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Putting Price More into the Picture

Buildings as Batteries: The Rise of 'Virtual Storage'

Efforts to reshape demand to curb peak load are prompting public and private investment in electricity storage technologies such as battery banks, compressed air systems and ultracapacitors. But investments in this kind of 'hard storage' are relatively expensive and in many cases misplaced. An embrace of what the authors call 'virtual storage' would accelerate the transition to a healthier, more resilient, economical and secure electricity grid.

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As a point of disclosure, Greg Kats serves on or has served on the board of several of the firms discussed in this article. Several of the graphics included are used with the permission of the firms described. In addition, all the opinions expressed in this article are those of the authors and not necessarily any of the companies or institutions with which they are affiliated.

When we learn how to store electricity, we will cease being apes ourselves; until then we are tailless orangutans. You see, we should utilize natural forces and thus get all of our power. Sunshine is a form of energy, and the winds and the tides are manifestations of energy.
– Thomas A. Edison, 1910

Energy storage technology is the silver bullet that helps resolve the variability in power demand.[1]
– Terry Boston, PJM president and CEO

I. Introduction

The argument for increased electricity storage is compelling. Electricity loads are increasingly concentrated in summer afternoons – meaning that a growing portion of generation, transmission, and distribution infrastructure is used relatively few hours each year. As a result, these huge utility capital investments are inefficiently used.

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Further, wind turbines do not generate power at predictable times, which adds uncertainty to grid operations. The expected addition of plug-in hybrid and electric vehicles (EVs) will exacerbate the uncertainty of timing of load demand, making the economic case for energy storage even more compelling. In addition, the worsening economics of nuclear power and coal plants and requirements for coal plants to limit health-damaging emissions are reducing the viability of these baseload generation sources. Over a dozen of America's largest utilities have announced coal plant retirements and it is estimated that in the next decade 10 to 20 percent of the U.S. coal fleet will be decommissioned.[2]

Facing these pressures, and encouraged by some public utility commissions, some utilities are making their own high cost of peak power transparent to end users through time-of-use pricing, capacity charges, and other pricing signals that encourage electricity users to reduce peak power consumption. Utilities are employing strategies such as storage, energy efficiency, and demand response programs that pay clients to cut or shift load from peak usage periods. Together these trends also make storage increasingly desirable as a means to reshape electricity loads that better match power availability to market needs.

Multiple studies have examined the impact of higher levels of intermittent renewable generation on grid operations (EnerNex Corp, 2006, 2010; GE Energy, 2010) and, more recently, on energy storage technology costs and benefits (Sandia National Laboratories 2011; EPRI 2010). Reflecting a broad consensus, these studies recommend expanding storage solutions but focus principally on what we call ''hard storage'' solutions. This view was captured in a recent speech by NYISO President and CEO Stephen Whitley at the June 2012 Windpower Conference:

> Energy storage can play a valuable role in the continued development of New York's renewable power resources. For example, the variable nature of wind generation poses special challenges to grid operators, such as the NYISO, that must constantly balance the supply of and demand for electricity on the grid. Flywheels, batteries and other energy storage systems expand our ability to address those needs.[3]

Reflecting a broad consensus, these studies recommend expanding storage solutions but focus principally on what we call ''hard storage'' solutions.

Hard storage of electric power has emerged in the last few years as a major area of utility and venture capital investment. Regulators, utility executives, and venture capital firms are investing in hard storage technologies such as batteries, compressed air energy storage (CAES), and more advanced technologies such as flywheels and capacitors. These hard storage technologies, however, share some serious limitations. Capacitors, batteries, and flywheels are often expensive, requiring large upfront capital costs. CAES and pumped hydro storage, though less costly per unit of power stored, are geographically limited because the easy and obvious sites have already been developed.

This rush to invest in new capital-intensive storage technologies overlooks a far larger, lower-cost, and lower-risk opportunity – what we call ''*virtual storage*.'' Unlike ''hard storage'' technologies virtual storage does not require large capital costs. Instead, virtual storage is about harnessing intelligent, distributed energy efficiency and the latent potential in building structure and systems to dynamically reshape building energy usage to – in effect – *reshape demand to match variable supply*.

Virtual storage offers a far more cost-effective and lower-risk solution than hard storage technologies to solve most power supply and demand mismatches. The rapid rise of virtual storage will better and more cost-effectively meet energy storage needs than most of hard storage technologies that are now receiving investment from

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utilities and VC firms. Shifting to a virtual storage strategy can save tens of billions of dollars, serve as a catalyst for the renewable energy industry, improve utility profitability, strengthen security, and slow global climate change.

