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September 30, 2016

Docket Control
Arizona Corporation Commission
1200 W. Washington
Phoenix, AZ 85007

RE: Arizona Public Service Company's 2017 RES Implementation Plan
Docket No. E-01345A-16-0238

In Decision No. 74522 (January 19, 2016), APS was ordered to:

> ...file with Docket Control in the docket that will be opened to evaluate Arizona Public Service Company's 2017 REST plan, as a compliance item, a report on the initial findings of the residential level energy storage pilot program.

Attached please find APS's Spotlight on Energy Storage report. If you have any questions regarding this information, please contact me at (602)250-3341.

Sincerely,

Kerri A. Carnes

KC/oa

cc: Thomas Broderick
Barbara Keene
Eric Van Epps

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Spotlight on Energy Storage

Docket No. E-01345A-16-0238

September 30, 2016

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Spotlight on Energy Storage:

An Update for the Arizona Corporation Commission

Synopsis

In this paper, Arizona Public Service (APS or the Company) reports on a variety of initiatives in place or under design to explore the benefits of energy storage to customers and to the grid. As an early leader in energy storage deployment, the Company offers an overview of market trends; discusses various use cases for energy storage; and explores the relative merits and control of residential- and grid-scale storage. APS shares its perspective on emerging data from other utility pilot programs and provides a high-level review of early lessons learned from the Company's own pilot programs and initiatives that are under way. Finally, APS describes the ways in which the Company has been preparing for the next big wave of technology advancement by updating interconnection requirements and incorporating battery design best practices.

I. Introduction

Electricity that powers the grid is generated and delivered nearly instantaneously. As the US Department of Energy notes, "one of the distinctive characteristics of the electric power sector is that the amount of electricity that can be generated is relatively fixed over short periods of time, ***although demand for electricity fluctuates throughout the day***."[1]

> **"The importance and attractiveness of energy storage as an integral part of the electrical supply, transmission and distribution system is receiving increasing attention by a wide range of stakeholders including utilities, end-users, grid system operators and regulators."**
>
> **—Energy Storage Association**

To power the homes and economies of Arizona, APS manages a diverse resource fleet that, in aggregate, operates 24/7/365. But not all hours or seasons are equal. Like APS, nearly all utilities are faced with the logistical challenge of dispatching energy when customer demand is highest. Price signals can help customers shift when they use energy. Technology can certainly have an impact, too. However, as has been seen with the rise of distributed, or rooftop, solar deployment (which provides an energy source only when the sun is shining), new technologies can create challenges for reliable energy delivery. Among these challenges is intermittency of generation and the

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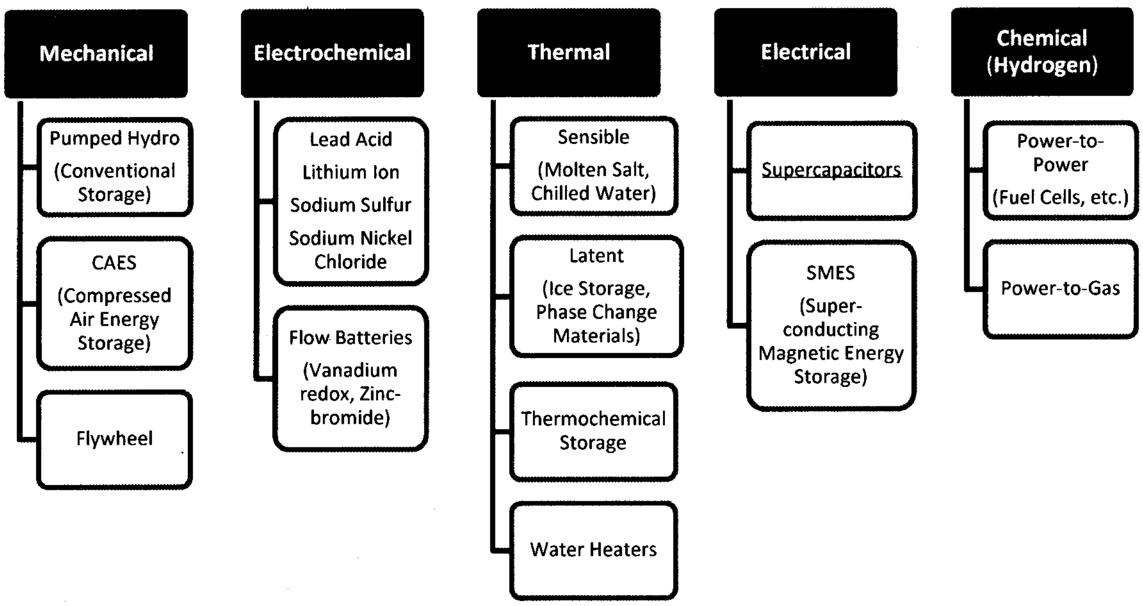
[1] US DOE Office of Electricity Delivery & Energy Reliability [Internet]. Washington, D.C.: US DOE [cited 9/15/2016]. Energy Storage; [1 paragraph]. Available from http://energy.gov/oe/services/technology-development/energy-storage. Emphasis added.

resulting voltage issues.

The utility industry has sought effective methods to store energy from electricity for use, on demand, for many years. Energy storage has and is continuing to evolve and adapt to advances in technology. Currently, there is a wide array of technological approaches to energy storage, ranging in scale from small systems used in homes for back-up power to utility-scale systems that interconnect to the bulk power grid.

Figure 1: Types of Energy Storage Technologies



Put simply, energy storage is not a new concept. Pumped storage hydroelectric projects have been providing energy storage capacity and transmission grid ancillary benefits in the United States and Europe since the 1920s. Even batteries have a 118-year product history in the United States.[2]

As the upward trend of solar energy resource development continues, implementing cost-effective ways in which to integrate these systems—most notably with other flexible generating resources in the grid—becomes more vital. Although battery storage is a promising resource, its near-term potential to displace flexible natural gas generation and integrate intermittent resources like solar remains limited due to its higher cost structure.

While currently above market in cost, battery storage is one subset in particular undergoing rapid innovation that is expected to deliver grid benefits across a whole host of applications in the near future that have, to date, not been possible within another single technology. These applications include:

[2] Batteries have been powering human endeavors since antiquity; even "recent" history stretches back to the 19th century, when the Columbia Dry Cell battery, produced by National Carbon Company (now known as Eveready), sparked an industry in 1898.

- As a generator, the ability to provide capacity and ancillary services to the broader grid;
- As a transmission and distribution resource, the provision of local benefits like backup power to customers, phase balancing, local VAR support, and deferment of investments in transformers, capacitor banks, and wires;
- As a load sink, the ability to alleviate local high voltage conditions through real-power absorption; and
- As a load-management resource, the ability to balance out renewable-resource intermittency and help manage the problems of system solar over-generation during shoulder months.

For these reasons and more, APS, stakeholders and policymakers are interested to see energy storage supported, deployed, and tested in the grid.

Even though the precise impact of customer- or utility-controlled energy storage is uncertain, APS is taking an industry lead through a variety of programs. Much of the current research APS is undertaking in this area revolves around assessing energy storage capabilities, costs, and benefits in a variety of applications to be maximally prepared for the future. While some of the Company's initiatives focus on testing the best use cases for energy storage, it is important also to validate performance, especially given the rather extreme summer climate in the desert Southwest. Batteries have an optimal operating temperature range (often around 0°F to 122°F)—but temperatures in an enclosed garage in Arizona can soar to 140°F. Even batteries with onboard fans are sensitive to ambient temperature. How often the battery shuts down due to ambient temperature can affect its value to the end customer, whether that is a residential user or the utility.

With respect to *where* storage can be most cost-effectively deployed on the grid, the limited size and relatively high cost of residential batteries makes residential applications an open question, particularly with respect as to whether they can provide the same cost-effectiveness or range of benefits as larger, grid-scale connected (12 kV+) batteries. Initiatives like APS Solar Partner and Solar Innovation Study-75 are expected to provide a first tranche of field experience and data to quantify the relative costs, benefits and challenges of each approach. These efforts will also help answer the question as to whether direct utility control of storage will provide fewer or greater grid benefits than storage deployed by customers in response to price signals embedded in the residential tariff.

A Changing Regulatory Landscape

In August of 2016, the Arizona Corporation Commission (Commission) opened a docket for the "Review, Modernization and Expansion of the Arizona Renewable Energy

Standards and Tariff Rules and Associated Rules".[3] The proceeding was initiated in consideration of industry changes that have occurred since the existing Renewable Energy Standard and Tariff (REST) rules were put in place in 2007. Since then, deployment of both utility-scale wind and solar resources has increased significantly as have residential solar photovoltaic (PV) installations. During that same timeframe, markets have matured and pricing for these resources has significantly decreased. The Commission believes that these developments call for a fresh examination of the REST to set the stage for what can be accomplished in Arizona under industry conditions prevalent today.

This docket intends to explore the following:

- Increasing the renewable energy component of generation requirement from 15% by 2025 to 30% by 2030;
- Eliminating carve-outs for specific technologies;
- Emphasizing "least-cost" principles;
- Including other technologies, such as energy storage;
- Examining Net Energy Metering (NEM) rules, to be informed by the Value and Cost of Distributed Generation Docket; and
- Simplifying existing REST Rules.

... and the Road Ahead

APS looks forward to the upcoming discussions on how to further expand the deployment of renewable energy resources and other technologies in the context of the resources (a) overall fit with resource plan needs; (b) ability to meet peak demand, (c) ongoing improvement in cost effectiveness, (d) improved operational performance, and (e) broader role in an industry that is becoming increasingly interconnected—a trend evidenced in the southwest by the growing footprint of the California Independent System Operator (CAISO) Energy Imbalance Market, or EIM. In October 2016, APS launches its participation in the EIM on the basis of the synergistic opportunities it offers its participants, namely through the pooling of resources that improves efficiency of dispatch and gives APS more opportunities to transact for the economic benefit of its customers.

That benefit is expected to become more pronounced as California implements its revised Renewable Portfolio Standard (RPS) of 50% by 2030, and the potential for low or negative wholesale energy market prices grows. The higher California RPS is expected to not only increase the surplus generation from solar resources during midday, non-summer hours, but also decrease prices during that time block—prices which even under current operating conditions can be very low and at times negative.

[3] Commission Docket No. E-00000Q-16-0289.

As an EIM participant, APS expects to be able to purchase energy at these low/negative prices and pass the savings on to customers.

II. Technology Roadmap and Market Considerations

APS tracks energy storage deployment and market trends closely. Not only does the Company want to be ready to take advantage of competitive pricing for grid-scale battery energy storage systems (BESS), but also to understand when it might make sense for the average customer—as opposed to the innovators and early adopters—to add storage to the growing list of distributed energy resources at the grid edge.

A. International Markets

Through its affiliation with the Electric Power Research Institute (EPRI) and the Energy Storage Integration Council (ESIC), and through independent research and benchmarking, APS continually reviews energy storage technologies and markets around the world, including those countries in which battery energy storage adoption has been increasing. Pursuit of energy storage technology in these countries is mainly due to government incentives. The following is a summary of some of the key trends and programs offered.

Germany. Germany is one of the world's leading energy storage markets. Feed-in tariffs during the 2000's created a high level of investment in Germany's renewable energy industry. However, today the resulting excessive renewable generation has required grid operators in Germany to curtail individual generating installations. If curtailed, the generators are compensated at 95% of any lost feed-in revenues. Any balancing payments by the grid operators to the generators are invoiced to ratepayers.

Correspondingly, retail electricity prices have increased 47% since 2006. The increase in retail electricity prices along with declining feed-in tariffs, as well as incentives for behind-the-meter storage, has created a market ripe for the growth of residential storage. Since 2013, Germany has offered homeowners an incentive known as "KfW 275" for customers who pair storage systems with new or existing solar systems. This incentive covered 30% of system costs between 2013 and 2015, currently covers 22% of the cost, and steps down by 3% every 6 months. This combination of variables has resulted in the installation of 67 MW (128 MWh) of energy storage between 2013 and 2015, the majority of which is attributed to residential storage systems. Since 2013, 43,000 applications for solar systems with battery storage have been approved, 19,328 in 2015 alone. In 2015, 41% of Germany's new solar installations included battery storage, compared with less than 14% in 2014.

