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Electricity Storage
Technologies, impacts, and prospects

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Deloitte Center *for* Energy Solutions

Executive summary

The electricity system in the US may be on the cusp of a period of more rapid change than at any time in the past 25 years or more. The rising role of renewable generation, both grid-scale and distributed; tightening emission limits on fossil-fuel based generation; the acceleration of smart grid deployment; and the emergence of multiple options for electricity consumers to better manage overall consumption and the shape of their load, together point to a very different landscape than in the past. One important barrier to these developments achieving their full potential has always been the absence of economic and reliable electricity storage solutions. But there appears to be an acceleration in research and development of various forms of electricity storage which offer the promise of more economic deployment at scale in the near term, bringing load-shifting and electricity reliability within reach of more and more utilities and consumers.

In the past, the main options for electricity storage at grid scale have been pumped hydro storage where water is pumped uphill during off-peak hours when electricity is cheap and then released during peak hours to provide electricity when it is expensive, and compressed air storage, which achieves similar load-shifting objectives by compressing air in caverns, then releasing it to drive turbines. However, in recent years, both the need and the technological solutions for electricity storage have been growing, driven by the proliferation of intermittent renewable electricity generation—primarily wind power and solar power—both at grid scale and distributed at building or local scale. In particular, the development of battery storage technologies targeted at distributed applications have also been facilitated by the increasing focus on both hybrid and all-electric vehicles in recent years, in which similar battery arrays could be used in stationary applications.

This paper examines the state of maturity of the various new technologies under development, the likely timing and impact of their deployment, and the implications for electricity providers and consumers of all sizes. How and how much will the electricity system be transformed by wider and more economic availability of electricity storage solutions? Which technologies will be best suited for which applications? How long might it take for widespread deployment of electricity storage in the US?

The key findings and conclusions from our examination of this matter are as follows:

- The pace of development and deployment of new electricity storage technologies is accelerating and these solutions could play an important role as the US electric grid incorporates more intermittent renewable sources of generation, and more distributed generation.
- These changes provide opportunities for new players as the technological and business landscape evolves to incorporate more energy storage.
- As an emerging element of electricity delivery systems, electricity storage faces both great opportunity and considerable challenges.
- Participants wishing to enter this market or expand their presence need to carefully consider many factors, related to choice of technology, type of applications they target, the regulatory framework, and the characteristics of the markets they wish to serve. Different business models may be necessary for different contexts and objectives; there is unlikely to be one dominant business model in this sector.

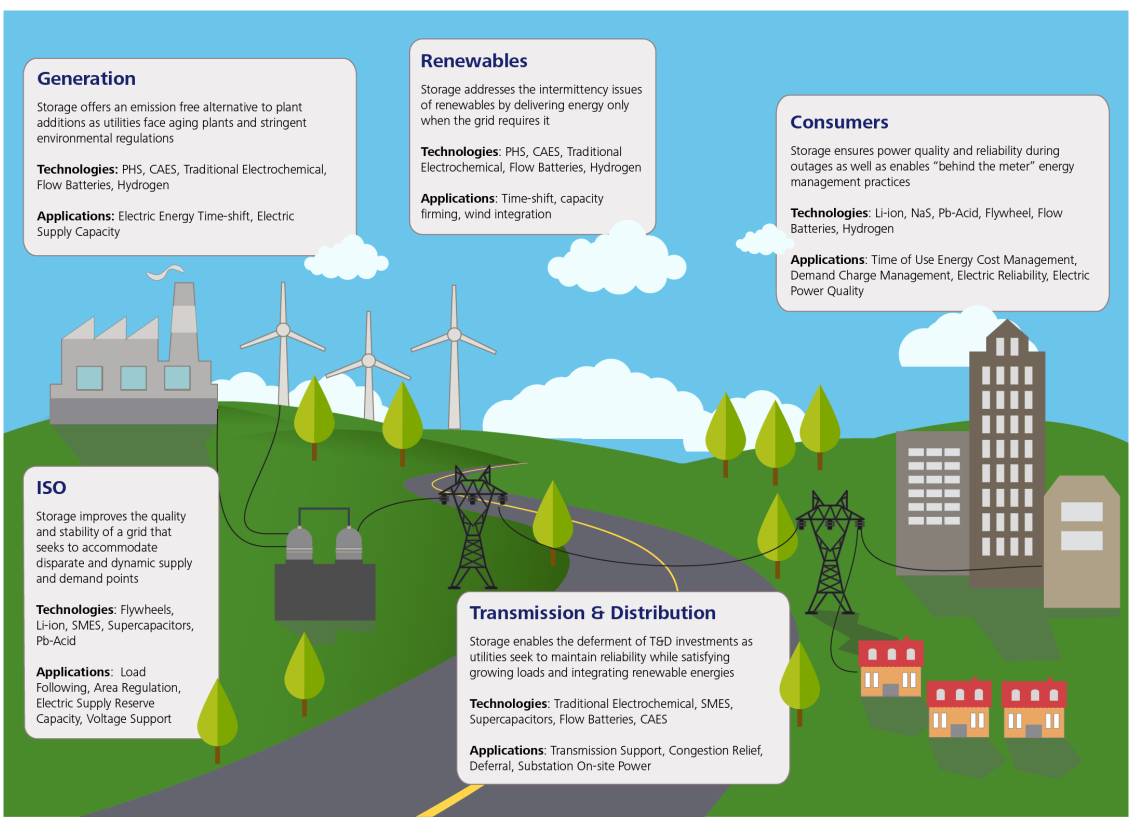
Why electricity storage now? Applications and technologies