II. The Changing Shape of Power Supply and Demand

Utilities spend tens of billions annually building generation capacity and constructing electricity T&D systems that are increasingly underutilized. New peaking power plants and transmission and distribution (T&D) systems are generally used relatively few hours a year – principally to satisfy air conditioning loads on summer afternoons – representing inefficient use of tens of billions of dollars of generating and T&D investments.

Even in California, perhaps the most advanced U.S. state in encouraging load reshaping through price signals and incentives, the expected capacity utilization of power generation is forecasted to decline in the coming years. Like most of the U.S., California's power consumption and generation is getting ''peakier.''[4] The state's load factor (the portion of time that generation capacity is used) is projected by the California Energy Commission to decline from about 55 percent in 2000 to roughly 50 percent in 2020.[5] And while peaking plants using low-cost natural gas at first appear to be a relatively low-cost option for electricity generators, they are expensive because peaking assets are used infrequently, and they are risky because natural gas prices are likely to rise from currently historical lows.

Under a declining capacity utilization scenario, power generation will be concentrated around peak power use periods (mainly the hottest summer days that require the highest amounts of air conditioning). In turn, T&D congestion during these peak times can cause losses of 10 percent or more, requiring additional generation to offset these losses. Accordingly, the opportunity to shift load from peak to off-peak in order to increase efficient use of utility assets, to reflect the true cost of peak generation assets, and to cut line losses motivates utilities to employ time-of-use rates and capacity charge pricing structures. In recent years forward-looking utilities have been building business models around ''demand response,'' which involves shedding electric load from users rather than generating additional power or even facing blackouts.

A growing number of America's best-managed utilities use price signals to secure substantial distributed peak load reduction from large commercial and industrial clients.

A growing number of America's best-managed utilities use price signals to secure substantial distributed peak load reduction from large commercial and industrial clients. Many of these utilities support peak time rebates and critical peak pricing to achieve this objective. Austin Energy in Texas, for example, can currently engage in more than 90 MW of load-shedding capacity *via* nearly 100,000 remotely controllable smart thermostats. Con Edison's initiatives facilitate energy savings of approximately 30 MW and an anticipated 40 percent to 50 percent reduction in outages. Southern California Edison (SCE) has over 1,600 MW enrolled in voluntary demand response programs and plans to grow to 1,900 MW by 2014 through increased automated load control devices.[6]

This cost avoidance opportunity also serves as the primary driver for billions of dollars of public and private investment in Smart Grid infrastructure, and is a major catalyst for the recent surge in venture capital investment in hard storage.

To be clear, demand response is a small subset of virtual storage. But interestingly, virtual storage involves value creation at levels simultaneously bigger and smaller than demand response. Why bigger *and* smaller? Because virtual storage can provide benefits at every point of the value chain from end user power quality (small voltage variations) to ISO markets price arbitrage (big market signals) and everything in between. Demand response, on the other hand, creates the majority of its value by providing capacity, which is a small segment of the virtual storage value chain. The Electric Power Resource Institute has mapped this value chain, and the value of individual benefits which our concept of virtual storage can capture (**Table 1**).[7]

The future of clean energy generation, efficiency and virtual storage is already taking shape in the U.S. military, beginning with the military's acceptance of the reality of climate change and its embrace of energy efficiency, and emerging renewable and smart control strategies as a powerful way to respond to the security threats of a brittle, aging grid, reliance on imported oil, and climate change.

III. Energy Efficiency: A 'Force Multiplier' for the U.S. Military

The U.S. military is a leading early adopter of green building design, renewable energy, energy efficiency, and microgrids, because these strengthen U.S. security and because these design strategies are cost-effective. The U.S. Navy, for example, has set a target of having half its bases be zero net energy (and largely self-sufficient) by 2020 through a combination of energy efficiency, clean energy generation, and smart controls. How the military achieves this and how it addresses power storage challenges will have a significant impact on the cost effectiveness and resilience of U.S. military installations – and will hold important lessons for the rest of the economy.