Australia. High PV penetration along with expensive electricity rates in Australia is creating a market for energy storage. The Australian government is supporting pilot programs to determine the value that energy storage can provide to the grid. The Australian Government's Renewable Energy Agency (ARENA) has commissioned a pilot program that includes the installation of 33 residential rooftop PV systems accompanied by battery storage. ARENA has also commissioned a community solar and energy storage pilot program that consists of more than 100 residential rooftop PV systems with a central 1.1 MWh lithium ion battery storage installation. Although just 1.9 MW of storage was installed in 2015, that number is expected to grow in 2016 and into the future. The biggest factor influencing the slower rate of adoption of storage technology in Australia has been its high cost.

Japan. The Japanese government is supporting energy storage for many of the same reasons as other countries, but also one unique to Japan. The Japanese government hopes to utilize the demand for energy storage in Japan and around the world to drive innovation and development of batteries in Japan, with the goal of developing world-leading battery technology. Japan's government also sees the deployment of battery storage as a way to ease concerns over solar curtailment, and to support balancing the grid.

B. U.S. Markets

Legislatures and utility commissions throughout the United States are also increasingly moving to conduct demonstration and pilot projects involving energy storage technologies as the effort to modernize the nation's electric system continues (*see* Table 1 below). Recognizing that practical and economical energy storage can play a key role in managing some of the challenges of modernization, several jurisdictions have shown interest in determining how to harness the ability of storage to improve the operating capabilities of the grid, ensure high reliability, and possibly defer or reduce infrastructure investments.

Table 1: U.S. Energy Storage Initiatives

Utility	Description[4]	Compensation	Status	Technology Partner(s)
California Investor-Owned Utilities (SCE, PG&E, SDG&E)	Self-Generation Incentive Program (SGIP) Financial incentives for customer-owned DER technologies including advanced energy storage; must provide load-shifting capabilities	$1.31/Watt	Ongoing; funded through 2019	n/a
Consolidated Edison (New York)	Demand Management Incentive Program Achievement of 125 MW of permanent peak-coincident load reduction through customer-owned technologies including energy storage; managed with NYSERDA	$2,100/kW for battery; $2,600/kW for thermal	Fully subscribed	n/a
Consolidated Edison (New York)	Virtual Power Plant Pilot Utility-owned and controlled solar-plus-storage systems for 300 residential customers (Solar leased from third-party, ConEd owns storage); goal of demonstrating network grid benefits from aggregate systems	None; Customer resiliency fee of $15 to $50 monthly	Pilot results expected Q4 2018	SunPower; Sunverge

[4] The name of the pilot or program shown in this table is also a link to the program's website or description in the electronic version of this report.

Utility	Description[4]	Compensation	Status	Technology Partner(s)
Detroit Edison (Michigan)	Advanced Implementation of Energy Storage – Demonstration Project Demonstrate benefits of community energy storage to strengthen grid reliability; test integration of secondary-use EV batteries	None; Utility-owned	Results published March 2016	S&C Electric; Chrysler
Green Mountain Power (Vermont)	Vermont Solar Storage Partnership Solar+storage program for residential customers; no up-front cost with fixed monthly payment for technology	None	Announced September 2016	SunCommon
New Jersey	Renewable Electric Storage Program Statewide program for non-residential storage projects integrated with behind-the-meter interconnected renewable energy systems	$300/kWh; max 30% of project	Ongoing	n/a
PowerStream (Ontario)	Power.House Technology Pilot Test behind-the-meter residential technology integration including solar, battery storage, and energy management system; controlled, operated, and owned by utility for 20 homes	None	Fully subscribed; initial five-year pilot ends 2020	Sunverge
Sacramento Municipal Utility District (SMUD)	PV Integrated Storage Partnership Pilot Demonstration project of newly constructed net-zero-energy homes with solar+storage with utility control of storage system	None	Complete; Final project report August 2016	Sunverge
Xcel (Colorado)	Innovative Clean Technology Stapleton Project Demonstration project to assist management of high solar penetration on distribution feeders by placing a series of batteries on an existing feeder (6 behind-the-meter on residences and 6 utility-scale)	No charge for backup power	2017 - 2018	EPRI; DOE
Xcel (Colorado)	Innovative Clean Technology Panasonic Project Demonstrate use of solar and batteries in utility-owned microgrid project (lithium)	None	2016 - 2018	Panasonic

California has the most aggressive energy storage policy, with the development of a statewide energy storage roadmap that identifies policy, technology, and process changes to address challenges faced by the storage sector.[5] In response to legislation requiring the California Public Utilities Commission (CPUC) to set utility energy storage procurement targets, investor-owned utility procurement targets were identified in October of 2013.[6] The purpose of these targets is threefold, as stated by the CPUC: 1) optimize the grid (peak reduction, reliability contributions, and deferment of transmission and distribution upgrades); 2) integrate renewable energy; and 3) reduce greenhouse gas emissions. The CPUC set a procurement target of 1,325 MW of energy storage by 2020, allocating the storage interconnection point to both utility and customer, with individual overall utility goals as shown in Table 2 below:

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[5] This roadmap was developed by the California Independent System Operator (ISO), the California Public Utilities Commission (CPUC), and the California Energy Commission (CEC), and is available from: https://www.caiso.com/informed/Pages/CleanGrid/EnergyStorageRoadmap.aspx.
[6] Public Utilities Commission of the State of California, Decision 13-10-040 in Rulemaking 10-12-007 dated October 17, 2013.

Table 2: California Investor-owned Utility Energy Storage Targets

Investor-owned Utility	Utility-scale Target	Customer-sited Target
Southern California Edison	495 MW	85 MW
Pacific Gas and Electric	495 MW	85 MW
San Diego Gas and Electric	135 MW	30 MW

In conjunction with this policy, the CPUC in September 2016 approved several energy storage projects and additional procurement plans for these utilities, all of which were specifically targeted at utility-scale energy storage:[7]

Table 3: Recent Energy Storage Contracts in California

Utility	Purpose	Resource	Size	Contract	Partner
PG&E	Market Bundled	Flywheel	20 MW; 4 hour discharge	Delivery date 2020; 20 years	Amber Kinetics
PG&E	Market Bundled	Lithium-ion battery	30 MW; 30 minute discharge	Delivery date 2019; 10 years	Golden Hills Energy Storage
PG&E	Market Bundled	Zinc-air battery	Distribution connected; 10 MW	Delivery date 2020; 20 years	Convergent
PG&E	Market Bundled	Lithium-ion battery	10 MW; 4 hour discharge	Delivery date 2020; 10 years	Hecate Energy
PG&E	Distribution Reliability	Lithium-ion battery	1 MW; 2 hour discharge	Online 5/1/18	Hecate Energy
PG&E	Distribution Reliability	Lithium-ion battery	1 MW; 2 hour discharge	Online 5/1/18	Hecate Energy
SCE	Resource Adequacy	Lithium-ion battery	10 MW and 5 MW; 4 hour discharge	Delivery date 2020; 15 years	Western Grid; EOS Energy Storage
SCE	Resource Adequacy	Lithium-ion battery	1.3 MW; 4 hour discharge	Delivery date 2020; 10 years	W Power LLC; General Electric
SCE	Distribution Reliability	Lithium-ion battery	20 MW	Online 12/31/16	AltaGas Pomona
SCE	Distribution Reliability	Lithium-ion battery	5 MW	Online 12/31/16; 3 year term	Western Grid
SCE	Distribution Reliability	Lithium-ion battery	2 MW	Online 12/31/16; 10 year term	Grand Johanna LLC
SCE	Distribution Reliability	Lithium-ion battery with NCM chemistry	100 MW	Delivery date 2021; 20 years	AES Southland

[7] Public Utilities Commission of the State of California, Decision 16-09-004 in Application 15-12-003 and 15-12-004 dated September 15, 2016, and Resolution E-4804 dated September 15, 2016.

C. Residential Energy Storage Market

The residential battery storage market is immature, but rapidly evolving. According to IHS Markit, "energy storage is set to grow as fast as solar photovoltaic energy has in recent years, sparking strong interest from a wide range of players and underscored by recent mergers and acquisitions among car manufacturers, major oil and gas companies, and conventional power suppliers."[8]

The number of major market players investing in battery storage technology and products is constantly expanding. Some suppliers are also seeking "secondary use" markets for their out-of-warranty automotive battery systems. Several established car companies have publicly committed to developing behind-the-meter storage systems, including BMW, Mercedes, and Nissan.[9] These companies are only beginning to introduce these products into the market and it is unclear what functionality will be available to customers in the future.

Rechargeable lithium ion technology is on its way to becoming the leading energy storage technology, capturing more than 80% of the market share for all residential interconnected storage, according to IHS Markit. And, IHS sees falling lithium-ion battery costs as a driving factor behind the global growth of energy storage.[10]

While the price of residential battery storage is projected to continue to fall over the next 5 to 10 years, its current price is too high for the technology to expand into the residential market in a meaningful way.

The deployment of residential battery storage is also hindered by current utility rate structures because these rates do not provide appropriate price signals for customers to install residential battery storage. Until utility rate structures reward customers for the value that battery storage can bring to peak demand reduction, a flourishing residential battery storage market will be difficult to attain.

In the meantime, some residential energy storage vendors promote batteries as a resiliency solution to power homes in the event of an outage (made more affordable if the batteries can be integrated into a solar sale). Backup-only systems have limited functionality and are uneconomic compared to other available backup power sources, such as gasoline and diesel generators. Recently, Sonnen's senior technical trainer,

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[8] Maloney, Peter. (8/1/2016). *Report: Growth of grid-tied storage to rival solar's recent trajectory in upcoming decade*. Retrieved September 29, 2016 from UtilityDive website: http://www.utilitydive.com/news/report-growth-of-grid-tied-storage-to-rival-solars-recent-trajectory-in-u/423555/.

[9] Pyper, Julia. (6/21/16). *BMW is Turning Used i3 Batteries Into Home Energy Storage Units.* Retrieved September 29, 2016 from Greentech Media website: http://www.greentechmedia.com/articles/read/bmw-is-turning-used-i3-batteries-into-home-energy-storage-units.

[10] Maloney, *Ibid*.

Greg Smith, spoke at Solar Power International,[11] saying that 90% of the batteries they've sold in North America "are being used for backup power."

Greentech Media followed up with Mr. Smith and confirmed that the percentage is "not based on customer surveys or estimation—it's based on the mode in which all those customers have chosen to operate their Sonnen batteries". As reporter Julian Spector notes, "almost all of Sonnen's customers are foregoing potential savings from a more active use of their home batteries [...] electing to pay a significant premium for backup power. Diesel generators sell in the range of $2,500, Mr. Smith said, whereas a 12-kilowatt-hour Sonnen Eco battery system would retail for around $18,000 plus installation costs." The (economic) value proposition is unclear for batteries whose main use to consumers is backup power in the event of an outage, but it is apparent that consumers aren't speaking with one voice yet. Indeed, the trade press recently reported on an Enphase-commissioned survey showing that residential solar customers polled are not interested in buying batteries for backup power because "batteries either don't offer enough days of power or they cost too much".[12]

Emerging understanding within the residential energy storage industry is that the value proposition for customers lies in lowering peak usage—but only once the technology costs come down, and provided the right price signals are in place.

