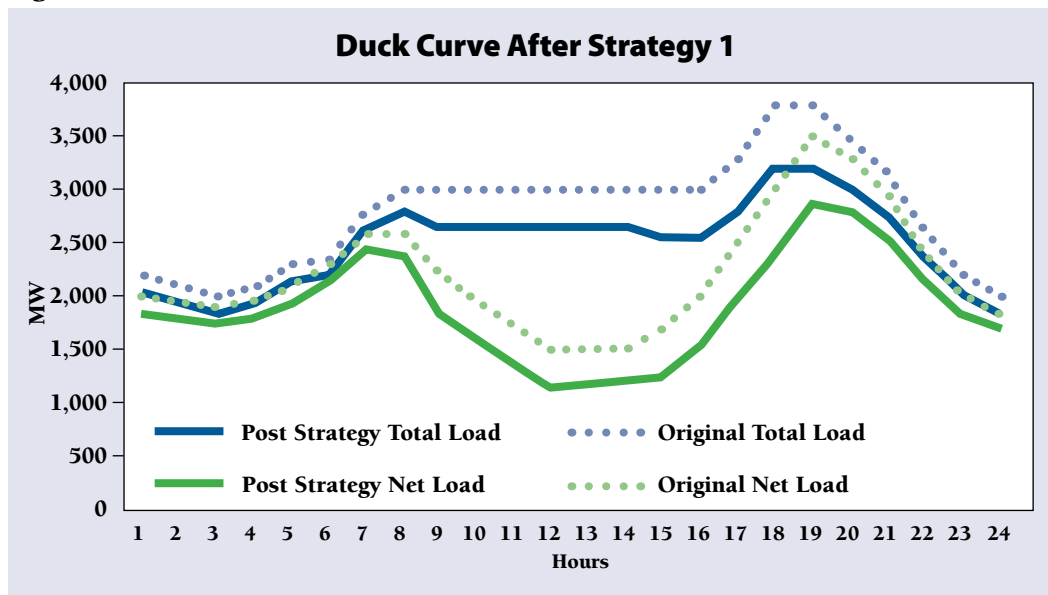
Strategy Description:

Acquire energy efficiency measures with a focus on measures that provide savings in key hours of system stress.

Amount:

11 percent of total system load, with a 4:1 ratio of on-peak to off-peak consumption (compared to a 3:1 ratio for overall load).

Figure 6



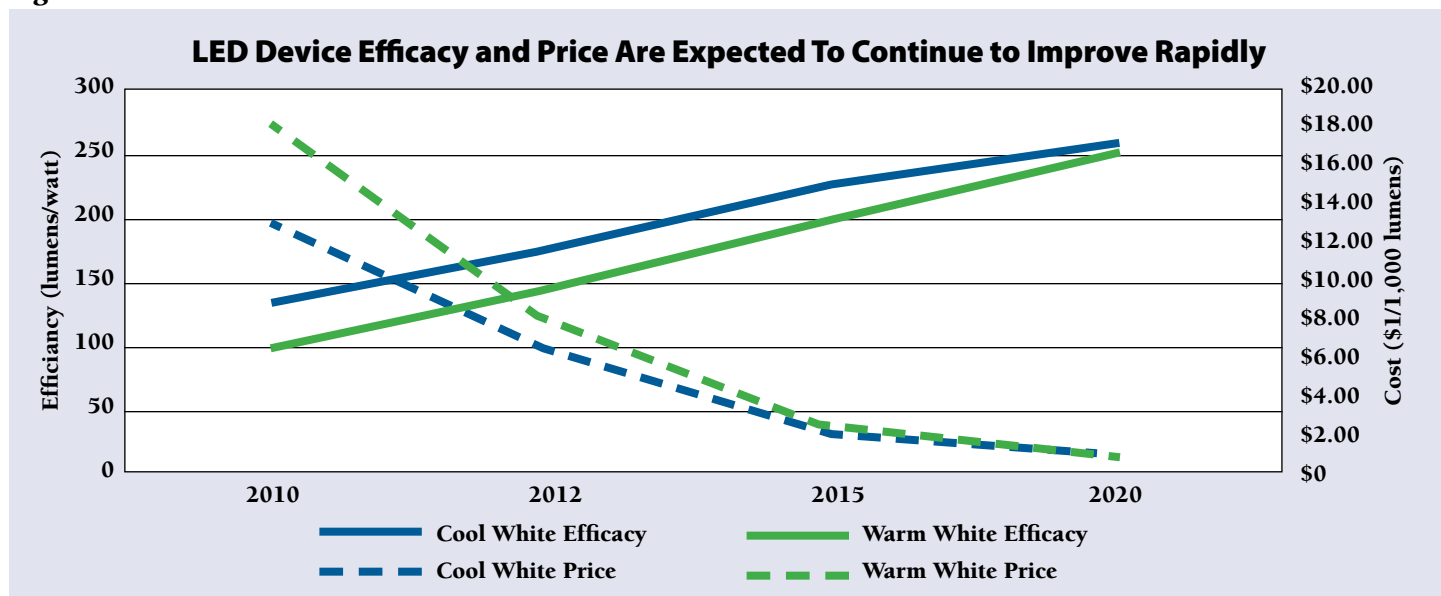
The rapid increase in loads to be served from dispatchable resources between 4 PM and 7 PM that dominates the Duck Curve is made up of discrete elements of electricity usage primarily in the residential and commercial sectors. It is a period when office building loads continue, while residential loads increase as residents return from school and work. People come home, turn on televisions, start cooking, and, in the winter, use significant amounts of lighting. This late-afternoon convergence of residential and commercial loads causes system peaks on most utility systems.

Overall, energy efficiency has about the same shape as

the system load, with contributions to peak load reduction about twice as great as the impact during off-peak hours. But many measures are available that have a higher level of peak-orientation. We address three of these: residential lighting, air conditioning, and office building lighting controls.

Residential lighting, particularly kitchen-area lighting, is concentrated around morning and evening peak periods. Higher-efficiency LED lighting is quickly becoming inexpensive, reliable, and of increasing efficacy. By 2020, efficacy (light output per watt of energy input) is forecast to be three times that of current CFL lamps. Thus, the

Figure 7



residential lighting load, already cut in half with CFL programs over the past decade, can be cut in half again with LED retrofits. The reduction in afternoon lighting also brings with it a reduction in residential air conditioning requirements, because less energy is released as heat.

Figure 7 shows the expected improvement in LED lighting efficiency and reduction in LED lighting cost over this decade. This suggests that even LED to LED replacement of early-vintage LED lighting may be cost-effective to reduce late afternoon peak usage.

Street lighting is unique in that it is *only* used during hours of darkness, beginning with the early-evening ramping hours. LED street lights can achieve a 30- to 70-percent reduction in ramping period lighting needs.

Lighting in the retail sector is another area in which efficiency opportunities are considerable, but because that sector uses light throughout the day and into the evening, this efficiency will reduce not only peak demands that cause a ramping need, but also mid-day demands that support minimum-level operations for power plants needed during the ramping period. Although the energy savings are significant, the ramping benefits may be small.

The office lighting sector presents a different opportunity. Workers in office buildings generally depart the office between 4 PM and 6 PM, depending on their starting time and work load. Often entire floors remain lit until the last worker has departed. Modern building

energy management systems can control lighting so that smaller zones are controlled, providing adequate light for remaining workers, and zoned lighting during custodial work, without needing to light entire floors. As much as one-half of office lighting loads can be curtailed during the 5 PM to 8 PM ramping hours without significant adverse impacts on building users.

High-efficiency residential air conditioners are an exemplary opportunity, because of the great opportunity to improve efficiency and the high peak-concentration of this load. These loads represent approximately ten percent of total residential sales, but up to 70 percent of residential peak demands. Simple measures, such as Energy Star® replacements of window and central air conditioners can produce 30- to 50-percent reductions in this load. More expensive alternatives, including ground-source heat pumps, can produce 60- to 80-percent reductions in this load. Ice storage and chilled-water storage air conditioning are discussed in Strategy 3, for commercial and institutional buildings, but are not considered commercially available for residential-scale applications.

Strategy 1 assumes that the illustrative utility can reduce its peak load by 16 percent, and off-peak loads by one-half that amount, with efficiency programs that target peak and ramping period loads. Figure 6 shows the effect of this strategy on the loads of the illustrative utility.

Updates from the First Edition

The magnitude of the **energy efficiency opportunity for air conditioning** is dramatically greater in most areas of the country than was assumed in the First Edition. The previous edition included energy efficiency equal to only five percent of the total load. In this edition, that has been increased to 11 percent of total load. This is a level of achievement that all the top states of the American Council for an Energy-Efficient Economy ratings⁴ have achieved.

Efficient kitchen lighting, including LED ceiling and task lighting, can reduce the kitchen lighting load by more than 50 percent. Because kitchen lighting is used primarily during morning and early evening peak periods, this is an ideal target to reduce ramping requirements resulting from high solar deployment.



Ground source heat pumps are up to five times as efficient as other heating and cooling systems, because they rely on a stable underground temperature geothermal resource.

These can dramatically reduce afternoon cooling needs—and winter heating requirements, when replacing conventional electric heat.



Source: ClimateMaster, Inc.

Controls Save Energy

Energy Management Strategies	Lighting Energy Savings Due to Lighting Controls			
	Multi-tenant Office Bldg 300K ft ²	Corporate Office Bldg 400K ft ²	Hospital Admin Bldg 175K ft ²	Major Sports Complex 1.3M ft ²
Adaptive Scheduling	14%	9%	22%	24%
Daylight Harvesting	1%	4%	8%	3%
Lighting Limits	9%	11%	13%	5%
Occupancy Control	31%	25%	25%	37%
Personal Task Control	6%	11%	2%	2%
Load Shedding	0%	5%	3%	5%
Cumulative Savings Due to Addressable Lighting Controls	61%	65%	73%	76%

Commercial building lighting controls can produce immense overall savings.

Office buildings are a key target for this strategy, because office *occupancy* drops off at the time of the late afternoon ramping period, but office lighting often remains on until the last workers leave and janitorial tasks are completed. Zoned lighting controls can preserve lighting for those still working, while reducing total building usage by up to two-thirds.

Line losses are highest during peak hours, because they increase exponentially with the demand on the distribution system.⁵ Most of the strategies in this paper are directed at reducing peak loads, and energy efficiency is Strategy 1. Reducing peak loads can sharply reduce line losses.



Source: Flickr, Bob Mullica

4 Massachusetts, Rhode Island, California, Oregon, Connecticut, Vermont, New York, Washington, Illinois, Minnesota, and Maryland. Retrieved from <http://aceee.org/state-policy/scorecard>.

5 Lazar, J., & Baldwin, X. (2011). *Valuing the Contribution of Energy Efficiency to Avoided Marginal Line Losses and Reserve Requirements*. Montpelier, VT: The Regulatory Assistance Project.



Strategy 2: Acquire and Deploy Peak-Oriented Renewable Resources

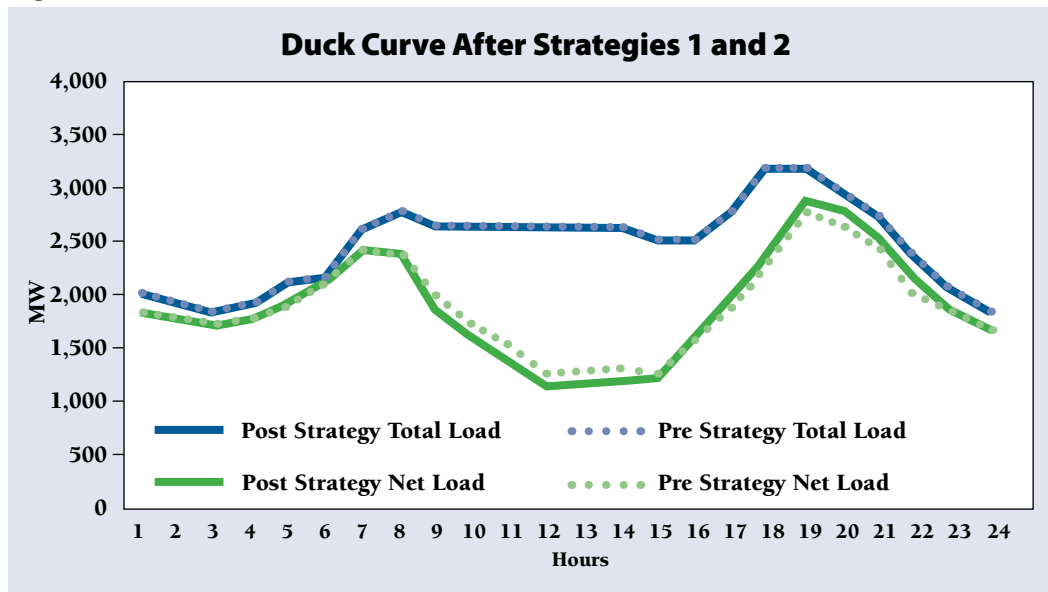
Strategy Description:

Acquire wind, solar, or hydro resources that have favorable hourly production. Modify the dispatch protocol for existing hydro resources with multi-hour pondage.

Amount:

Substitution of anticipated renewable portfolio with 100 MW of solar PV oriented to the west; 100 MW of solar in the form of solar thermal with 3-hour storage capacity; 100 MW of wind with late afternoon/early evening concentration of output.

Figure 8



Many utilities have acquired renewable energy from wind and solar facilities to comply with state renewable portfolio standards. These standards typically apply to an annual obligation and do not differentiate between times when the renewable energy is produced. We have learned that timing does matter. Fortunately, there are many renewable resources that produce energy at favorable times of the day, or can be controlled or modified to do so.

These options include:

Storage Hydro Facilities. Most hydro facilities have lakes or at least “pondage” where the water is stored before flowing through turbines to produce power. These projects allow the utility to produce power when it is most valuable, and, in many cases, utilities have installed additional turbines on dams to increase their hydro potential. The largest example of this is the Third Powerhouse at Grand Coulee Dam, which adds 4,500 MW of peaking capacity

but involves no additional storage, and adds little in the way of additional annual energy production. There are some facilities that are strictly run-of-river or purely as-available, and those do not offer any flexibility. In addition, some hydro projects are subject to fish, irrigation, navigation, flood control, and other operating conditions that may limit productivity.