Table 1:

		PV $/kW hr		PV $/kW	
Value Chain	Benefit	Target	High	Target	High
End User	1 Power Quality	19	96	571	2,854
	2 Power Reliability	47	234	537	2,686
	3 Retail TOU Energy Charges	377	1,887	543	2,714
	4 Retail Demand Charges	142	708	459	2,297
Distribution	5 Voltage Support	9	45	24	119
	6 Defer Distribution Investment	157	783	298	1491
	7 Distribution Losses	3	15	5	23
Transmission	8 VAR Support	4	22	17	83
	9 Transmission Congestion	38	191	368	1,838
	10 Transmission Charges	134	670	229	1,145
	11 Defer Transmission Investment	414	2,068	1,074	5,372
System	12 Local Capacity	350	1,750	670	3,350
	13 System Capacity	44	220	121	605
	14 Renewable Energy Integration	104	520	311	155
ISO Markets	15 Fast Regulation (1 hr)	1,152	1,705	1,152	1,705
	16 Regulation (1 hr)	514	761	514	761
	17 Regulation [15 min]	4,084	6,845	1,021	1711
	18 Spinning Reserves	80	400	110	550
	19 Non-Spinning Reserves	6	30	16	80
	20 Black Start	28	140	54	270
	21 Price Arbitrage	67	335	100	500

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Table 2: U.S. Military Timeline for Energy.

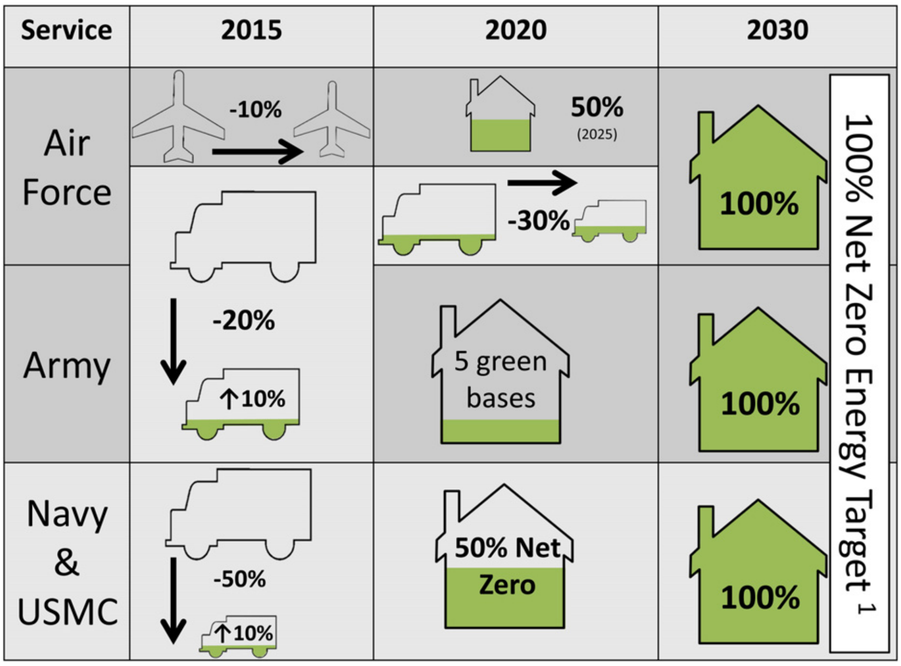

Table 2 illustrates[8] how each branch of service plans to reduce its fuel consumption and/or add renewable fuels and electricity to their usage over time. By publication date, the Navy and Marine Corps have set the most aggressive targets – planning to simultaneously reduce non-tactical vehicle petroleum fuel use by 50 percent and increase the use of alternative fuels 10 percent by 2015, and have 50 percent of their installations net zero energy with renewables by 2020.

As the largest energy consumer in the world, the U.S. Department of Defense (DoD) has realized the value and practicality of energy efficiency, officially codifying it as ''a force multiplier'' in the 2010 Quadrennial Defense Review.[9] This should come to no surprise to those familiar with the DoD's track record of technological innovation, which includes advances such as geographical positioning systems (GPS) and the Internet. Advances in energy – such as increasing the use of renewable energy supplies and reducing energy demand – are simultaneously enhancing military operational capability in forward-deployed combat environments and generating enormous cost savings to U.S. military installations. All the while, these efforts make our troops and mission critical systems more secure, and reduce risks associated with climate change. Stated succinctly by Admiral Mike Mullen, chairman of the Joint Chiefs of Staff, ''Saving energy saves lives.''[10]

Due to a $21.3 billion annual energy bill and because the fragility of the ''grid leaves DoD vulnerable to service disruptions and places continuity of critical missions at serious and growing risk,'' the U.S. military has set ambitious targets to reduce energy use and deploy renewable energy sources.[11,12] The DoD, however, has missed recent facility energy intensity and renewable energy consumption goals.[13] The virtual storage focus discussed here can help close this gap, enabling DoD to achieve its goals through increasing renewable generation, at lower cost than conventional energy solutions.[14]

Eliminating mission-essential single points of failure, i.e., ''critical nodes,'' in order to strengthen national defense was at the heart of the Internet's strategic development. Similarly, the U.S. military is now adopting an energy design strategy involving microgrids to enhance security and reduce reliance upon the increasingly brittle electricity grid. As noted recently by a senior defense official, ''we see microgrids as our salvation.''[15] These systems will combine on-site clean energy generation, energy efficiency, and smart controls to allow greater energy efficiency and reliability. Integral to this approach will be the use of a virtual storage approach to shed and reshape load. Intelligent controls can increase efficiency of energy usage to augment the reliability and survivability of critical functions that require power to operate.