There are a number of different applications where energy storage solutions can usefully be deployed. Some technologies are uniquely suited to specific applications, while some can be more broadly used across a range of applications. Matching the application to the technology in a way that is both effective and economic will be a key success factor in increasing the market presence of energy storage technologies.

Research into electricity storage has identified five broad families of applications:

1. **Electricity supply applications:** Generally at grid-scale where storage is used either to add additional capacity at peak periods or to shift electricity generation over time from an off-peak period to an on-peak period, usually within the same day
2. **Ancillary services:** For the grid operator to maintain quality and reliability of electricity delivery; these services would include such items as provision of reserve or surge capacity, load-balancing across the grid, and over time and voltage support
3. **Grid support applications:** Support the transmission grid, relieve congestion, allow deferral of expensive transmission system upgrades, or provide on-site power for sub-stations across the system
4. **Renewables integration applications:** Where intermittent power sources become a more important part of the overall power generation mix, which allows the time-shift of renewables inputs to the grid and the firming of intermittent capacity; without energy storage solutions, wind is primarily an off-peak, night-time contributor, while solar power only delivers electricity when the sun is shining during daylight hours

Figure 1. Energy storage across the power sector



Source: "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide: A Study for the DOE Energy Storage Systems Program," SANDIA, December 2010.

5. **End-user applications:** Often, but not always, associated with distributed generation; these include maintaining electricity quality and reliability, matching distributed generation delivery with time-of-use requirements, and allowing consumers to more effectively manage their exposure to demand charges

It is immediately clear that energy storage applications are useful across the whole electricity value chain, thus challenging the traditional separation between generation, transmission, and distribution to consumers, which has dictated investment and business model design over most of the past several decades. Before considering the implications for future strategies and business models, we can describe the technological landscape which serves the diversity of applications and assess their level of maturity and future prospects.

Mapping technologies to applications

Electricity supply: For the first category of energy supply and storage applications at grid scale, both pumped storage and compressed air storage have long been options which are technologically available and have the scale characteristics to be part of a grid-based supply portfolio. Because their main function is to store electricity so that its delivery can be shifted from off-peak to on-peak times of day, these options can allow a utility to avoid investment in additional peak-load generating capacity. Both pumped hydro and compressed air systems can provide large-scale electricity storage and load-shifting capacity, typically in the hundreds of megawatts (MW), but their deployment is limited by the availability of suitable sites—for reservoir development at differentiated altitudes in the case of pumped storage and for storage caverns in the case of compressed air. Both are capital intensive options, with