Wind Site With Favorable Characteristics. Wind energy sites are normally developed only after extensive monitoring of wind conditions. Some locations are most productive in the night-time hours, and others in day-time hours. Seeking sites with favorable late afternoon production can provide a favorable resource addition to the utility system.

West-Facing Solar Panels. These produce power up to two hours later in the afternoon than south-facing panels do, but produce fewer annual kilowatt-hours (kWh). Without time-differentiation in compensation, solar system owners will choose the easiest installation with the

most annual kWh. Time-varying prices will induce these producers to install tracking systems or west-facing panels to increase generation during the ramping hours when generation may be most valuable.

Solar/Thermal. These power plants gather sunlight and concentrate it to heat water or another fluid that drives a conventional turbine to produce electricity. Storage of the heated fluid allows for production of electricity several hours after the sun has set, producing a more valuable product.

Figure 8 shows the load shape for our illustrative utility if 100 MW of solar facilities were west-facing, if 100 MW of solar-thermal with storage were installed instead of PV, and if 100 MW of wind energy with favorable afternoon production were selected. We have not included any redispatch of hydro resources, as that option is only available to utilities with flexible hydro generation in their fleet.

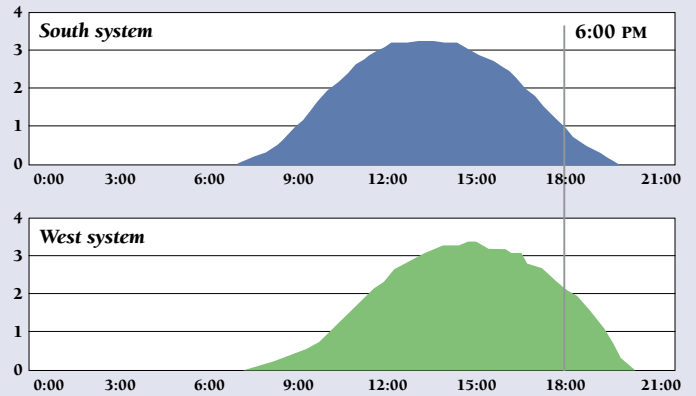
Updates from the First Edition



Hoover Dam and many other hydro facilities, particularly in the western states, typically have only enough water to operate the turbines a few hours per day. By **scheduling that operation in the ramping hours**, the utilities receiving this power can both receive a carbon-free resource and use that resource to better integrate variable wind and solar resources.

Additional research may identify other projects with favorable patterns. Additional interconnections between Texas and other grids may enable higher levels of wind production in all areas.

Average daily generation profile (kW) from rooftop PV systems for south and west systems

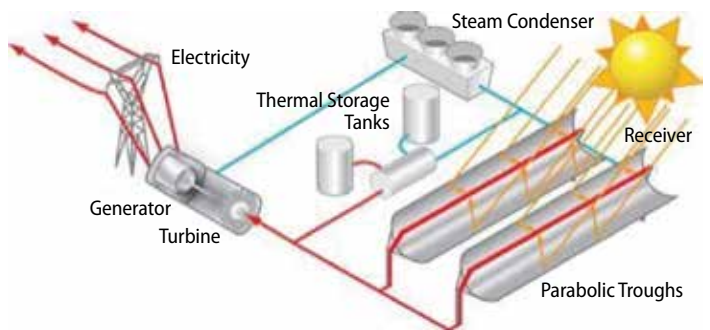
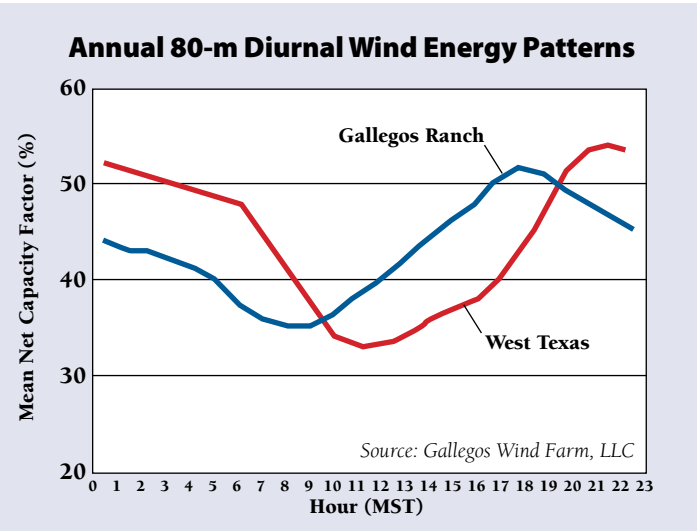


Source: Pecan Street Research Institute. (2013). South-facing solar cut peak demand from grid 54% - west-facing systems 65%.

Some wind projects have **favorable afternoon production patterns**. This graph compares the expected production from the Gallegos Wind Farm in New Mexico, where production peaks closer to 7 PM in the evening, to the typical wind pattern found in West Texas, where electricity peak production is closer to 10 PM.

This figure demonstrates that west-facing PV projects produce useful output up to two hours longer in the evening, when the most serious ramping challenges are experienced.

Using **solar-thermal generators** in place of PV systems provides the opportunity to store solar energy in the form of superheated fluids or salts, allowing generation to occur hours after the solar energy has been gathered.



Source: EcoMENA. (2015). CSP-Powered Desalination Prospects in MENA



Strategy 3: Manage Water and Wastewater Pumping Loads

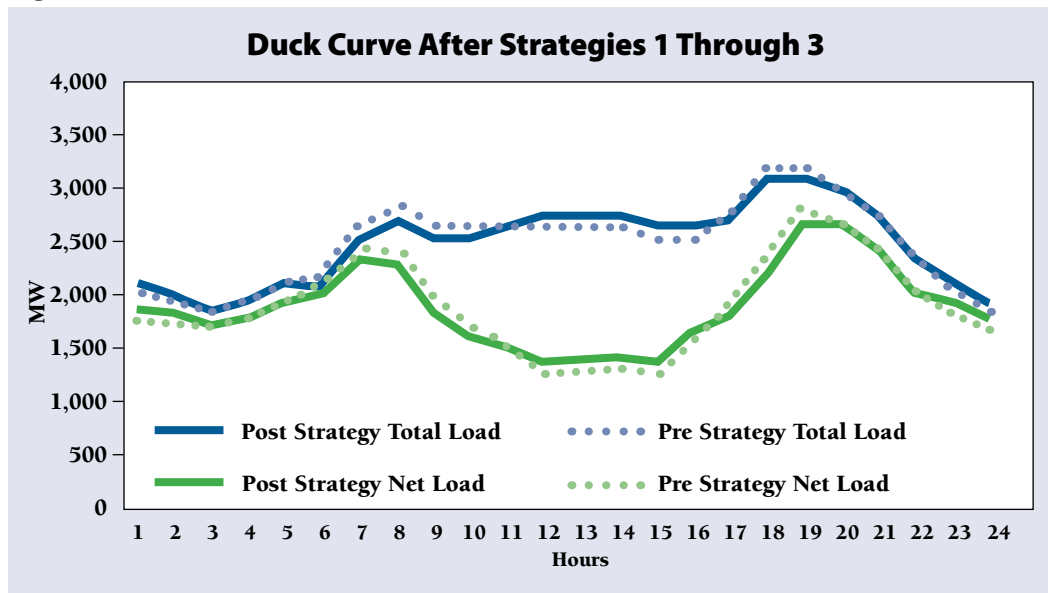
Strategy Description:

Control water and wastewater pumps to operate during periods of low existing load or high solar output, curtailing pumping load during ramping hours.

Amount:

100 MW of pumping load (two percent of total system load) controlled to decrease usage in ramping hours and increase usage in off-peak hours.

Figure 9



This is a new strategy in *Teaching the “Duck” to Fly*. Nationally, water pumping consumes approximately seven percent of our electricity; in California it is much higher than this, owing to long-distance transmission of water from northern California to southern California, and high irrigation pumping loads. The category includes electricity used for water well production, water transmission, irrigation, water treatment, water distribution, and wastewater treatment.

Water pumping is a unique opportunity to shift load, because water is a physical good that can be stored in water tanks and reservoirs. Most water system pumps operate

between two set-points: a minimum level in the reservoir or tank, and a maximum level. The water purveyor is relatively indifferent as to when pumps operate within this constraint, and it is possible to add storage capacity to take advantage of lower-cost electricity prices.

In many parts of the world, irrigation systems are now being operated directly with solar PV power, with the systems sized to the daily pumping water requirement. This direct use of solar electricity eliminates the grid and grid management entirely.

Most utilities have demand-charge rate designs that impose a significant charge based on the highest level

Table 1

Conventional and Recommended Smart Utility Rate Designs for Water Systems and Irrigation Pumps			
Conventional Rate Design for Water Pumping		Smart Rate Design Alternative for Water Pumping	
Demand	\$10/kW	Demand	None
Energy		Energy	
All Hours	\$0.10/kW	Ramping Hours	\$0.15/kW
		All Other Hours	\$0.10/kW

of usage during the month. This type of rate design encourages water and wastewater utilities to install relatively small pumps, and operate them at a uniform level throughout the day. Table 1 presents a typical utility rate design that applies to water system and irrigation pumps, and a smarter alternative rate design that would encourage

the use of larger pumps operated off-peak. We discuss rate design in greater detail in Strategy 7.

Even California utilities that have time-varying energy rates generally impose a “distribution demand charge” that creates the incentive to run pumps during all hours. By eliminating demand charges during off-peak periods, and recovering system capacity costs in time-varying energy rates, electric utilities can replace this incentive with a reward for installing larger pumps that run only at low-cost periods, to provide the same overall level of service.

This strategy assumes that our illustrative utility has approximately 150 MW of pumping load at all hours, and that two-thirds of this load can be shaped into desired hours. One-third is assumed to be essential to maintain distribution system pressure for reliable water service, and is not controlled.

Figure 9 depicts the change in our illustrative utility load shape after re-dispatch of water and wastewater pumping loads.

Updates from the First Edition

Direct use of **PV electricity for water pumping** in India.



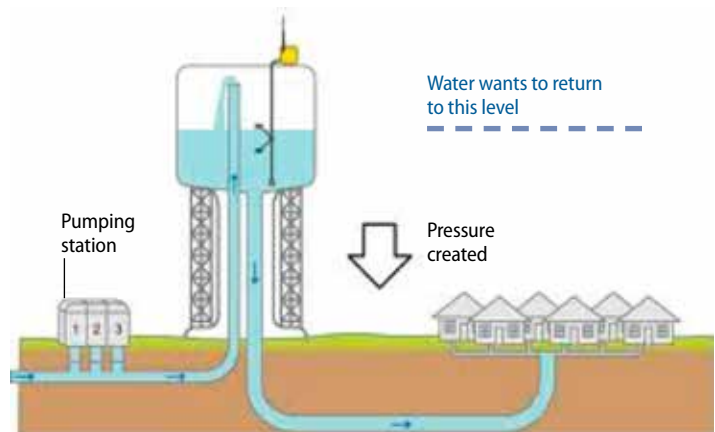
Source: Surya Urza Enterprises

Low-energy **precision application irrigation** can put the correct amount of water directly onto the crops.

Scheduling irrigation pumping to exclude key peak hours has little effect on crop production, and a potential significant economic savings for farmers.



Source: Natural Resources Conservation Service



Source: Bright Mags. (undated). How do water towers work?

Municipal water supply pumping normally keeps water in a tank or reservoir from which water flows using gravity; this eliminates the need for standby generators.

By **filling the tank or reservoir when low-cost power is available**, and turning off pumps during ramping periods and high-cost periods, the water pumping load is shifted, with no impact whatsoever on water customers.



Source: City of Iowa City

The Iowa City wastewater treatment plant has a maximum capacity of 24 million gallons per day but normally treats only about 10 million gallons per day. The **onsite storage capacity** allows some flexibility as to when pumping and treatment are scheduled.



Strategy 4: Control Electric Water Heaters to Reduce Peak Demand and Increase Load at Strategic Hours

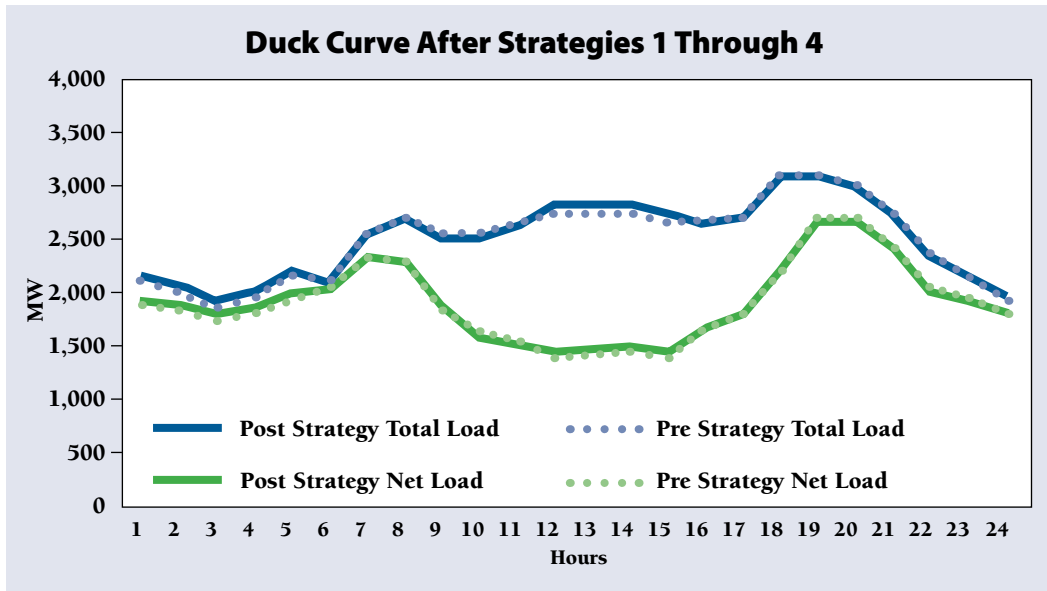
Strategy Description:

Control electric water heaters to increase electricity usage during night hours and mid-solar-day hours, and decrease usage during morning and evening peak demand periods.