We believe this next generation of innovation will be unique among DoD breakthroughs because the prospect for energy is, in the words of Admiral Mullen, about ''not just defense but security, not just survival but prosperity.''[16] As recognized by Secretary of Defense Leon Panetta, we face systemic threats in the 21st Century, and ''the reality is that there are environmental threats which constitute threats to our national security. For example, the area of climate change has a dramatic impact on national security.''[17] The good news according to the chair of the Joint Chiefs of Staff Mike Mullen, is that our national defense infrastructure and systems hold the potential to ''help to stem the tide of strategic security issues related to climate change''[18] while improving operational effectiveness.[19] Virtual storage can serve both strategic and tactical level defense needs, delivering costs while arming troops with ''more fight – less fuel.''

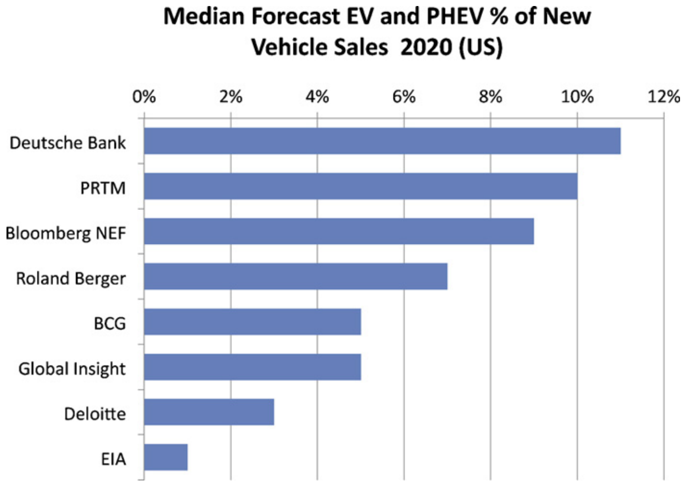

Figure 1: US Median Forecast of EV and PHEV New Vehicle Sales.

IV. Uncertainty in Future Utility Load Demands

Enormous uncertainty about future electricity demand is exacerbated by the unclear growth trajectory of electric and plug-in hybrid vehicles. **Figure 1** provides a recent summary of various credible projections about likely new EV penetration in the U.S. in 2020, ranging from a 1 percent projection by the Energy Information Agency, up to 11 percent in the U.S. (and even higher in Europe) by Deutsche Bank.[20]

Where these vehicles recharge – or potentially discharge – their power adds further uncertainty. Cars charging at work could add to peak load demand. Or, if charged at home during off-peak periods, these vehicles could provide load demand to efficiently use nighttime wind. Alternatively, these vehicles could potentially charge at home, and then discharge some of their power back to the grid through connections at work during peak hours. The potential for plug in hybrids to ameliorate – or possibly, worsen – electricity demand and supply will emerge as a large policy issue in the coming decade.

From 2007 through 2010, an average of 38 percent of new U.S. generating capacity was wind. Since wind is available only part time (i.e., 35 percent), and at varying times, this translates into substantially lower power available (i.e., MWh) than baseload power such as coal, nuclear, or some hydro and gas plants. While the large increase in wind generation – jumping from 2 percent of new capacity in 2004 to a high of 43 percent in only five years – represents huge gains for U.S. security and U.S. employment, it also creates uncertainty for utility planning and investment. This uncertainty is worsened by volatile year-to-year changes in federal support for wind.