Figure 2. Energy storage technologies

Kinetic energy			Potential energy		
Thermal technologies	Electrical technologies	Mechanical technologies		Electrochemical technologies	Chemical technologies
Hot water	Supercapacitors	Flywheels	Pumped hydro	Lithium ion	Hydrogen
Molten salt	Superconducting magnetic energy		Compressed air energy	Lead acid	Synthetic natural gas
Phase change material				Redox flow	
				Sodium sulfur	

Source: "Electricity Storage Fact Book," SBC Energy Institute, September 2013.

operational risk still a factor, particularly for compressed air, a technology which has not yet been widely applied. For grid scale applications, battery storage solutions could also be used, such as conventional lead-acid and sodium-sulphur batteries, as well as more recently developed lithium-ion batteries. However, these do not seem to be as suitable for larger loads. The largest sodium-sulphur battery deployed is 4 MW, in Texas, providing back-up supply for a small town of about 5,000 people.

Ancillary services: Most types of ancillary services require frequent, short-duration power discharge to bolster power quality and reliability. As such, the various battery solutions referred to above are better placed to meet this kind of demand, as well as the mechanical option of flywheels. Flywheels have the advantages of longer operating lives and lower maintenance costs, although they typically suffer from larger efficiency losses in operation.

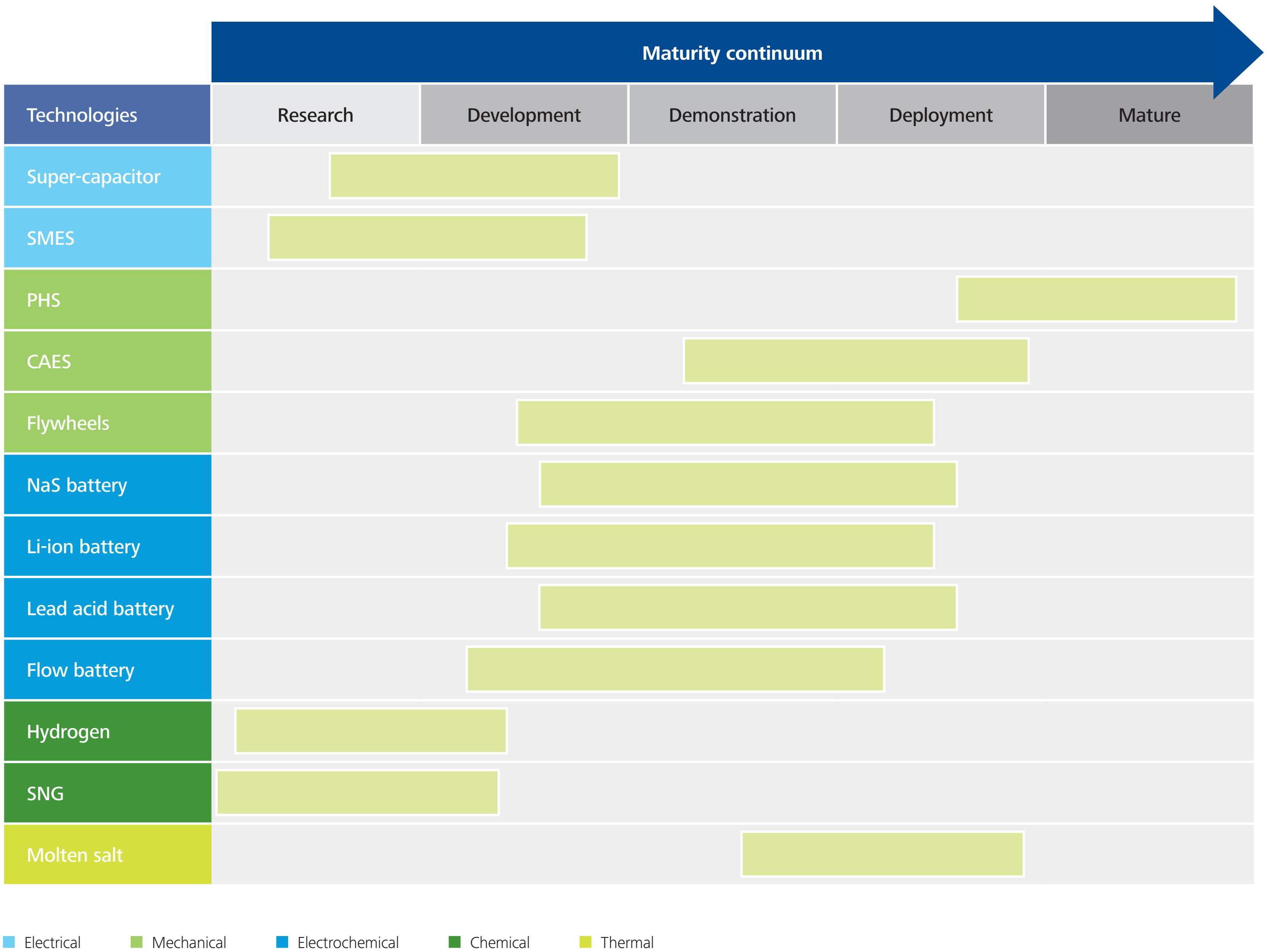
Grid support: With respect to grid support in the transmission and distribution functions, battery systems seem to be the most widely deployed technologies and also provide the most economically viable and operationally effective solutions to relieving transmission and distribution congestion at peak demand periods. They are usually deployed at electricity sub-stations to provide more localized grid-flow reinforcement than would be the case for more centralized systems, and are thus able to alleviate local bottlenecks with favorable economics relative to system-wide upgrades.