Amount:

70 MW (approximately 16,000 units) of electric water heaters controlled to provide high reliability of hot water service, low draw of hot water heaters during key morning and evening hours, and increased draw of water heater loads during off-peak and solar-day hours.

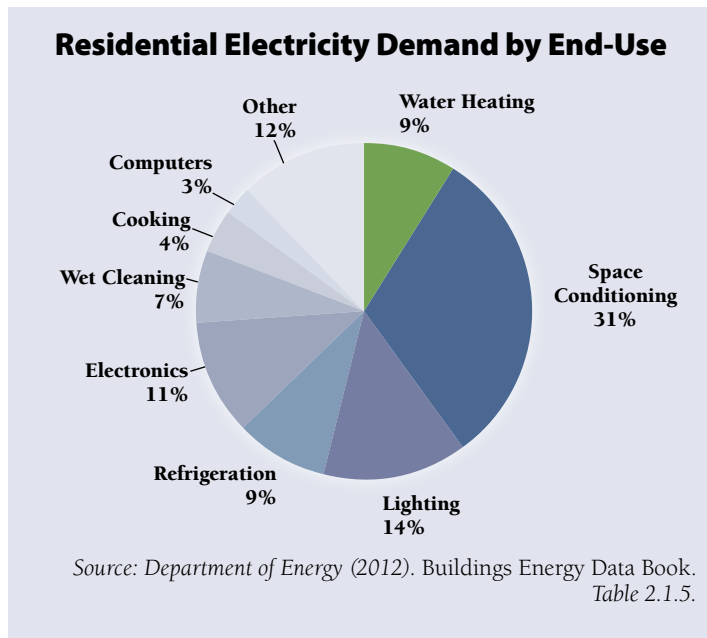
Figure 10



The United States has about 45 million electric water heaters in service. After space conditioning, water heating is one of the largest components of residential electricity demand (Figure 11). This hot water use is concentrated in the morning and evening hours, when residential consumers are getting up in the morning, and again when they return home at the end of the day, contributing significantly to peak demands.

By their nature, water heater tanks are energy storage devices; each water heater is, in effect, a 15-kWh battery waiting to be used, because the water can be heated when power is most available, and the hot water used at a later time. Although the normal pattern of hot water use (and water heater electricity use) is concentrated in the morning and evening, in a world with high levels of variable renewables, it may make more sense to charge these water

Figure 11



heaters at night (wind) or at mid-day (solar).

Control of these water heaters could provide the shaping and storage to integrate up to 100,000 MW of additional variable wind and solar energy in the US grid. The simple arithmetic: a water heater uses about 4,000 kWh/year; each 1 kW of wind or solar generation produces about 2,000 kWh/year. Essentially, each controlled water heater can provide the flexibility needed for about 2 kW of wind or solar generation.

In 2013, Maui Electric Company curtailed approximately 18 percent of the wind energy available from local wind farms owing to system flexibility limitations.⁶ Hawaiian Electric estimated in 2014 that control of 6,300 electric water heaters in Maui would enable them to resolve the frequency excursion issues resulting from a 30-MW wind farm.⁷

Water heaters are excellent targets for load control, and more than 100 rural electric cooperatives already have simple load controls on electric water heaters. By shifting water heating load from morning and evening to mid-day (when the solar bulge may appear) and overnight (when wind and thermal capacity is underutilized), water heat energy requirements can be served more economically. But water heaters can also be controlled on a minute-to-minute basis to provide voltage support and frequency regulation service to the grid at a much lower cost than generating units or batteries.

Three different approaches to grid-integrated water heating (GIWH) have promise. First, active control of water

Table 2

U.S. Water Heaters by Region (×1,000)

	US	North-east	Mid-west	South	West
Total	115,745	21,085	25,896	42,893	25,871
Electric	48,607	5,149	8,005	28,363	7,090
Market Share	42%	24%	31%	66%	27%

heaters, monitoring water heater storage levels and hot water usage, and feeding each water heater sufficient power to ensure that shortages are not experienced. Second, installing larger tanks to ensure a full day's supply without active management during the day. Third, substitution of heat pump water heaters to also reduce total kWh usage, operated at controlled times, together with larger tanks to ensure adequate supplies.

Although electric water heating is dominant in the Pacific Northwest and in the South, every region of the country has millions of electric water heaters (Table 2).⁸

Even the investor-owned utilities in California have about ten-percent electric water heat saturation, or about one million installed units. Using these water heaters to help balance the loads and resources of an electric utility will require new institutional arrangements with customers, but the controls can easily be installed and managed. Several vendors, including Steffes Corporation, Sequentric, and Integral Analytics, are working with many utilities already.

Control of one million electric water heaters means that up to 4,400 MW of load could be “turned on” as needed to absorb wind or solar energy, and that up to 1,000 MW of water heating load that occurs during periods of high demand could be “turned off” as needed to manage peak loads. In addition, up to 10,000 MWh per day of electricity consumption could be shifted between time periods as needed.

6 Maui Electric. (2013). Understanding Renewable Energy and Wind Energy Integration.

7 Hawaiian Electric Company. (July 28, 2014). Demand Response Report. Docket No. 2007-0341, p 64.

8 KEMA. (2010). 2009 California Residential Appliance Saturation Study. Prepared for the California Energy Commission.

For our illustrative utility, with about ten percent of this statewide total load, full implementation of water heater controls on 100,000 electric water heaters would enable it to add about 400 MW at any single hour, and to shift a total of about 1,000 MWh of energy between periods of the day.

To be conservative, we use only one-half of this total (a maximum of 200 MW in any hour, and 500 MWh cumulative in any 24-hour period) to recognize that some water heat energy use already occurs at times convenient to a solar/wind influenced power system, and that the quality of water heating service must not be impaired. This potential storage resource is charged both during mid-day solar hours and overnight off-peak hours. This is a conservative implementation compared with projects being advanced in Canada and Hawaii to use electric water heating controls to add system flexibility.⁹

Electric water heating is more prevalent in multi-family housing, manufactured housing, and rental housing than in the general population. These are lower-income consumers who may benefit greatly from the potential for lower energy bills, but are less likely to have funds available to invest in capital improvements. For this reason, program design is

very important to secure this resource.

Implementation of this strategy is best achieved with a combination of program elements, including:

- A first-cost rebate that covers at least the incremental cost of a GIWH unit over a standard unit to make it the economical choice at the time of purchase;
- A monthly bill credit to customers who participate in a GIWH program to make it economical for renters and homeowners;
- A manufacturer and vendor incentive program to ensure high availability and strong marketing;
- A multi-family housing retrofit program, providing funding and technical support to this easily targeted group of customers; and
- A utility service standard that requires new electric water heaters to enroll in GIWH programs.

Figure 10 shows our illustrative utility load after control of 70 MW of electric water heating, equal to about four percent of the residential customer base; in regions with higher penetration of electric water heating than is found in California, the potential would be much greater.

9 Integral Analytics (Kallock). (2013). *Renewable Integration Utilizing GIWH Technology*. Peak Load Management Association.

Updates from the First Edition

Real-World Illustrations of the Value of Grid-Integrated Water Heating

Option 1. Active Management
Courtesy of Steffes Corporation

The grid operator or demand-response program manager actively monitors customer hot water levels and usage. Power flows to each water heater are optimized to ensure hot water availability, and to provide both diurnal storage and ancillary services to the utility. Water can be heated to a higher temperature and blended with cold water at the outflow pipe to increase thermal storage capacity.

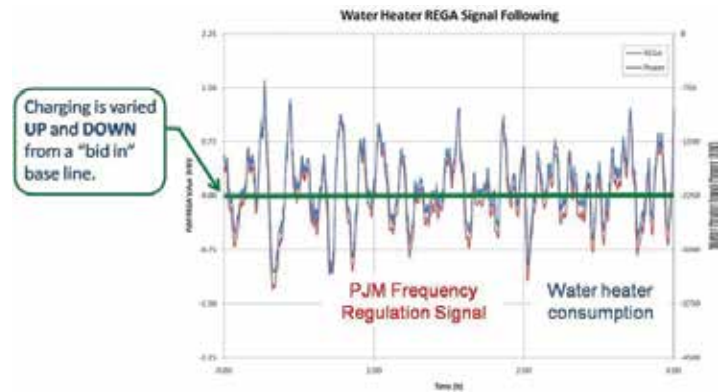


Left: GIWH control unit, installed on an electric water heater.

Below: Control panel available to grid operator showing available storage and total storage capacity in a water heater.



Illustration of hourly data for two days' operation of a group of nine households with GIWH; red illustrates the water heater "charging" with solar or wind-supplied energy; blue depicts hourly consumption of hot water. Green shows the storage of available hot water in each hour.

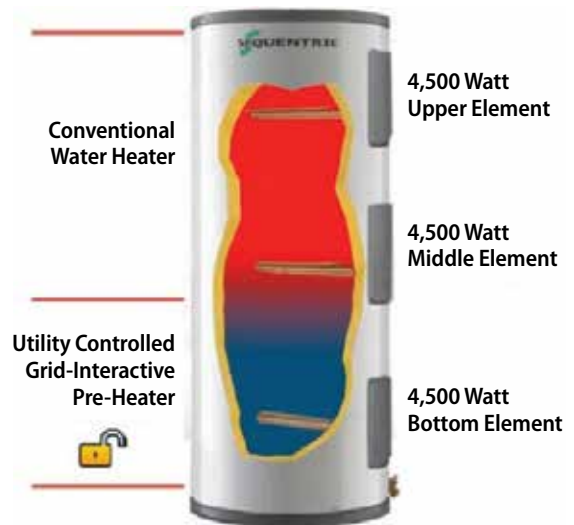


Ancillary services: The red line shows the PJM frequency regulation signal; the blue line is the minute-by-minute following of that signal by a GIWH unit. Because they can be operated second-by-second, GIWH provides more accurate voltage support and frequency regulation than generating units at a fraction of the cost of batteries.

Option 2. Larger Tanks
Courtesy of Sequentric

A larger tank with three heating elements is installed; the utility controls the lower element, while customer hot water usage controls the upper element. The customer has as much hot water under their own usage-driven control as a conventional tank.

Variable-Capacity Grid Interactive Water Heater
 US Patent 8,571,692



Above, Sequentric's patented variable-capacity grid-interactive water heater.

Option 3. Controlled Heat-Pump Water Heater Serving Multiple Apartments

Courtesy of Washington State University Energy Program

A large-capacity split-system heat pump water heater is installed to serve the demands of multiple apartment units. Sufficient storage is installed to allow control of the heat pump unit for off-peak hours only. Total kWh usage is reduced by two-thirds, and all of this is during controlled usage periods. Hot water metering can also be used to assign costs to the individual apartment units.



Using Water Heater Controls to Integrate Wind Power

According to the Hawaiian Electric Company’s¹⁰ *Integrated Demand Response Portfolio Plan*, GIWH can be remotely turned on and off rapidly, making them a source of regulating reserves with the potential to “counterbalance the intermittency of a given wind or solar power source.”¹¹ Additionally, a “simulation of the results showed that approximately 6,300 units would be needed to effectively counterbalance the frequency excursions associated with a 30-MW wind farm on Maui. Furthermore, results indicate that customer comfort is not affected by the controlled use of GIWH, and surveys point to strong customer interest.”¹²

10 Hawaiian Electric Company, Inc., Hawaii Electric Light Company, Inc., and Maui Electric Company, Ltd, submitted in No. 2007 0341, in compliance with Hawaii Public Utilities Commission Decision and Order No. 32054, April 28, 2014.

11 Hawaiian Electric Company Inc. (July 28, 2014). p. 64.

12 Hawaiian Electric Company Inc. (July 28, 2014).



Strategy 5: Convert Commercial Air Conditioning to Ice Storage or Chilled-Water Storage

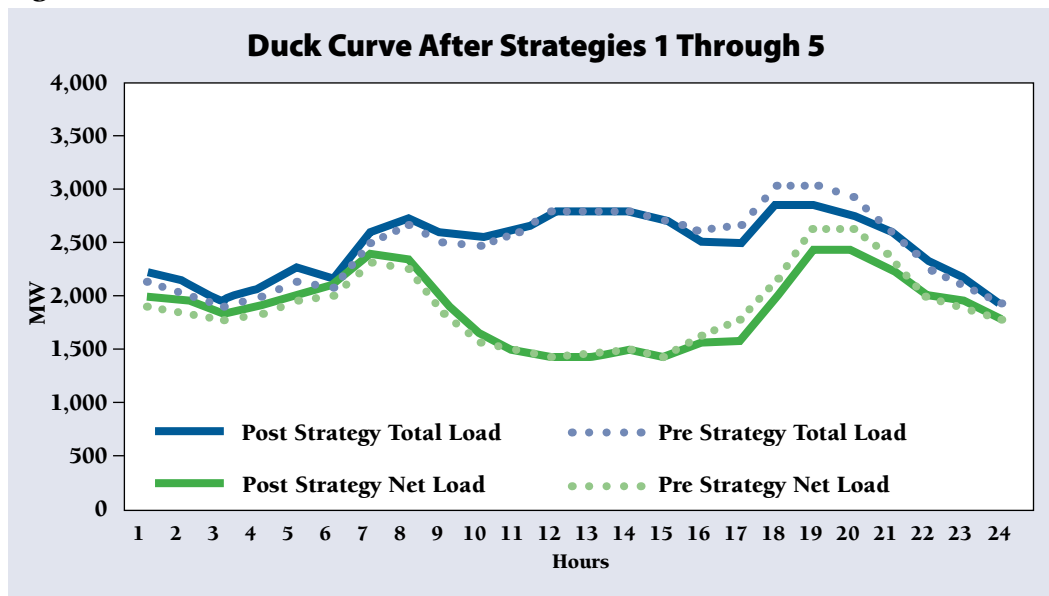
Strategy Description:

20 percent of commercial air conditioning converted to ice storage or chilled-water storage technologies; compressors and chillers operated during the solar day and at night, and curtailed during ramping hours.