Wind and solar, like all other forms of energy including nuclear, coal, and natural gas, receive substantial and diverse federal subsidies including tax breaks and tax credits. Unlike fossil fuels and nuclear power, however, federal wind power tax credits are highly uncertain and have commonly been renewed only on an annual basis. This situation makes it difficult for private investors, developers, and utilities to plan investments, undercutting the objective of promoting clean energy and U.S. competitiveness. In the years

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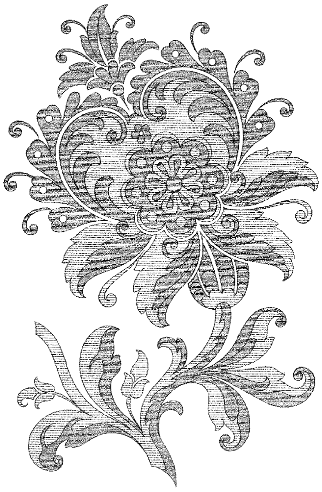
where federal tax support for wind was withdrawn, wind investment collapsed. This adds further uncertainty for utility regulators and planners and in turn creates increasing need for storage to shape and balance uncertain power demand and shifting supply.

In Europe, subsidies for renewables are like subsides for fossil and nuclear fuels in the U.S. – they are committed for multiple years in advance, providing a long-term certain financial planning period on which to build a strong domestic renewable energy industry. With its more predictable market environment, Europe secured two-thirds of its new generation capacity from wind and solar in 2011.[21]

Power generation for solar photovoltaics peaks when the sun is highest at mid-day, some hours before the grid's peak power needs, which is typically between 3 and 6 pm. Storage can shift forward solar power by several hours to make it coincident with greatest demand – and higher prices. And because on-site storage does not need to traverse congested power transmission lines, it reduces transmission congestion and power line losses.

The uncertainty of load growth contributes to the need for storage – or the ability to reshape load. Hard storage investments – e.g., CAES and battery banks – are expensive, relatively inflexible, and slow to install compared to virtual storage. In contrast, virtual storage relies mainly on software and low-cost hardware such as sensors and building management software upgrades. Through load shifting and efficiency, virtual storage delivers similar load management benefits as hard storage but at far lower cost, making it the optimum strategy to manage risks and cut the costs of increasingly uncertain electricity demand and supply. Hard storage does provide backup power – an important service that virtual storage does not offer. Standby power provided by hard storage can be very valuable or even critical. For example, ensuring continued operations of critical needs such as communications when grids fail is an excellent use of hard storage. However, the majority of demand for storage is for load reshaping, peak flattening, renewables integration, and the ability to respond dynamically to utility needs to cut power consumption. These services are far more cost-effectively provided by virtual storage.



V. Investment Trends

The potential market for energy storage is estimated at over $100 billion globally,[22] rising to as high as $650 billion by 2030.[23] However, these estimates appear exaggerated for hard storage solutions because market demand for hard storage capacity will be limited due to the comparatively high capital costs involved. U.S. venture capital investment in storage technologies has jumped sharply, rising almost six-fold from $108 million dollars in 2007 to $617 million dollars in 2011.[24] U.S. federal spending on research and development has followed this trend, with allocations approaching a half-billion dollars. These investments, both public and private, have been steered primarily to hard storage technologies, thus missing out on more cost effective opportunities in virtual storage we describe here.

Solar manufacturers such as SolarWorld, Samsung, and Kyocera are developing and selling integrated photovoltaic (PV) (solar) + hard storage (e.g., batteries) solutions. And industry observers have noted the emergence of new partnerships with similar PV + hard storage objectives, including GE and Arista, and Tesla and Solar City.[25] San Diego Gas & Electric is integrating MW-size lithium ion battery banks to help shape and manage the grid. The Sacramento Municipal Utility District recently announced a $2 million, 500 kW lithium-ion battery installation to help reshape and integrate expanding solar generation. But at $2 to $4 watt, the cost of these battery banks is as costly – on a capacity (kW) basis as installed solar. This high cost, especially compared with virtual storage, will sharply limit the economic potential for batteries and other ''hard storage'' technologies as a load reshaping strategy.

VI. Buildings as Batteries: The Rise of Virtual Storage

Because policies can be reversed, and fuel costs, technology, incentives and pricing models can all change, flexibility is the greatest value provided by storage applications. Enabling load shifting requires the ability or *means* to control or shift load, and the motivation or *incentive* to do so – e.g., utility incentives or price differences between peak load and off-peak load. This is illustrated by analysis by the Berkeley Wireless Research Center[26] (see **Figure 2**). Peak load (indicated by the yellow band) designates the surge in power consumption during peak load, principally from air conditioning load in summer afternoons. Communicating thermostats, sensors, and smart energy management systems provide the *means* for building occupants to reduce peak demand (indicated by dotted line). When critical peak pricing (i.e., substantially higher rates for peak typically combined with lower rates for off-peak) provides the *incentive* to load shifting, there is a large reduction in peak power consumption.