Renewables integration: For the integration of renewable energy generation into the grid, both pumped storage and compressed air storage can provide the scale and responsiveness needed to shift relatively large loads across periods extending up to several hours. However, their deployment is limited by siting constraints. While battery technologies and even hydrogen storage could be candidates to fill this role as prices decline and they continue to reach scale, balancing generation systems with higher renewable generation intensity will likely continue to require use of other options. These include using existing natural gas peaker plants; deploying grid automation tools like smart inverters, physical sensors and advanced analytics; incorporating new weather forecasting tools; employing energy efficiency and demand response programs; and transmitting electricity over greater distances and coordinating across a wider range of generation technologies to smooth out supply.

End-user: At the level of distributed generation at building scale or local scale—for residential and commercial consumers—battery systems are making the biggest inroads at the moment. The smaller scale involved, and therefore the lower capital outlays, can encourage the use of battery storage systems and eventually reduce the need for more complex commercial arrangements like net metering. Currently, lithium-ion and lead-acid batteries are becoming popular for residential users, while sodium-sulphur and advanced lead-acid batteries with higher capacity, are being deployed in commercial buildings. Where power quality is a concern, such as for commercial data servers or in health care facilities, flywheels provide a viable option for smoothing out power variations.

In an electric power market in which storage is emerging and set to grow its contribution substantially over the next decade, it is important to assess the level of maturity of the range of technologies available. They range from quite mature, such as pumped storage, to those still in the research and development phase, such as hydrogen storage or super-capacitors, with the various battery technologies mainly around the middle of the pack. Technology promoters will be working on reducing the costs and increasing the reliability and scalability of the various solutions. In the near-term, battery technologies look capable of providing the most immediate improvements in these areas.