Amount:

200 MW of chiller and compressor load controlled to decrease usage in ramping hours and increase usage in off-peak hours; no net kWh savings assumed

Figure 12



Air conditioning (AC) is a huge contributor to peak demands for most US utilities. Late afternoon loads can triple between a cool day and a hot day.

Air conditioning takes several forms. In the residential sector, there are window air conditioners, central air units, and ductless air conditioners. Reducing the load of residential air conditioners by 50 percent is achievable with structural improvements and equipment retrofits. These are all considered as part of Strategy 1, targeted energy efficiency.

In the commercial sector, air conditioning units are large enough that it is cost-effective to install ice or chilled-water storage capacity to shift the cooling load. Ice storage is possible for systems such as those installed on strip malls that rely on five-ton rooftop units, as well as the large 1,000-ton central chiller systems installed in high-rise buildings. Chilled-water storage is an alternative anywhere a central chiller unit is used, and the real estate required for large tanks is available; university campuses are typical applications. We call all of these “storage AC” in this strategy.

Storage AC is not a very complex technology, although sophisticated electronic control systems can optimize the use of the investment. Most of us have an ice-maker in our home refrigerator that dutifully makes 12 ice cubes per hour, allowing us to use 288 ice cubes per day whenever we need them. Storage AC uses essentially the same principle: making cold when the power is cheap, and using that cold when the buildings are warm.

Austin Energy’s downtown central cooling system is an excellent example of this. By offering central cooling, the utility has both created a business opportunity to provide chilled water to dozens of office buildings and hotels, and created a market for off-peak electricity. The utility has also shaved approximately 15 MW off its summer afternoon peak demand.

This strategy assumes that our illustrative utility has 200 MW of commercial AC operating at the time of their afternoon peak demand (approximately five percent of the total load), and can shift up to 100 MW of this demand

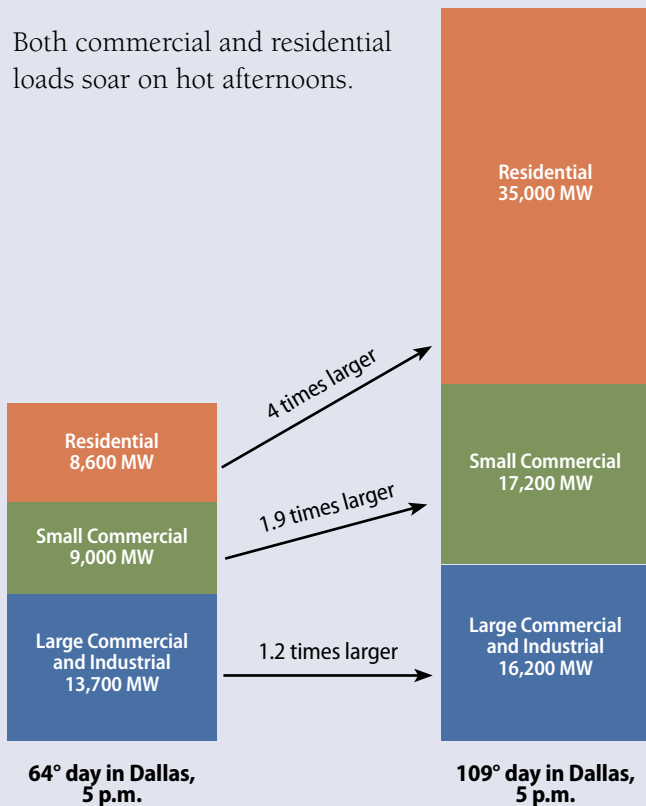
into making ice or chilled-water storage that can provide all of the “cold” during peak hours. A minimum AC load of 10 MW continues during peak hours, to operate pumps and fans when all of the “cold” is being provided by storage. This allows our utility to reduce demand during the ramping hours by as much as 190 MW, and augment loads in the early part of the solar day and late at night by up to 90 MW.

Storage AC also may provide energy efficiency savings in two different ways. First, because the chiller load is shifted to times when air temperatures are lower (wee hours and the early part of the solar day), the chillers actually operate more efficiently, with improved heat rejection. Second, because the draw on the electric utility is reduced during peak hours, very high marginal line losses are avoided. Together these can reduce the total cooling kWh by up to 20 percent.

Figure 12 shows the impact this has for our illustrative utility, compounded on the effect of Strategies 1 to 4.

Updates from the First Edition

Both commercial and residential loads soar on hot afternoons.



Source: Wattle, P. (2012). Demand Response and ERCOT Grid Reliability.

This paper treats residential AC as an energy efficiency opportunity in Strategy 1, whereas commercial AC is partly a load shifting strategy through the use of ice and chilled-water storage.

The First Edition assumed a very small amount of storage AC, as the Ice Bear, a storage rooftop AC unit of the type used by retail spaces and other single-story commercial locations, was at that time just beginning to make inroads into the commercial AC market. Since that time, we have learned of the extensive deployment of ice storage and chilled-water storage in the central chiller market, and the Ice Bear has been field-proven and is more widely accepted. In this edition, we consider 100 percent of the central chiller load, and the majority of the retail sector air conditioning loads to be candidates for storage AC.

Real-World Applications of Ice Storage

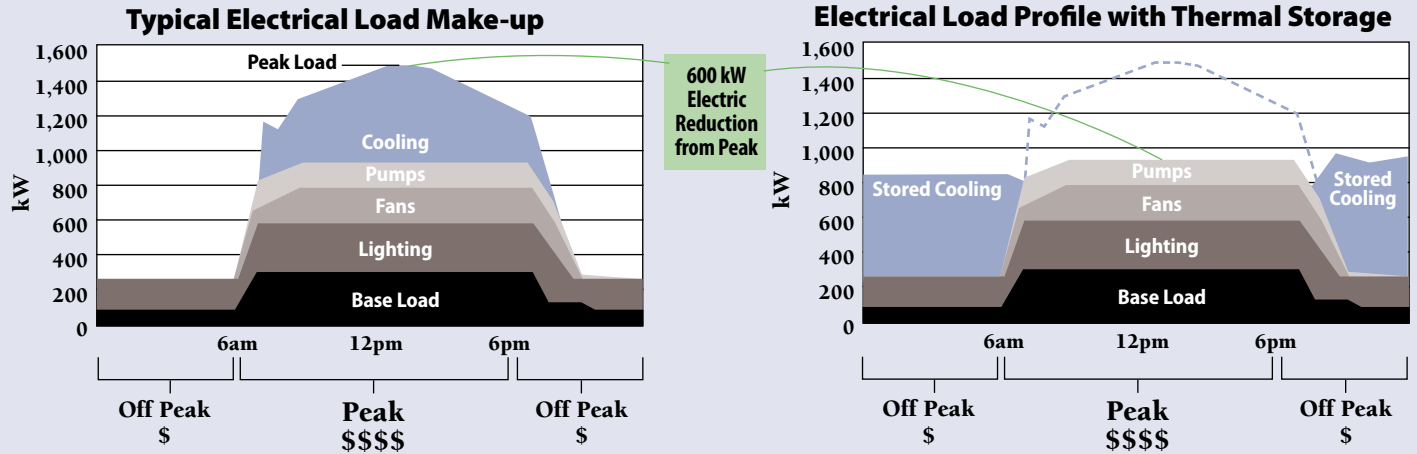
Ice Energy, based in California, is the manufacturer of the Ice Bear. They have developed storage management algorithms to work with available solar PV energy and utility time-varying rates to minimize total consumer costs and shape AC loads to meet changing utility supply profiles.



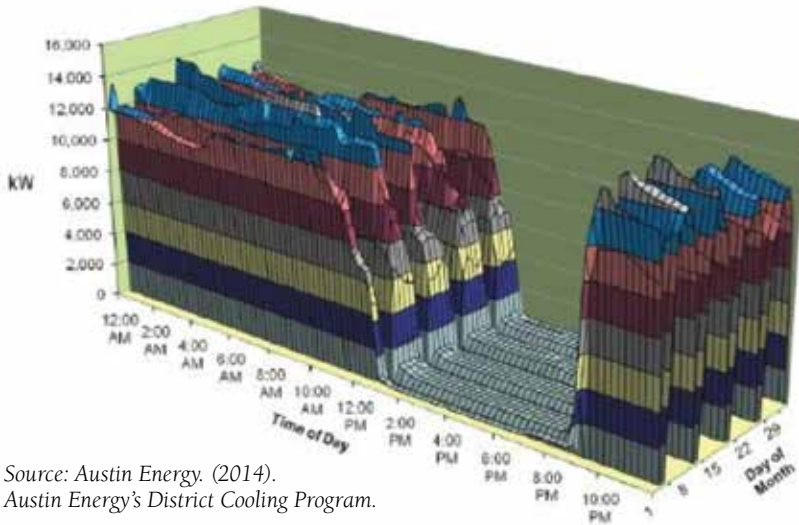
Ice storage for large and high-rise commercial buildings is commercially used throughout the world. This Bank of America building in New York City requires ice storage equal in size to about 20 automobile parking spaces.



The traditional use of ice storage has been to move the AC load off of the building peak, and fill in the night-time demand. Time-varying energy rates will improve the economics of this technology, but in some solar-rich areas it will be desirable to add cooling load in the early part of the solar day, 10 AM to 2 PM.



Source: CALMAC



Source: Austin Energy. (2014). Austin Energy's District Cooling Program.



Source: International District Energy Association.

The Austin Energy district cooling system consists of three separate systems, and incorporates more than 100,000 tons of ice storage. The systems draw up to 15 MW of electricity during off-peak periods to make ice, but less than 1 MW during on-peak periods to distribute chilled water, as shown in the load profile graphic across a month's time.

Customers benefit from redundant reliability, space savings, noise and vibration savings, and monetary savings. The utility benefits by avoiding peak demand, enhancing off-peak demand, and generating an additional revenue stream providing cooling service.



Strategy 6: Rate Design: Focus Utility Prices on the “Ramping Hours” to Enable Price-Induced Changes in Load

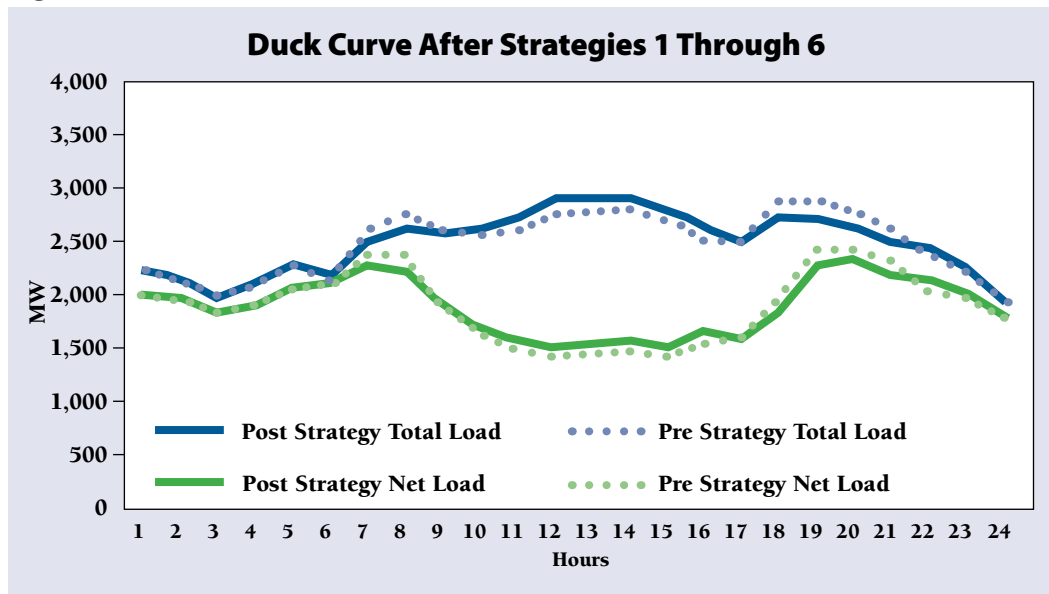
Strategy Description:

Modify rate design for all customer classes to focus pricing on the most crucial hours. Time of use rates replace flat rates and demand charge rate forms. Avoid high fixed charges that reduce customer incentive to control usage levels.

Amount:

150 MW of load reduction in high-cost ramping hours, offset by an equal increase in usage in other hours. No net kWh savings assumed.

Figure 13



Utility systems have evolved greatly in the past half-century, and new approaches to rate design are needed to adapt to these changes. These changes should include time-of-use (TOU) rates for all customers, and the modification of “demand charges” in commercial and industrial tariffs to reflect the diversity of power supply resources that are used to meet loads at different times of the day and year.

Residential rates provide a great opportunity for load shifting. Experiments by many utilities have found that customers are willing to shift their hours for laundry, dish washing, and other tasks where the financial incentive is meaningful. Broad period TOU rates produced typical load reductions of about ten percent. This is a significant shift, and could greatly ease daily afternoon ramping issues for many utilities. For short periods, customers are willing

to reduce usage by as much as 35 percent in response to critical peak pricing rates.¹³

Electric utilities use tariffs that contain demand charges for commercial and industrial consumers. Most utilities apply these based on the non-coincident peak demand of each customer, meaning that customer’s maximum demand, regardless of when it occurs relative to the system peak demand. This creates an incentive for customers to improve their individual load factors (ratio of average usage to peak usage). One goal of a demand charge is to even out the demand on the utility generation, transmission, and distribution system.

This type of rate design was developed when utility generation was of a homogenous nature, with similar costs for all types of capacity, and when the overall goal was to level out usage and to charge those customers who had uneven usage a higher average price. Today we have some resources used for only a few hours each year, and they have very different costs than baseload resources used throughout the day. Demand charges do not discriminate between these types of resources as well as time-varying energy prices. The effect of a demand charge is that once a customer has “triggered” a demand level for the month owing to usage over a limited period, they have a diminished incentive to control their usage during high-cost or ramping hours at the remaining times of the month.