Buildings represent close to three-quarters of electricity consumption, with building energy demand peaking during hot summer afternoons when demand for air conditioning is greatest. While buildings are the dominant source of unbalanced load demand, buildings – through virtual storage – also represent the largest opportunity to cost-effectively reshape load and save tens of billions of dollars in inefficient generation and T&D infrastructure costs.

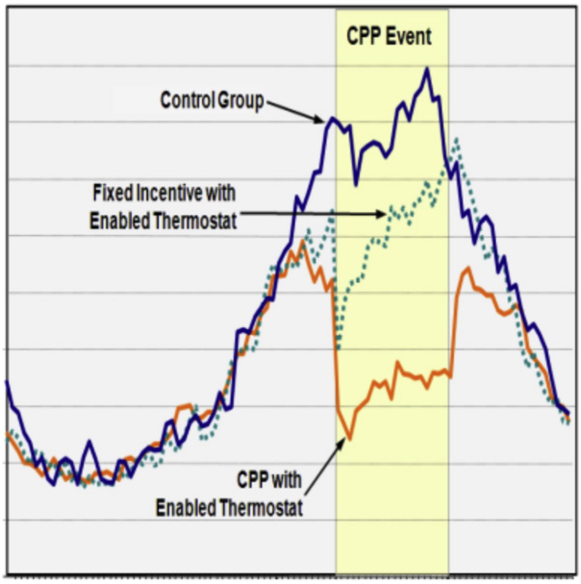


Figure 2: Critical Peak Pricing Incentivizes Load Shifting.

There are a set of new technologies designed to reduce peak power consumption and these will be part of ''building as battery'' designs in achieving zero net energy, integrated low or zero net energy building, and military base designs. These new technologies are varied, and include hardware solutions, energy efficiency control devices, and Smart Grid solutions. One of the most effective of these hardware solutions is dynamic, electrochromic glass that allows building occupants to manually or automatically control amount of light and heat emitted through the glazing. A small electricity current passing through an electrochromic layer on glass causes the window shift from clear to tinted and back. In the clear state, up to 63 percent of light passes through – ideal for an overcast winter day when the solar heat gain helps warm the building and natural light reduces need for artificial lighting. In the tinted state as little as 2 percent of light and solar heat gain comes through the window – keeping out almost all unwanted heat in summer afternoons and avoiding glare (and the need for shades), while providing sufficient light to keep internal lights off. For an average commercial building in areas where peak demand occurs

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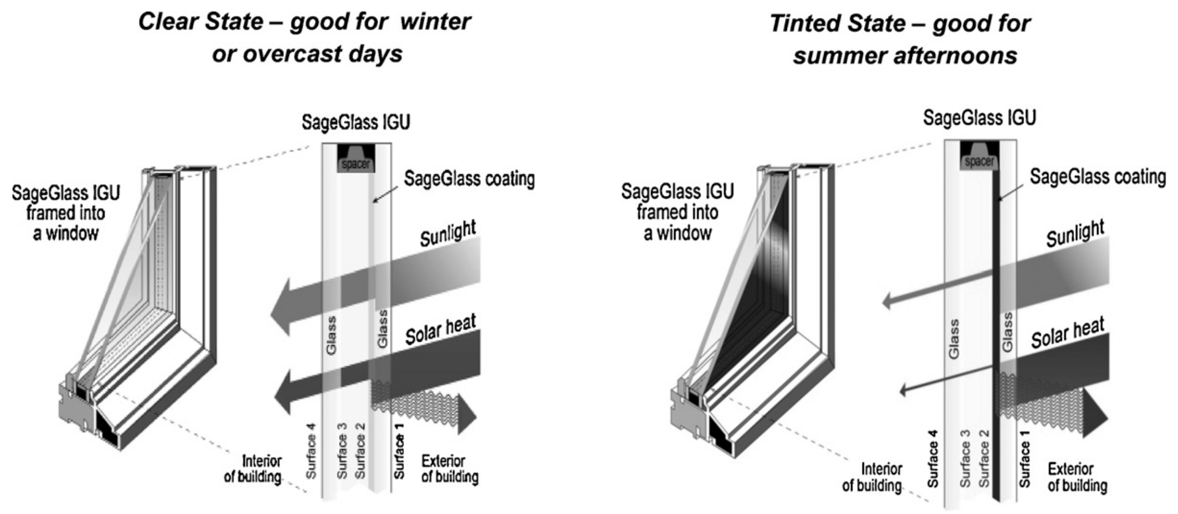

Figure 3: Electrochromic Windows.

during the summer afternoons, electrochromic windows can cut total commercial building electricity peak load by 15 to 20 percent, and can make windows a net energy saver by increasing solar heat when needed, and rejecting it when not wanted (**Figure 3**).