Figure 3. Maturity varies across technologies



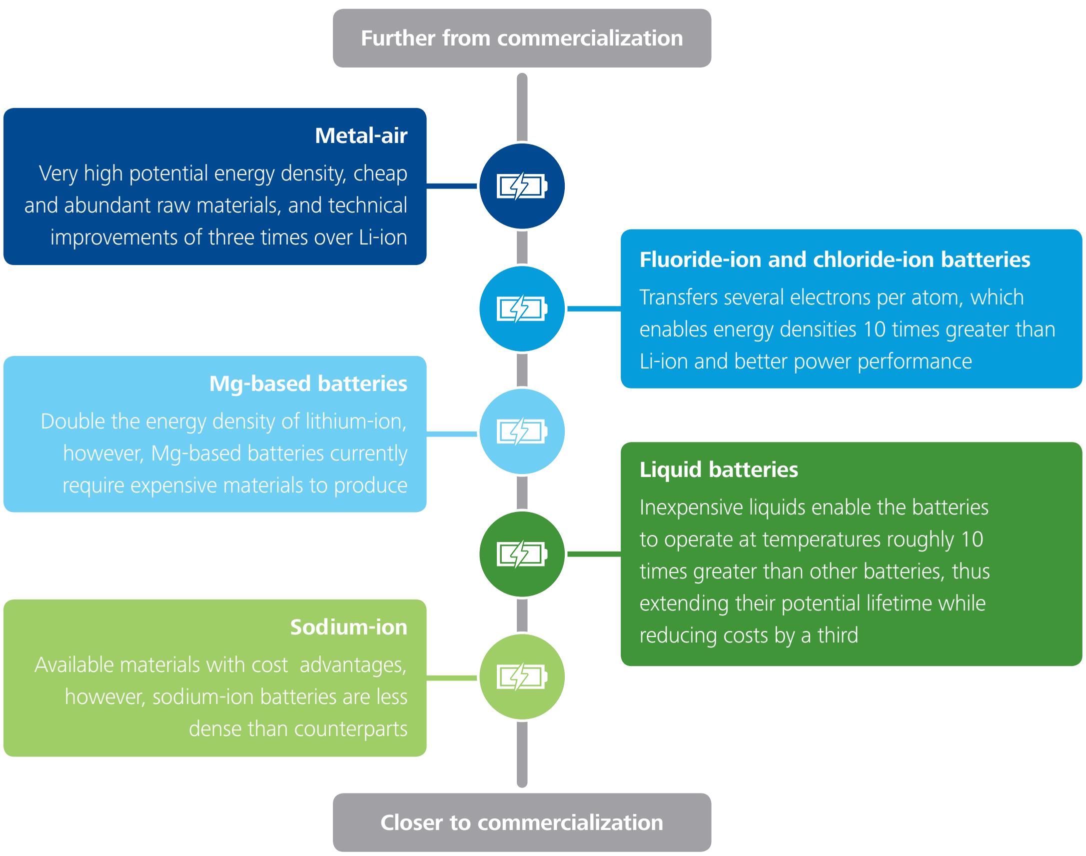
Source: SBC Energy Institute

The pathway for longer-term electricity storage technology development also looks quite promising with a number of options in the early research and development phase, led by a combination of academic and government research and funding, as well as more entrepreneurially-led technology start-up companies. Most of these involve testing new ideas for battery technology, with approaches ranging from using cheaper, more available input components; to improving energy density of existing designs; or extending the lifetime and performance ranges of battery options.

Recent outlooks from GTM Research foresee rapid growth for electricity storage over the balance of this decade, with penetration of electricity storage solutions accelerating in grid-scale utility markets, residential markets, and commercial building markets.[1] There are available technologies today for applications in all three of these sectors, but as technologies mature, we can expect growth curves to continue for a much longer period, leading to novel business models and strategic choices for utilities and investors in technology.

Figure 4. Next generation technologies

Emerging technologies employ new materials and innovative configurations to drive performance and cost improvements.