A Closer Look at Cost

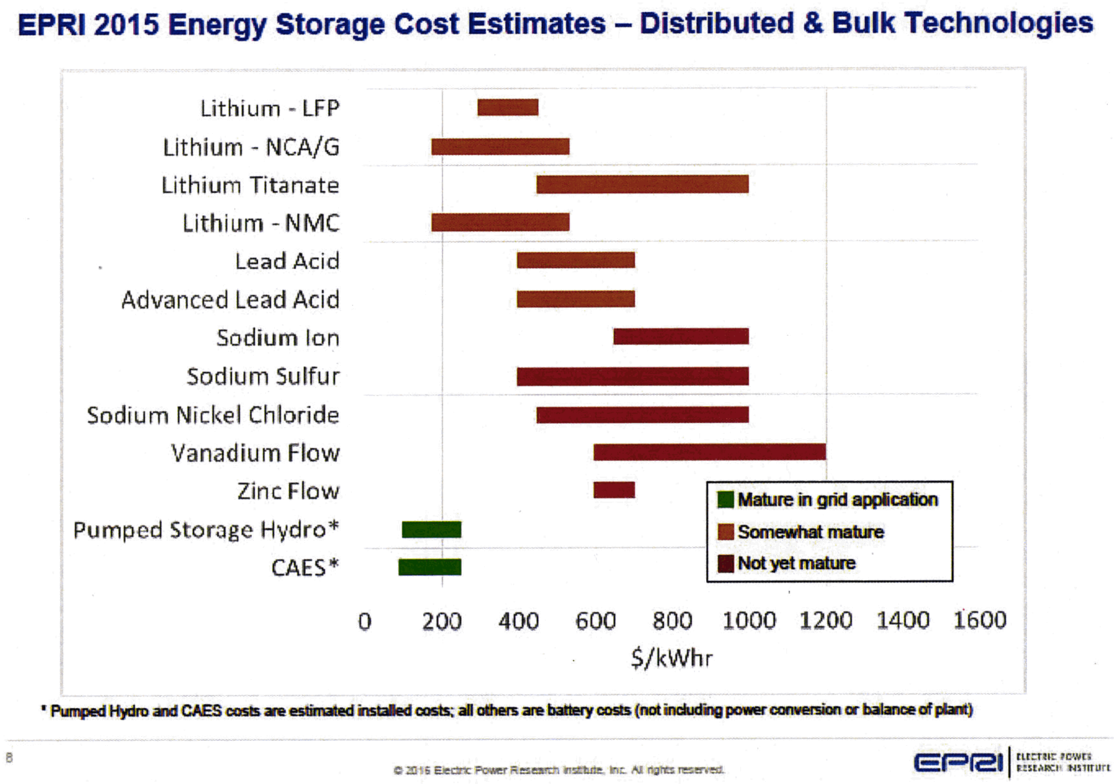
In 2015, the Electric Power Research Institute (EPRI) performed a review of various energy storage technologies and indicates the range of costs for each type of storage system type (or battery chemistry) below in Figure 2. Costs shown include both residential- and grid-scale applications. Note that costs listed for the batteries in this chart do not include installation, whereas the costs provided for the mature storage technologies like pumped hydropower include installation cost. This slide is helpful in that technologies are presented in terms of their maturity in the energy industry.

Rechargeable lithium ion batteries, represented as LFP in Figure 2, are the most prominent in the market, and are expected to achieve dominance in the stationary battery market.

[11] Spector, Julian. (9/14/2016). *Selling Energy Storage When the Economics Don't Work*. Retrieved September 24, 2016 from Greentech Media website: http://www.greentechmedia.com/articles/read/how-to-sell-energy-storage-when-the-economics-dont-work.

[12] Lacey, Stephen. (9/15/2016). *Survey: Batteries Still Can't Give Consumers What They Expect for Backup Power*. Retrieved September 24, 2016 from Greentech Media website: http://www.greentechmedia.com/articles/read/batteries-still-cant-give-consumers-what-they-expect-for-backup-power

Figure 2. Storage Technology Cost Estimates[13]



Navigant Research has compiled more recent data which shows only residential energy storage, but folds into the analysis a deployment estimate against a ten-year cost curve (fully-installed). As is shown in Figure 3 below, in the next ten years residential battery costs are expected to fall about 42% from $1,400/kWh to $800/kWh.

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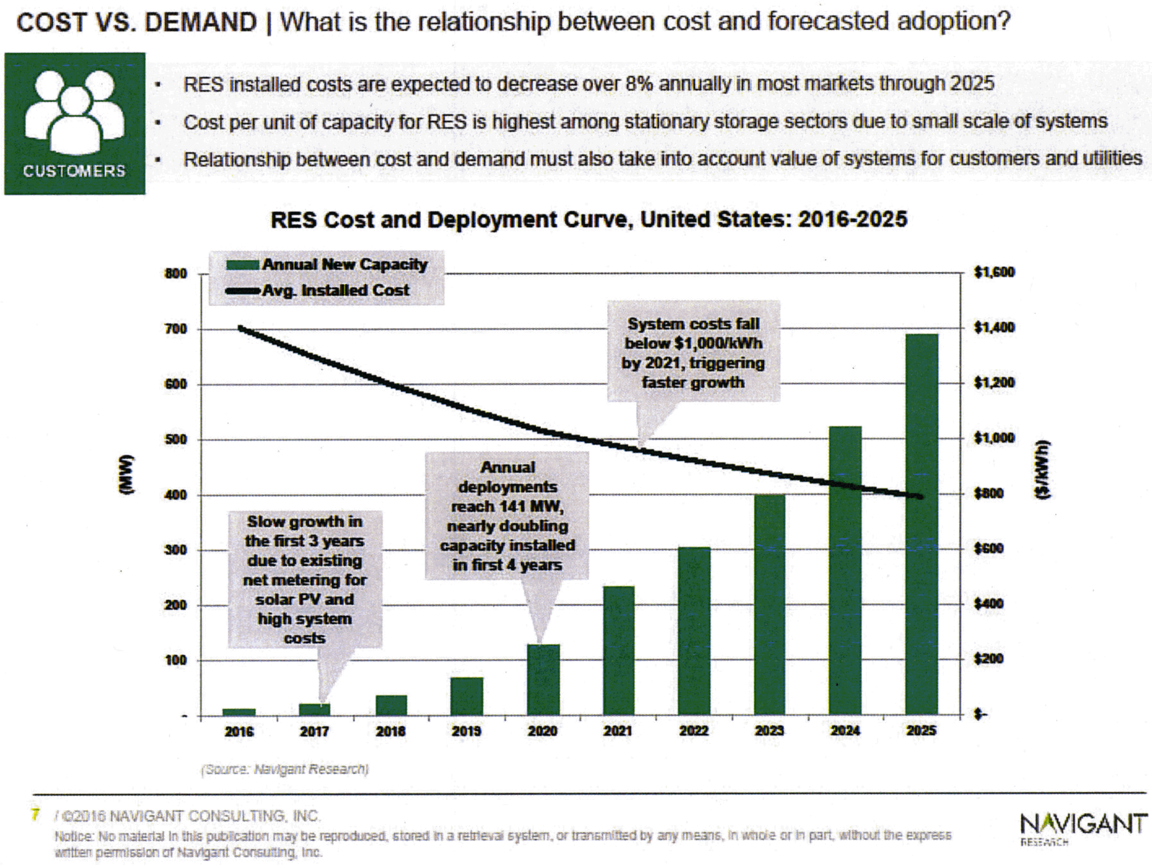
[13] Kamath, Haresh. (5/24/2016). EPRI Program for Energy Storage and Distribution Generation (Program 94), slide 8. Presentation from Quarterly Update Webcast, used with permission. For more information on Program 94, see: http://www.epri.com/Our-Portfolio/Pages/Portfolio.aspx?program=053125.

Figure 3. Navigant Research Cost Model[14]



While the current economics of residential battery storage appear daunting, it is important to consider the rate structures in question. Table 4 shows the expected simple payback of energy storage using the above Navigant cost figures, under existing and proposed APS tariffs. As seen in the table, storage is nearly twice as economical when APS's existing ECT-2 demand rate scenario is utilized versus the ET-2 time-of-use rate.[15] The economics would improve even more in APS's proposed R-3 rate.

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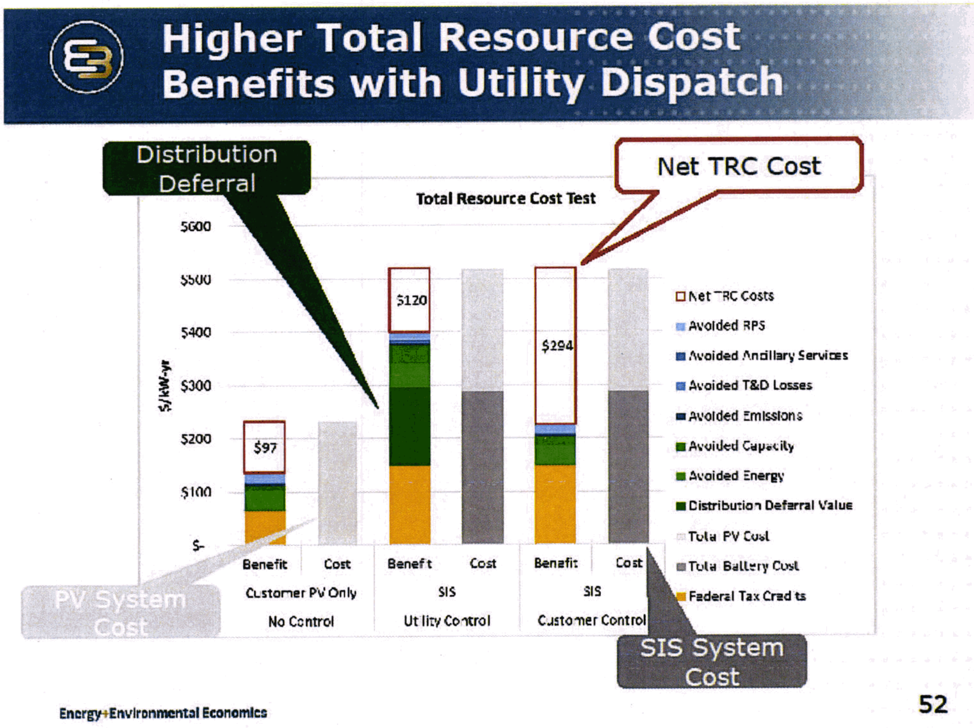
[14] Eller, A. and Feldman, B. (Q3 2016). Residential Energy Storage Systems, slide 7. Presentation from Navigant Research Utility Technology Disruption Report, used with permission. For more information on this report, see: https://www.navigantresearch.com/research/residential-energy-storage-systems.

[15] Based on APS analysis of 70 randomly selected homes, 2015 AMI data, and optimal charge and discharge of the battery.

Figure 4. Distribution Grid Impacts and Ratepayer Benefits—SMUD case study[18]



Note: SIS in this context refers to "Solar Integration System", a technology solution developed by SMUD's vendor partner, Sunverge.

E3's conclusions about today's residential energy storage market, based on SMUD's example are as follows:

- Total resource cost (TRC) test shows that cost-effectiveness is still a challenge for storage, but can be positive with reliability, local capacity, and distribution deferral values;
- Adding storage increases the NEM cost-shift to non-participating ratepayers (under customer dispatch);
- TRC benefits increase 2.5x with utility dispatch and high deferral value in this case study (eliminating NEM cost-shift);
- TOU and CPP rates do not necessarily align with distribution peak loads; and
- Incorporating dispatch for utility benefit is technically feasible and significantly increases ratepayer benefits relative to current storage incentive programs.

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[18] Cutter, Eric. August 11, 2016. *Distribution Grid Impacts and Ratepayer Benefits*. Energy+Environmental Economics. Demonstrated Utility Partnerships for PV Integrated Storage, CSI RD&D Project Final Webinar (slides 52 and 57). Retrieved September 20, 2016 from Go Solar California website: http://www.calsolarresearch.ca.gov/funded-projects/108-pv-integrated-storage-demonstrating-mutually-beneficial-utility-customer-business-partnerships.

III. APS Energy Storage Initiatives

Energy storage is anticipated to play a role in APS's future resource fleet, providing that costs come down as expected. The deployment of residential energy storage at scale is hindered by current utility rate structures, however, which do not provide adequate price signals for customers to adopt these technologies. Furthermore, adding residential solar systems with storage that are not dispatched for grid support—meaning, the batteries are deployed *only* to optimize bill savings—can create a larger NEM cost shift. Until utility rate structures incent customers for reducing peak demand (via demand rates), the distributed energy storage market will face unnecessary obstacles embedded in rate design throughout most of the U.S.