Today, with variable wind and solar generation creating bulges in the availability of low-cost energy supply at distinct times of the day, it makes more sense to shift these charges toward TOU energy prices, or to concentrate these charges during the hours when the system is expected to be under stress. This can be done in either of two ways:

- Greatly limit the number of hours when the demand charge is imposed, or
- Eliminate some or all of the demand charges and collect this revenue through a TOU energy charge during the hours when the system is expected to face stress.¹⁴

A rate design change such as that shown in Table 3 would tell the commercial customer to concentrate its high-use energy requirements during the middle of the solar day, from 10 AM to 4 PM, filling the “belly of the duck.” Usage during the afternoon ramping period would be much more expensive. Many businesses can adapt to this type of rate. For example, with this type of rate design, office buildings may choose to schedule building janitorial service during regular working hours, rather than leaving lights on until 8 PM for the benefit of janitors. Single-shift industrial

Table 3

Typical and Smart Rate Design Alternative for Commercial Customers			
Conventional Rate Design		Smart Rate Design Alternative	
Customer Charge	\$10/month	Customer Charge	\$10/month
Demand	\$10/kW	Demand	\$2/kW
Energy		Energy	
All Hours	\$0.10/kWh	7-10 AM	\$0.15/kWh
		4-9 PM	\$0.20/kWh
		All Other Hours	\$0.10/kWh

customers may schedule their production to conclude by 4 PM. There are many other opportunities for load shaping in response to prices.

For this to be effective, it is crucial that utilities not have demand ratchets that would require payment of a demand charge based on usage in a different month, or a period other than the targeted hours. A demand ratchet charges customers throughout the year based on their highest monthly usage, and thus weakens the price information that a peak-concentrated demand charge provides.

Where significant demand charges remain, they should be concentrated on the key hours of the day, so that customers can manage around them.

Although some form of advanced metering is needed to measure and bill a time-varying demand charge or energy charge, these meters may be installed initially only on larger commercial customers, and they can be manually read. It is not necessary to have a full smart grid installation or meter data management system to implement this strategy for larger commercial customers.¹⁵ On most utility systems, these customers make up nearly half of total consumption.

13 See Lazar, J., & Gonzalez. (2015). *Smart Rate Design for a Smart Future*. Montpelier, VT: The Regulatory Assistance Project, for an extensive discussion of pricing options for residential and small commercial customers.

14 We address demand-response programs directed at a small number of hours per year separately in Strategy 9.

15 Lazar, J. (2012). *Rate Design Where Advanced Metering Infrastructure Has Not Been Fully Deployed*. Montpelier, VT: The Regulatory Assistance Project.

In addition, they may be installed for residential consumers who opt for a TOU rate without being deployed system-wide.

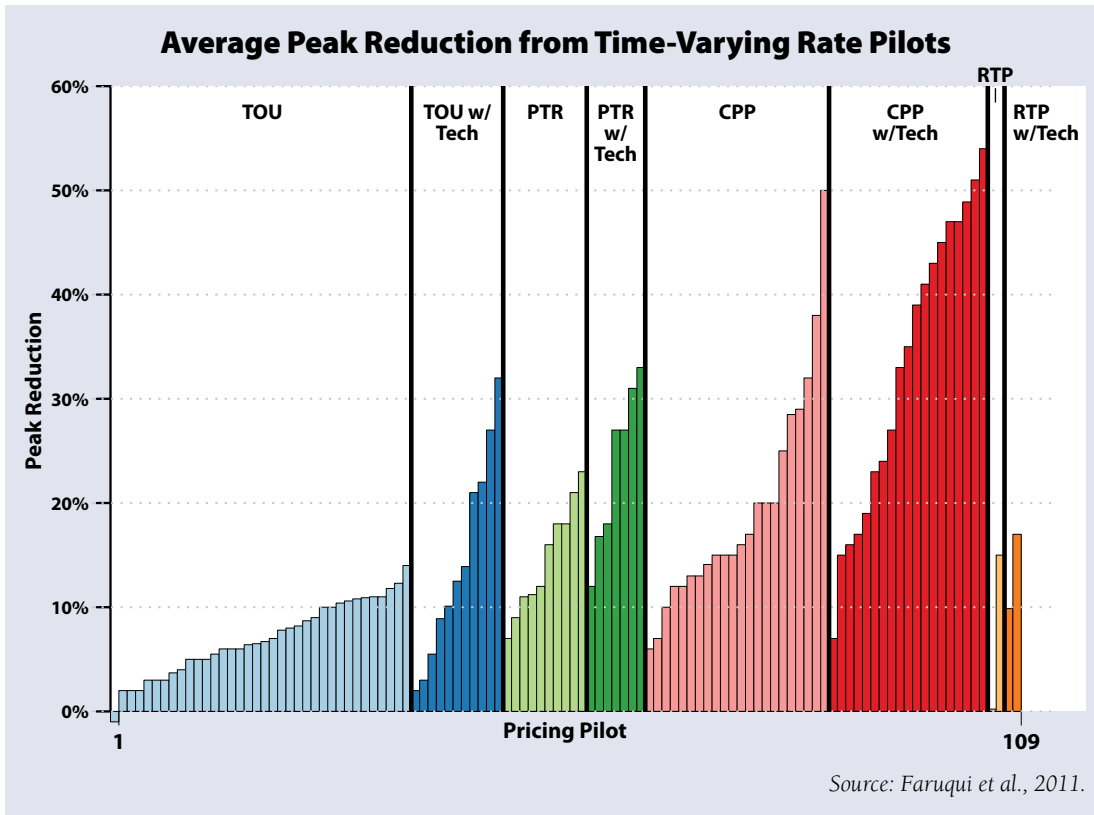
One essential element of forward-looking pricing is to minimize the fixed monthly charges that customers face. These should be limited to only the costs that actually vary with the number of customers, such as the service connection, billing, and collection. Shared distribution system costs should be recovered in time-varying energy charges, to give consumers the clearest possible incentives to control usage during key hours of the day.

Our assumption is that targeted pricing can reduce load by seven percent during those hours with the largest gap between total load and the output of wind and solar generators. We assume that the reduced load is offset by increased usage in adjacent daytime hours. Experience suggests that TOU prices that leave the customer too few hours (e.g., only in the middle of the night) to recover needed energy end-uses do not produce very good results.¹⁶

Figure 13 shows the system load and net load after incorporating load shifts resulting from rate design changes.

16 See: Faruqui, A., Hledik, R., & Palmer, J. (2011). *Time-varying and Dynamic Rate Design*. Montpelier, VT: The Regulatory Assistance Project.

Updates from the First Edition



In the Second Edition, we include TOU rates for all customer classes, not just time-varying demand charges for commercial customers. More than half of utility customers now have smart meters, and essentially all new meter installations have TOU capability. Although additional smart grid investments are needed to implement critical peak pricing, smart meters can be used for TOU billing before these systems are complete. The publication of *Smart Rate*

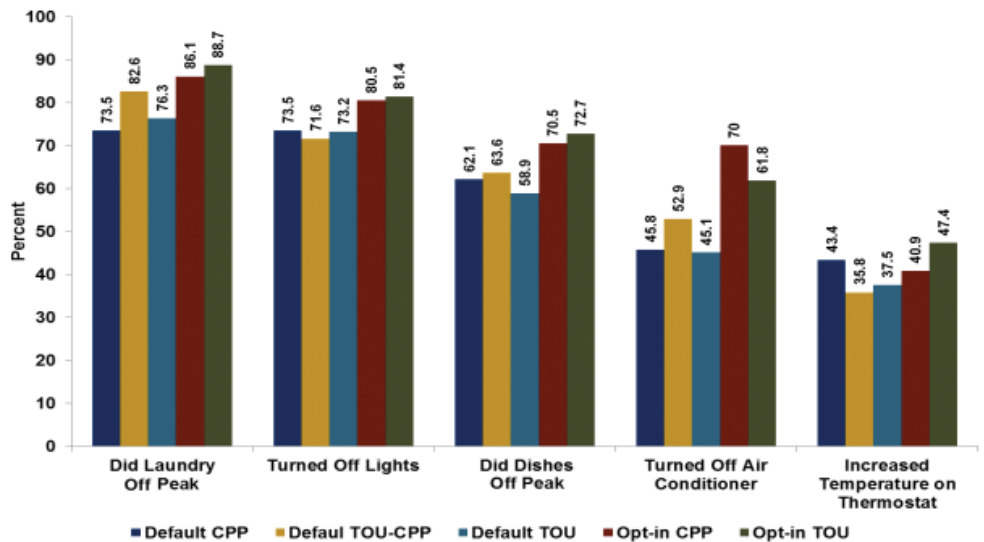
Design for a Smart Future since the First Edition provides extensive guidance on forward-looking rate design.

An evaluation of 109 different pricing pilots found that residential customers would reduce peak demand by up to 55 percent in response to a critical peak pricing rate design, combined with technology to enable customers to respond automatically.

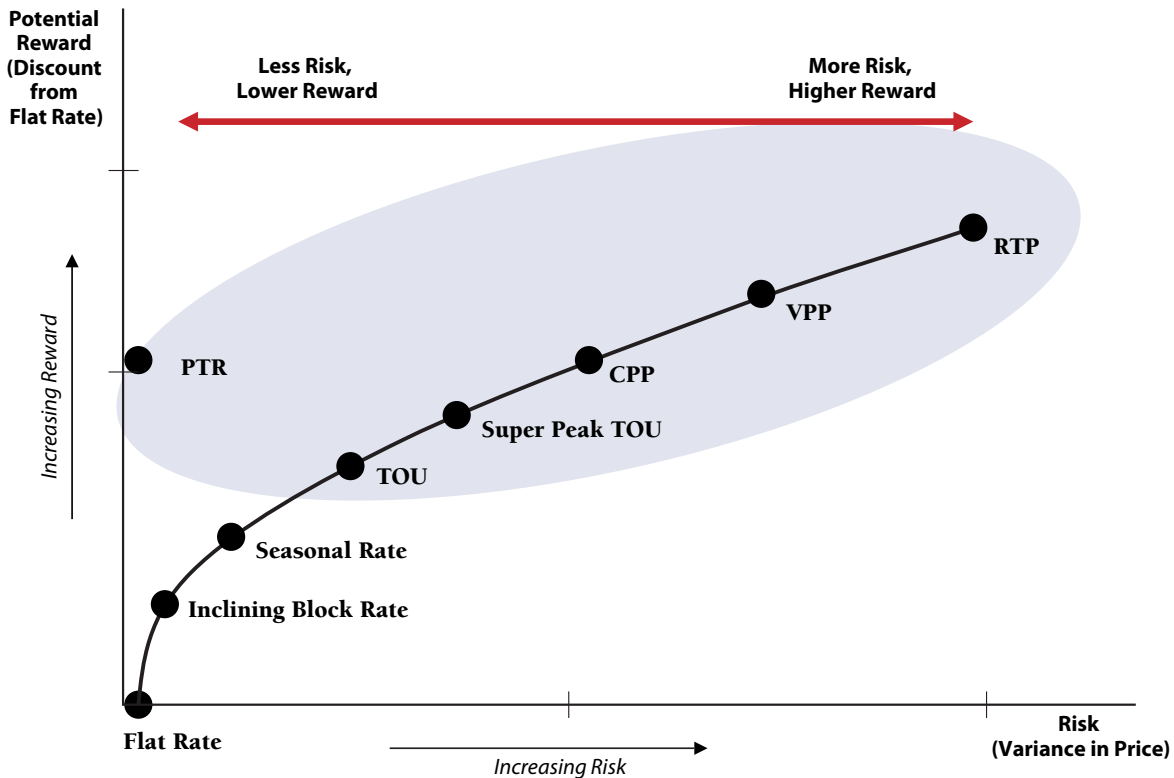
The Sacramento Municipal Utility District TOU/Critical Peak Pricing pilot program found that most customers were willing to take significant actions to reduce their usage at critical hours (right).¹⁷

Although seasonal and inclining block rates provide significant peak load reduction and significant potential savings for consumers who respond, these savings and benefits are enhanced with TOU and critical peak pricing rates (below).

Behavioral Actions Taken to Reduce Load Between 4 and 7pm



Conceptual Representation of the Risk-Reward Tradeoff in Time-Varying Rates



Source: Faruqui et al., 2011

17 Potter, J., George, S., Jimenez, L. (2014). *Smart Pricing Options. Final Evaluation*. Prepared for US Department of Energy.



Strategy 7: Deploy Electrical Energy Storage in Targeted Locations

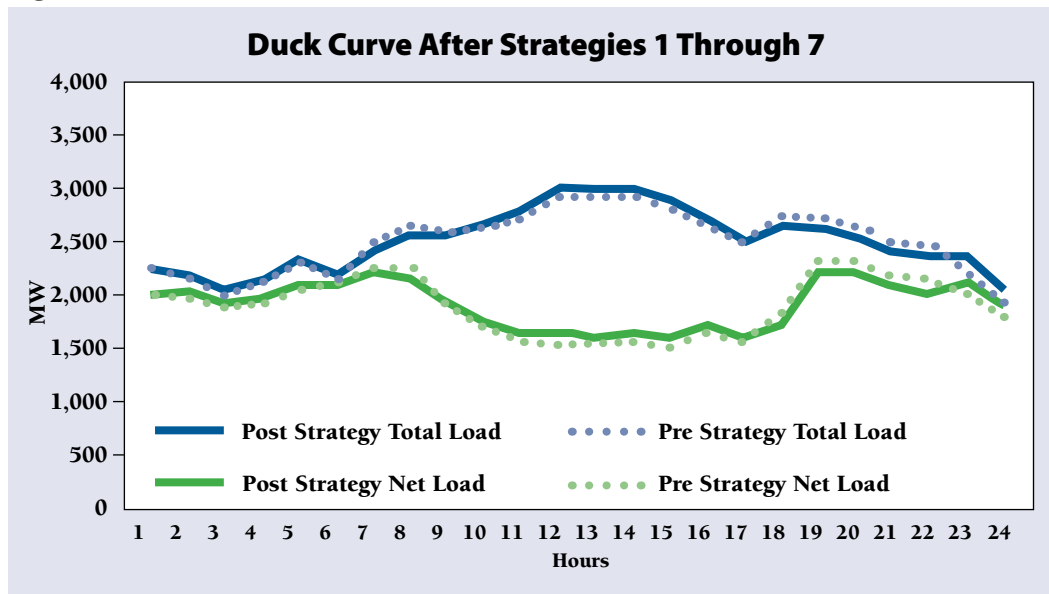
Strategy Description:

Identify locations where electricity storage, including batteries, can provide more than one function. Deploy storage to simultaneously reduce the investment needed for transmission and distribution, and to provide intra-day storage of energy from intermittent renewable resources.