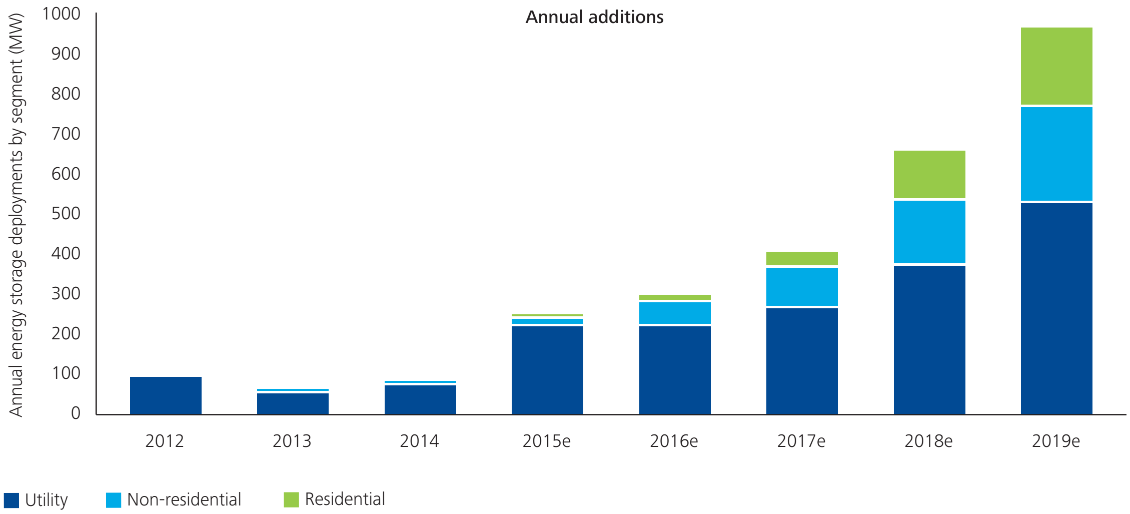


Source: EOS: "NY BEST: Metal-Air Batteries" (2012); MIT Technology Review: "TR10 Liquid Battery" (2009); EASE: "European Energy Storage Technology Development Roadmap towards 2030" (2014); Joint Center for Energy Storage Research (JCESR)

1 "US Energy Storage Monitor," GTM Research, September 2015, http://www.greentechmedia.com/research/subscription/u.s.-energy-storage-monitor.

Figure 5. The US energy storage market is expecting substantial growth across customer segments

The US energy storage market is projected to grow by 250% in 2015, with annual additions to exceed 850 MW by 2019



Source: GTM Research

What will electricity storage deployment mean for utilities, for technology developers, and for consumers?

For traditional utilities, the advent of wider deployment of electricity storage represents both an opportunity and a challenge.

Traditional utilities: On the opportunity side of the ledger, the increased availability of electricity storage provides scope for improving system performance and efficiency while reducing the need for lumpy, large-scale capital investment commitments. Load-balancing across time periods, relieving local and regional congestion along the wires, and reinforcing power quality and reliability for the end-users are all benefits that can be achieved through judicious use of electricity storage, thus enhancing the utility's quality of service. The key will be to realistically assess the costs and benefits of deploying the most appropriate technology in each specific context and to work with regulators to ensure that benefits are economically monetizable in the design of the relevant electricity service rates.

However, the challenge will come if consumers use the combination of distributed generation, such as rooftop solar, and electricity storage to cut links with grid-based providers. The loss of customers, the need to spread fixed system costs over a smaller number of consumers, and the need to manage aging generation and transmission and distribution infrastructure with lower incentives to reinvest are all issues that utilities could have to face in varying degrees. Some may choose to go the route of maximizing efficiency in existing operations to boost profitability and sustain cash flow. Others, like technology and/or maintenance providers, distributed generation and storage installers, providers of finance to residential and commercial customers, or partners/financial backers, may choose to add new service lines to their offering to technology developers.

Technology developers: For technology developers, the biggest challenge, assuming demonstrated technical viability, is often to advance from small-scale pilot and demonstration installations to a commercial scale where the economics and performance characteristics of a solution are transparent to the market, where growth becomes a vehicle for economies of scale in manufacturing and installation, and where sustainable and profitable cash flow allows ongoing investment in system improvements. These are no small challenges. High-profile, big bets are being made by technology entrepreneurs. It remains to be seen whether a go-it-alone strategy will be more viable than the option of partnering with existing incumbent electricity providers to gain access to financial backing, regulatory support, and access to a large existing customer base.

Consumers: For residential and commercial consumers, growth in adoption rates will depend on calculations of reliability, cost, and risk compared to the existing model of electricity delivery on-demand from remote utility providers. Those consumers who are early adopters of distributed generation solutions, including such technologies as rooftop solar, will likely be the initial candidates for electricity storage. And the development of local micro-grids provides a further opportunity for storage deployment at an intermediate scale, larger than for individual buildings, but smaller than required for grid support, which could provide improved scope and economics for technology providers.

In some US regional electric markets, regulators are anticipating the role of electricity storage by adopting plans and regulatory modifications which are adapted to electricity storage.