APS has an optional, demand-based rate in its current residential service plan portfolio, and the Company is requesting in its rate review a nearly universal three-part-rate pricing structure. This rate modernization effort sets the stage for an enabling grid that fosters the smooth integration of distributed energy resources like energy storage.

To gain more experience with both battery and thermal technologies, APS has launched a number of initiatives that have a storage component (*see* Table 5 below). Two specific programs in the implementation phase at APS are especially noteworthy. The first is the APS Solar Partner program, which will evaluate the ability of energy storage located on high-penetration feeders to manage solar intermittency and feeder voltage issues versus other technologies that can produce similar benefits, such as integrated volt/VAR control (IVVC) and advanced inverters. The second is the Solar Innovation Study-75 (SIS 75), which seeks to evaluate the cost-effectiveness of energy storage to—when coupled with solar—reduce customer demand compared with other technologies that accomplish similar benefits, such as residential load controllers and heating, ventilation, and air conditioning (HVAC) pre-cooling.

> The guiding principle for APS program development is to create a customer-friendly program suite that aligns market-ready technologies, grid support, price signal interaction, and a maximal return on investment to all utility customers via the control of the battery resources.

Table 5: APS Energy Storage Initiatives

Initiative	Description	MW	MWh	Status
Carroll Springs Microgrid	Small microgrid supporting isolated community with generators, photovoltaic (PV) panels, and battery storage	<1	<1	In Service 1995
Solana Generating Station	Parabolic trough solar generating station with molten salt storage using solar concentrators; plant output wholly contracted for by APS under a PPA	250	1,000	In Service 2013
Solar Partner Project (SPP)	Project: Determine if Battery Energy Storage Systems (BESS) can improve power quality on high penetration PV feeders and substations and compare its performance to IVVC and residential advanced inverters	4	4	Design and Procurement; expected in-service date Q4 2016
Solar Innovation Study-75 (SIS 75)	Field Test: Integration of advanced behind-the-meter technologies (including both thermal and battery storage) with demand rates	<1	<1	Design and Procurement; expected in-service date Q1 2017
Punkin Center	Project: Install utility-scale battery energy storage system to augment existing conductor capacity in lieu of replacing conductor	2	8	Design and Procurement; expected in-service date Q2 2018

In addition to the above initiatives, APS has included battery storage as a qualifying resource in the recently issued 2016 All-Source RFP and is in the process of evaluating it compared with conventional generation alternatives at the bulk-system level. Battery storage is anticipated to play a role in APS's future resource fleet as costs come down. As to cost for grid-scale storage, APS expects that by the early- to mid-2020's, bulk-system battery storage (10 MW+) will begin to be cost-effective relative to conventional technologies.

Further, in Decision No. 75679 (August 8, 2016), the Arizona Corporation Commission (Commission) required APS to develop a residential demand response or load management program that facilitates residential energy storage technology, with the goal of aiding residential customers to reduce electricity demand during periods of the Company's system peak. Program participants will be placed on time-differentiated rate plans that will include price signals encouraging customers to place emphasis on reducing peak demand. The guiding principle for APS program development is to create a customer-friendly program suite that aligns market-ready technologies, grid support, price signal interaction, and a maximal return on investment to all utility customers via the control of the battery resources. APS is currently engaged in a technology assessment process with a host of qualified vendors to determine the best technology fit for the purpose of the program given Arizona's climate, housing stock, technology options and resource needs. The Company is also performing due diligence on energy storage vendors and other pilot programs across the country that may provide insight into a well-structured program for APS customers. The program will be presented to the Commission in December of 2016.

Finally, the Company is also evaluating the feasibility of several other energy storage projects, including deferral of conductor upgrades for other high-demand feeders (*see* Punkin Center project above) and water heater controllers to manage energy demand. For example, in the Company's 2017 DSM Implementation Plan, APS proposes a Load Management Pilot which would deploy load control and load shifting technologies to enable customers to manage and shift load to lower demand periods by employing such technologies HVAC, thermal storage and grid-interconnected water heating.

IV. Preliminary Results from APS Programs and Pilots

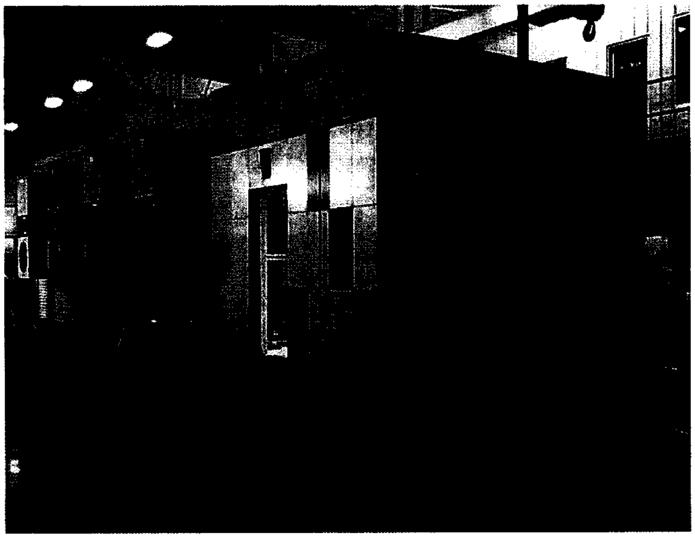
A. APS Solar Partner Program

In Decision No. 74878 (December 23, 2014), the Commission acknowledged that there is a place in the industry landscape for utility involvement in distributed solar ownership in order to ensure grid reliability and resiliency. The Commission noted that a targeted utility ownership project would permit APS to study grid benefits that might be realized through strategically locating rooftop solar systems within the distribution grid, and assess the benefit of a southwest or west panel orientation to maximize production during system peak periods.

With these goals in mind, the Company launched APS Solar Partner, an APS-owned rooftop solar research and development program aimed at learning how to efficiently enable the integration of rooftop solar and battery storage with the grid.

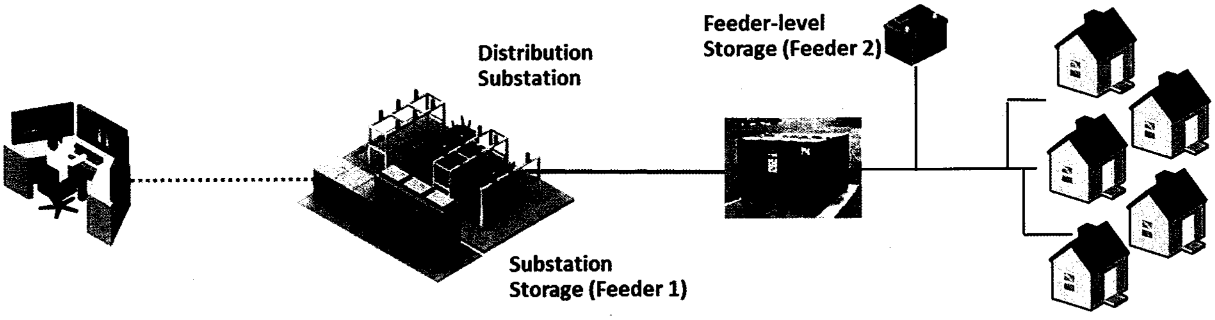
Specifically, the energy storage component of this study includes two storage systems sized at 2 MW/2 MWh (1 hour duration at full output), using lithium-ion batteries located on two different high solar penetration feeders. The main use cases in this research project are to test voltage regulation, power factor improvement, peak-shaving, and interoperability of utility-scale battery systems. Installation of these batteries is planned to be complete in 2016.

EPRI is APS's research partner for this program, and is assisting APS in the development of a fully-integrated research and test plan. Currently, the Company is performing baseline analysis on the existing power quality for the two selected feeders. This study will document the causes of any system instability or voltage issues and identify the ways that the battery systems are expected to alleviate system issues in comparison to other technologies like IVVS and solar advanced inverters.



A grid-scale battery unit, complete with cooling fans and a sophisticated management system.

Figure 5. APS Solar Partner Battery Energy Storage Systems on High-penetration Solar Feeders



B. Update on Other Grid-scale Battery Energy Storage System (BESS) Development, 2016-2017

In addition to the grid-scale batteries under development for APS Solar Partner Program, APS is evaluating its transmission and distribution systems to look for other siting opportunities where large battery energy storage systems might allow us to defer line upgrades to improve the economics of energy storage deployment.

The first of these opportunities is currently under development. APS expects to develop specifications for new requests for a proposal that should be announced in 2017 for a utility-scale storage system in the 5 to 10 MWh range. This system is anticipated to be placed in service in 2018.

C. Early Learnings from APS Solar Innovation Study - 75

The research period for the APS Solar Innovation Study - 75 is still under way. Despite the early nature of the research, several key lessons have already surfaced that will help APS better collaborate with the industry and develop consistent and reliable energy storage technologies for APS customers.

Key learnings to date include:

- Control strategies and rate design must be aligned;
- Residential demand management technologies can augment and even improve battery discharge strategies;
- The industry needs to continue to focus on standard and streamlined UL-type certifications; and
- The interrelationship between battery sizing and solar array configurations is critical.

i. Aligning Charge Control Strategies and Rate Design

Residential battery systems tend to offer three ways of charging:

- Charging from the solar array (DC charging)
- Charging from the grid (AC charging)
- Hybrid (both AC and DC charging)

In the SIS 75 study, APS selected a hybrid charging battery system with the intention of offering the most flexible and reliable solution for customers. The flexibility to charge off the grid or the solar array presents key challenges in designing the battery charge controls.

A well-designed charging logic that optimizes customer savings and grid impacts will meet the following requirements:

1. The battery is fully charged when heading into the on-peak period; and
2. The battery charges off the solar production first to keep that energy production on-site and assist in duck curve management.

Residential battery solutions are being sold in a range of kWh capacities, typically 5 to 20 kWh. The systems being utilized in the SIS 75 study are 20 kWh. However, it is important to note that unlike a cellphone battery, there are specific "depth of discharge" restrictions that limit the available capacity that can be discharged at any given time. For the SIS 75 study, the 20 kWh batteries have a depth of discharge of 80%, which creates a usable capacity of 16 kWh that can be dispatched in a given period.

The goal in dispatching the batteries is to use as much of the available capacity on-peak to reliably shed demand without exhausting the total available capacity before the end of the peak period. Differences in weather and usage trends experienced from day-to-day mean that the amount being discharged by the battery on a daily basis will vary.

To consistently strike the balance between the two charging requirements defined above, battery vendors must consider:

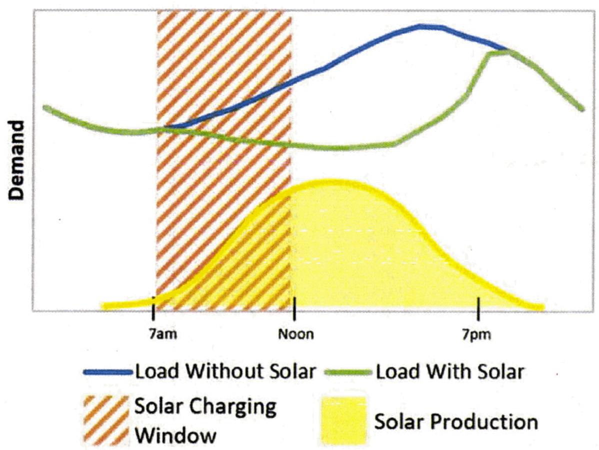
- Current amount of capacity needing to be refilled;
- Solar availability based on both average seasonal production trends and weather;
- Customer usage patterns; and
- Timing of on-peak periods based on current rate structures.