There is a new class of intelligent building controls that are enabling large cost-effective virtual storage at building and campus-wide levels. The best of these are able to incorporate past, current, and projected future (e.g., next day) temperature projections in designing lowest-energy-use strategies to achieve desired comfort.

The capacity to shift building and campuswide energy load has been demonstrated in residential buildings. Tendril, a leading U.S. residential Smart Grid firm, works with utilities to demonstrate the potential for peak load reduction/shifting. An example of smart building management providing virtual storage is illustrated in the test results shown in **Figure 4**.

In a fall 2011 test run by Colorado-based Tendril, and illustrated in Figure 4, 60 buildings responded to utility incentives to reduce peak demand 2.5 kW on average, or approximately 2.0 kWh during the three-hour peak period from 3 pm to 6 pm, as indicated by the grey band. The average peak load reduction is about 40 percent, a dramatic reduction considering that participation in events is voluntary and occupants may opt out at any time before or during an event. This virtual storage capacity costs far less than hard storage solutions such as batteries. And virtual storage capacity is available for both residential and commercial buildings.

A growing number of commercial building monitoring management services enable large virtual storage gains by allowing all aspects of building energy use and generation to be monitored, linked, and managed efficiently. One of the challenges for building energy management systems is that they have

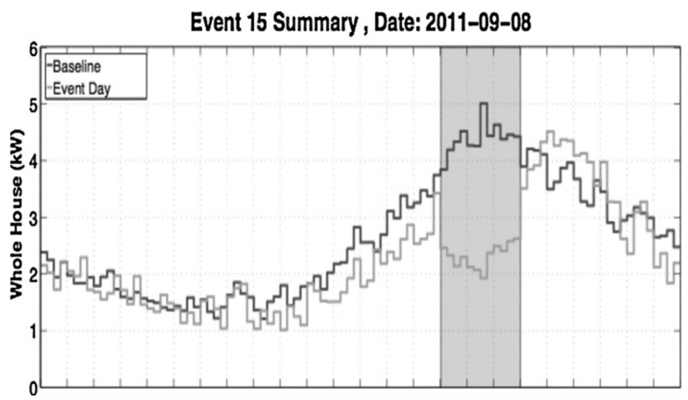

Figure 4: Buildings Respond to Utility Incentives.

commonly been unable to use the thermal mass of buildings to optimize energy use. Thermal mass refers to the large concrete, brick, stone, or other mass that make up the building structures and that absorb and emit significant amounts of heat. The best of new virtual storage building controls systems, such as Building IQ, can in effect use the thermal mass of buildings as an integral part of achieving occupant comfort at lowest energy costs.

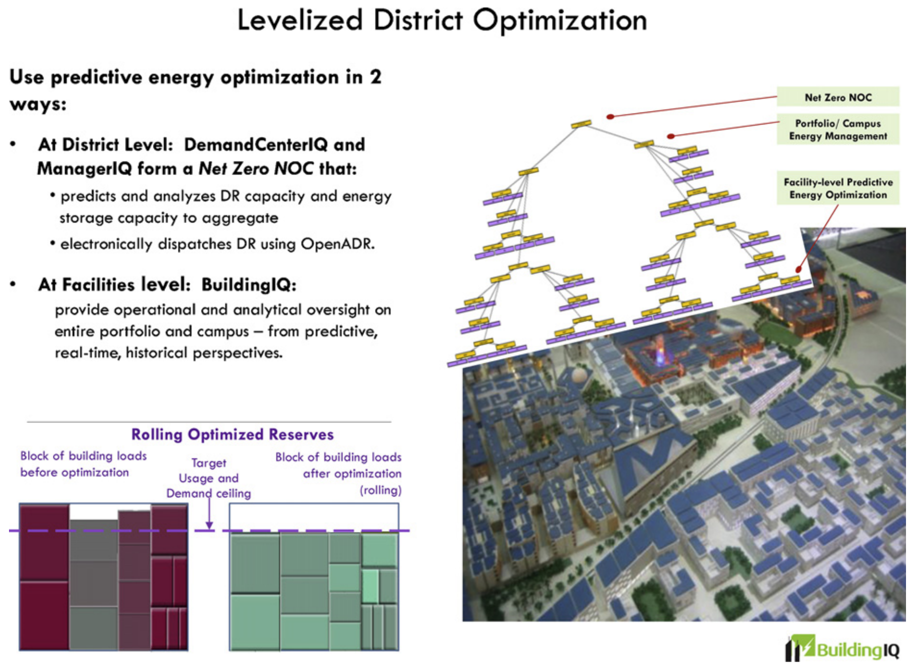

Figure 5: Levelized District Optimization.