In California, for example, the Public Utilities Commission has targeted storage procurement for the system of 1.3 gigawatts by 2020, as well as updating rules for interconnections and net metering. In New York, the development of micro-grids to serve critical facilities is being funded; these micro-grids are intended to bolster resiliency and should include electricity storage components. It is notable that both California and New York have higher rates of renewable energy production and retail electricity rates which are above the national US average. While these conditions are neither necessary, nor perhaps the primary drivers for the policies of these two states, they certainly enhance the attractiveness of new storage solutions.

Conclusions

The acceleration of new technologies, changing consumer expectations and behaviors, and the structural evolution of the electricity generation and delivery system over the past decade is providing fertile ground for the emergence of maturing electricity storage technologies as key components of the new landscape in electric power. Wider deployment of electricity storage can benefit utilities by improving grid performance and reliability, allowing the avoidance of investment in peaking generation capacity. On the consumer side, electricity storage can enhance local, distributed generation by providing a load-matching capability under the control of the consumer, minimizing the need for net-metering arrangements. As solar rooftop installations grow, a natural complementary market for electricity storage is emerging, to be realized when consumers are convinced of the availability, reliability, and economics of storage.[2] Widespread proliferation may take time, and may progress unevenly across regions, depending on local electricity markets, grid conditions, regulatory structures, and other factors. But conditions are increasingly favorable and so the time is now to begin planning for this new market.

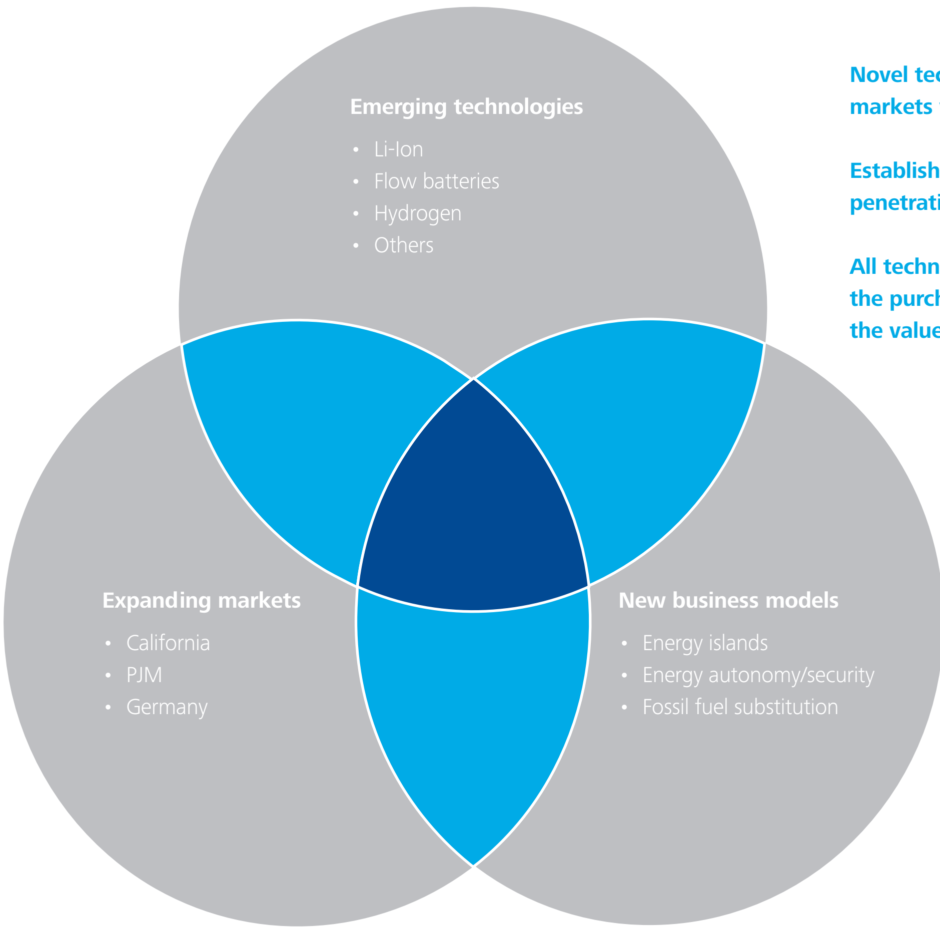
- **Technology developers** should focus on validating and demonstrating performance, reducing costs, identifying the most appropriate applications for their technology, and developing the commercial relationships which will enable them to begin penetrating the market. Not all technologies will be winners and not all commercial approaches will be effective. The technology players will need to closely monitor the parallel development of technical solutions and markets to assess the competitive landscape and determine the most effective applications, market positioning, and need for partnerships for their technology.
- **Utilities** should consider where, and in what applications, electricity storage can be deployed to reinforce existing grid-based systems. This will likely require working with regulators to jointly agree on the investment and return implications while considering the expected improvement of system performance. Utilities will also need to consider how to position themselves relative to consumers who have new options to loosen their connections with the utility providers. Do utilities embrace new consumer needs by providing services which are aligned, or do they concentrate on the most efficient and reliable operations of existing electricity delivery infrastructure?
- **End-use consumers**, both residential and commercial, will need to assess which energy storage solutions are best fitted to their needs and the impact on both the cost and reliability of electricity supply. Increasingly, consumers will assess distributed generation and electricity storage options as an integrated solution, and be able to have the opportunity to go off-grid to become autonomous in the provision and consumption of electric power.
- **Regulators** will need to assess the role of electricity storage in meeting the needs of the systems and consumers under their jurisdiction, and what regulatory changes may be needed to enable these new options to meet that role efficiently and effectively, in the new world of optionality implied by distributed generation and electricity storage.