While battery systems are getting more sophisticated in optimizing charge controls, most systems in the market today rely on less sophisticated rule sets and hard programmed charging schedules. With this current state of technology, it is important to be conservative with charging strategy to ensure that the customer has a fully charged battery before the peak period, even if that means charging when there is no solar production.

ii. Learning: On-peak Definition and Solar Charging

APS's Combined Advantage demand rate currently defines the peak period as noon to 7pm weekdays, which offers a narrow window for customers to charge batteries off of solar production. There are only approximately five hours between sunrise and noon, when the on-peak window begins. Residential solar systems are fixed onto rooftops, typically, and by definition they cannot track the sun. During the early morning, the sun's rays are not able to directly strike what are typically south-facing solar panels. Therefore, the solar array can capture very little sunlight early in the day to charge batteries (Figure 6).

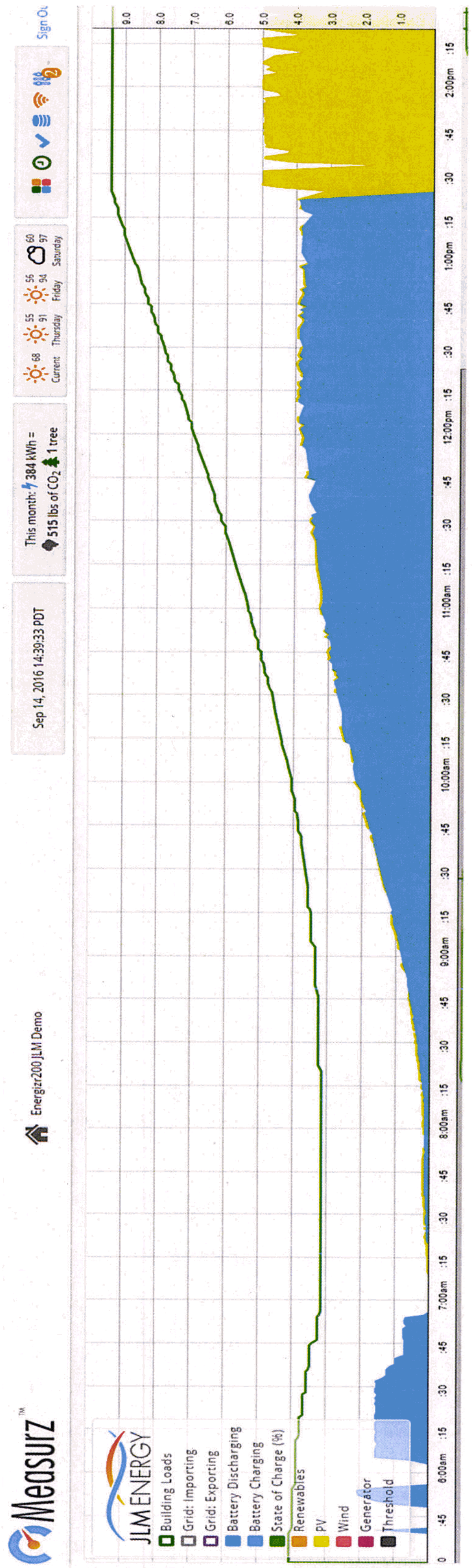
Figure 6: Current ECT-2 Summer Solar Charging Window



For larger capacity systems, the smaller solar charging window makes it difficult to fully charge off the solar array. In early testing for SIS 75, battery systems at 80% discharge take until approximately 2pm to reach full charge, if only charged off the solar array (Figure 7).

Figure 7: Solar Charging Rate at the APS Test Site

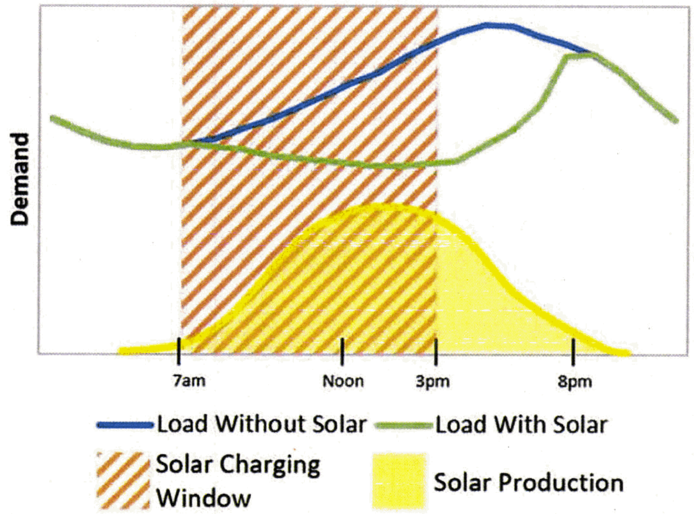
Source: JLM Measurz from the APS testing site



To extend solar production even later into the evening to help reduce on-peak demand, many systems are being oriented to the southwest or west. While this helps to align solar production with APS's system peak—a very high value in APS's grid-scale plants and in APS Solar Partner—this will further reduce a solar array's early morning production.

By switching to a rate design with a later peak period, such as 3pm to 8pm, the effective solar charging window will increase to allow the battery to more effectively charge during peak solar production (Figure 8).

Figure 8: Summer Solar Charging Window with a 3 – 8 pm peak period



These impacts are not limited to summer and actually are further exacerbated by shorter days in the winter, fall and spring.

To ensure that the charge control logic for residential distributive storage delivers maximum benefit to the customer and serves the future needs of the grid, it is critical that both APS rate design and the coding from battery control developers are working in collaboration to drive optimal benefits.

iii. How Demand Management Can Improve Battery Discharge Strategies

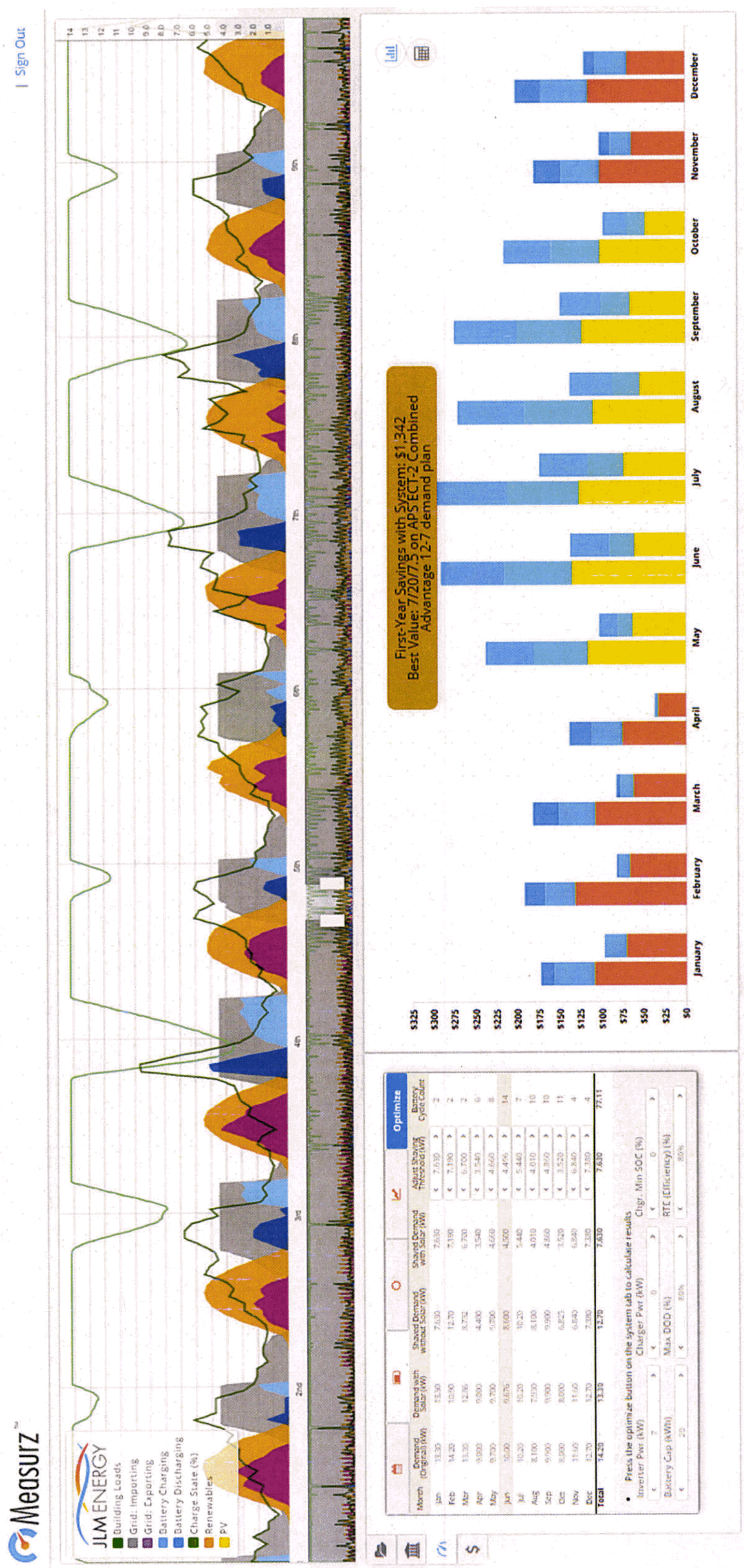
Often lost in the conversation about new technology is that the latest gadgets aren't really needed to manage demand when you have clear price signals.

For customers who do want to adopt behind-the-meter technologies, residential energy storage can be a reliable demand-shedding resource that minimally impacts customer lifestyle. Many residential energy storage solutions on the market today use a dispatch strategy in which a calculated demand threshold is set based on the customer's historical usage and calibrated for the size of the solar and battery systems installed.

To maximize the customer's benefit, the whole home demand threshold for the battery system must be set to curtail as much load as possible, while ensuring that the battery capacity is not fully exhausted before the end of the peak period. To achieve this at the highest level of precision, battery systems need to leverage advanced modeling tools to establish baseline curtailment targets and deploy systems that continually learn and adjust curtailment settings based on changing usage patterns. Furthermore, backup measures or notifications should be in place to manage atypical usage conditions.

Leading vendors have built different levels of technology to assist in initial system design and forecast baseline settings (*see* Figure 9, next page). As an example, JLM's Measurz EST system featured below takes historical energy usage data and completes an energy simulation model to assist in the sizing of solar and battery storage technologies. Based on final system sizing, the tool will optimize demand settings for the installer and produce savings estimates for customers.

Figure 9: Measurz™ EST— Sample System Sizing and Optimization



Beyond the initial system design and setup, predictive algorithms and machine learning tools for managing demand thresholds are still in the very early stages of development. As such, battery system designers need to be conservative in setting the demand threshold for battery systems to ensure that the battery's capacity is not exhausted too early. Early test results from the SIS 75 study have already identified how cost-efficient load management technologies can potentially assist battery systems in delivering reliable demand reduction and drive more savings potential from the technology.

iv. Learning: Pre-cooling and Load Control Impacts on Storage Performance

Applying other load management technologies, like connected thermostats, may play a larger role in assisting residential battery storage systems by maximizing the system's demand management potential. The Company's main observation to date is that the much-touted predictive intelligence of many a battery system on the market is still evolving and is not ready to be widely deployed. As a by-product, the demand curtailment settings for battery systems will be set more conservatively to account for variability in daily loads.

Over the course of the current on-peak period, it is expected that the battery will dispatch the majority of its capacity in the last half of the peak. The main reason for this is that under normal conditions, there is still solar production in the early hours of the peak helping to off-set demand. Figure 4 shows this impact.

Pre-cooling Scheduling and Demand

In the SIS 75 study, APS is implementing secure, Wi-Fi-connected thermostats programmed to pre-cool homes by 3-4 degrees from the customer's set-point before the peak period starts. Once the peak starts the set-point is raised by 3-4 degrees above the customer's set-point, creating a total of 6-8 degrees of temperature drift. The temperature drift is effectively using the home's own thermal characteristics as a form of storage.

A typical existing home in the Phoenix area should experience about 2-3 degrees of temperature increase per hour on an average summer day due to heat gain. This of course will depend largely on the efficiency of the home's thermal envelope. As a part of the study, APS will evaluate pre-cooling on both the "typical existing home" built between 1970 and 2000, as well as high performance ENERGY STAR homes to measure the impact of the home efficiency on this strategy.