Amount:

Electricity storage capacity of 500 MWh, approximately one percent of daily consumption, is deployed. A net increase in total kWh is assumed, owing to round-trip losses associated with charging and discharging storage systems.

Figure 14



Electrical energy storage is very expensive, but costs are dropping rapidly. Storage is a potential part of a comprehensive approach to system optimization. Although there are multiple technologies currently available, including batteries, pumped storage hydro, compressed air energy storage, flywheel technology, and perhaps others, all of these are expensive. Compared with thermal and mechanical energy storage addressed in Strategy 3 (water pumping), Strategy 4 (water heat), and Strategy 5 (ice and chilled water), where

the energy is stored in the form it is eventually used, all electricity storage options include significant “round trip” losses as electricity is converted into another form (mechanical or chemical) energy, and then reconverted to electricity. These losses range from as little as 15 percent for lithium-ion batteries, to as much as 35 percent for compressed air energy storage systems.

Storage has multiple roles. One is bulk energy storage, and pumped hydro has been used extensively for this. These storage units are typically in remote locations

and require additional transmission investment to bring that capacity to the service territory. Other large-scale technologies, including large-scale compressed air energy storage, are emerging. Another role for storage is fast response for ramping and system reliability, and here batteries and flywheel systems seem to be the preferred technologies.

There are targeted locations where electricity storage can be cost-effective and should be pursued. These include placement at strategic points where storage provides supplemental generation capacity during some hours, and a place to “park” surplus generation from high renewable penetration or nuclear generation at times when it is not needed for current demand. It also includes areas where strategic storage can help avoid expensive transmission and distribution system upgrades and provide ancillary services such as frequency control and voltage support. For example, installation of battery banks at the site of wind generators where they may help avoid transmission capacity upgrades should be compared to installing batteries at distributed points where they may displace distribution grid upgrades.

This strategy includes both installation of new battery banks or compressed air storage units, as well as the use of existing batteries, such as those in electric vehicles and uninterruptible power supplies (UPS). The strategy is to selectively charge storage batteries when power is available and to use the battery resources when power is scarce. For example, one hospital is using the existing batteries for the UPS in its surgical suites (which are seldom used in the late afternoon) to peak-shave their demand charge on particularly hot days.¹⁸ This allows both testing of the UPS systems and reduction of electricity costs.

The simplest application of this principle of dual-purpose batteries is to turn electric vehicle chargers on and off as power supply market conditions change and to meet ancillary service needs. More sophisticated selective discharge systems—vehicle to grid—are being tested and may become available within this decade. These vehicle to grid opportunities are not considered here, but may soon emerge as a valuable resource.

By 2020, this would include a significant number of controllable electric vehicle chargers, plus discrete battery or compressed air energy storage installations at substations or other locations where distribution capacity upgrades are imminent. The economics of these must be compared to the full generation, transmission, distribution, and environmental benefits they provide, not just to the deferred distribution capacity upgrades.

For purposes of this paper, we assume that the illustrative utility system would add energy storage available up to about one percent of total load, or a total of 500 MWh of electricity storage, with a maximum charge or discharge rate of 100 MW per hour.¹⁹

There are many regions where pumped storage hydro capacity greatly in excess of this amount exists today. We assume 20-percent round-trip losses, so 620 MWh of energy must be generated in order to provide 500 MWh of usable energy augmentation during peak load periods, but displacement of peaking unit operation and avoided high marginal line losses may save more fuel in the 500 MWh of generation displaced during peak hours than is used to produce 620 MWh during periods of surplus energy.

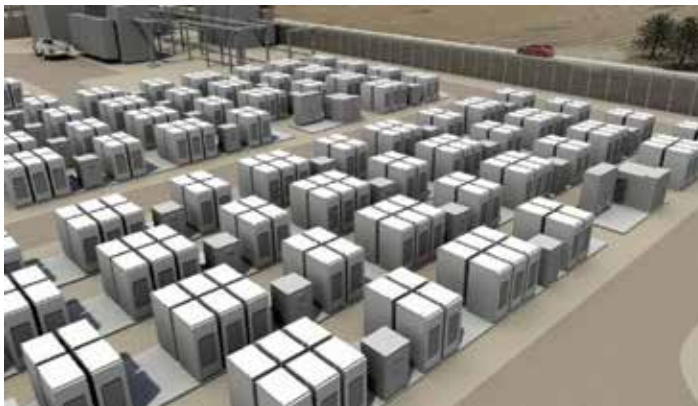
Figure 14 shows the system load and net load after incorporating load shifts resulting from targeted electric energy storage.

18 Personal discussion with Geoff Glass, Providence Hospital Network, 2014.

19 In October 2013, the California Public Utilities Commission directed regulated utilities to acquire 1,325 MW of storage capacity by 2020 in Rulemaking 10-12-007; Strategy 8 is slightly less aggressive than the California requirement.

Updates from the First Edition

Tesla offers battery storage systems ranging from multi-MW utility scale systems to the single home Powerwall.



Source: Tesla

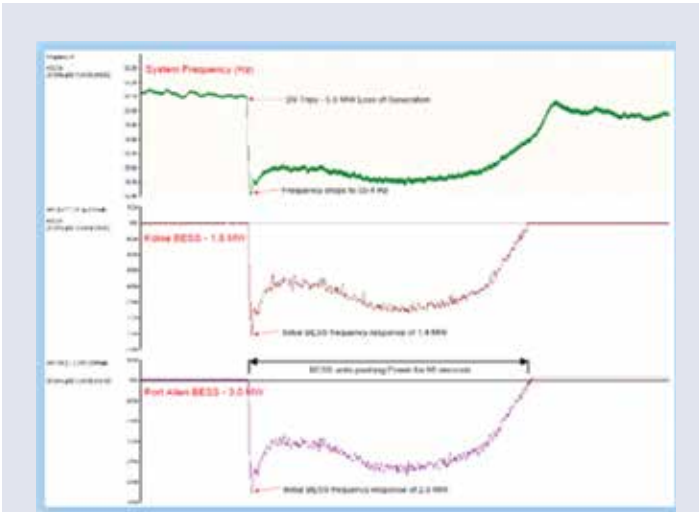


Grand Coulee Dam includes 314 MW of pumped storage capability. Six reversible pump/generators lift water to Banks Lake, at the upper right. Although this water normally feeds a 670,000-acre irrigation system, the water can be drawn back through the turbines into the reservoir during peak hours for additional generation.

Source: U.S. Bureau of Reclamation

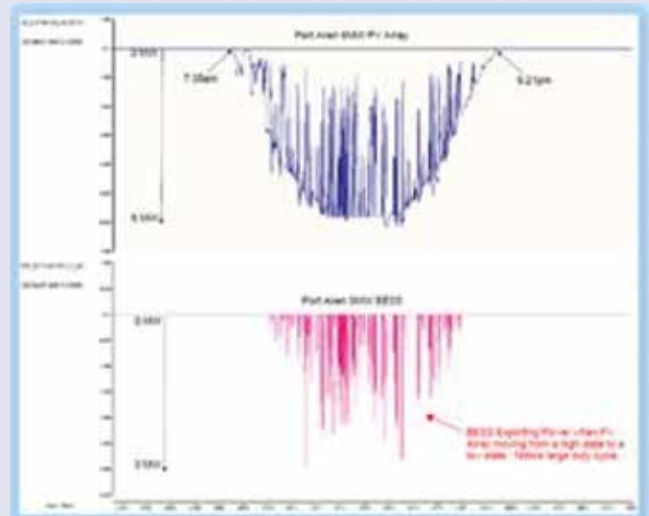
Kauai Island Utility Cooperative has deployed battery storage on its system. The system has reduced petroleum consumption in three ways: enabling “smoothing” of PV output, enabling the system to serve night-time load

with PV-generated power, and avoidance of conventional generation to provide spinning reserves. The utility is on-target to achieve a 50-percent renewable portfolio by 2023.



Source: Yamane, M. (2014). KIUC's Perspective.

This screenshot graphic shows how quickly the Kauai battery storage system responded to a unit trip of one generating unit. The top section shows system frequency dropping to 59.4 hz at the time of the trip. Within 95 seconds, the frequency was restored to 60 hz by automated dispatch of two battery banks responding as shown in the second and third sections. The batteries here are serving a function of spinning reserves.



Source: Yamane, M. (2014). KIUC's Perspective.

The upper portion of this graphic shows the minute-to-minute production of a solar farm on Kauai as clouds pass over the area. The bottom portion shows how the battery storage system is used to smooth out this flow. The batteries here are serving a function of voltage support and frequency regulation, in addition to their primary purpose of diurnal storage.



Strategy 8: Implement Aggressive Demand-Response Programs

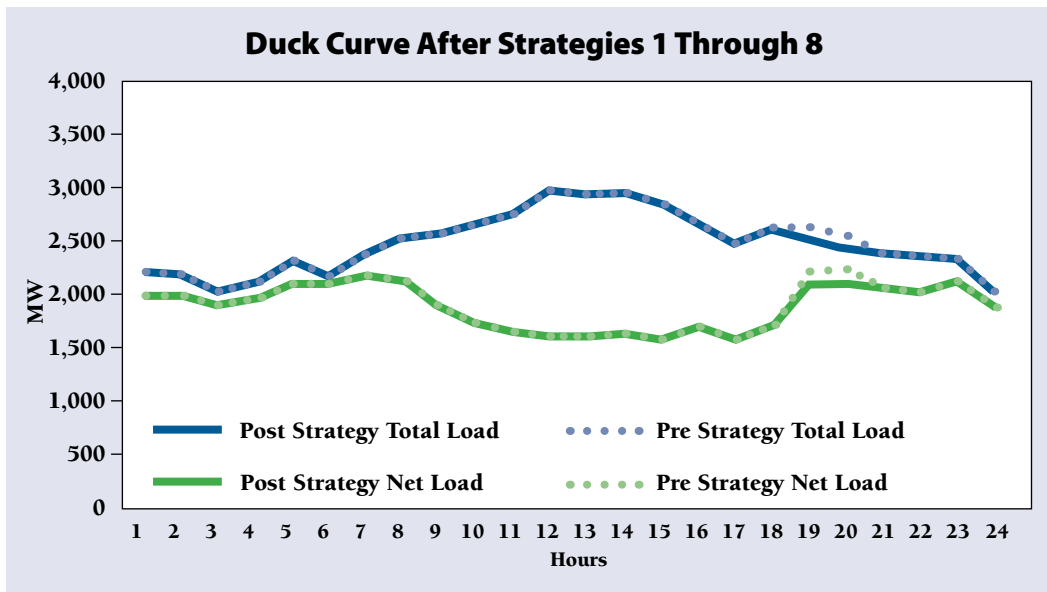
Strategy Description:

Deploy demand-response programs that shave load during critical hours of the year, only on days when system stress is severe.

Amount:

Only 200 MWh of demand response is assumed, because much of this potential will be achieved through Strategies 3 (water pumping), 4 (water heat), 5 (air conditioning), and customer response to Strategy 7 (TOU rates). This is approximately equal to 3 percent of peak demand, or 0.3 percent of total consumer usage.

Figure 15



Many of the strategies listed previously have the characteristic of what is known as “demand response”—programs to entice consumers to change their load patterns. Control of water pumping, water heating, and air conditioning, coupled with customer response to time-varying rates, is assumed to capture most of the potential load shifting that is economic. But for a limited number of critical hours, compensation to customers can achieve additional load curtailment.

Experience with the New England Independent System Operator (ISO-NE) in particular has shown that the creativity of private sector aggregators can attract significant demand response during peak load periods. ISO-NE has been able to secure over 2,100 MW of demand-response commitments (out of a total of about 25,000 MW of peak demand), or about eight percent of peak demand.²⁰

²⁰ ISO-New England. Demand Resources webpage. Retrieved from: <http://www.iso-ne.com/markets-operations/markets/demand-resources>.

The experience in New England shows that demand response of about eight percent of peak demand is possible and cost-effective. Given the measures we have already counted, such as time-focused pricing, water pump controls, storage air conditioning, and storage water heating, we assume that three-percent peak demand attenuation (about 100 MW for our illustrative utility) through demand-response programs for the two highest

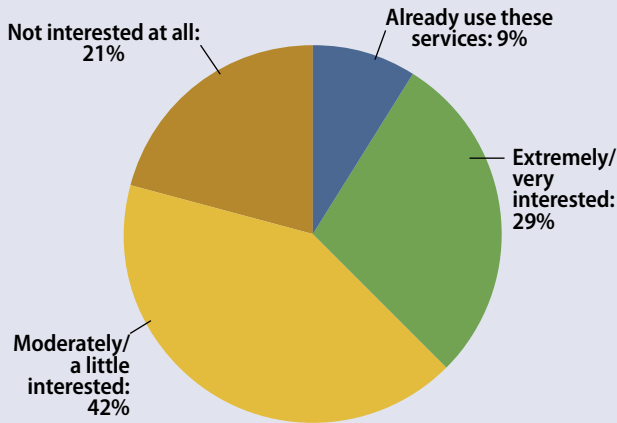
peak hours of a day is reasonable in addition to the measures already identified.

Because the measures we have already counted are largely peak-shifting measures, we assume this residual demand response is economic curtailment—a cut in peak demand without any associated growth in other hours. Figure 15 shows the system load and net load after incorporating load shifts resulting from demand response programs.

Updates from the First Edition

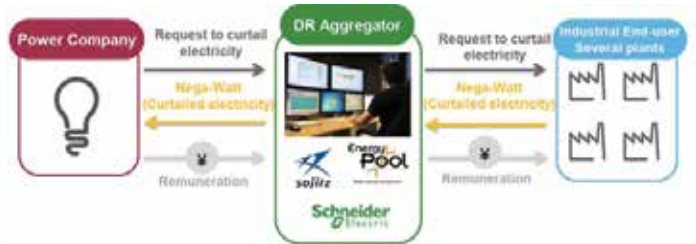
When surveyed, the majority of electricity consumers are interested in reducing their energy bills by curtailing usage for short periods of time when the grid is stressed.