Operating in demanding environments such as New York's Rockefeller Center, Building IQ incorporates real-time energy measurement with projected energy (e.g., next-day temperature), thermal mass of building (i.e., heat or cooling latent in buildings thermal mass), and current energy prices to optimize building energy use to achieve desired comfort. Building IQ typically delivers total building electricity savings in the 25 percent range. And it is able to integrate multiple energy elements – onsite generation and onsite storage to provide desired comfort in a way that is most efficient and lowest cost. In effect the building itself becomes a battery.

Building energy optimization can be scaled to a campus, a city, a military base, or district-wide to achieve a lower-cost, more reliable, and robust energy system (**Figure 5**). Sites like the U.S. Navy's zero net energy bases will combine onsite renewable energy, plug-in hybrid/EVs, ice or water storage capacity, ground sourced heat pump, and energy efficiency measures that anticipate next-day temperatures to reduce and shape power and air conditioning needs.

The lower left panels and the larger right panel in Figure 5 indicate how multiple buildings can be controlled in an integrated way to ensure total power demand requirements meet set objectives – i.e., to avoid capacity charges or to ensure power consumption stays below transformer capacity thresholds. This solution is far less expensive and more rapid than hard storage.

Virtual storage will also become an enormously valuable design approach at the city level. The failure of federal congressional leadership to act responsibly on climate change has prompted widespread shouldering of this responsibility by states and cities. Over 1,000 U.S. mayors representing some 85 million people have committed to some level of CO^2 capping and/or reduction. And because buildings represent on the order of 70 percent of their CO^2, building load efficiency and enabling cost-effective integration of energy efficiency, virtual storage, renewable power, and EVs offer the potential for tens of billions of dollars of avoided costs and improved reliability. Increasing scale and complexity creates greater opportunity of integration and virtual storage, e.g., military bases with onsite renewables, ground source heat pumps, intelligent buildings, and vehicle recharging stations.

City digitization tools such as Screampoint will enable city managers to visualize, understand, and dynamically manage their complex energy, transport, and water systems – creating the opportunities for cities to save hundreds of billions of dollars in avoided infrastructure and operational costs. Software-based smart tools, sold as monthly service fees with little or no upfront costs, are emerging to provide far greater transparency and more informed energy, transportation, and office design and management. An example of this is Better Workplace, now being used by companies such as Bank of America, ING, and TIAA-CREF to provide greater support to employees to enable them to work from home or on the road more effectively, in turn enabling greater efficiency in use of office space and substantial energy savings.

VII. Conclusion

The rise of virtual storage will have its fits and starts as this systems-based approach emerges. But it will rise, catalyzed by leading cities, some utilities, smart/green buildings, and the military. As noted by *Forbes* magazine, ''one of the biggest proponents of green technology in the United States is that most conservative of organizations, the U.S. military''[27] and ''no matter which way the political winds are blowing at any given time, the U.S. military has made a long-term commitment to develop and utilize renewable clean energy.''[28] With buildings representing close to three-quarters of U.S. electricity consumption, and building energy usage dominating the timing of electricity demand, utilities have been forced to invest hundreds of billions of dollars in generation and T&D capacity to serve this market. Public utility commissions that manage and regulate utilities have increasingly pushed utilities to adopt time-of-use power pricing and provide financing incentives such as time-of-use rates to customers to encourage them to reduce peak load, thus unlocking and rewarding building efficiency.

The next step in the U.S. grid evolution should be widespread adoption of virtual storage to harness the potential for smart buildings, especially green buildings, to serve in effect as standalone and linked distributed batteries . . . that is, to reshape demand to better match increasingly variable load. Virtual storage opportunities are already available from new energy management tools that are scaling rapidly. Already, individual building energy use profiles can be reshaped at very low cost to move peak power consumption off peak and/or to enable the most cost-effective deployment of on-site renewable energy. And the rise of virtual storage offers a larger, faster, cheaper, and less-risky strategy than hard storage options for load reshaping and renewable energy integration. Private and public investors and regulators should embrace virtual storage as a critical and cost effective pathway to enabling the transition to a healthier, more resilient, economical, and secure electricity grid and economy.■

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The failure of federal congressional leadership to act responsibly on climate change has prompted widespread shouldering of this responsibility by states and cities.