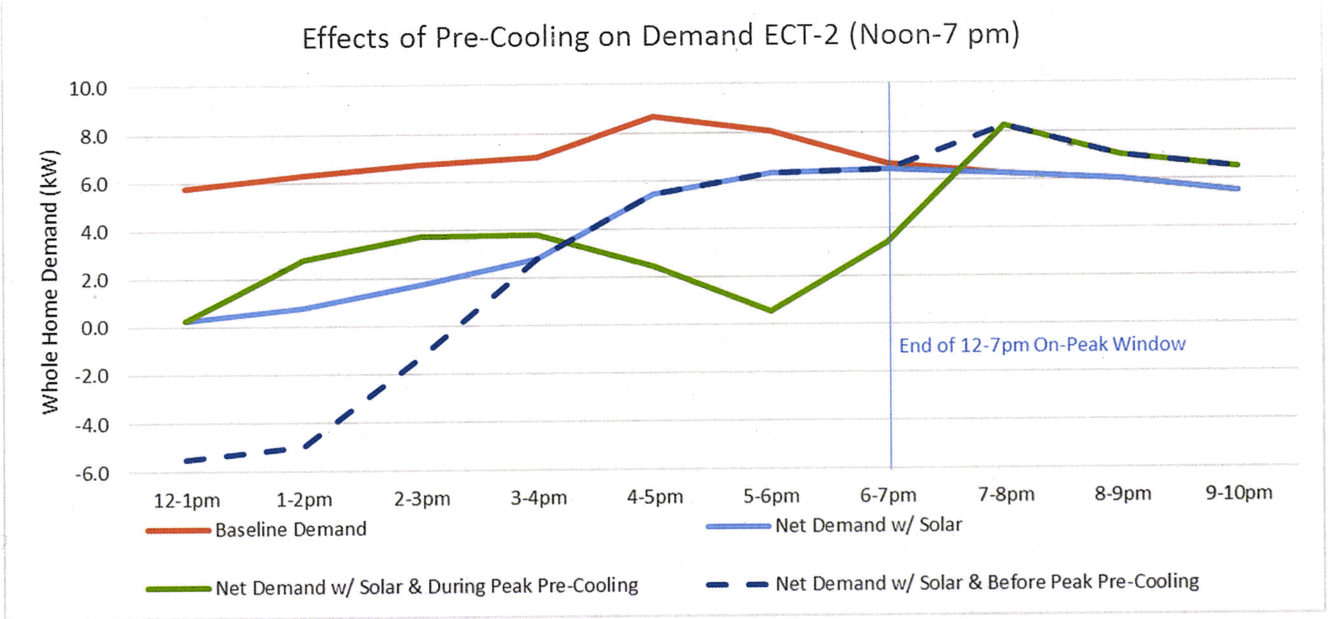
Pre-cooling is a strategy that originated from demand response type programs. In these programs the conventional wisdom is to pre-cool prior to the peak event and then drift throughout the peak event. As a part of the SIS 75 study, the same methodology is being tested. One central hypothesis is that pre-cooling can prove effective in more efficient homes, but may struggle in typical existing homes due to less efficient building envelopes, limitations in HVAC cooling capacity, and aging HVAC equipment.

However, early learnings suggest that integrating pre-cooling with solar for demand management may challenge conventional pre-cooling wisdom. An interesting effect occurs when the solar production is similar to the average hourly demand profile of the HVAC unit. When the control strategy is to begin drifting the HVAC unit at the beginning of the peak period, especially if the peak is Noon to 7pm, there will be enough solar production still coming from the array that the home can become a net exporter of energy during the first few hours of the peak. Furthermore, the heat gain in typical existing homes can cause the temperature to drift the full 6-8 degrees before the end of the peak, effectively resulting in no demand savings for the customer.

The potential solution to this challenge is to delay the pre-cooling and drift schedule to allow the HVAC unit to pre-cool during the peak period, while solar production is still high. As solar production begins to drop off, the pre-cooling will switch to drifting for the remainder of the peak. Even better, early modeling suggests that this may be able to effectively reduce demand in a wide range of homes while relying on a smaller drift of temperature overall and thereby creating a more positive customer experience.

To illustrate this point, APS has developed an example based on a typical existing home in the SIS 75 study on an average summer day using the current ECT-2 noon to 7 pm peak (Figure 10). The solar array will naturally offset demand in the early on-peak hours, but diminish quickly toward the end of the peak period. Pre-cooling before the peak period and drifting once the peak starts can further increase the demand off-set, potentially creating a net-exporting condition during the first few hours. Alternatively, if pre-cooling continues during the first few hours of the peak period and the drift does not start until 4 to 5pm, then the load shape is more flat overall and delivers a measurable reduction in peak demand.

Figure 10: Effects of Solar and Pre-cooling Strategies on On-peak Demand



Based on a typical existing home in the APS service territory. Homes are 1500-3000 sq.ft, built between 1970-2000, and have no significant energy efficiency upgrades. The solar output is modeled on a 6 kW to 7.6 kW solar array with an average south/western orientation. The battery system has 20 kWh of storage with an 80% depth of discharge.

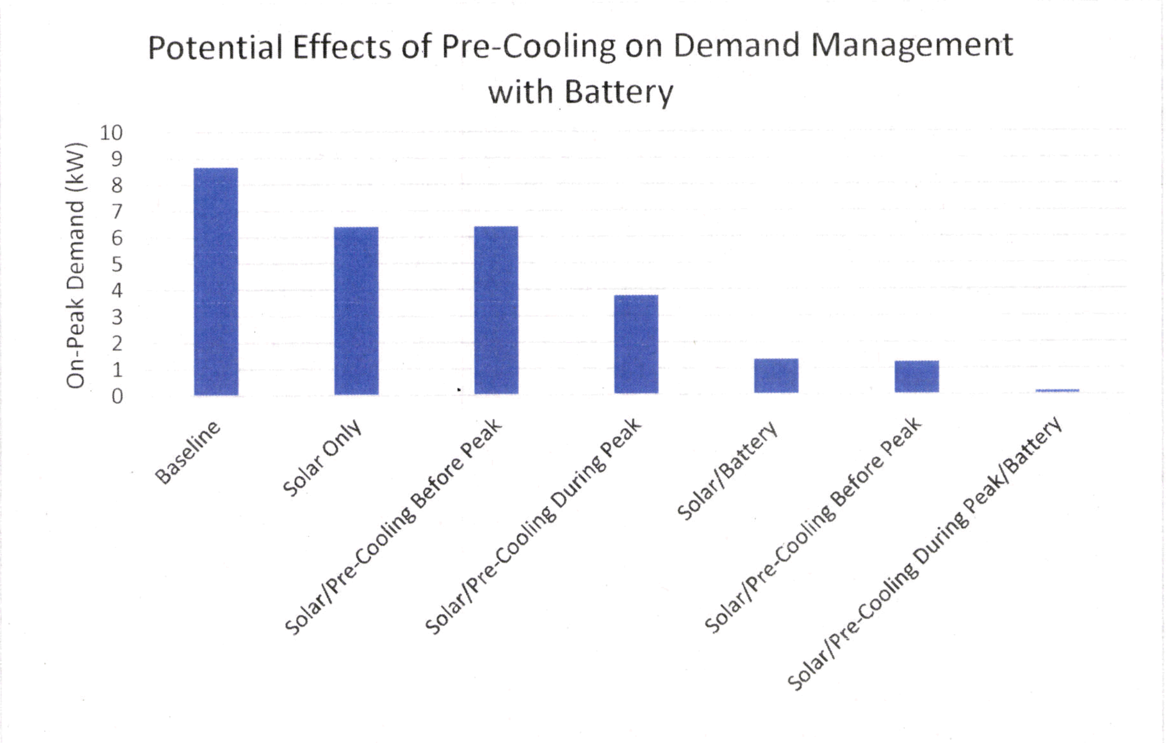
APS will continue to test this revised pre-cooling protocol, along with other pre-cool-and-drift schedules, throughout the remainder of the study period in SIS 75.

v. Pre-cooling Strategies and Battery Sizing

When optimized pre-cooling is coupled with battery storage there is the potential for pre-cooling to both increase the depth of demand impact and potentially decrease the battery sizing needed to make sustained demand reductions.

Different technology combinations and pre-cooling schedules can have a measurable impact on total demand reduction achieved. Based on the same base load shape and system sizing in Figure 10, Figure 11 shows a breakdown of net on-peak demand for a fully optimized system.

Figure 11: Effect of Pre-cooling on Demand Management Impacts

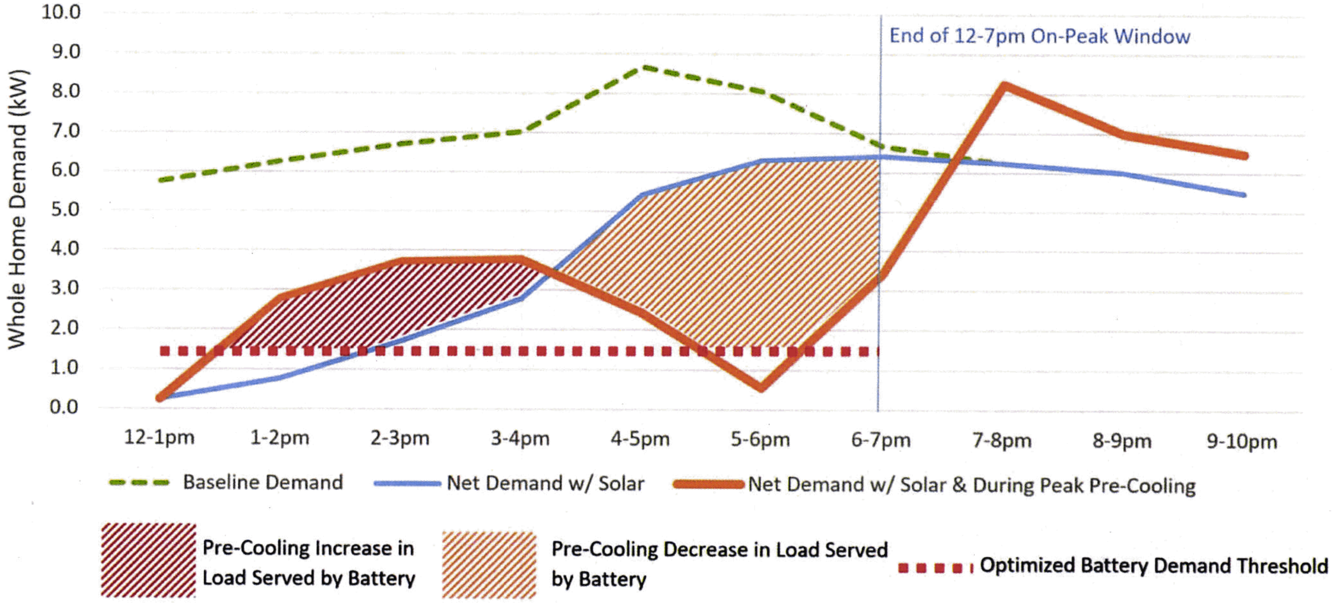


For this example, systems are optimized to dispatch the full 80% depth of discharge of a 20 kWh battery system over the course of a noon-7pm peak period. Model is based on a typical existing home in the APS service territory. Homes are 1500-3000 sq. ft., built between 1970-2000, and have no significant energy efficiency upgrades. The solar output is modeled on a 6 kW to 7.6 kW solar array with an average south/western orientation.

In the example above, pre-cooling improved the demand reduction potential of the battery system by 1.2 kW.

The interaction between pre-cooling and battery storage extends beyond demand reduction to potentially augment the storage capacity of the battery. To illustrate this point, the shaded areas in Figure 12 represent the impact of pre-cooling on battery dispatch. The red-shaded area represents an increase need for battery dispatch due to on-peak pre-cooling. However, as the drift period begins, the orange-shaded area represents the reduction in load no longer being served by the battery.