Interest Levels in Demand Response

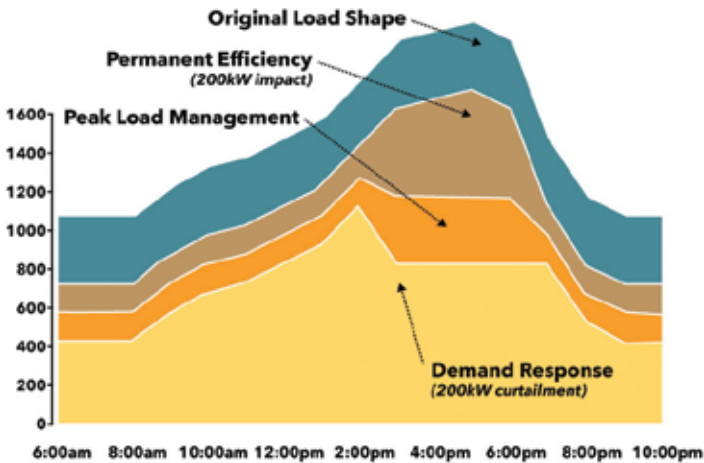


Source: Energy Research Council. (2013). *Best Practices: Demand Response*.

In many regions, demand-response programs are operated through aggregators that work with multiple industrial or commercial customers to secure a significant and reliable level of curtailment.



Source: Sojitz Corporation. (2013). *Energy Pool, Schneider Electric, Sojitz, TEPCO Launch Industrial Demand Response Demonstration Project for the first time in Japan after Being Chosen for Government-led Next-Generation Energy & Social System Project*.



Source: CPower Corp.

Load reductions from demand response are commonly in addition to other load reductions from permanent efficiency and from peak load management in response to time-varying rates.



Source: Flickr Faz Besharation

Demand response can take the form of a communicating thermostat that applies additional adjustment (beyond the normal time-of-day setting) when prices rise sharply or the grid operator calls for curtailment.



Strategy 9: Use Inter-Regional Power Exchanges to Take Advantage of Diversity in Loads and Resources

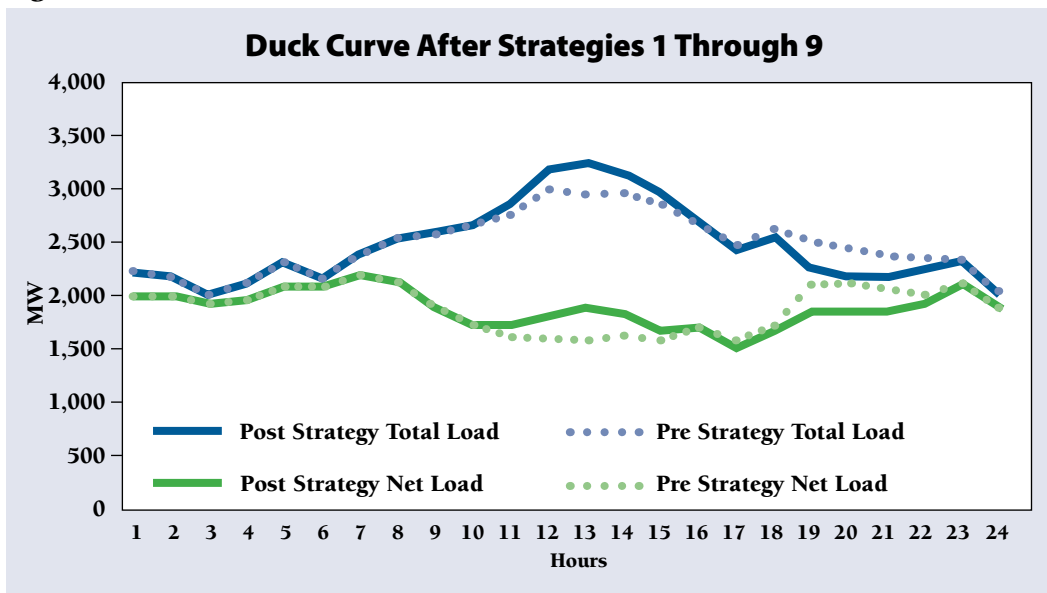
Strategy Description:

Import power from other regions with different peaking periods when it is available; export power to these regions when it is economic to do so.

Amount:

900 MWh per day of exchanges is assumed, an amount equal to about 1.5 percent of total daily consumption.

Figure 16



Different regions have different load patterns and different resource profiles. Although solar energy performs best at mid-day, and in summer, other loads and resources have much more geographic diversity. Wind blows at different hours in different places. Some regions are summer-peaking, and others winter-peaking. Some utility systems face peak demands in the morning, and others in the evening. Transmission interconnections, often built for other primary purposes, can enable power exchanges that take advantage of this diversity.

California is a summer-peaking region with maximum loads in the late afternoon. It has thousands of MW of excess capacity during the winter months. The Pacific Northwest is a hydro-rich winter-peaking region, with maximum loads in the mid-morning. It has thousands of MW of excess capacity during the summer months.

For decades, power has flowed from the northwest to California during the spring runoff, and transmission lines were constructed to facilitate these low-cost energy purchases. Use of transmission lines, originally designed for off-peak usage to also enable on-peak power exchanges, has

increased in the past decade, with many utilities engaged in peak capacity swaps. With over 8,000 MW of inter-regional transfer capability, using the flexibility of this system to enhance the integration of renewable resources in both regions is widely recognized as a sound and economic option.

Resource exchanges with other regions can also provide diversification benefits. Wind resources in different parts of the west have different production profiles. Some regions have other renewable resources, such as geothermal, biomass, or solar-thermal storage resources, that could be part of mutually beneficial exchanges. Some regions also have

low-cost, high-efficiency gas generation that may be available for dispatch and export at the requisite time of need.

This strategy involves drawing upon regional resources and exchanging about 900 MWh per day from 5 PM to 9 PM to the period from 10 PM to 3 AM. We consider this to be a very conservative application of the inter-regional power exchange potential to address the ramping challenges posed by renewable energy development.

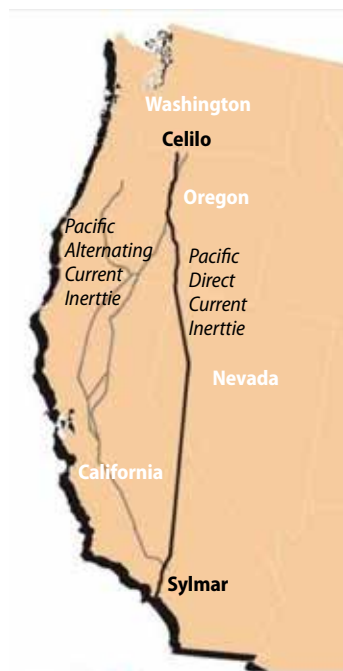
Figure 16 shows the system load and net load after incorporating load shifts resulting from inter-regional power exchanges.

Updates from the First Edition

California's electricity grid is connected to the Pacific Northwest through a DC intertie that runs from Celilo, Oregon, to Sylmar, California (near Los Angeles), plus three 500-kV AC interties that feed into northern California at the Oregon/California border.

Together these lines can move about 8,000 MW of power into California.

Source: Northwest Power and Conservation Council / Bonneville Power Administration

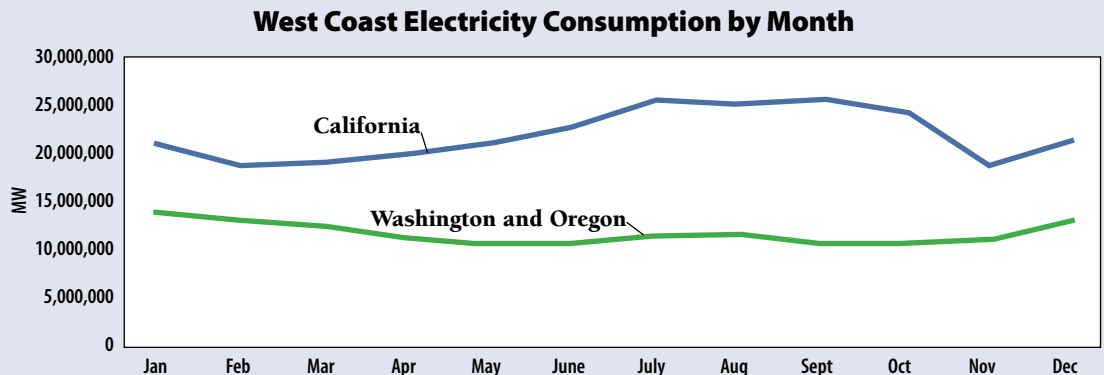


Source: Los Angeles Department of Water and Power

The Los Angeles area is connected to Utah by the Southern Transmission System, originally built to bring power from the Intermountain Coal Plant. This is being phased out of the California power mix, but the transmission line will remain available for inter-regional transactions.

Similarly, transmission lines currently serving Arizona and New Mexico coal plants will become available for other transactions as these units are retired.

California electricity use peaks in the summer months, whereas Oregon and Washington electricity use peaks in the winter months.



Source: <http://www.eia.gov/electricity/data.cfm#sales>.

Strategy 10: Retire Inflexible Generating Plants With High Off-Peak Must-Run Requirements

Strategy Description:

Anticipate the retirement of older coal, natural gas, and nuclear power plants that cannot be cost-effectively maintained and operated in the current power system owing to high fixed costs and limited flexibility to ramp up and down. As these plants retire and are replaced with a mix of renewable resources, flexible (mostly natural gas) resources, and storage, the level of intermittent renewable energy that the system can absorb increases.

Amount:

No specific amount assumed. The “end analysis” is whether the modified load shape after all other strategies are deployed is a shape that the remaining resources on the system can serve.

Many utilities rely on older generating units with limited ramping capability. Much of this consists of coal and nuclear units built more than 30 years ago and that are nearing the end of their useful lives. Indeed, approximately 40 GW of older coal and nuclear units have been retired in the past decade, and another 40 GW are expected to be retired in the next decade.

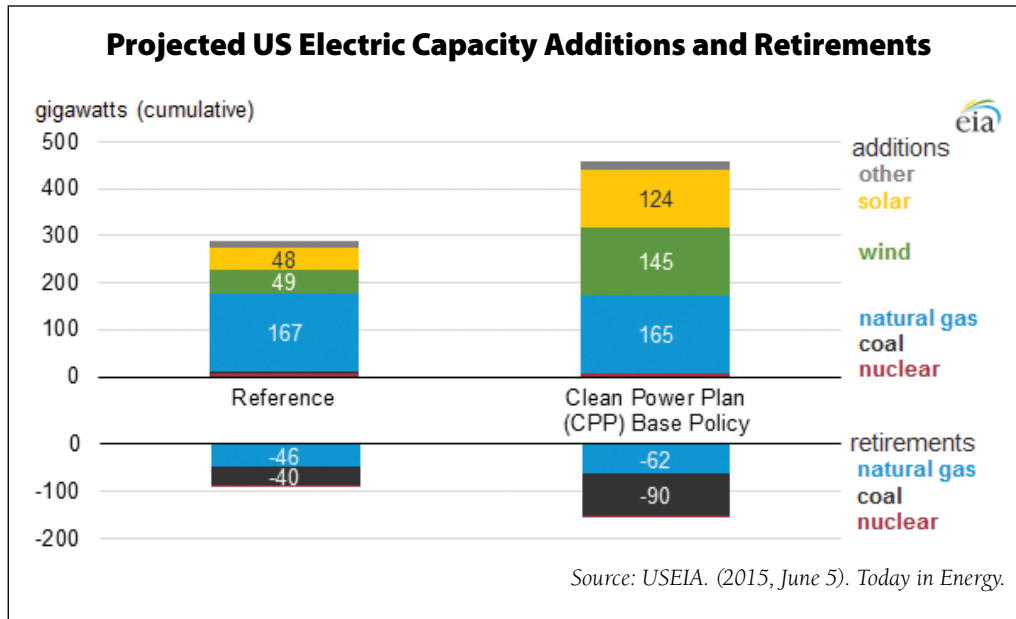
California is an example of this trend: coal power flowing to California from Arizona, Nevada, Utah, New Mexico, and Oregon is being phased out, and the San Onofre nuclear units were retired in 2013. In addition, California utilities are retiring older steam gas-fired units, generally repowering these sites with high-efficiency natural gas combined-cycle units. Although these retirements do not alter the utility’s total load or residual load—the load filled by wind and solar that must be met when these resources are absent—they do reduce its “must-run” thermal capacity during both night hours and mid-day hours. Older gas steam units must be run at about 20 percent of their maximum capacity overnight to be available to meet higher loads during the daytime, whereas modern “flex” natural gas combined-cycle plants can operate on an as-needed basis.

The US Energy Information Administration (USEIA) forecasts retirement of 62 GW of natural gas (mostly less-flexible steam units) and 90 GW of coal plants over the period 2014 to 2040. As indicated in Figure 16, this is expected to be replaced by high levels of wind, solar, and more flexible new natural gas generation.

This strategy leaves more room on the system for replacement units, generally natural gas-fueled, that can be ramped more readily to meet load. There is no question that retirement of coal and nuclear baseload units that were built decades ago will result in higher power costs in the short run, but most of the retirements we anticipate are inevitable because of aging of the units, high costs for pollution control retrofits, and emerging safety and environmental regulations. The point here is not to suggest changing the date of these retirements, but to recognize that they create opportunities to procure more flexible replacement capacity.

The United States has been experiencing nuclear unit retirements in recent years, evidenced by announcements related to the San Onofre, Kewaunee, Pilgrim, Oyster Creek, and Vermont Yankee reactors, and other potential retirements. The retirement of baseload nuclear units has adverse impacts on greenhouse gas emissions, but because

Figure 17



these units are highly inflexible, the loss of this capacity improves conditions for integration of variable renewable resources. For example, Southern California Edison and San Diego Gas and Electric Company received approval to adapt to the loss of the San Onofre plant by adding a mix of renewable energy, storage, and flexible natural gas generation.