The intersection of technologies, markets, and evolving business models provides a rich and fascinating set of opportunities for all players in the emerging electricity storage sector. It looks like conditions are ripe for a period of rapid growth in the near term. All participants should consider carefully the implications for their own activities and needs, and plan accordingly.

2 *"US Solar Power Growth through 2040: Exponential or inconsequential?," Deloitte Center for Energy Solutions*

Figure 6. Ready for take off

Watch out for the intersect of winning technologies, disruptive business models, and regions with clear demand for storage.



Novel technologies will gain traction in niche markets where cost is competitive

Established technologies will maximize market penetration through creative partnerships

All technologies will require an understanding of the purchasing drivers within a customer class and the value proposition of incumbent technologies

This paper is a shorter version of a more extensive research project developed by colleagues at Deloitte in the spring and early summer of 2015 – Energy storage: Tracking the technologies that will transform the power sector.

Appendix A: Characteristics of energy storage technologies

Technologies	Power rating (MW)	Storage duration (h)	Cycling or lifetime	Self-discharge (%)	Energy density (Wh/l)	Power density (W/l)	Efficiency (%)	Response time
Super-capacitor	0.01-1	ms-min	10,000-100,000	20-40	10-20	40,000-120,000	80-98	10-20ms
SMES	0.1-1	ms-min	100,000	10-15	~6	1000-4000	80-95	< 100ms
PHS	100-1,000	4-12h	30-60 years	~0	0.2-2	0.1-0.2	70-85	sec-min
CAES	10-1,000	2-30h	20-40 years	~0	2-6	0.2-0.6	40-75	sec-min
Flywheels	0.001-1	sec-hours	20,000-100,000	1.3-100	20-80	5,000	70-95	10-20ms
NaS battery	10-100	1min-8h	2,500-4,400	0.05-20	150-300	120-160	70-90	10-20ms
Li-ion battery	0.1-100	1min-8h	1,000-10,000	0.1-0.3	200-400	1,300-10,000	85-98	10-20ms
Flow battery	01-100	1-0h	12,000-14,000	0.2	20-70	0.5-2	60-85	10-20ms
Hydrogen	0.01-1.000	min-weeks	5-30 years	0-4	600 (200 bar)	0.2-20	25-45	sec-min
SNG	50-1.000	hours-weeks	30 years	negligible	1,800 (200 bar)	0.2-2	25-50	sec-min

☐ Electrical ☐ Mechanical ☐ Electrochemical ☐ Chemical

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