Figure 12: Impact of Pre-cooling on Battery Storage Capacity (ECT-2)



Using the example of a "typical home" in the SIS 75 program, pre-cooling will increase dispatch rate of battery storage during the first few hours of the peak, but significantly reduce the dispatch rate from the critical 4 to 7 pm timeframe. The net effect in this example: approximately 7.5 kWh of additional storage is usable.

In SIS 75, APS will test optimal schedules for pre-cooling to identify strategies that help customers manage demand with or without a battery.

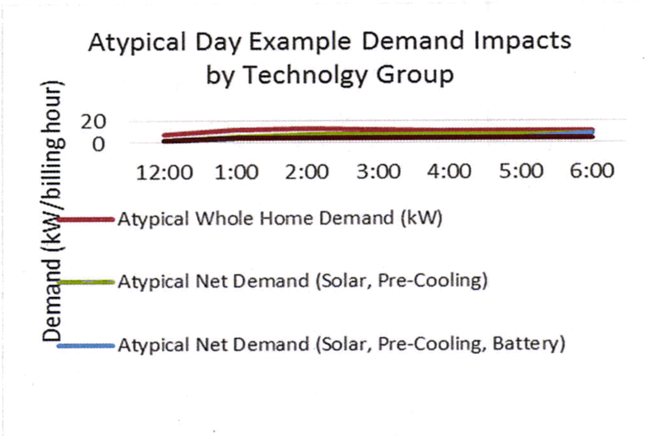
Load Control Devices

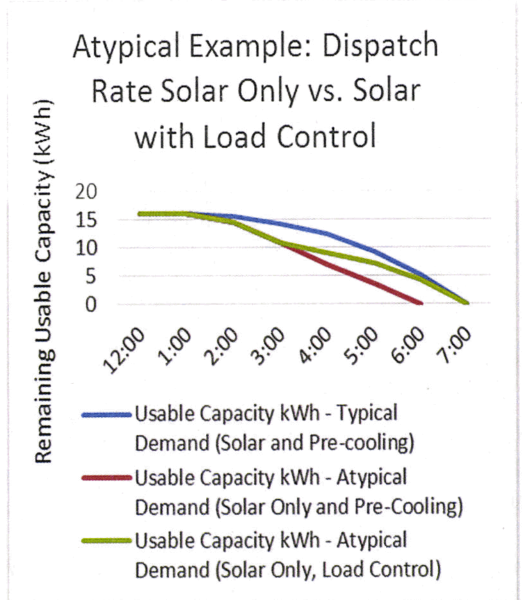
Load control devices can also be used to improve battery performance and reliability. Since load control devices can only curtail load, they are often thought of as the technology of last resort, targeting high demand appliances, such as electric water heaters and dryers. Early results in SIS 75 suggest that load control can also help battery systems manage atypical usage days.

Figure 13 shows the same technology ecosystem as Figures 10-12 above, but simulates what would happen if the home experienced atypical usage driven by customer behavioral or weather. In this example, the first few hours of the peak period see an increase in demand. If no other battery dispatch controls are modified the battery system will seek to keep the home at the demand threshold of 4 kW.

As seen in the dispatch curve below, the battery can dispatch too quickly. If the customer runs out of usable storage at least an hour before the end of the peak, the customer could experience an increase in demand. Battery providers are building multiple approaches to managing this type of scenario. One of those options is to utilize the load control systems to slow the rapid dispatch and help realign the dispatch schedule with the peak period. In the example below, the battery control system recognized that the rate of dispatch was too great. By 3pm, the system will activate the load control device to slow the rate of dispatch.

Figure 13: Atypical Load Shape Impacts across Technology Mix—Impact on Battery Discharge Rate





Battery vendors are assessing a wide range of options to improve the predictive and learning capabilities of energy storage systems. For now, simple solutions like pre-cooling and load control can enhance the performance of residential battery systems and provide the customers with a more reliable storage solution.

D. An Evolving Industry Needs Updated Certifications

As energy storage technologies evolve and applications of these technologies become more grid-interactive, the industry has recognized a need to advance UL certifications to address a changing market. Furthermore, it critical to ensure that safety is maintained while components are integrated into a single technology ecosystem.

Over the last several years, UL has been working with energy storage stakeholders to create a new certification for energy storage systems: UL 9540. According to the UL 9540 outline:

> 1.1 These requirements cover energy storage systems that are intended to store energy from power or other sources and provide electrical or other types of energy to loads or power conversion equipment. The energy storage systems may include equipment for charging, discharging, control, protection, communication, controlling the system environment, fuel or other fluid movement and containment, etc. The system may contain other ancillary equipment related to the functioning of the energy storage system.

> 1.2 These systems may be used in systems that are standalone to provide energy for local loads, in parallel with an electric power system, electric utility grid or applications that perform multiple operational modes.

UL 9540 will become the primary UL certification for energy storage systems. The standard has recently completed its final stage of review and is expected to be published in November 2016. While this represents an important step, UL 9540 is not the only certification that systems will need moving forward.

UL 1741, or the *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources*, has long been the primary certification for the inverters and controls used in distributed solar applications. As inverter technology has become more grid-interactive and utilities are beginning to control these systems for grid support activities, as with APS Solar Partner, addition testing criteria is being developed for these functions. An addendum to UL 1741 is almost complete and will be released soon to better address the grid-interactive controls.

It is important to note that while it is critical to have UL 1741 for the inverter, this certification does not cover other integrated devices. Energy storage solutions in particular have a wide range of components and controls: if the battery system is separate from the inverter, the system will need to be evaluated for its own UL certifications.

i. Learning: Transitional UL Certification Approach

As stated above, UL 9540 is still a standard in development. As such, current energy storage efforts must lean on existing UL certifications for systems being installed today. For systems being installed as a part of SIS 75, the following UL Certifications are being used today:

- UL 1741: Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
- UL 1642: Standard for Lithium Batteries
- UL 1973: Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications

For residential energy storage being installed in Solar Innovation Study – 75, the Company is utilizing systems that have received all three of the UL certifications above, though batteries will not be added to the residential systems until all technology is tested for compliance to UL 9540, the comprehensive system standard for stationary battery storage systems. UL9450 is planned to be published by UL before the end of November 2016.

A typical battery system can include a wide range of components, all of which require separate certifications. At the highest level this includes: battery cells, battery management system, inverter, chargers, charge controllers, wiring, connections, communications systems, and external housing. Most of these components are housed inside the battery cabinet, with the exception of the inverter, which for Solar Innovation Study-75 is external.

In addition to peak-shaving use cases, energy storage systems will carry the following certification by part:

- Lithium Iron Phosphate Battery Cells: UL 1642
- Full Battery Back-up System (emergency or off-grid applications): UL 1973
- Inverter: 1741

Any other individual part is also required to carry relevant UL or safety certification and must be installed in compliance with local building codes.

Once UL 9540 standard is released, the rest of the residential energy storage market will transition to that standard. This transition will take time, but many industry-leading systems are already gearing up for the certification process to start.

E. Battery Sizing and Solar Array Configurations

One objective of the SIS 75 study is to analyze the cost/benefit impact of battery system sizing on demand management performance. Manufacturers and installers have developed different methods to assist in system design, including some modeling tools that can analyze customers' prior energy data and model the impact of certain system sizes. Variables for assessing sizing include:

- Load profile of the home
- Size of the solar being installed
- Usable capacity of the battery solution
- Impact of other DER solutions being installed
- Rate design
- Location
- Lifestyle

Of course systems designed solely for demand management are more focused on the depth of impact desired based on the customer's load profile and the duration of peak. If the system is also being installed as a backup system, this can impact the sizing decisions being made.

i. Lessons from the Field: Sizing Limits for Solar + Battery Systems

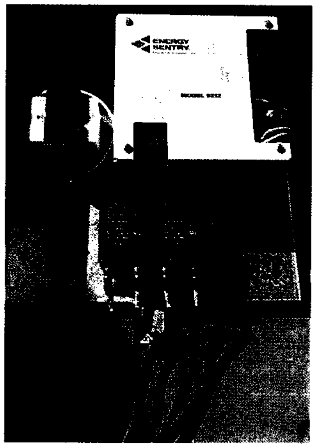
One of the key lessons from SIS 75 is that many of the major battery solutions on the market that DC charge (*i.e.*, off the solar array) require specific array sizing and installation characteristics. For example, the 20 kWh systems being installed under SIS 75 require a 7.6 kW solar array wired in a specific way in order for the battery to charge properly. The ratio of solar sizing and battery sizing differs from manufacturer to manufacturer.

The impact of this is that for DC charged systems, there is not a lot of flexibility in the energy storage sizing options. This means that some houses may not be able to install larger DC charged storage systems depending on the roof configuration. Conversely some battery solutions limit the amount of solar connected to the battery system. For those homes, additional solar can be installed, but may require a separate inverter.

These inherent limitations must be taken into consideration when optimizing customer-controlled solutions. If a customer is not able to achieve a larger storage system due to limitation in roof orientation or design, other DER technologies can augment the storage solution they can achieve. Further findings will be shared once the study is complete.

ii. Lessons from the Field: Solar Innovation Study - 125

A related initiative, Solar Innovation Study - 125 (SIS 125), is also a field study examining the integration of behind-the-meter DERs—typically rooftop solar and demand management devices (demand managers). APS keeps informed of solutions developed by the local Arizona installation market[19] and on the resulting customer experience as residential customers operate DERs with demand rates. SIS 125 differs from SIS 75 in that customers design and purchase technology ecosystems with help from APS in the form of a cash incentive. In a market heavily saturated with no-money-down leasing options, the uptake in this 2016 program has been slow. No systems have come into the program with energy storage to date—which is to be expected due to the high cost of residential battery systems. The recruitment phase for SIS 125 is winding down and, so far, 21 installations are complete or under way.



Brayden Automation's Energy Sentry, a whole home demand manager.

After all SIS 125 systems are installed, APS will perform annual billing reviews and a survey for each participant to gauge customer experience and satisfaction with their advanced energy system.

V. Evolving Best Practices

A. APS Interconnection Requirements: Ready for Energy Storage

Grid-connected residential battery systems in the APS service territory have typically offered only a single-use case: backup power applications. More use cases for

[19] Limited to participants in APS's 2016 Qualified Solar Sales & Installation program. See aps.com/findsolar.

residential battery systems are emerging, including demand management, firming of intermittent resources like solar and wind power, and of course voltage regulation and other grid support services. The rapidly changing battery market is trending toward new battery designs as well. APS continually reviews and updates its interconnection requirements and sample design sets, and they are publicly available at aps.com/dg.

What has not changed in this environment of innovation is APS's commitment to safety; all customer-sited distributed generation systems, including batteries not paired with solar, must be reviewed for compliance with interconnection requirements and must have a permit clearance from the authority having jurisdiction. This is true for APS pilot program installations and for all other customer interconnection requests. As a reminder, all customer-initiated interconnection requests must be received prior to installation—this safety consideration is stipulated both in APS interconnection requirements and in Arizona statutes as A.R.S. §44-1764, commonly known as S.B. 1417.

B. Proposed Interconnection Rules

In its recommendations to the Commission on proposed interconnection rules, APS has noted that any such rules should contain provisions requiring the use of advanced inverters for all interconnections. This is especially critical for battery interconnections—with or without solar.

As the Company has indicated to the Commission, including provisions in interconnection rules to require advanced inverters greatly facilitates the smooth integration of distributed energy resources, and will help mitigate impacts that distributed generation systems can have on individual feeders. Widespread deployment of distributed energy resources without advanced inverters increases the likelihood of voltage excursions on the grid. This impacts system reliability for all customers, including non-distributed energy resource customers. Requiring advanced inverters enables customers to both interconnect a rooftop system and minimize any negative impact to system reliability.

In fact, advanced inverter capabilities are *necessary* for future interconnected rooftop solar-interfaced distributed generation. This position is broadly shared in the utility

Lessons from the Field:
Demand-shaving battery systems have new wiring configurations.