We do not show an adjusted Duck Curve for this resource change because we assume that all utilities, including our illustrative company, have incorporated

retirement of aging plants in their existing resource plans (but may or may not be factoring in the increased flexibility of replacement capacity). We discuss the ultimate net load after our proposed strategies in the context of a more flexible generating fleet after describing each of the strategies. If the residual ramping requirement is within the capability of a modern fleet of power plants, including significant levels of high-efficiency natural gas generation, we have met our challenge.

Conclusions

It is useful now to compare our final result—with all ten strategies—to the starting point with acquisition of renewable resources, but without the strategies. The difference is quite dramatic. From a sharp peak at

8 PM, our load profile has changed to where the existence of a “peak period” is difficult to identify. Figure 18 shows the end result compared with the starting point.

Figure 18

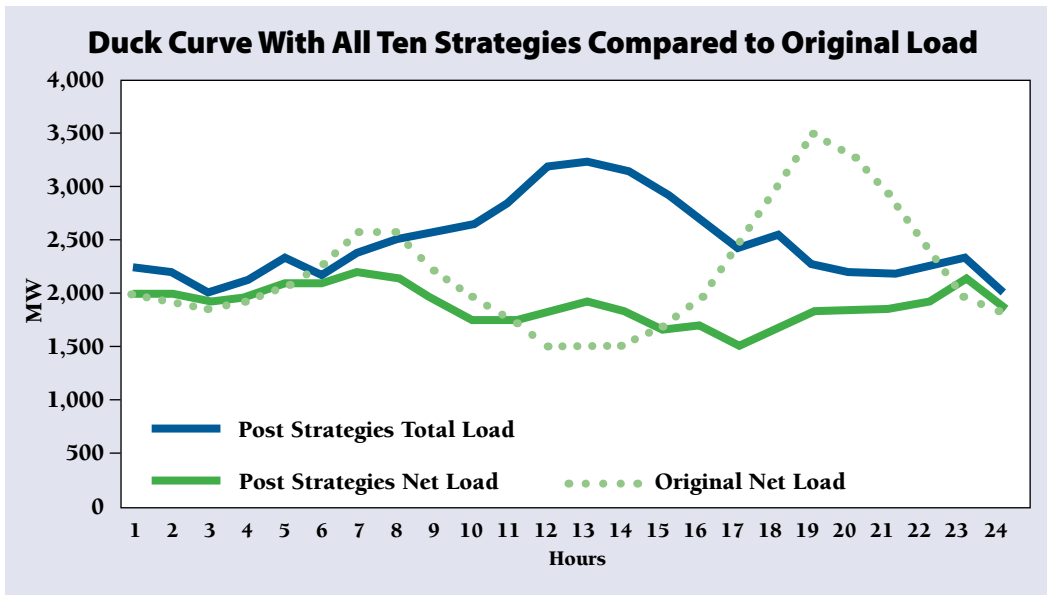


Figure 19
Ducks in Flight



Our newly streamlined duck needs only to stretch his wings, try a few beats, and see if he can become airborne like his cousins.

How the Duck Curve With All Ten Strategies Compares to Original Conditions

The existing power system evolved with varying demand, and includes baseload, cycling, and peaking units. It is not necessary to modify load to a completely flat profile in order to eliminate the ramping challenge of the renewable energy transition, only to bring that ramping requirement within the capability of evolving utility grids. The future power system will also contain a mix of resources, and those resources that are acquired to serve growth or replace retiring units can be selected over time to meet the needs of the future.

Figure 17 and Table 4 compare our modified “net load” profile (after solar and wind) with the total load that would have existed without the solar and wind resources and prior to application of our ten strategies. We simply note that the load factor is improved far beyond that which would exist without the renewable resources, and also that the hour-to-hour ramping requirements are smaller than would otherwise exist. Table 4 also compares the results of the Second Edition of this publication to the original. Primarily because of the addition of water pumping load controls, and the expansion of air conditioning storage, the Second Edition improves further on the dramatic results of the original publication.

Thus, our modified post-renewable load is easier to

serve than the actual load projected to exist would have been without the addition of renewable resources. The load factor is higher, at 86.5 percent. The maximum hourly ramping requirement is about one-third of the original challenge. The total difference between the highest load of the day and the lowest load of the day is one-third of the original value. This kind of load flattening is desirable for almost any electric utility system, including those without significant renewable energy deployment issues.

It is evident that the net load (including solar and wind) after application of the ten strategies is a much more uniform load to serve from dispatchable resources, even with the non-solar/wind resources, than the load that was forecast for this period without solar and wind. The peaks have been lowered, the troughs raised, and the utility has control over a significant portion of the load to schedule when it can most economically pump water and charge water heaters, air conditioners, and batteries. The effect of the ten strategies is to reduce both peaking needs and ramping requirements. The statistics in Table 4 illustrate this.

The post-renewable and post-strategy load/resource balance would be much easier to manage than that which was forecast absent the renewables and strategies. In fact, using less than one-half of the energy shifting and shaping incorporated in these ten strategies would result in the load following with renewables in 2020 being no more challenging than load following without renewables.

Table 4

Load Factor and Maximum Hourly Ramping Requirements Before and After the Ten Strategies				
	Total Load Without Renewables or Strategies	Net Load With Renewables and Without Strategies	Net Load With Renewables and First Edition Strategies	Net Load With Renewables and Second Edition Strategies
Load Factor	73.6%	63.6%	83.3%	86.5%
Maximum Hourly Ramp	500 MW	550 MW	350 MW	198 MW
Total Difference Between Highest and Lowest Hour	1,800 MW	2,000 MW	950 MW	660 MW

Key Ideas to Engage Customer Resources to Better Manage the Transition

- Implement time-varying power supply and distribution rates for all customers that concentrate on the key ramping hours for each utility;
- Reduce, eliminate, or time-focus demand charges that otherwise discourage customers from scheduling usage in response to these time-varying rates;
- Explore options for the utility grid operator to control electric vehicle charging;
- Ensure that renewable acquisition programs consider the time of expected energy production;
- Modify energy codes to require ice storage in new air conditioners and controls in new water heaters;
- Expand demand-side management programs to include retrofit of water heater control systems, particularly in multi-family and mobile-home communities where split incentives may prevent participation in price-based programs;
- Provide simple incentive structures to encourage customers to participate in load scheduling and demand response programs;
- Require that integrated resource plans fully consider both the retirement of existing inflexible generation and the inclusion of load control and scheduling strategies;
- Require that integrated resource plans fully consider inter-regional exchanges of energy and capacity to better utilize generation and transmission assets;
- Fully engage water and wastewater utilities in the electric utility resource planning process to ensure that physical storage options are considered; and
- Carefully examine plans for pollution control and other retrofit capital expenditures associated with older power plants to ensure that carbon dioxide values, criteria pollution values, flexibility values, and reliability values of alternatives are fully examined.

We conclude that adequate strategies and technologies are available today to readily manage the transition to a much higher level of variable renewable resources. Their implementation will, however, require time, effort, a change in the utility–consumer relationship, some significant investment, and some serious resolve.

Time is of the essence. Solar and wind energy are becoming more cost-effective every year. The need to displace thermal generation to slow climate impacts is urgent. And the public demands and expects utilities, grid operators, and policymakers to do what is needed to ensure reliable and economical electricity service.

Other Related RAP Publications Include the Following:

Teaching the Duck to Fly

Available at: <http://www.raonline.org/document/download/id/6977>

Jim Lazar takes aim at the widely circulated “duck curve” in this brief policy paper, which highlights ten low-carbon strategies for “teaching the duck to fly.” Mr. Lazar utilizes existing technologies to address the load shape of emerging utility requirements as increasing penetrations of wind and solar resources create ramping challenges for conventional generation. These strategies not only enable greater renewable integration, but they also enhance system reliability, and reduce capital and fuel costs by modifying the load profiles. Metaphorically, Mr. Lazar teaches the duck to fly, by implementing strategies to both flatten the load and introduce supply resources that can deliver more output during the afternoon high load hours. The resulting “duck” is easier to serve than the projected load would have been without the addition of renewable resources—a desirable outcome for almost any electric utility system, including those without significant renewable energy deployment issues. Fundamentally, this issue is no different from the problem utilities have faced for over a century in matching the supply of energy to changing consumer demand. Only in this case, the challenges created by renewables have evolved over a much shorter time frame. Mr. Lazar provides a set of tools to readily manage the transition to renewables and teach the duck to fly.

Valuing the Contribution of Energy Efficiency to Avoided Marginal Line Losses and Reserve Requirements

Available at: <http://www.raonline.org/document/download/id/4537>

While utilities and their regulators are familiar with the energy savings that energy efficiency measures can provide, they may not be aware of how these same measures also provide very valuable peak capacity benefits in the form of marginal reductions to line losses that are often overlooked in the program design and measure screening. This paper is the first of two that the Regulatory Assistance Project is publishing on the relationship between energy efficiency and avoiding line losses.

Smart Rate Design for a Smart Future

Available at: <http://www.raonline.org/document/download/id/7680>

The electric utility industry is facing a number of radical changes, including customer-sited generation and advanced metering infrastructure, which will both demand and allow a

more sophisticated method of designing the rates charged to customers. In this environment, traditional rate design may not serve consumers or society best. A more progressive approach can help jurisdictions meet environmental goals and minimize adverse social impacts, while allowing utilities to recover their authorized revenue requirements. In this paper, RAP reviews the technological developments that enable changes in how electricity is delivered and used, and sets out principles for modern rate design in this environment. Best practices based on these principles include time-of-use rates, critical peak pricing, and the value of solar tariff.

Rate Design Where Advanced Metering Infrastructure Has Not Been Fully Deployed

Available at: <http://www.raonline.org/document/download/id/6516>

This paper identifies sound practices in rate design applied around the globe using conventional metering technology. Rate design for most residential and small commercial customers (mass market consumers) is most often reflected in a simple monthly access charge and a per-kWh usage rate in one or more blocks and one or more seasons. A central theme across the practices highlighted in this paper is that of sending effective pricing signals through the usage-sensitive components of rates in a way that reflects the character of underlying long-run costs associated with production and usage. While new technology is enabling innovations in rate design that carry some promise of better capturing opportunities for more responsive load, the majority of the world’s electricity usage is expected to remain under conventional pricing at least through the end of the decade, and much longer in some areas. Experience to date has shown that the traditional approaches to rate design persist well after the enabling technology is in place that leads to change.

Time-Varying and Dynamic Rate Design

Available at: <http://www.raonline.org/document/download/id/5131>

This report discusses important issues in the design and deployment of time-varying rates. The term, time-varying rates, is used in this report as encompassing traditional time-of-use rates (such as time-of-day rates and seasonal rates) as well as newer dynamic pricing rates (such as critical peak pricing and real time pricing). The discussion is primarily focused on residential customers and small commercial customers who are collectively referred to as the mass market. The report also summarizes international experience with time-varying rate offerings.

Recognizing the Full Value of Energy Efficiency

Available at: <http://www.raponline.org/document/download/id/6739>

Energy efficiency provides numerous benefits to utilities, to participants (including ratepayers), and to society as a whole. However, many of these benefits are frequently undervalued, or not valued at all, when energy efficiency measures are assessed. This paper seeks to comprehensively identify, characterize, and provide guidance regarding the quantification of the benefits provided by energy efficiency investments that save electricity. It focuses on the benefits of electric energy efficiency, but many of the same concepts are equally applicable to demand response, renewable energy, and water conservation measures. Similarly, they may also apply to efficiency investments associated with natural gas, fuel oil, or other end-user fuels. This report is meant to provide a comprehensive guide to consideration and valuation (where possible) of energy efficiency benefits. It provides a real-world example that has accounted for many, but not all, of the energy efficiency benefits analyzed herein. We also provide a list of recommendations for regulators to consider when evaluating energy efficiency programs.

Meeting the Challenge of Integrating Renewables into the Western US Grid at Least Cost

Available at: <http://www.raponline.org/document/download/id/6074>

RAP Senior Advisor Lisa Schwartz addressed the challenges of integrating renewables into the Western US Grid in a presentation to the State-Federal Renewable Portfolio Standard Collaborative. Her presentation highlighted the key topics of a paper RAP, in partnership with the National Renewable Energy Laboratory and Exeter Associates, recently prepared for the Western Governors’ Association. The project explores approaches for reducing costs to integrate wind and solar in the Western U.S., barriers to adopting these cost-saving measures and possible state actions. Drawing from existing studies and experience to date, the paper identifies nine ways Western states could reduce integration costs—operational and market tools as well as flexible demand- and supply-side resources. Among other recommendations, Ms. Schwartz focused on ways to improve institutional flexibility, explore demand response that complements variable generation, and develop a more flexible generating fleet.

Demand Response as a Power System Resource

Available at: <http://www.raponline.org/document/download/id/6597>

Demand response refers to the intentional modification of electricity usage by end-use customers during system imbalances or in response to market prices. While initially developed to help support electric system reliability during peak load hours, demand response resources currently provide an array of additional services that help support electric system reliability in many regions of the United States. These same resources also promote overall economic efficiency, particularly in regions that have wholesale electricity markets. Recent technical innovations have made it possible to expand the services offered by demand response and offer the potential for further improvements in the efficient, reliable delivery of electricity to end-use customers. This report reviews the performance of demand response resources in the United States, the program and market designs that support these resources, and the challenges that must be addressed in order to improve the ability of demand response to supply valuable grid services in the future.

Integrating Energy and Environmental Policy

Available at: <http://www.raponline.org/document/download/id/6352>

Energy issues are environmental issues, and environmental issues increasingly are energy issues. This link is inescapable: energy decisions have profound environmental and public health impacts, and energy-related emissions are changing the heat balance of Earth. The purpose of this paper is to demonstrate that greater integration and coordination of energy and environmental regulation can improve both environmental and energy outcomes—as well as citizens’ quality of life and economic wellbeing—and to provide some advice and guidance for moving effectively in this direction.



The Regulatory Assistance Project (RAP)[®] is a global, non-profit team of experts focused on the long-term economic and environmental sustainability of the power sector. We provide technical and policy assistance on regulatory and market policies that promote economic efficiency, environmental protection, system reliability, and the fair allocation of system benefits among consumers. We work extensively in the US, China, the European Union, and India. Visit our website at www.raponline.org to learn more about our work.



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