- **Hybrid charging with a single inverter**. The battery system being tested for Solar Innovation Study - 75 utilizes a single third-party inverter connected to the battery system and solar array. In addition, an AC grid-side charger is connected between the battery system and the main electric panel. This particular configuration requires APS to use an additional bi-directional meter to net out any grid-side charging of the battery systems and solar array and accurately report power flow on the system.

- **Systems may not need a critical loads subpanel**. Battery systems installed for load management rather than backup power can typically be installed without a critical loads subpanel. This configuration is a significant deviation from traditional battery back-up systems. The good news is that without a secondary panel in the customer's home, the cost for installation should be lower.

Review APS's interconnection guidance, technical standards, and sample drawing sets for various solar and battery configurations at aps.com/dg.

industry.[20] Advanced inverters should be viewed as an essential component of the modern grid.

Any interconnection rules must also contain provisions to address the interconnection and operation of energy storage systems.[21] Currently, the interconnection of an energy storage system at distribution voltages (21 kV and less) is processed through the Non-FERC interconnection process as specified in the APS Interconnection Requirements. All energy storage units connecting directly to the APS system for the purpose of providing ancillary services and/or capacity support are subject to the Non-FERC Interconnection Study process irrespective of alternative current output rating. All energy storage units connecting behind the customer's meter for the purposes of peak shaving or to back up customer load are also subject to the Non-FERC Interconnection Process.

Operation of widely deployed energy storage devices is an emerging challenge. Energy storage interconnections present unique challenges in the sense that these technologies operate as both a load and a generator. Operating requirements need to be developed, and control and mitigation strategies need to be clearly identified. There exists a risk that energy storage, if not coordinated with larger grid operation strategy, can have a negative impact on congestion and system peak. If properly coordinated, the storage capability may be used to modify load shapes and reduce peak demand.

Looking ahead, APS anticipates that qualifying distributed energy storage systems in concert with advanced inverters have the potential to provide grid support (reactive power, voltage stabilization, capacity planning support), if needed, to support reliability. APS will continue to offer insights and guidance into any emerging interconnection issues as the Company's energy storage initiatives progress.

VI. Training to Support DER Integration—the Qualified Solar Sales & Installation Program Course

As Arizona energy consumers become more interested in new distributed energy resources to pair up with solar, the Arizona solar installation market will need expanded vendor relationships and skill sets. In 2016, APS facilitated the development of a new, DER-focused training curriculum for Arizona-based installers. APS worked with Tierra Resource Consultants and Solar Energy International to significantly update SEI's solar and battery installation course to include modules on energy efficiency and home performance concepts, demand rates, and peak load management. Nine local installers participated in this training and are working to develop solutions to help customers manage peak usage.

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[20] Western Electric Industry Leaders (WEIL). August 7, 2013. Letter to Governors, Commissioners and Legislators. Retrieved September 28, 2016 from San Diego Gas and Electric website: https://www.sdge.com/sites/default/files/documents/1843346665/WEIL%20Smart%20Inverters%20Letter%20Final%20Aug%207%202013.pdf?nid=8436.

[21] APS has provided these comments to Commission Staff and other interested parties in the Commission's Distributed Generation Interconnection Rulemaking Docket, RE-00000A-07-0609.

VII. Conclusion

APS has a long history of research and development into emerging technologies that have the potential to provide increases in efficiency and reliability for customers. With recent dramatic increases in residential customer adoption of rooftop solar technology, technologies which may increase the resilience, reliability, and stability of a distribution grid with high customer renewable penetration are increasingly important to develop. These technologies include energy storage technologies.

Energy storage technologies can be deployed both behind the meter on the customer's site and, at a larger scale, on the utility's distribution grid. They have the potential to mitigate the inherent intermittency of renewable generation sources, reduce the use of grid-transmitted electricity during peak load hours, and allow for utilities to dispatch stored energy to meet demand when needed. Energy storage technologies can also be instrumental in grid hardening because of the potential to provide backup power and grid stabilization services.

However, not every type of energy storage technology is suitable for every type of application. Only rigorous and thorough testing will determine which of the available technologies will be the most appropriate and cost-effective for each potential location and function in each utility's service territory.

As described in this report, APS is testing the effectiveness of energy storage technologies—specifically battery storage technology—in initiatives like APS Solar Partner and Solar Innovation Study-75, and has plans to broaden that testing through additional deployment of energy storage as part of its 2016 and 2017 DSM Implementation plans. Although these programs are still in early phases of deployment, the Company is already gathering useful information which will inform the next phase of storage deployment.

Today, challenges remain to the widespread deployment of energy storage. Energy storage technologies are not yet cost competitive, especially when taking into account grid integration requirements. And, although grid-scale battery technology is currently more cost-effective than residential applications, a marketing spotlight is shining on residential battery technology deployment. APS is committed to continuing its research and testing into energy storage in order to reap the many benefits of this emerging technology, both to maintain and enhance customer reliability and to create a sustainable energy future.

Appendix. Glossary of Terms

Ampere or Amp - An Ampere or an Amp is a unit of measurement for an electrical current. One amp is the amount of current produced by an electromotive force of one volt acting through the resistance of one ohm. Named for the French physicist Andre Marie Ampere. The abbreviation for Amp is A but its mathematical symbol is "I". Small currents are measured in milli-Amps or thousandths of an Amp.

Amp Hour or Ampere-hour - A unit of measurement of a battery's electrical storage capacity. Current multiplied by time in hours equals ampere-hours. One amp hour is equal to a current of one ampere flowing for one hour. Also, 1 amp hour is equal to 1,000 mAh

Ampere-hour Capacity - The number of ampere-hours which can be delivered by a battery on a single discharge.

Actual Capacity or Usable Capacity - The total battery capacity, usually expressed in ampere-hours or kWh, available to perform work. The actual capacity of a particular battery is determined by a number of factors, including the cut-off voltage, discharge rate, temperature, method of charge and the age and life history of the battery.

Battery Capacity - The electric output of a cell or battery on a service test delivered before the cell reaches a specified final electrical condition and may be expressed in ampere-hours, watt- hours, or similar units. The capacity in watt-hours is equal to the capacity in ampere-hours multiplied by the battery voltage.

Battery Charge Rate - The current expressed in amperes (A) or milli amps (mA) at which a battery is charged.

Battery Charger - A device capable of supplying electrical energy to a battery. This typically comes in the form of either DC or AC charging. DC charging charges directly from the solar array. AC charging is connected to the home and charges using grid power.

Battery Pack - An integrated electrochemical device used to store energy. The term is usually applied to a group of two or more cells connected together electrically and may include a battery management system to control the charging and discharging of the cells.

C - Used to signify a charge or discharge rate equal to the capacity of a battery divided by 1 hour. Thus C for a 1600 mAh battery would be 1.6 A, C/5 for the same battery would be 320 mA and C/10 would be 160 mA. Because C is dependent on the capacity of a battery the C rate for batteries of different capacities must also be different.

Capacitor – a passive electronic component that stores energy in the form of an electrostatic field, consisting of two conducting plates separated by an insulating material. The ability to store energy is directly proportional to the surface areas of the plates.

Capacity - The capacity of a battery is a measure of the amount of energy that it can deliver in a single discharge. Battery capacity is normally listed as amp-hours (or milli amp-hours) or as watt-hours.

Cell - An electrochemical device, composed of positive and negative plates and electrolyte, which is capable of storing electrical energy. It is the basic "building block" of a battery.

Charge - The conversion of electric energy, provided in the form of a current, into chemical energy within the cell or battery.

Charge Rate - The amount of current applied to battery during the charging process. This rate is commonly expressed as a fraction of the capacity of the battery. For example, the C/2 or C/5. See definition "C" above.

Charging - The process of supplying electrical energy for conversion to stored chemical energy.

Compressed Air Energy Storage (CAES) – a energy storage system in which ambient air is compressed and stored under pressure in an underground cavern. When electricity is required, the pressurized air is heated and expanded in an expansion turbine driving a generator for power production.

Cycle - One sequence of charge and discharge.

Cycle Life - For rechargeable batteries, the total number of charge/discharge cycles the cell can sustain before it's capacity is significantly reduced. End of life is usually considered to be reached when the cell or battery delivers only 80% of rated ampere-hour capacity.

Direct Current (DC) - The type of electrical current that a battery can supply. One terminal is always positive and another is always negative.

Discharge - The conversion of the chemical energy of the battery into electric energy.

Depth of Discharge (DOD) - The amount of energy that has been removed from a battery or battery pack. Usually expressed as a percentage of the total capacity of the battery. For example, 50% DOD means that half of the energy in the battery has been used. 80% DOD means that eighty percent of the energy has been discharged, so the battery now holds only 20% of its full charge.

Discharge, deep - Withdrawal of all electrical energy to the end-point voltage before the cell or battery is recharged.

Energy - Output Capability - expressed as capacity times voltage, or watt-hours.

Energy Demand (kW) – is the rate of electrical power draw, measured in Watts (W). Bill demand is typically calculated as an average over a time period.

Energy Usage (kWh) – is power consumed over a time period, measured in Watt-hours (Wh).

Flow Battery – a type of rechargeable battery where recharges are provided by two chemical components dissolved in liquids contained with the system. Types of flow batteries include iron-chromium, vanadium redox, and zinc-bromide.

Flywheel – a heavy revolving wheel in a machine that is used to increase the machine's momentum and thereby provide a reserve of available power during periods of interruption of power. A flywheel is able to capture energy from intermittent energy sources over time, and deliver a continuous supply of uninterrupted power.

Fuel Cell – a device that produces a continuous electric current directly from the oxidation of a fuel, as that of hydrogen by oxygen.

Latent Heat – heat released or absorbed by a chemical substance during a phase change from solid to liquid or liquid to gas without a change in temperature.

Pumped Hydroelectric Storage – a method of storing energy in the form of water in an upper reservoir pumped from another reservoir at a lower elevation. During periods of high electricity demand, power is generated by releasing the stored water through turbines. During periods of low demand, the upper reservoir is recharged by pumping water back into the upper reservoir.

Rated Capacity - The number of ampere-hours a cell can deliver under specific conditions (rate of discharge, end voltage, temperature); usually the manufacturer's rating.

Primary Cell – A single-use, non-rechargable battery.

Secondary Storage Cell - An electrolytic cell for the generation of electric energy in which the cell after being discharged may be restored to a charged condition by an electric current flowing in a direction opposite the flow of current when the cell discharges. Synonym: Secondary Cell. See Storage Battery.

Sensible Heat – the heat absorbed or released when a substance only undergoes a change in temperature.

Separator - The permeable membrane that allows the passage of ions via the electrolyte, but prevents electrical contact between the anode and the cathode.

Storage Battery - An assembly of cells in which the electrochemical action is reversible so that the battery may be recharged by passing a current through the cells in the opposite direction to that of discharge. While many non-storage batteries have a reversible process, only those that are economically rechargeable are classified as storage batteries. Synonyms: Accumulator; Secondary Battery. See Secondary Cell.

Sub-panel – A separate electrical panel services a limited number of loads in a home or business. Many storage solutions utilize a sub-panel to facilitate battery backup solutions. In the case of a grid power outage, batteries can be attached to the set of emergency loads that will be served during the outage.

Supercapacitor – a high-capacity electrochemical component capable of holding hundreds of times more electrical charge than other capacitors that bridge the gap between electrolytic capacitors and rechargeable batteries. *See* Capacitors.

Superconducting Magnetic Energy Storage (SMES) – a system that stores energy in a superconducting coil in the form of a magnetic field which is created with the flow of a direct current through the coil. The coil must be cooled adequately to achieve superconducting properties – no resistance to the flow of current – which enables the current to circulate indefinitely with almost zero loss so the energy remains stored as a magnetic field.

Trickle Charging - A method of recharging in which a secondary cell is either continuously or intermittently connected to a constant-current supply that maintains the cell in fully charged condition.

Vent - A normally sealed mechanism that allows for the controlled escape of gases from within a cell.

Volt - The unit of measurement of electromotive force, or difference of potential, which will cause a current of one ampere to flow through a resistance of one ohm.

Watt - A measurement of total power. It is amperes multiplied by volts. 120 volt @ 1 amp = 12 volts @ 10 amps.